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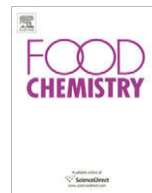

Flavonoid composition of red sorghum genotypes

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The effect of genotype on flavonoid composition was investigated in 13 sorghum varieties using HPLC-DAD. Sorghums with red/purple secondary plant colour had the highest levels of 3-deoxyanthocyanins (32–680 μg/g) with the black pericarp sorghums having the highest. Sorghums with red secondary plant colour had a high proportion of apigeninidin compounds (66–89%), which suggested that secondary plant colour affects 3-deoxyanthocyanin composition. Red pericarp sorghums with tan secondary plant colour had the highest levels of flavones (60–386 μg/g). Flavanones were also detected in all sorghums with a red pericarp (8–48 μg/g) and secondary plant colour did not affect their levels ($p > 0.05$). The elevated 3-deoxyanthocyanin levels in the black sorghums were due to their pericarp colour. Black sorghum panicles that were exposed to sunlight during their development had three times more 3-deoxyanthocyanins (617 μg/g) than those that were covered with a paper bag (212 μg/g). This study showed that flavonoid levels and composition were affected by sorghum genotype. This information will help sorghum breeders to produce sorghum genotypes with maximum levels of desired flavonoids.

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1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth leading cereal crop in the world after wheat, maize, rice, and barley (FAO, 2007). It is used primarily in Asia and Africa as a food crop whereas the Western Hemisphere uses sorghum mainly as feed (Dykes, Rooney, Waniska, & Rooney, 2005). Several potential health and pharmaceutical benefits of sorghum have been reported. These include slow digestibility, cholesterol-lowering, antioxidant, anti-inflammatory, and anti-carcinogenic properties (Bralley, Greenspan, Hargrove, & Hartle, 2008; Dykes & Rooney, 2006).

Phenolic compounds are present in all sorghums and the types and quantities of those compounds are affected by the genotype (Dykes & Rooney, 2006). Genetic factors controlling pericarp colour, the presence of a pigmented testa, pericarp thickness, and secondary plant colour were described by Rooney (2000). Pericarp colour is controlled by the *R* and *Y* genes. A pericarp is white when *Y* is homozygous recessive (*rryy* or *R_yy*); it is yellow when *R* and *Y* are homozygous recessive and homozygous dominant (*rrYY*), respectively. When both *R* and *Y* are dominant (*R_Y_*), the pericarp is red. Some sorghums with the *R_Y_* genes for red pericarp turn black when maturing in the presence of sunlight and thus are termed as "black" sorghums (Dykes et al., 2005). The genetics causing this phenomenon are unknown. The presence of a pigmented testa is controlled by the B_1 and B_2 genes. When both genes are dominant, a pigmented testa is present. Pericarp thickness is controlled by the *Z* gene. Finally, secondary plant colour is controlled by the *P* and *Q* genes to produce tan, red, and purple pigmented plants. Tan plant sorghums have *ppqq* or *ppQQ* genes. Red and purple plant sorghums have the *PPqq* and *PPQQ* genes, respectively. The genes for pericarp colour and secondary plant colour act independently. However, secondary plant colour affects leaf, stalk, sheath, glume, and grain kernel appearance. Sorghums with red or purple secondary plant colour have red or purple spots on the pericarp unlike those with tan secondary plant colour. Dykes et al. (2005) reported that sorghums with red/purple secondary plant colour have higher phenolic levels than those with tan secondary plant colour.

Sorghum flavonoids, especially the 3-deoxyanthocyanins, have been identified over the years and these include the orange luteolinidin and the yellow apigeninidin (Nip & Burns, 1969, 1971; Wu & Prior, 2005; Pale et al., 1997). They are classified as phytoalexins since they are produced in response to fungal invasion or other stresses in sorghum (Lo, De Verdier, & Nicholson, 1999; Waniska & Rooney, 2000). The 3-deoxyanthocyanins are more stable than the common anthocyanins, which make them potential natural food colorants (Awika, Rooney, & Waniska, 2004). Wu and Prior (2005) identified several 3-deoxyanthocyanin compounds in four sorghum varieties but their levels were not determined. Luteolinidin and apigeninidin were reported to be highest in black sorghum brans (Awika et al., 2004).

Other flavonoids identified in sorghum include the flavanones eriodictyol, naringenin, and eriodictyol glucoside and the flavone apigenin (Gujer, Magnolato, & Self, 1986; Kambal & Bate-Smith, 1976). However, quantitative data are lacking especially for differ-

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ent genotypes (i.e. pericarp colour, secondary plant colour, pericarp thickness). Analysis of selected sorghum genotypes will assist in the production of sorghums with optimum levels of desired flavonoids. The objective of this study was to compare flavonoid levels in red sorghums of varying genotypes using high performance liquid chromatography with diode array detection (HPLC-DAD).

2. Materials and methods

2.1. Samples

Twelve sorghum varieties with the *R_Y_* genes for red pericarp were grown in a sorghum breeding nursery in College Station, TX, USA in 2003. A white pericarp (*R_yy*) sorghum with tan secondary plant colour, free of evident pigments (02CA4796) was grown in the same nursery in 2003 and was used as the control. The genetic and physical descriptions of all thirteen varieties are summarized in Table 1. The line designations for all germplasms were provided by breeders in the Texas AgriLife Research Sorghum Improvement Program.

The effect of sunlight on flavonoid levels in black sorghum was investigated using Tx430 Black that was grown in the same nursery in College Station, TX, USA in 2004. Pollinating bags were used to cover ten randomly selected panicles at anthesis while ten other panicles were randomly selected and left uncovered. All sorghum samples were collected at maturity, air-dried, and manually cleaned, and the glumes were removed from the kernels. All samples were relatively free of visible mould or weathering.

2.2. Standards and reagents

Naringenin was obtained from Sigma–Aldrich (St. Louis, MO, USA). Apigenin and luteolin were obtained from Indofine Chemical Co., Inc. (Hillsborough, NJ, USA). Eriodictyol, luteolinidin chloride, and apigeninidin chloride were obtained from ALSACHIM (Strasbourg, France) and 7-methoxyapigeninidin chloride was obtained from ChromaDex (Santa Ana, CA, USA). Methanol, acetonitrile, and HCl were purchased from VWR (West Chester, PA, USA). Formic acid was purchased from Fisher Scientific (Fair Lawn, NJ, USA). All reagents were HPLC or analytical grade.

2.3. Sample preparation

Samples were ground for 2 min using a Cuisinart DCG-20 coffee grinder (East Windsor, NJ, USA) immediately prior to analysis. All samples were ground to achieve a particle size that passed through a 500-μm sieve. Ground samples (1 g) were extracted in 10 mL of 1% HCl/methanol (v/v) for two h in a shaker. The extracts were centrifuged at 2790*g* for 10 min and then decanted. All extracts were immediately filtered using a 0.45 μm nylon membrane filter (Whatman Inc., Maidstone, UK) prior to HPLC and LC-MS analyses. To avoid oxidation of sorghum phenolics, all samples were analysed within 24 h.

2.4. HPLC-DAD analysis of sorghum flavonoids

Extracts were analysed on an Alliance 2695 system (Waters Corp., Milford, MA, USA) connected to a Waters 996 diode array detector. Sorghum flavonoids were separated using a Luna C18 column (150 mm × 4.6 mm i.d., 5 μm) from Phenomenex (Torrance, CA, USA). Column temperature was maintained at 35 °C. Injection volume was 20 μL. The mobile phase consisted of 4% formic acid in water (v/v) (Solvent A) and acetonitrile (Solvent B). The solvent flow rate was 1.0 mL/min. The 3-deoxyanthocyanins were separated using the following gradient: 0–20 min, 12–20% B; 20–40 min, 20–50% B; 40–50 min, 50% B. Flavones and flavanones were separated using the following gradient: 0–45 min, 15–41% B; 45–50 min, 41% B. The 3-deoxyanthocyanins, flavones, and flavanones were detected at 485 nm, 340 nm, and 280 nm, respectively. Identification of sorghum flavonoids was determined based on the retention times of commercial standards, UV–vis spectra, and LC-MS data. Quantification of each compound was accomplished by comparing peak areas with that of a calibration curve of each standard. Limit of detection (LOD) and limit of quantification (LOQ) for all compounds were 20 ng/mL and 67 ng/mL, respectively with the exception of luteolinidin (LOD: 15 ng/mL; LOQ: 50 ng/mL). Quantification of 5-methoxyluteolinidin and 7-methoxyapigeninidin were determined using the calibration curve for luteolinidin and apigeninidin, respectively, along with the appropriate molecular weight correction factor (Chandra, Rana, & Li, 2001). Each sample was analysed in triplicate. Data was collected and processed using the Empower software (Waters Corp., Milford, MA, USA).

2.5. Identification of 5-methoxy-luteolinidin using LC-MS-ESI

Identification of 5-methoxy-luteolinidin was obtained by LC-MS-ESI analysis, which was performed on a Thermo Finnigan LCQ Deca XP Max MS^n ion trap mass spectrometer equipped with an ESI ion source (Thermo Fisher, San Jose, CA, USA). Separation was conducted using the same Luna C18 column mentioned earlier. Column temperature was maintained at 20 °C. The mobile phase consisted of 0.5% formic acid in water (v/v) (Solvent A) and 0.5% formic acid in acetonitrile (v/v) (Solvent B). The solvent flow rate was 0.4 mL/min. The compounds were separated using the following gradient: 0–5 min, 15–40% B; 5–15 min, 40–85% B. Electrospray ionization was conducted in negative mode under the following conditions: sheath gas (N_2), 40 units/min; auxiliary gas

Table 1
Genotypes and physical characteristics of varieties of red sorghums.

Variety	Genotype	Plant Color	Pigmented Testa	Pericarp	Kernel Appearance
02CA4796	$b_1b_1B_2B_2RRyyZZppQQ$	Tan	Absent	White, thin	Pearly, white
B.01336	$b_1b_1B_2B_2RRYYZZppQQ$	Tan	Absent	Red, thin	Pearly, yellowish-red
99GWO92	$b_1b_1B_2B_2RRYYZZppQQ$	Tan	Absent	Red, thin	Pearly, orange-brown
98BRON155	$b_1b_1B_2B_2RRYYZZppQQ$	Tan	Absent	Red, thin	Pearly, yellowish-red
99LGWO50	$b_1b_1B_2B_2RRYYzzppQQ$	Tan	Absent	Red, thick	Chalky, red
B.9904	$b_1b_1B_2B_2RRYYZZPPqq$	Red	Absent	Red, thin	Pearly, brown
Tx2911	$b_1b_1B_2B_2RRYYzzPPqq$	Red	Absent	Red, thick	Chalky, red
SC719-11E	$B_1B_1B_2B_2RRYYzzPPqq$	Red	Present	Red, thick	Chalky, reddish-orange
98CA4779	$b_1b_1B_2B_2RRYYZZPPQQ$	Purple	Absent	Red, thin	Pearly, orange
SC103 x SC748 (light)	$b_1b_1B_2B_2RRYYZZPPQQ$	Purple	Absent	Red, thin	Pearly, yellowish-brown
SC103 x SC748 (dark)	$B_1B_1B_2B_2RRYYzzPPQQ$	Purple	Present	Red, thick	Chalky, dark brownish-red
Tx430 Black	$b_1b_1B_2B_2RRYYzzPPQQ$	Purple	Absent	Red, thick	Chalky, mostly black
Black PI Tall	$B_1B_1B_2B_2RRYYzzPPQQ$	Purple	Present	Red, thick	Chalky black

(N_2), 5 units/ min; spray voltage 3.5 kV; capillary temperature, 250 °C; capillary voltage, −29 V; tube lens offset, −60 V.

2.6. Statistical analysis

Flavonoid levels were expressed as means ± standard deviation for three replicates. One-way analysis of variance (ANOVA) was used to determine significant differences between sorghum genotype groups (i.e. secondary plant colour and pericarp thickness) and flavonoid levels. Differences at $p < 0.05$ were considered significant. Statistical analysis was performed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1. Evaluation of sorghum 3-deoxyanthocyanins

Four major 3-deoxyanthocyanins were detected: luteolinidin (LUT), apigeninidin (AP), 5-methoxyluteolinidin (5-MeO-LUT), and 7-methoxyapigeninidin (7-MeO-AP). These compounds were identified using commercial standards with the exception of 5-MeO-LUT, which was identified based on its UV spectra (λ_{max} = 486 nm), LC-MS data ($[M]^-$, *m/z* 283; MS/MS, *m/z* 269) (data not shown), and data from the literature (Lo et al., 1996).

Sorghums with red/purple secondary plant colour had the highest levels of 3-deoxyanthocyanins (32–680 μg/g). Among these types, the black sorghums (Tx430 Black and Black PI Tall) had the highest levels (Table 2). The 3-deoxyanthocyanin levels in tan plant sorghums were very low (0–1 μg/g). Previous studies indicated that the 3-deoxyanthocyanins are concentrated in the pericarp (Awika et al., 2004). Among red/purple plant sorghums, the 3-deoxyanthocyanin levels in sorghums with a thick pericarp were significantly higher than those with a thin pericarp ($p < 0.05$) even when the two black sorghums were removed from the set. This finding could be coincidental since the difference between thin and thick pericarp sorghums is that the latter have starch granules in the mesocarp (Dykes & Rooney, 2006). More studies are needed to confirm the effect of pericarp thickness on 3-deoxyanthocyanin levels.

The 3-deoxyanthocyanin profiles varied among samples (Table 2). AP and 7-MeO-AP were the predominant 3-deoxyanthocyanins in sorghums with red secondary plant colour (B.9904, Tx2911, and SC719-11E), which, combined, accounted for 66–89% of the total 3-deoxyanthocyanins. However, all sorghums with purple secondary plant colour (with the exception of Tx430 Black), had a higher proportion of LUT and 5-MeO-LUT combined, which accounted for 61–75% of the total 3-deoxyanthocyanins. The 3-deoxyanthocyanins in Tx430 Black were almost evenly distributed between the two types. The high proportion of AP and 7-MeO-AP in red plant sorghums suggested that 3-deoxyanthocyanin composition might be predicted by secondary plant colour. If yellow apigeninidin pigments are desired for food applications, then sorghums with red secondary plant colour could be a good source. Further studies using a larger number of samples are needed to confirm the effect of secondary plant colour on 3-deoxyanthocyanin composition.

3.2. Evaluation of sorghum flavones

Apigenin and luteolin were the two flavones identified in the varieties. Red sorghums with tan secondary plant colour had higher flavone levels (60–386 μg/g) than sorghums with red/purple secondary plant colour (0–41 μg/g) (Table 3) with 99LGWO50 having the highest. Among the tan plant sorghums, the control (02CA4796), which had a white pericarp, had the lowest flavone levels. Flavones are concentrated in the pericarp since their levels were increased almost four-fold in the 99LGWO50 bran fraction (1461 μg/g) (data not shown). Among the sorghums with red/purple secondary plant colour, the black pericarp sorghums had the highest flavone levels (36–41 μg/g). Pericarp thickness had a posi-

Table 3
Flavone levels (μg/g) in red sorghum varieties.[a]

Variety	Luteolin	Apigenin	Total
02CA4796	4.5 ± 0.2	25.4 ± 2.2	29.9 ± 2.4
B.01336	5.6 ± 0.3	54.5 ± 1.9	60.1 ± 2.0
99GWO92	88.1 ± 3.7	11.7 ± 0.7	99.8 ± 4.3
98BRON155	75.7 ± 1.4	13.9 ± 0.2	89.6 ± 1.4
99LGWO50	182.2 ± 7.0	203.7 ± 5.5	385.9 ± 12.5
B.9904	2.6 ± 0.1	3.2 ± 0.1	5.8 ± 0.1
Tx2911	20.8 ± 0.4	nd	20.8 ± 0.4
SC719-11E	nd[b]	nd	nd
98CA4779	8.4 ± 0.2	nd	8.4 ± 0.2
SC103 x SC748 (light)	11.2 ± 0.2	3.5 ± 0.1	14.7 ± 0.3
SC103 x SC748 (dark)	11.0 ± 0.3	2.8 ± 0.2	13.8 ± 0.5
Tx430 Black	34.2 ± 0.5	6.7 ± 0.1	40.9 ± 0.5
Black PI Tall	31.6 ± 0.5	4.6 ± 0.1	36.2 ± 0.5

[a] Values are mean of triplicates ± standard deviation.
[b] Not detected.

Table 2
3-Deoxyanthocyanin levels (μg/g) in red sorghum varieties.[a]

Variety	LUT[b]	AP[c]	5-MeO-LUT[d]	7-MeO-AP[e]	Total
02CA4796	nd[f]	0.4 ± 0.1	nd	0.4 ± 0.1	0.8 ± 0.1
B.01336	nd	nd	nd	nd	nd
99GWO92	0.5 ± 0.1	nd	0.3 ± 0.2	nd	0.8 ± 0.3
98BRON155	nd	nd	nd	nd	nd
99LGWO50	0.4 ± 0.1	nd	nd	nd	0.4 ± 0.1
B.9904	2.0 ± 0.1	19.4 ± 1.1	1.6 ± 0.1	9.4 ± 0.3	32.4 ± 1.4
Tx2911	20.0 ± 0.5	42.4 ± 1.3	27.0 ± 0.2	49.8 ± 0.6	139.2 ± 1.5
SC719-11E	6.1 ± 0.2	25.0 ± 0.9	8.2 ± 0.3	23.1 ± 1.2	62.4 ± 1.0
98CA4779	29.2 ± 0.9	18.2 ± 1.5	30.2 ± 0.4	8.6 ± 0.2	86.2 ± 3.0
SC103 x SC748 (light)	13.5 ± 0.2	5.7 ± 0.2	14.1 ± 0.5	3.5 ± 0.1	36.8 ± 0.9
SC103 x SC748 (dark)	29.1 ± 0.8	16.4 ± 0.7	11.9 ± 0.7	6.3 ± 0.3	63.7 ± 2.3
Tx430 Black	174.2 ± 2.0	165.4 ± 2.0	153.5 ± 3.1	137.4 ± 3.1	630.5 ± 10.0
Black PI Tall	282.6 ± 3.3	166.2 ± 1.2	126.0 ± 1.9	104.9 ± 1.8	679.7 ± 6.2

[a] Values are mean of triplicates ± standard deviation.
[b] Luteolinidin.
[c] Apigeninidin.
[d] 5-Methoxyluteolinidin.
[e] 7-Methoxyapigeninidin.
[f] Not detected.

tive effect on flavone levels in red/purple plant sorghums ($p < 0.05$) probably because both black sorghums had a thick pericarp. When those two samples were removed from the set, no significant differences were found ($p > 0.05$).

Flavone profiles varied among the samples (Table 3). Apigenin was the main flavone in 02CA4796 and B.01336, which accounted for 85–91% of the total flavones. Luteolin was the only flavone detected in Tx2911 and 98CA4779. Luteolin and apigenin were almost evenly distributed in 99LGWO50 and B.9904. However, luteolin was the main flavone in the remaining samples, which accounted for 76–88% of the total flavones.

The high flavone and low 3-deoxyanthocyanin levels for 99LGWO50 were not expected. In a previous study (Dykes et al., 2005), 99LGWO50 was classified as a red plant sorghum, which was based on visual observations. Secondary plant colour is mostly determined by the presence of pigments in leaves, stalks, and sheaths, which are produced by fungal invasion and insect attacks (Lo et al., 1999; Rooney, 2000). Red specks were observed on some plants of 99LGWO50 and one of the plants had bright red stains on the inside of the sheath. Dykes et al. (2005) reported that 99LGWO50 had total phenol, flavan-4-ol, anthocyanin, and antioxidant activity levels that were in the same range as those in the red/purple plant sorghums. However, these results were based on colorimetric assays, which did not identify the specific compounds that contributed to their elevated levels. In this study, the flavonoid profile of 99LGWO50 indicated that the variety is a tan plant sorghum. The high total phenol levels reported by Dykes et al. (2005) for 99LGWO50 could have been contributed by its elevated flavone levels. Secondary plant colour determination by visual observation could be misleading as was observed in 99LGWO50. Our current study showed that flavonoid profile determination by HPLC could be a good method to determine secondary plant colour.

Table 4
Flavanone levels (μg/g) in red sorghum varieties.[a]

Variety	Eriodictyol	Naringenin	Total
02CA4796	nd[b]	nd	nd
B.01336	6.5 ± 0.4	5.6 ± 0.5	12.1 ± 0.9
99GWO92	nd	8.1 ± 0.8	8.1 ± 0.8
98BRON155	nd	48.4 ± 0.5	48.4 ± 0.5
99LGWO50	nd	19.2 ± 0.1	19.2 ± 0.1
B.9904	9.5 ± 0.8	7.2 ± 0.9	16.7 ± 1.7
Tx2911	nd	26.0 ± 0.3	26.0 ± 0.3
SC719-11E	nd	15.8 ± 0.7	15.8 ± 0.7
98CA4779	nd	19.1 ± 1.0	19.1 ± 1.0
SC103 x SC748 (light)	5.6 ± 0.5	21.8 ± 0.7	27.4 ± 1.2
SC103 x SC748 (dark)	12.9 ± 0.2	28.8 ± 0.7	40.7 ± 0.9
Tx430 Black	nd	nd	nd
Black PI Tall	nd	nd	nd

[a] Values are mean of triplicates ± standard deviation.
[b] Not detected.

3.3. Evaluation of sorghum flavanones

Eriodictyol and naringenin were the two flavanones identified in some sorghums. Flavanone levels ranged from 0 to 48 μg/g with 98BRON155 having the highest (Table 4). These compounds were not detected in the white and black sorghums (02CA4796, Tx430 Black, Black PI Tall). Secondary plant colour and pericarp thickness did not affect flavanone levels ($p > 0.05$).

Flavanone profile varied among the samples. Naringenin was the only flavanone detected in some samples (i.e. 98BRON155, Tx2911, SC719-11E) (Table 4). Both eriodictyol and naringenin were detected in B.01336, B.9904, SC103 x SC748 (light), and SC103 x SC748 (dark), and their proportions varied. Eriodictyol was the predominant flavanone in B.9904 and B.01336, which accounted for 54–57% of the total flavanones. Naringenin was the main flavanone in SC103 x SC748 (light) and SC103 x SC748 (dark) which accounted for 69–80% of the total flavanones.

3.4. Effect of sunlight exposure on flavonoid levels in Tx430 Black

Black sorghums are, genetically, red sorghums. However, their pericarp turns black when exposed to sunlight during maturation. The elevated 3-deoxyanthocyanin levels in black sorghums may be due to its unique pericarp colour (Awika et al., 2004; Dykes et al., 2005). To test this hypothesis, Tx430 Black panicles were selected and covered with pollinating bags from anthesis to physical maturity during the 2004 crop year. When the bags were removed, the grains of Tx430 Black were red (Fig. 1). Grains from the uncovered panicles had three times more 3-deoxyanthocyanins (617 μg/g) than those that were covered (212 μg/mL) (Fig. 2A), which suggested these compounds were produced while the panicles were exposed to sunlight. The production of anthocyanins in the presence of sunlight during fruit development was reported in grapes, and it was suggested that light exposure of the fruit prior to pigment accumulation could increase the activity of enzymes responsible for anthocyanin synthesis (Dokoozlian & Kliewer, 1996).

The flavone and flavanone levels of the covered and uncovered panicles were almost similar (Fig. 2A). The 3-deoxyanthocyanin composition of the grains from the covered and uncovered panicles varied (Fig. 2B). However, the flavone and flavanone compositions of both samples were almost identical (Fig. 2C and D).

All compounds responsible for the black colour of the pericarp were not extracted because the residues remained black. Pericarp colour is perhaps developed by the oxidation of flavonoids in the

Fig. 1. Tx430 Black grains from panicles that were (A) covered and (B) uncovered during their development in College Station, TX, USA in 2004.

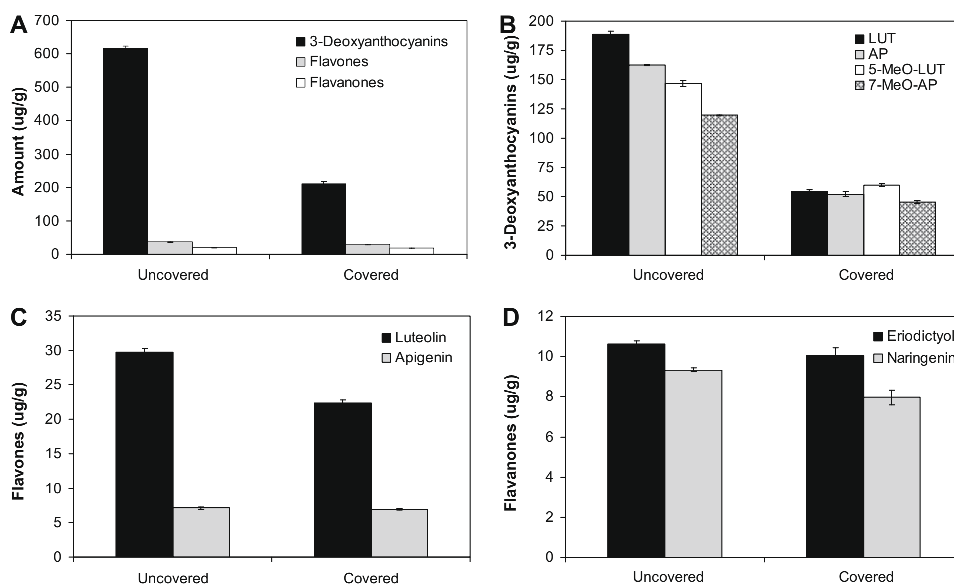

Fig. 2. (A) Flavonoid, (B) 3-deoyxanthocyanin, (C) flavone and (D) flavanone compositions of Tx430 Black from panicles that were left uncovered and covered during their development in College Station, TX, USA in 2004.

pericarp during maturation (Waniska & Rooney, 2000). However, this hypothesis was not tested since no documentation on the extraction of compounds contributing to pericarp blackness exists. The production of black pigments and the elevated levels of 3-deoxyanthocyanin in the black sorghums make these genotypes different from the other typical red sorghums. Thus, they should be reclassified into a fourth category, black sorghum, in terms of pericarp colour even though they have the *R_Y_* genes for red pericarp. There is a necessity to determine which gene(s) causes the pericarp to turn black in the presence of sunlight.

4. Conclusions

Red sorghums contain numerous flavonoids and their composition varied among genotypes. Red/purple plant sorghums, especially those with a black pericarp, had higher 3-deoxyanthocyanin levels than those from tan plants. However, tan plant sorghums had higher levels of flavones. Secondary plant colour did not affect flavanone levels, which were relatively low. Some red sorghum genotypes, when exposed to sunlight, turned black, which increased 3-deoxyanthocyanin levels three-fold. Further work is needed to determine differences in flavonoid composition among other sorghum genotypes. This information will be useful to sorghum breeders for the selection of sorghums with increased levels of desired healthy components. Sorghum as a source of flavonoids has many advantages. Sorghum is dry, easy to store for long periods of time, and easy to process into shelf-stable concentrates.

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