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Changes in whole grain polyphenols and antioxidant activity of six sorghum genotypes under different irrigation treatments

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ABSTRACT

Sorghum grain containing elevated polyphenolic antioxidant content may provide foods with benefits to human health. A study was undertaken to determine the potential role of irrigation on the content of polyphenols and antioxidant levels in sorghum grain. Bound, free and total polyphenols were investigated in six diverse sorghum genotypes grown under either full irrigation or a deficit irrigation regime. Results showed genotype, irrigation and their interaction had a significant effect on polyphenols and antioxidant activity ($P \leqslant 0.05$). The deficit irrigation treatment significantly increased polyphenol content and antioxidant activity compared to the full irrigation treatment. Of the six genotypes Shawaya black short 1 and IS1311C (brown) showed the highest polyphenols levels and antioxidant activity. Therefore, both irrigation treatments and genotype need to be considered by sorghum breeders and farmers during sorghum production to produce grain with the required levels of polyphenolics and antioxidant activity for targeted end-use.

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most valuable global cereal crop after wheat, rice, maize and barley. Due to its adaptability to drought and high temperatures, sorghum is widely grown in semi-arid and arid regions, where sorghum porridge is consumed as a major part of the diet (Stefoska-Needham, Beck, Johnson, & Tapsell, 2015). Although sorghum has been a significant component of the diet for populations in developing areas of the world for centuries, there has been less interest in sorghum as a human food source in developed countries, such as Australia and the United States, where it has been primarily used as livestock feed and biofuel production (Lemlioglu-Austin, 2015). However recently, more attention has been paid to the consumption of sorghum as a human food source, in developed countries, as a gluten free alternative to wheat and due to its high content health-promoting components, such as phenolic antioxidant compounds (Althwab, Carr, Weller, Dweikat, & Schlegel, 2015; Dykes, Peterson, Rooney, & Rooney, 2011).

Phenolic compounds possess a benzene ring with one or more hydroxyl groups, and could be negative in terms of reducing starch, protein and minerals digestibility (Stefoska-Needham et al., 2015; Wu et al., 2016). However, recently, phenolic compounds have gained increased interest because of their antioxidant activity. The consumption of these compounds is thought to have potential health benefits, such as reducing oxidative stress and providing anti-inflammatory and anti-carcinogenic properties (Stefoska-Needham et al., 2015). A wide array of phenolic compounds, including phenolic acids, flavonoids, and condensed tannins, has been found in sorghum grain (Stefoska-Needham et al., 2015). Sorghum genotypes with pigmented testa have been found to have

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the highest phenolic content and antioxidant activity (Dykes, Rooney, Waniska, & Rooney, 2005). Most sorghum flavonoids are in the outer layers of the grain, and consequently their concentrations and profiles are related to pericarp colour, pericarp thickness and the presence of testa; these profiles being under genetic control (Taleon, Dykes, Rooney, & Rooney, 2012). For example, the white-grained sorghum genotypes have lower phenolic content and simpler phenolic profiles than coloured ones (Wu et al., 2016). It has long been known that the antioxidant activity of plant foods is affected not only by total amount of phenolic compounds but also by specific individual phenolic compounds (Rice-Evans, Miller, & Paganga, 1996). Therefore, it is important to investigate both total and individual phenolic compounds of sorghum genotypes to better understand which may be most suited to particular food applications.

Water deficit is one of the principal factors restricting crop performance in arid and semiarid regions, due to irregular annual rainfall during the growing season (Alderfasi, Selim, & Alhammad, 2016). Irrigation treatments can improve the quality of the crop in areas of low rainfall where there is access to water for irrigation purposes. Pernice et al. (2010) planted tomato with three irrigation treatments and found that no irrigation and reduced irrigation could increase the flavonoid concentrations and antioxidant activity of tomato fruits, when compared to standard irrigation. Romero, Tovar, Girona, and Motilva (2002) found that water stress had significant effects on phenolic profile and content of fruit from young olive trees, which in turn was related to increase oxidative stability, but could enhance bitterness index of virgin olive oils, which may negatively affect consumer acceptance. Servili et al. (2007) also reported that the phenolic profiles of virgin olive oil were affected by water stress during plant growth, which in turn influenced its sensory characteristics, such as increase“bitter” and “pungent” characteristics. However, no information is available on how water stress can affect the phenolic compounds in sorghum grain, which will be of particular importance in selection of genotypes and irrigation regimes to provide polyphenolic levels in the grain for food products, targeted at those with different nutritional and health status.

Therefore, the purpose of this work was to investigate both the effects of water stress on content of phenolic compounds and antioxidant activity of sorghum grain, and the response of six different sorghum genotypes. In addition, selected individual phenolic compounds were quantified, in order to gain preliminary understanding of the extent to which water stress might affect the biosynthesis of individual phenolic compounds in sorghum grain.

2. Materials and methods

2.1. Plant material and treatments

Experiments were carried out at Curtin University Field Trials Area, Perth, Western Australia (latitude 32°00/S, longitude115°53/E, altitude 20 m) during 2014–2015. Fig. 1 presents the daily values of rainfall and air temperature, which were adopted from the nearest Bureau of Meteorology weather station (Perth Airport WA) (BOM (Bureau of Meteorology), 2014). Six sorghum genotypes: black pericarp ‘Shawaya’, brown pericarp ‘IS131C’, white pericarp ‘QL12’ and three red pericarp genotypes ‘QL33/QL36’, ‘B923296’ and ‘QL33’ were used. The seeds for these genotypes were provided from the Australian sorghum pre-breeding program, a partnership between the University of Queensland, the Queensland Department of Agriculture and Fisheries and the Grains research and Develop Corporation, courtesy of Professor David Jordan (Supplementary Table S1). They were chosen to represent a diverse range of seed colours and hence polyphenolic profiles. Seeds were planted in 1 m^2 fibre-glass chambers with a depth of 0.5 m. Within each chamber were planted one row each of three sorghum genotypes, rows spaced 0.25 m apart, with each row containing five plants spaced 0.2 m apart.

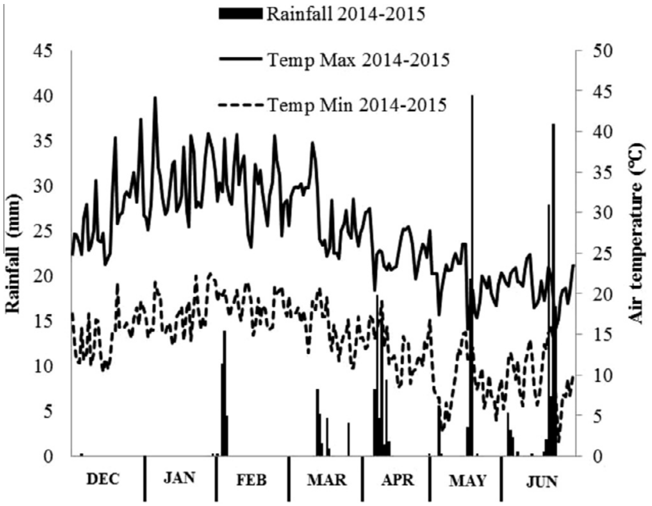

Fig. 1. Daily rainfall, and minimum and maximum air temperatures recorded by the Bureau of Meteorology weather station at Perth Airport from December 2014 to June 2015.

Irrigation treatments were applied according to the crop potential evapotranspiration (PETc), which was calculated from the reference crop evapotranspiration (PET_0) and the FAO crop coefficient (Kc) for sorghum (Allen, Pereira, Raes, & Smith, 1998). PET_0 from a weather station close to the experimental field was 876.7 mm during the growing season, and PETc was 606.93 mm during the growing season. The experimental irrigation implementation was based on PETc, and two irrigation treatments were applied. The total amount of water supplied for full irrigation was 600 mm (100% PETc.), while the water for the deficit irrigation was 450 mm (75% PETc.) during the growing season.

Sorghum seed was sown on 9th December 2014. The sowing date was defined as day 0, and the irrigation treatments were applied two weeks after sowing. Sorghum was irrigated every 3–4 days with a total of 24 watering days during the growing season. Two replication rows of each genotype were sown per irrigation treatment in a randomised complete block design across 12 planting chambers. All grains were harvested, air-dried (to moisture content of around 10%), manually threshed and cleaned, vacuum packed and stored at −20 °C until analysis.

2.2. Standards and reagents

Hydrochloric acid, formic acid, sodium carbonate, sodium hydroxide, sodium nitrite, aluminum chloride, methanol, acetonitrile, ethyl acetate, Folin-Ciocalteau reagent, trolox, 2,2′–azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), 2-2-diphenyl-1-picrylhydrazyl (DPPH), catechin, gallic acid, ferulic acid, caffeic acid, luteolin, apigenin, and naringenin were all purchased from Sigma-Aldrich (St. Louis, MO, USA). Taxifolin, luteolinidin chloride, and apigeninidin chloride were obtained from EXTRASYNTHESE (Neuville-sur-Saône, France). All chemicals were of analytical or HPLC grade.

2.3. Physical characteristics of grain

The physical characteristics of weight (mg) and diameter (mm) were measured using a Single Kernel Characterization System