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Physicochemical and Nutritional Potential of Fifteen Sorghum Cultivars from Burkina Faso

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Abstract: (1) Background: Sorghum (*Sorghum bicolor* (L.) Moench) is a staple food cereal for most of the rural populations in sub-Saharan Africa. In Burkina Faso, a great diversity of sorghum cultivar is cultivated, but its nutritional potential still needs to be assessed. This study aims to characterize the physicochemical and nutritional profile of grains from 15 sorghum cultivars grown in Burkina Faso in order to identify the best ones for selection and breeding programs. (2) Methods: The physicochemical, nutritional, and antioxidant-activity characterizations of the grains were performed according to standard methods. (3) Results: The study shows significant differences between cultivars according to the physicochemical traits of the grains, such as 1000-grain weight, moisture, and germination rate. For nutritional parameters, the best contents of carbohydrates (79.36%), proteins (9.21%), and fats (4.40%) were recorded with cultivars V12, V8, and V11, respectively. The heavy grains are flouriest with high contents of carbohydrates with high ABTS antiradical activity. However, these grains have low contents of proteins and flavonoids. Those with high ash contents are the richest in amylose and phenolic compounds. Principal component analysis based on physicochemical and nutritional characteristics of sorghum grains identified four groups of varieties with specific characteristics. Group 1 (G1), which includes cultivars V1, V12, V13, V14, and V15, is characterized by a high weight of 1000 grains and mealy cultivars with relatively high total carbohydrate content and $ABTS^{\cdot+}$ antiradical activity. Group 2 (G2) includes cultivars V7, V9, and V11 and is characterized by cultivars with low 1000-grain weight, less floury but good germination rate, high protein, flavonoids, and relatively high antioxidant activity. Group 3 (G3) includes cultivars V3, V4, and V8 with relatively high ash, amylose, and polyphenol contents, while group 4 (G4), which includes cultivars V2 and V6, has high antioxidant activity and high fatty acid content. Conclusions: The study recorded a variation of physicochemical and nutritional characteristics of sorghum grain according to cultivars. The cultivars were divided into four groups. Among them, the group 1 cultivars have the best nutritional traits and could therefore be used in breeding and selection programs to improve the nutritional potential of sorghum.

Keywords: sorghum cultivar; grain characteristics; physicochemical; nutritional potential

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1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) ranks as the fifth-most important cereal crop behind wheat, rice, maize, and barley, [1]. Current annual production of sorghum is estimated to be 60.4 million tons worldwide and 30.4 million tons in Africa [2]. Sorghum

is the staple food of many people in the dry tropics of Africa and Asia [3]. It is a strategic crop for food security in some African countries due to its capacity to withstand drought, compared to other crops, such as maize [3,4]. Sorghum is grown in the developed nations essentially for animal feed. However, in Africa and Asia, the grain is used both for human nutrition and animal feed [5].

Based on its utilization, *S. bicolor* is divided into three groups, namely grain sorghum for human consumption, forage sorghum for animal feed, and sweet sorghum, which is harvested for its stems to be processed as sweetener [3,6]. Grain sorghum is a staple food with many advantageous properties, including high fiber content, gluten-free composition, and low glycemic index, and contains many phytochemicals, including phenolic compounds, phytosterols, polycosanols, etc. [7].

In Burkina Faso, sorghum is the dominant cereal with a production of 1.9 million tons. It is generally grown by subsistence farmers in diverse, low-input systems, with production occupying 1.9 million ha, i.e., 42% of arable land [8]. In the country, the grain is used in the manufacture of specific local foods, such as "tô", a fine porridge for infants, granulated foods such as "couscous", and local beers such as "dolo" [5,9]. Several varieties of sorghum, including imported varieties and local varieties of the guinea botanical race, are the most widely grown crops in traditional cropping systems. This preference is related to the characteristics of their endosperms that are suitable for food use by rural populations and also to their low crop requirements in terms of fertilizer and life cycle [10,11]. Crop emphasis is generally based on agronomic traits and sociocultural uses [12]. Unfortunately, the biochemical characteristics and nutritional values of these sorghum varieties are unknown or poorly characterized [13]. Many studies have linked biochemical characteristics to grain nutritional value and processing ability in cereals [14]. Knowledge of the nutritional potential and antioxidant activities of varieties in Burkina Faso could make it possible to identify and make the best varieties available to breeding and varietal improvement programs to improve the nutritional potential of sorghum [15]. The hypothesis underlying this study is that there is variability in the physicochemical and nutrient potential of sorghum varieties grown in Burkina Faso that can serve as a basis for breeding and improvement programs. However, the lack of information on the nutritional value of sorghum grain does not allow varietal improvement programs to undertake adequate genetic improvements on varietal profiles, which could facilitate the choices for industrial and agri-food processing. This study aims to characterize the nutritional profile and antioxidant potential of grains from fifteen sorghum cultivars grown in Burkina Faso in order to identify the best ones for selection and breeding programs.

2. Materials and Methods

2.1. Plant Material

Grains of 15 sorghum cultivars, including 13 local ones, collected in the Centre-West, Centre-East, and East regions of Burkina Faso [9], and two improved from the Institute of the Environment and Agricultural Research of (INERA)/Saria gene bank were used in this study. These cultivars are habitually involved in ordinary consumption or other uses (Table 1). Their agro-morphological traits are known. They have undergone several cycles of self-pollination to make them homozygous at the INERA Saria research station, located between 12°16′ North latitude and 2°09′ West longitude, at an altitude of 300 m. From a climatic and soil point of view, Saria is representative of the entire central plateau. The climate is of the North Sudanian type [16], characterized by a rainy season from May to October and a dry season from November to April. Precipitation undergoes large interannual variations. The average rainfall of the Saria station during the period 2007–2016 was 870 mm, with 65 rainy days.

Table 1. Origin and botanical race of the sorghum varieties studied.

Variety Code	Local Name of Variety	Type of Variety *	Region/Origin	Village or Structure of Provenance	Botanical Race **	Cycle Sowing to 50% Heading (Day)
V1	Wal vêguin lobé	OLV	Centre-East	Dirlakou	G-C	64
V2	Yaga 2	OLV	Centre-East	Zabatourla	G-g	68
V3	Ibiari moani	LVP	East	Konli 2	G-g	93
V4	Ikparbinuani	LVP	East	Konli 2	G-g	93
V5	Icuari 2	OLV	East	Konli 2	G-g	89
V6	Icourbobi moani	LVP	East	Koulga	G-M	109
V7	Icuari moani	OLV	East	Koulga	G-g	93
V8	Kiodi ou Balinga	LVP	East	Diora	G-g	82
V9	Woubri glume rouge	OLV	East	Kossougou-dou	G-g	71
V10	Woubri	OLV	East	Dassari	G-g	75
V11	Kourbouli glume rouge	OLV	East	Kossougou-dou	G-g	71
V12	G1296	IV	Gene bank	INERA/Saria	G-C	74
V13	Nafo-natogué (775)	ILV	Gene bank	INERA/Saria	G-g	64
V14	Sorgho sucré Baoghin	OLV	Centre-West	Nadiala	G-g	66
V15	Sorgho sucré Villy	OLV	Centre-West	Villy	G-g	66

Legend: * Type of variety: OLV = ordinary local variety, LVP = local variety used in pharmacopeia, ILV = improved local variety, IV = improved variety; ** Botanical race: G-C = Guinea-caudatum, G-g = Guinea-gambicum, G-M = Guinea-margatitiferum.

2.2. Methods

Grains were placed in a sieve, with a mesh smaller than the grain size, before being washed with tap water to remove foreign particles. They were then dried out using direct sunlight in the laboratory for 7 days. For each cultivar, 100 g of grains were ground using a blender (BINATONE) to obtain flour with a particle size $\Phi \leq$ of 0.5 mm. The flour was stored at a temperature below 4 °C away from light and was used for the assays.

2.2.1. Determination of Grain Characteristics

The assessed traits were carried out for germination rate, 1000-grain weight, vitreousness, and the color of the grains. The germination of the seed was done at room temperature (25–30 °C) according to the Dedi and Allou [17] method. For each sample, three batches of 100 grains drawn at random were placed in petri dishes (lined with wattman n°1 filter paper) and watered regularly (every 12 h) with distilled water for 120 h. The appearance of the radicle was the germination criterion. The 1000-grain weight was determined by manual counting [18]. The grain vitreousness index was assessed by visual observation of the endosperm texture on a scale of a one-to-five equivalent to the IBPGR and ICRISAT [19] code: one is a completely vitreous endosperm and five is a completely floury endosperm. The color of the pericarp was determined by using a colorimeter (PCE-CMS 2) as described by Black and Panozzo [20]. Grains placed on white paper were flashed using the colorimeter. The L*, a*, b*, and ΔE parameters were determined according to the "CIE-LAB" colorimetric system.

2.2.2. Determination of Sorghum Grain Nutritional Value

The moisture content, dry matter content, and crude ash content were determined according to the thermogravimetric methods using an oven (BANDER) (ISO 2171:2007). The determination of total proteins was performed by the spectrophotometric method of using Bradford's reagent with a UV–visible spectrometer (Epoch, BioTeK) [21]. The fat content (% DM) was determined by differential weighing before and after extraction with a Soxhlet apparatus [22]. Indeed, samples of five grams of flour were extracted with 200 mL petroleum ether (CARLO ERRA Reagents) for six hours at 65 °C. Total carbohydrate content was calculated by difference. The starch, amylose, and amylopectin contents

were determined by using a spectrometric method described by Jarvis and Walker [23]. The energy value of the sorghum grains was calculated using the coefficients of Atwater and Benedict.

2.2.3. Determination of Phenolic Compounds Content

The determination of total phenolic content (TPC) was performed by the spectrophotometric method of using Folin and Ciocalteu's reagent, as described by Singleton et al. [24], with a hydro-ethanolic (20:80 v/v) sample extract. The TPC is expressed in mg of gallic acid equivalent per 100 mg of dry matter (mg GAE/100 mg DM).

The total flavonoids content (TFC) was determined according to a spectrophotometric method of using aluminum trichloride ($AlCl_3$), as described by Arvouet-Grand et al. [25]. The total flavonoids contents were determined from a quercetin calibration curve (0–100 ug/mL) and are expressed in mg of quercetin equivalent/100 mg (mg EQ/100 mg, DM).

Determination of 3-deoxyanthocyanidins (3-DAs) was performed by the direct spectrophotometric quantification method with a UV–visible spectrometer (Epoch, BioTeK), as previously described [5]. The 3-DAs contents are expressed in mg of apigeninidin equivalent per 100 mg of dry matter (mg EA/100 mg DM).

2.2.4. Determination of Antioxidant Activity

The assessment of antiradical activity by the 2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) radical cation (ABTS.+) test was carried out according to the method described by Re et al. [26]. The antioxidant activity is expressed in µmol of ascorbic acid equivalent per 100 mg of dry matter (µmol AAE/100 mg DM).

The assessment of the antioxidant activity by the Ferric Reducing Antioxidant Power (FRAP) test was carried out according to the method described by Hinneburg et al. [27]. The concentration of reducing compounds in the extract is expressed in mg of ascorbic acid equivalent per 100 mg of extract.

The assessment of antioxidant activity by trapping the free 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical was carried out as described by [28]. The results are expressed in mg of ascorbic acid equivalent per 100 mg of dry flour (mg AAE/100 mg DM).

2.2.5. Statistical Analysis of Data

All data are expressed as mean ± standard deviation (SD) of three replicates. Statistical analysis was performed using the XLSTAT software (version 2021.1). Significant differences among the samples were calculated using one-way ANOVA, followed by Tukey's multiple –comparison test at 5% level ($p \leq 0.05$). Linear correlations coupled with a principal component analysis (PCA) were carried out with the traits' mean values to establish the relationships between the variables and the similarities between the individuals.

3. Results

The characterization of the traits, physicochemical and nutritional potential, of the grains show a very significant variation ($p < 0.001$) between the different cultivars for all the variables measured.

3.1. Sorghum Grain Traits

Analysis of grain traits (Table 2) showed significant variation in grain color, presence of Testa layer, glassiness, germination capacity, and 1000-grain weight. The average seed germination rate after 120 h was 84.4%. Cultivars V14 and V7 showed the lowest (53%) and the highest rates of germination (99%), respectively. The average weight of the 1000-grain weight ranged from 16.63 g (V8) to 34.70 g (V4). The vitreousness varied from 1.5 to 5. The cultivars V12, V13, V14, and V15 showed the flouriest grains (5), while V7 was the most vitreous (1.5). Regarding the grain color, the total color difference (ΔE) varied from 41.64 (V14) to 76.60 (V7), according to the CIELAB chromatic space.

Table 2. Grain characteristics of studied cultivars.

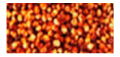
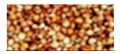
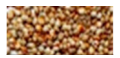
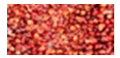
Variety Code	Vitreous Index [(a)]	Testa [(b)]	Rate of Germination (%)	1000-Grain Weight (g)	Grain Color				Grain Images
					L*	a*	b*	ΔE	
V1	4.5	P	73.0 ± 0.57 ^{c}	26.86 ± 1.50 ^{bc}	42.81 ± 0.31 ^{a}	15.05 ± 0.39 ^{de}	15.83 ± 0.53 ^{bc}	48.07 ± 0.26 ^{a}	
V2	4.5	P	90.0 ± 0.40 ^{efg}	28.37 ± 0.10 ^{bcd}	43.26 ± 0.31 ^{a}	12.70 ± 0.02 ^{cd}	14.66 ± 0.11 ^{b}	47.42 ± 0.32 ^{a}	
V3	3.5	A	88.0 ± 0.54 ^{e}	33.61 ± 1.88 ^{e}	43.90 ± 3.35 ^{a}	24.86 ± 1.54 ^{g}	26.55 ± 0.76 ^{e}	57.06 ± 2.31 ^{bc}	
V4	3	A	98.0 ± 0.48 ^{ijk}	34.7 ± 1.50 ^{e}	60.19 ± 0.30 ^{bc}	7.81 ± 0.05 ^{ab}	16.34 ± 0.19 ^{bc}	62.86 ± 0.33 ^{cd}	
V5	3	A	84.0 ± 0.60 ^{d}	27.91 ± 0.05 ^{bc}	70.59 ± 0.56 ^{de}	5.17 ± 0.26 ^{a}	19.44 ± 0.36 ^{cd}	73.40 ± 0.43 ^{e}	
V6	3	A	92.0 ± 0.51 ^{fgh}	33.39 ± 1.27 ^{de}	37.83 ± 5.60 ^{a}	23.26 ± 0.28 ^{g}	16.38 ± 4.46 ^{bc}	47.44 ± 5.98 ^{a}	
V7	1.5	A	99.0 ± 0.30 ^{k}	28.43 ± 0.07 ^{bc}	73.80 ± 0.75 ^{e}	6.16 ± 0.06 ^{a}	19.56 ± 0.18 ^{cd}	76.60 ± 0.69 ^{e}	
V8	3	A	95.0 ± 0.57 ^{hij}	16.63 ± 1.50 ^{a}	64.29 ± 1.05 ^{bcd}	7.31 ± 0.34 ^{ab}	21.88 ± 0.51 ^{d}	68.30 ± 1.12 ^{de}	
V9	3	A	89.0 ± 0.42 ^{ef}	25.21 ± 0.10 ^{b}	68.52 ± 0.35 ^{cde}	6.94 ± 0.76 ^{a}	15.10 ± 1.09 ^{b}	70.51 ± 0.65 ^{de}	
V10	3.5	P	68.0 ± 0.56 ^{b}	28.71 ± 0.15 ^{bcd}	71.38 ± 0.09 ^{de}	5.35 ± 0.01 ^{a}	18.37 ± 0.06 ^{bcd}	73.90 ± 0.08 ^{e}	
V11	3	A	92.0 ± 0.49 ^{fgh}	26.09 ± 0.76 ^{b}	57.60 ± 0.02 ^{b}	10.57 ± 0.03 ^{bc}	21.64 ± 0.01 ^{d}	62.43 ± 0.02 ^{cd}	
V12	5	P	96.0 ± 0.58 ^{ijk}	31.03 ± 1.04 ^{cde}	39.92 ± 1.08 ^{a}	19.27 ± 0.13 ^{f}	21.05 ± 1.40 ^{d}	49.07 ± 1.53 ^{ab}	
V13	5	P	93.0 ± 0.45 ^{ghi}	27.51 ± 0.05 ^{bc}	40.67 ± 0.10 ^{a}	16.81 ± 0.21 ^{ef}	18.58 ± 0.32 ^{bcd}	47.77 ± 0.28 ^{a}	

Table 2. *Cont.*

Variety Code	Vitreous Index [(a)]	Testa [(b)]	Rate of Germination (%)	1000-Grain Weight (g)	Grain Color				Grain Images
					L*	a*	b*	ΔE	
V14	5	P	53.0 ± 0.56 [a]	33.42 ± 1.50 [de]	41.01 ± 4.21 [a]	6.46 ± 1.30 [a]	2.79 ± 0.82 [a]	41.64 ± 3.91 [a]	
V15	5	P	56.0 ± 0.53 [a]	33.97 ± 1.24 [e]	41.19 ± 9.02 [a]	7.99 ± 3.58 [ab]	4.74 ± 1.81 [a]	42.48 ± 8.09 [a]	
F			619.583	27.241	58.42	110.25	60.30	54.72	
Proba. F			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
Significant			Yes	Yes	Yes	Yes	Yes	Yes	

Legend: [(a)] Vitreous index (Gervex code) and correspondence to IBPGR code: 1 = 1, 2 = 3, 3 = 5, 4 = 7, 5 = 9 where 1 is total (100%) vitreous endosperm texture, and 5 is total (100%) floury endosperm texture. [(b)] Testa: "P" = presence, "A" = absence. The means in each column not sharing any letter in common are significantly different ($p < 0.05$).

3.2. Chemical Analysis and Nutritional Potential of Sorghum Grains

Chemical analyses (Table 3) showed significant variation in proximate composition and energy values of the grains among cultivars. Dry matter showed an average of 1.56% DM. Cultivars V9 and V8 had the lowest (1.06% DM) and highest (2.22% DM) values, respectively. The average total carbohydrate content of the grains was 75.91%. It varied from 73.25% to 79.36% DM with V5 and V12, respectively. The average starch content was 62.52% DM. V5 and V10 had the extreme values (54.19% and 73.86% DM). In addition, cultivar V5 had the lowest amylose (15.38% DM) and amylopectin (38.81% DM) contents, while V10 had the highest amylose (23.48% DM) and amylopectin (50.44% DM) contents. The average protein content was 7.51% compared to the dry matter (DM). The lowest content (5.09% DM) and the highest content (9.21% DM) were observed with cultivars V12 and V8. For all 15 cultivars, the average fat content was 3.25% DM. Cultivars V3 and V12 had the lowest content (2.48% DM) and V11 the highest content (4.40% DM). The energy value was, on average, 362.87 kcal/100 g DM. It varied from 355.63 kcal/100 g DM for V5 to 370.26 kcal/100 g DM for V11.

3.3. Phenolics Content and Antioxidant of Sorghum Grains

3.3.1. Phenolics Content

The total phenolic content varied from 1.83 mg of gallic acid equivalent (GAE)/100 g MS for V5 to 7.67 mg GAE/100 g DM for V8 (Figure 1). The total flavonoid content varied from 1.71 mg Quercetin equivalent (QE)/100 g DM (V5) to 2.48 mg QE/100 g DM (V4). The 3-das content varied from 0.11 mg EA/100 mg DM (V7) to 0.94 mg EA/100 g DM (V7).

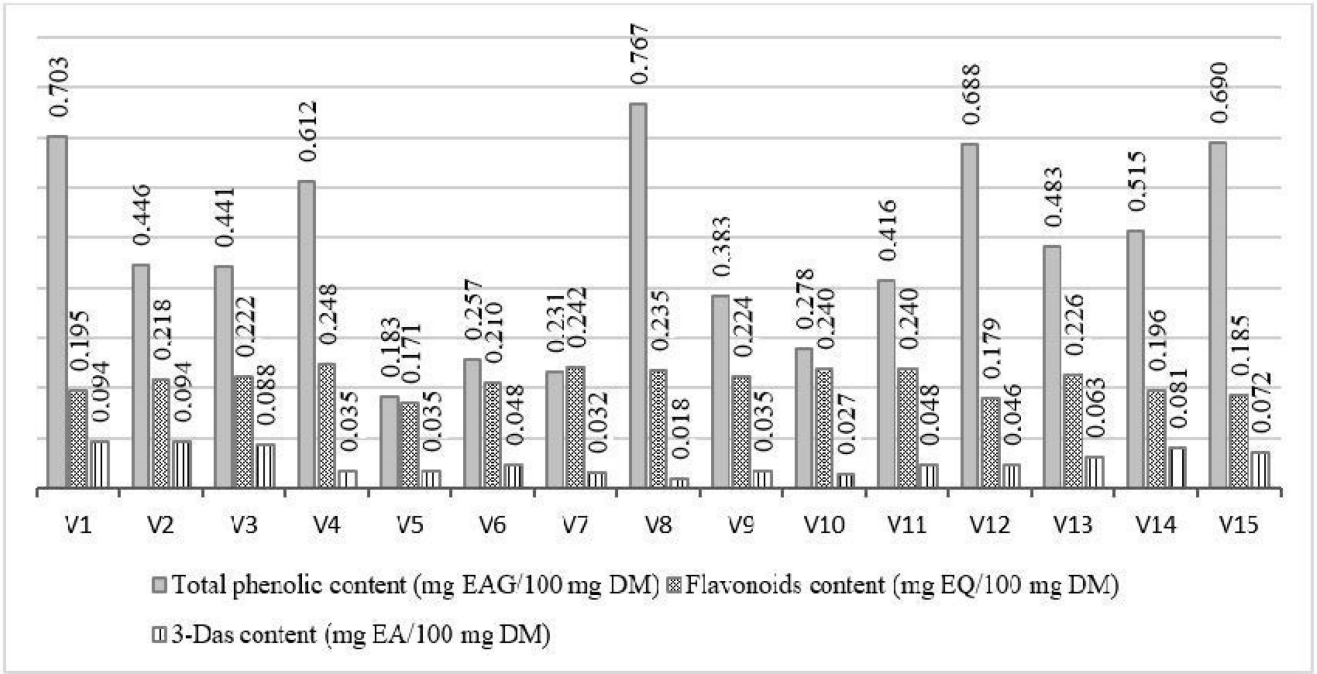


Figure 1. Phenolics content of sorghum cultivars.

Table 3. Chemical analysis and nutritional potential of sorghum grains.

Variety Code	Moisture Content (% FM)	Dry Matter Content (% FM)	Crude Ash Content (% DM)	Carbohydrate Content (% DM)	Fat Content (% DM)	Protein Content (% DM)	Energetic Value (kcal/100 g DM)	Starch Content (% DM)	Amylose Content (% DM)	Amylopectin Content (% DM)
V1	12.40 ± 0.31^{bc}	87.60 ± 0.31 ^{ab}	1.58 ± 0.10 ^{cde}	77.13 ± 1.03 ^{def}	2.74 ± 0.15 ^{ab}	6.14 ± 0.76 ^{abc}	357.78 ± 1.24 ^{ab}	67.70 ± 0.01 ^{ef}	21.52 ± 0.01 ^{bcd}	46.17 ± 0.01 ^{c}
V2	11.83 ± 0.36 ^{abc}	88.17 ± 0.36 ^{bc}	1.42 ± 0.10 ^{bc}	77.66 ± 0.78 ^{ef}	3.20 ± 0.15 ^{cd}	5.87 ± 0.54 ^{ab}	362.99 ± 1.44 ^{bcde}	64.69 ± 0.01 ^{cde}	19.76 ± 0.01 ^{abcd}	44.93 ± 0.00 ^{c}
V3	11.39 ± 0.96 ^{ab}	88.60 ± 0.96 ^{bc}	1.73 ± 0.10 ^{ab}	75.25 ± 1.01 ^{bcde}	2.48 ± 0.15 ^{a}	9.14 ± 0.10 ^{fg}	359.92 ± 3.86 ^{abcd}	66.41 ± 0.05 ^{de}	21.60 ± 0.04 ^{cd}	44.81 ± 0.05 ^{c}
V4	11.81 ± 0.17 ^{abc}	88.19 ± 0.17 ^{bc}	1.85 ± 0.10 ^{ef}	74.64 ± 0.52 ^{abc}	2.62 ± 0.15 ^{ab}	9.06 ± 0.42 ^{fg}	358.44 ± 0.68 ^{abc}	64.81 ± 0.00 ^{cde}	19.26 ± 0.00 ^{abcd}	45.55 ± 0.00 ^{c}
V5	12.97 ± 0.29 ^{c}	85.87 ± 1.43 ^{a}	1.40 ± 0.10 ^{bc}	73.25 ± 1.45 ^{a}	3.54 ± 0.15 ^{de}	7.67 ± 0.03 ^{cde}	355.63 ± 5.74 ^{a}	54.19 ± 0.02 ^{a}	15.38 ± 0.02 ^{a}	38.81 ± 0.01 ^{a}
V6	10.43 ± 1.16 ^{a}	89.57 ± 1.16 ^{c}	1.64 ± 0.10 ^{de}	77.20 ± 1.21 ^{ef}	3.06 ± 0.15 ^{bc}	7.66 ± 0.10 ^{cdef}	367.0 ± 4.64 ^{def}	65.63 ± 0.03 ^{cde}	19.69 ± 0.01 ^{abcd}	45.95 ± 0.02 ^{c}
V7	11.85 ± 0.02 ^{bc}	88.14 ± 0.02 ^{ac}	1.38 ± 0.10 ^{bc}	74.67 ± 0.47 ^{abcd}	3.26 ± 0.15 ^{cd}	8.83 ± 0.44 ^{fg}	363.39 ± 0.10 ^{bcdef}	60.84 ± 0.03 ^{bcd}	17.77 ± 0.02 ^{abc}	43.06 ± 0.01 ^{bc}
V8	11.51 ± 0.10 ^{ab}	88.49 ± 0.10 ^{bc}	2.22 ± 0.10 ^{g}	73.61 ± 0.08 ^{ab}	3.44 ± 0.15 ^{cde}	9.21 ± 0.06 ^{g}	362.30 ± 0.40 ^{abcde}	62.11 ± 0.02 ^{bcde}	18.43 ± 0.01 ^{abc}	43.69 ± 0.01 ^{bc}
V9	11.87 ± 0.02 ^{bc}	88.13 ± 0.02 ^{bc}	1.06 ± 0.10 ^{a}	75.45 ± 0.58 ^{abcde}	3.78 ± 0.15 ^{e}	7.83 ± 0.82 ^{defg}	367.20 ± 0.08 ^{ef}	56.74 ± 0.02 ^{ab}	16.56 ± 0.01 ^{a}	40.18 ± 0.01 ^{ab}
V10	11.25 ± 0.55 ^{ab}	88.74 ± 0.55 ^{bc}	1.36 ± 0.10 ^{bc}	76.83 ± 1.04 ^{cde}	3.46 ± 0.15 ^{cde}	7.08 ± 0.83 ^{bcde}	366.86 ± 2.22 ^{def}	73.86 ± 0.01 ^{f}	23.42 ± 0.01 ^{d}	50.44 ± 0.01 ^{d}
V11	11.42 ± 0.43 ^{ab}	88.58 ± 0.43 ^{bc}	1.52 ± 0.10 ^{bcd}	74.20 ± 0.65 ^{ab}	4.40 ± 0.15 ^{f}	8.45 ± 0.02 ^{efg}	370.26 ± 1.72 ^{f}	62.17 ± 0.05 ^{bcde}	16.88 ± 0.03 ^{abc}	45.29 ± 0.02 ^{c}
V12	11.42 ± 0.17 ^{ab}	88.57 ± 0.17 ^{bc}	1.62 ± 0.10 ^{cde}	79.36 ± 0.16 ^{f}	2.48 ± 0.15 ^{a}	5.09 ± 0.61 ^{a}	360.20 ± 0.70 ^{abcde}	61.22 ± 0.02 ^{bcd}	18.32 ± 0.02 ^{abc}	42.90 ± 0.01 ^{bc}
V13	11.22 ± 0.35 ^{ab}	88.77 ± 0.35 ^{bc}	1.42 ± 0.10 ^{bc}	76.72 ± 0.92 ^{cde}	3.54 ± 0.15 ^{de}	7.09 ± 0.18 ^{bcde}	367.14 ± 1.42 ^{ef}	59.41 ± 0.02 ^{abc}	16.68 ± 0.01 ^{ab}	42.73 ± 0.02 ^{abc}
V14	11.68 ± 0.07 ^{abc}	88.31 ± 0.07 ^{bc}	1.24 ± 0.10 ^{ab}	76.77 ± 0.24 ^{cde}	3.44 ± 0.15 ^{cde}	6.86 ± 0.71 ^{bcd}	365.52 ± 0.30 ^{cdef}	57.83 ± 0.04 ^{ab}	17.44 ± 0.02 ^{abc}	40.39 ± 0.02 ^{ab}
V15	12.44 ± 0.07 ^{bc}	87.56 ± 0.07 ^{ab}	1.98 ± 0.10 ^{fg}	75.82 ± 0.78 ^{bcde}	3.20 ± 0.15 ^{cd}	6.55 ± 0.57 ^{abcd}	358.34 ± 0.28 ^{ab}	60.23 ± 0.02 ^{bcd}	17.30 ± 0.00 ^{abc}	42.93 ± 0.02 ^{bc}
F	4.962	5.635	26.304	12.386	35.991	18.785	10.186	15.658	5.528	14.332
Proba. F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Legend: * The means in each column not sharing any letter in common are significantly different ($p < 0.05$). FM = fresh matter, DM = dry matter.

3.3.2. Antioxidant Activity

The antioxidant activities (Table 4) were assessed according to the DPPH, FRAP, and ABTS methods. With the FRAP method, V2 cultivar showed the best antioxidant activity (0.036 ± 0.003 mg AAE/100 mg DM). With the DPPH method, the highest antioxidant activity was observed with cultivar V7 (0.126 mg AAE/100 mg DM). Using the $ABTS^{\cdot+}$ radical cation reducing power method, the highest antioxidant activity was recorded for cultivar V13 (0.158 mg AAE/100 mg DM).

Table 4. Antioxidant activities of sorghum grain.

Cultivar Code	FRAP (mg AAE/100 mg DM)	ABTS (mg AAE/100 mg DM)	DPPH (mg AAE/100 mg DM)
V1	0.009 ± 0.003 ^{a}	0.026 ± 0.001 ^{i}	0.091±0.007 ^{i}
V2	0.036 ± 0.003 ^{e}	0.002 ± 0.001 ^{f}	0.092±0.004 ^{bc}
V3	0.016 ± 0.004 ^{abc}	0.011 ± 0.000 ^{bcde}	0.102 ± 0.008 ^{cd}
V4	0.010 ± 0.002 ^{a}	0.011 ± 0.001 ^{bc}	0.117 ± 0.005 ^{def}
V5	0.018 ± 0.009 ^{abc}	0.007 ± 0.001 ^{a}	0.118±0.002 ^{def}
V6	0.027 ± 0.003 ^{bcde}	0.012 ± 0.001 ^{cde}	0.107±0.006 ^{cde}
V7	0.026 ± 0.004 ^{bcde}	0.011 ± 0.000 ^{bcd}	0.126 ± 0.003 ^{f}
V8	0.019 ± 0.002 ^{abcd}	0.013 ± 0.001 ^{de}	0.118 ± 0.003 ^{def}
V9	0.020 ± 0.001 ^{abcd}	0.009 ± 0.001 ^{b}	0.121 ± 0.004 ^{ef}
V10	0.028 ± 0.004 ^{cde}	0.010 ± 0.000 ^{bc}	0.119 ± 0.003 ^{def}
V11	0.032 ± 0.004 ^{de}	0.013 ± 0.002 ^{e}	0.113 ± 0.007 ^{def}
V12	0.019 ± 0.005 ^{abcde}	0.020 ± 0.001 ^{fg}	0.113 ± 0.003 ^{def}
V13	0.015±0.002 ^{abc}	0.028 ± 0.000 ^{i}	0.083 ± 0.004 ^{b}
V14	0.014 ± 0.007 ^{ab}	0.021 ± 0.000 ^{gh}	0.058 ± 0.010 ^{a}
V15	0.012 ± 0.002 ^{a}	0.022 ± 0.000 ^{h}	0.066 ± 0.009 ^{a}
F	9.684	251.494	40,897
Proba. F	<0.0001	<0.0001	<0.0001
Significant	Yes	Yes	Yes

Legend: The means in each column not sharing any letter in common are significantly different ($p < 0.05$). FM = fresh matter, DM = dry matter, FRAP = ferric reduction activity power, ABTS = antiradical activity according to the 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) radical cation method, DPPH = antioxidant activity according to the free 2,2-diphenyl-1-picrylhydrazyl radical trapping method.

3.4. PCA Analyses

The PCA analysis performed on the basis of the grain traits studied shows the relationships between the variables and the cultivars on the first two factorial axes. The 1000-grain weight and grain texture are strongly and positively correlated with carbohydrate content and free-radical scavenging activity by the ABTS method and negatively correlated with protein content, flavonoids, DPPH free-radical scavenging activity, and germination capacity of seeds.

On the basis of the characteristics of the grains studied, four main groups of cultivars were distinguished. Group 1 (G1), which includes cultivars V1, V12, V13, V14, and V15, is characterized by heavy-grained and mealy cultivars with relatively high total carbohydrate content and $ABTS^{\cdot+}$ antiradical activity. Group 2 (G2) includes cultivars V7, V9, and V11 and is characterized by cultivars with low 1000-grain weight, less floury but good germination rate, high protein, flavonoid, and relatively high DPPH antioxidant activity. Group 3 (G3) includes cultivars V3, V4, and V8 and is characterized by relatively high ash, amylose, and polyphenol contents, while group 4 (G4), which includes cultivars V2 and V6, have high FRAP antioxidant activity and high fatty acid content (Figure 2).

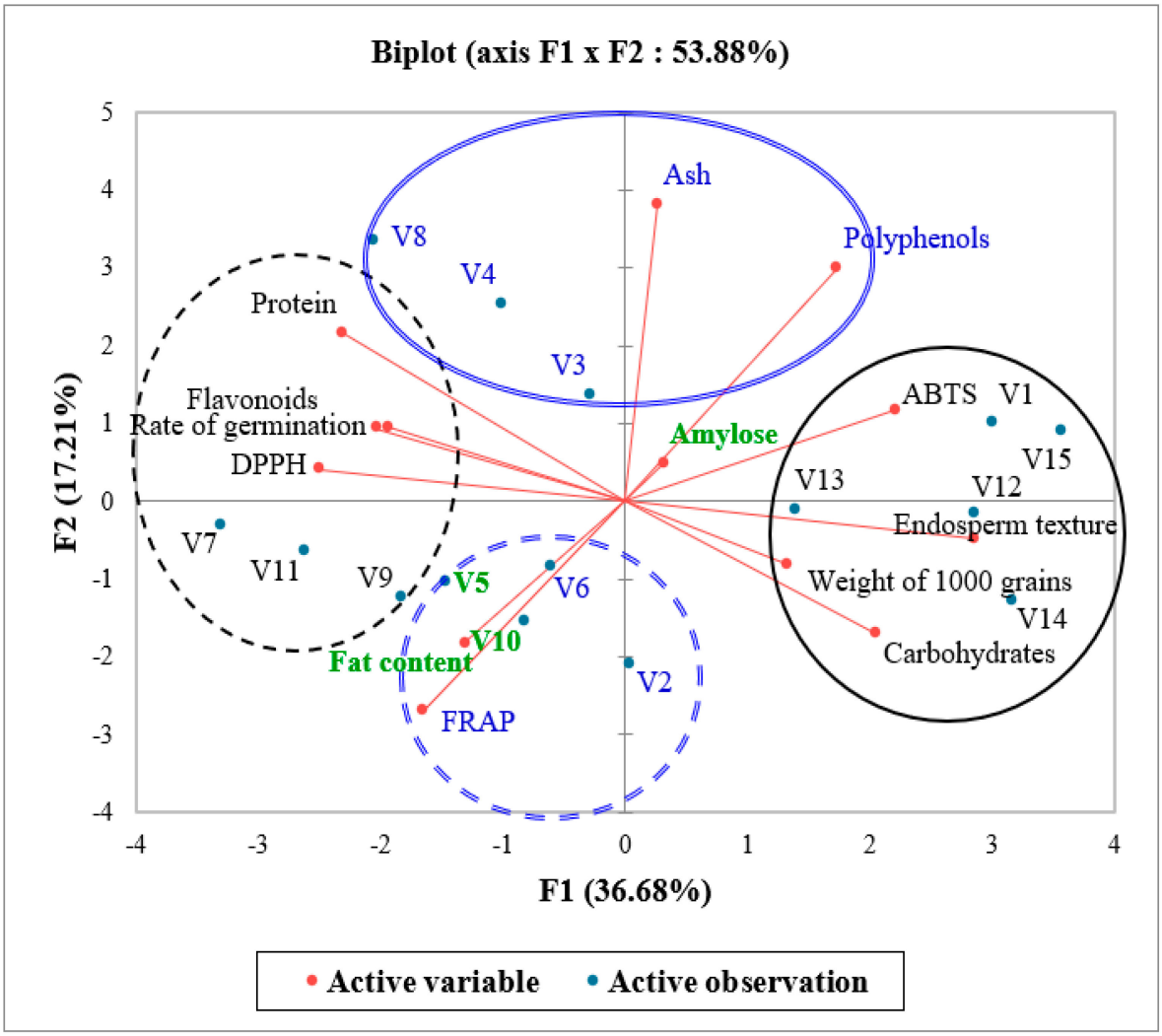


Figure 2. Principal component analyses based on grains characteristics.

4. Discussions

This study aims to characterize the physicochemical and nutritional potential of grains from 15 sorghum cultivars grown in different regions of Burkina Faso. The study reveals significant variation among the sorghum cultivars selected in this study. The color of the pericardium first distinguished the different cultivars. The pericarp color and the endosperm texture (floury or vitreous) appear to be important criteria that determine the use of the grain for different end uses. Indeed, red and heavy grains were preferred for malting and are used in the production of alcoholic beverages [9], while white, vitreous grains were preferred for "tô", a local dish prepared as a thick paste [29]. Thus, the red and floury grain cultivars (V1, V2, V12, V13, V14, and V15) of this study are preferred for malting, while the white and vitreous grain cultivars (V7, V8, and V9) are better appreciated for processing into "tô".

For physicochemical analyses, the values of the study are comparable to those reported by other authors. Indeed, the average rate required to certify the good biological quality of seeds is 80% [29]. Ash and protein contents reported for other sorghum varieties in Burkina Faso ranged from 1.3–2.0% DM and 71–77% DM, respectively [14]. The carbohydrate and fatty acid values are lower than those reported, which were 9.6–12.5% DM and 3.0–6.3% DM, respectively [14]. The contents of starch (54.19–73.86% DM), amylose (15.38–23.42% DM), and amylopectin (38.81–50.44% DM) are similar to those previously reported [11]. This difference in values observed could be explained by the difference in cultivars, which

could lead to genetic variability, but also by environmental factors. The phenolic compound content of the 15 cultivars varied relatively from the values reported in the literature [30]. They were indeed lower than those reported by [5,31], which ranged from 0.08 to 2.6 and 0.46 to 3.1 mg of GAE/100 mg DM, respectively. For total flavonoids, the variations in the cultivars studied were comparable to those found by Triki et al. (2018) with barley extracts. The 3-DA content (0.018–0.094 mg EA/100 mg DM) was variable among cultivars but comparable to values reported by [11]. The high levels (0.063–0.094 mg EA/100 mg DM) recorded with the red grain cultivars could be explained by the "natural" contribution of 3-DAs to the sorghum grain color.

The characteristics of the grains of the cultivars show their good nutritional and nutraceutical potential. The protein content is an important parameter of nutritional value. It plays a role in the properties of flour and creates the food structure [32]. Carbohydrates are essential to the proper functioning of our bodies. They are above all a major energy fuel that can be used quickly and are necessary for the proper functioning of the cells, in particular the muscles, the brain, the heart, and the red blood cells. The phenolic compounds are secreted in response to intrinsic factors as well as stressful environmental conditions [11]. They are an interesting nutraceutical characteristic and play an important role in overall antioxidant activity [30]. It is well known that sorghum is in general richer in phenolic compounds compared to others [5,30,33].

Positive and negative correlations were recorded between some traits. Indeed, the study recorded a negative relationship between grain texture and protein, which shows that when the grain is floury (End $\approx$ 5), the protein content is low. The positive relationships between the starch, amylose, and amylopectin contents, as well as that between polyphenols and ash, show that these traits can be selected simultaneously. This result confirms those of other authors who reported that the antioxidant activity potential of an extract depends on its content of phenolic compounds [34]. Indeed, amylose plays a role in the swelling, gelatinization, and firmness properties of starch gels [33]. For traditional dishes, such as "tô, ugali", amylose and protein would affect the firmness of the dough. The high amylose content (>20.5% DM) of the whole grain, combined with a low protein content, would ensure dough firmness, which is one of the desired qualities in these dishes [35]. Thus, these two traits could be selected simultaneously for varietal profiles targeting these types of processing. The positive correlations between the traits of interest are a very interesting result that allows a judicious choice of the desired cultivars for the simultaneous varietal improvement of the traits. Some cultivars, due to their nutritional and nutraceutical characteristics present interesting characteristics, especially for their richness in proteins, flavonoids, and antioxidant activity (V7, V9, and V11), with FRAP activity and fatty acid (V2, V5, V6, and V10) ABTS activity, and 1000-grain weight and carbohydrates (V1, V12, V13, V14, and V15). These results are very interesting for breeding and varietal improvement programs to improve the nutritional and nutraceutical potential of grains.

5. Conclusions

This study shows great variability in physicochemical, nutritional, and antioxidant traits among the 15 sorghum cultivars of Burkina Faso. Sorghum cultivars have different biochemical profiles. This study reveals that the pericarp color and the endosperm texture (floury or vitreous) appear to be important criteria that determine the final use of the grain for different end uses. The physicochemical traits (low moisture content and high germination rate) suggest good grain quality. Cultivars with a high 1000-grain weight were the flouriest. These grains also had high carbohydrate content with high ABTS activity. However, these grains have low contents of proteins and flavonoids. Those with high ash contents are the richest in amylose and phenolic compounds. Groups of cultivars with specific traits have been identified for breeding and varietal improvement programs to improve the nutritional and bioprotective potential of varieties.

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