BIODIVERSITAS
Volume 24, Number 7, July 2023
Pages: 3903-3915

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240729

Morphological responses of six sorghum varieties on cadmium-contaminated soil

NUR AZIZAH USWATUN HASANAH[1,2], EDI PURWANTO[3,4,♥], PUJI HARSONO[3], SAMANHUDI[3,4], AMALIA TETRANI SAKYA[3]

[1]Doctoral Program of Agricultural Science, Faculty of Agriculture, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

[2]Akademi Komunitas Perkebunan Yogyakarta. Jl. Petung 2, Sleman 55281, Yogyakarta, Indonesia

[3]Departement of Agrotechnology, Faculty of Agriculture, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-637457. ♥email: edipurwanto@staff.uns.ac.id

[4]Center for Research and Development of Biotechnology and Biodiversity, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia

Manuscript received: 19 October 2021. Revision accepted: 16 July 2023.

Abstract. *Hasanah NAU, Purwanto E, Harsono P, Samanhudi, Sakya AT. 2023. Morphological responses of six sorghum varieties on cadmium-contaminated soil. Biodiversitas 24: 3903-3915.* Six sorghum varieties were planted on cadmium-contaminated soil and characterized from April to July 2020 at a rice field in Balecatur Gamping, Yogyakarta. The objectives of this experiment were to characterize the morphological responses of six sorghum varieties and select a variety with a high biomass and Cd uptake for a potential phytoremediator. This experiment used six sorghum varieties, namely Super-1, Samurai-1, Suri-3, Numbu, Kawali, and Hitam, following completely randomized design procedures with four replications. The observation of morphological and agronomical characteristics focused on ten plants as the sample of each plot. The result showed that there were differences in the morphological and agronomical characteristics among six sorghum varieties. Varieties were assessed in terms of distinctness and grouped based on the time of panicle emergence, plant height, panicle shape, and caryopsis color. There were three classes as follows: Class 1, i.e. time of panicle emergence: very early (Super-1, Suri-3, Numbu, and Hitam); plant height: long (Super-1), medium (Suri-3), short (Numbu and Hitam); panicle shape: panicle broader in the upper part (Numbu), symmetrical (Super-1 and Suri-3), pyramidal (Hitam); caryopsis color: white (Super-1), grayish orange (Suri-3 and Hitam), yellowish orange (Numbu). Class 2, time of panicle emergence: early (Samurai-1); plant height: medium (Samurai-1); panicle shape: panicle broader in the lower part (Samurai-1); caryopsis color: yellowish orange (Samurai-1). Class 3, time of panicle emergence: medium (Kawali); plant height: medium (Kawali); panicle shape: panicle broader in the lower part (Kawali); caryopsis color: yellowish white (Kawali). Assessment of agronomical characteristics revealed that fresh plant weight had a significant positive correlation with plant height R1, plant height R5, stem diameter, leaf blade width, thousand-grain weight, and stem sugar content. Several varieties, namely Super-1, Samurai-1 and Kawali, were found to have excellent agronomical characteristics to provide a solid varietal basis for selecting varieties as phytoremediators.

Keywords: Cadmium, morphological characteristics, phytoremediation, sweet sorghum

INTRODUCTION

Rice is the Indonesian people's staple food. Efforts to guarantee the availability of sufficient and safe food for the community through the intensification of plant cultivation have caused negative impacts. Therefore, it is necessary to ensure food quality and safety by preventing food from possible chemical contamination, especially agrochemicals (Rahman et al. 2020; Rosariastuti et al. 2020; Sukarjo et al. 2021). The use of fertilizers and other agrochemicals is crucial for improving rice production (Liao et al. 2021); these two agro-inputs also play a role in the higher levels of heavy metals, particularly cadmium (Cd) (Rahman et al. 2020; Rosariastuti et al. 2020; Sukarjo et al. 2021). Impurities from inorganic fertilizers, liquid waste, animal waste/animal husbandry waste, pesticides, and compost are some harmful elements, especially cadmium (Nookabkaew et al. 2016; Purbalisa et al. 2017; Niño-Savala et al. 2019; Li et al. 2020). According to several studies, heavy metal contamination in agricultural land lower soil productivity (Sherameti and Vaema 2010; Seshadri et al. 2016; Guo et al. 2018; Hussain et al. 2021b), diminish crop yields, and degrade food quality, which can build up in the edible component and cause a variety of diseases (Dias et al. 2013; Genchi et al. 2020; Oliver and Gregory 2015; Zwolak et al. 2019). According to reports, cd contamination in intensively farmed areas ranges from 0.15 to 1.23 mg/kg (Khasanah et al. 2021; Sukarjo et al. 2021). Even at low concentrations, heavy metal contamination can impact soil biology, plants, and human health (Demarco et al. 2018; Zhu et al. 2021).

One of the efforts to improve the quality of rice fields contaminated with heavy metals is phytoremediation (Yuan et al. 2019; Hussain et al. 2021a). Phytoremediation is regarded as a contaminant removal method, particularly for heavy metals, that is simple, sustainable, and economical (Erakhrumen and Agbontalor 2007; Sharma and Pandey 2014). Several studies have reported employing hyperaccumulators in phytoremediation applications (Zhao et al. 2003; Liu et al. 2009; Rascio and Navari-Izzo 2011;

Zhong et al. 2019; Raza et al. 2020). Sorghum can be used as a phytoremediator to clean up heavy metal-contaminated land in addition to being flexible and renewable for bioenergy production, an important plant for land restoration and an agronomically acceptable plant for sustainable integrated agriculture (Epelde et al. 2009; Liu et al. 2010; Angelova et al. 2011; Soudek et al. 2014; Sathya et al. 2016; Yuan et al. 2019). Yet, there hasn't been much focus on sorghum variants that are good phytoremediators. It is easier to characterize the varieties based on important morphological characteristics of phytoremediation (Reddy et al. 2009; Rakshit et al. 2012; Sattler et al. 2018) and use as a tool for preliminary evaluation because they provide a quick way to assess the level of diversity (Sinha and Kumaravadivel 2016). This research was carried out to characterize sorghum's morphological characteristics, which were used to determine the growth performance of six sorghum varieties to obtain varieties with stable qualitative and quantitative characteristics, particularly plants with high biomass as candidates for phytoremediators.

MATERIALS AND METHODS

Study area

The experiment was conducted in Gamping, Sleman, Yogyakarta, Indonesia (7°48' 3" S, 110°18'10" E) (Figure 1). The land used in this study was technically agricultural irrigated with rice crops throughout the season. Soil samples were taken from ex-rice paddy fields, then analyzed for several metal elements. The results were C-organic 1.016%, Organic materials 1.751%; Nitrogen 0.207%; P_2O_5 0.084%; K_2O 0.253%; Cr 0.758 ppm; Cu 0.162 ppm; Cd 2.914 ppm; Pb 0.167 ppm and Zn 0.233 ppm.

The material for the present study comprised six varieties of sorghum. The detail of the varieties is given in Table 1. The grains were supplied by Cereal Crop Research Center, Agricultural Research and Development Agency, The Indonesian Ministry of Agriculture; The National Nuclear Energy Agency of Indonesia, and CV. Agrindo, Yogyakarta, Indonesia (Table 1).

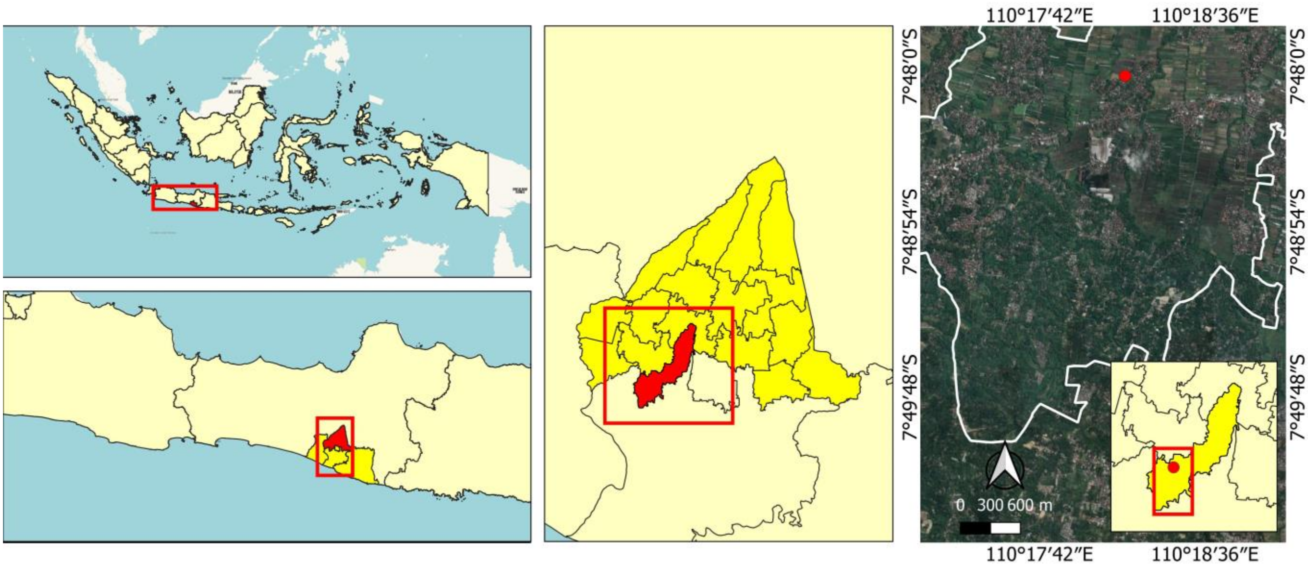

Figure 1. Location of the experiment in Gamping Sub-district, Sleman District, Yogyakarta Province, Indonesia

Table 1. Description of varieties used

Description	Super-1	Samurai-1	Suri-3	Numbu	Kawali	Hitam
Origin	Sumba, NTT	BATAN	India	India	India	China
Year of release	2013	2014	2014	2001	2001	-
Days to 50% flowering (days)	56	61	54	69	70	55
Plant height (cm)	204.8	187.7	230.4	187	135	150
Harvest age (days)	105-110	111	95	100-105	100-110	100-105
Panicle length (cm)	26.67	32.7	29.1	22-23	28-29	24-29
1000 grain weight (grams)	32.10	29.4	33.5	36-37	30	21
Average yield (tonnes / ha)	2.66	6.1	4.5	3.11	2.96	-
Potential yield (tonnes / ha)	5.75	7.5	6.0	4.0-5.0	4.0-5.0	-
Purpose of varietal release	Food; bioethanol	Food; bioethanol	Food; feed; bioethanol	Food; bioethanol	Food; feed: bioethanol	Food; bioethanol

Source: Balitsereal (Super1, Suri3, Numbu, Kawali), BATAN (Samurai1), and CV. Agrindo (Hitam)

Table 2. Qualitative characteristics by the Protection of Plant Varieties and Farmers Rights Authority (PPV & FRA)

Characteristics	States	Stage of observation	Type of assessment
Seedling: Anthocyanin coloration of coleoptile	Yellowish green Grayish purple	Seedling 7-8 days after sowing	VS
Leaf sheath: Anthocyanin coloration	Yellowish green Grayish purple	5 leaf	VS
Leaf: Mid rib color (5th fully developed leaf)	White Yellowish green Grayish yellow Grayishpurple	5th leaf	VS
Plant: Time of panicle emergence (50% of the plants with 50% anthesis)	Very early Early Medium Late Very late	Panicle emergence	VG
Plant: Natural height of plant up to base of flag leaf	Very short Short Medium Tall Very tall	Panicle emergence	MS
Flag leaf: Yellow coloration of midrib	Absent Present	Panicle emergence	VS
Lemma: Arista formation	Absent Present	Flowering	VS
Stigma: Anthocyanin coloration	Absent Present	Upper portion of the panicle at the end of flowering	VS
Stigma: Yellow coloration	Absent Present	Flowering	VS
Stigma: Length	Short Medium Long	Flowering	MS
Flower with pedicel: Length of flower	Very short Short Medium Long Very long	Flowering	MS
Anther: Length	Short Medium Long	Flowering	MS
Anther: Color of dry anther	Yellowish orange Orange Red orange Grayish orange	End of flowering	VG
Glume: Color	Greenish white Yellowish white Grayish yellow Grayish orange Grayish red Grayish purple	Physiological maturity of grain	VG
Plant: Total height	Very short Short Medium Long Very long	Physiological maturity	MS
Stem: Diameter (at the bottom one third of plant height)	Small Medium Large	Physiological maturity	MS
Leaf: Length of blade (the third leaf from top including flag leaf)	Short Medium Long Very long	Physiological maturity	MS
Leaf: Width of blade (the third leaf from top including flag leaf)	Narrow Medium Broad Very broad	Physiological maturity	MS

Panicle: Length without peduncle	Very short Short Medium Long Very long	Physiological maturity	MS
Panicle: Length of branches (middle third of panicle)	Short Medium Long Very long	Physiological maturity	MS
Panicle: Density at maturity (ear head compactness)	Very loose Loose Semi loose Semi compact Compact	Physiological maturity	VG
Panicle: Shape	Inverted pyramid Panicle broader in upper part Symmetrical Panicle broader in lower part Pyramidal	Physiological maturity	VG
Neck of panicle: Visible length above sheath	Absent or very short Short Medium Long Very long	Physiological maturity	MS
Glume: Length	Very short Short Medium Long Very long	Physiological maturity	MS
Grain: Threshability	Freely threshable Partly threshable Difficult to thresh	Maturity	VG
Caryopsis: Color after threshing	White Greyish white Yellowish white Yellowish orange Greyish orange	After threshing	VG
Grain: 1000 grain weight	Very low Low Medium High Very high	After threshing	MG
Grain: Shape (in dorsal view)	Narrow elliptical Elliptical Circular	After threshing	VG
Grain: Shape in profile view	Narrow elliptical Elliptical Circular	After threshing	VG
Grain: Size of mark of germ	Very small Small Medium Large Very large	After threshing	VG
Grain: Texture of endosperm (in longitudinal section)	Fully vitreous ¾ vitreous Half vitreous ¾ farinaceous Fully farinaceous	After threshing	VG
Grain: Color of vitreous albumen	Grayish yellow Grayish orange Grayish purple	After threshing	VG
Grain: Luster	Non lustrous Lustrous	After threshing	VG

Note: VS: Visual assessment by observation of individual (single) plant or plant parts, VG: Visual assessment by a single observation on group of plants or plant parts

Procedures

The experiment followed the principles of a randomized block design (RBD), with one treatment component: variety. The treatment consisted of six varieties, each of which was four replicates, with 24 experimental units. Each experimental unit was a plot of 3m x 4m area size, with 20 plants in each row. Observed variables were taken from ten sorghum plants per plot as samples.

Land preparation included cleaning and processing the land with a hoe. Urea (300 kg ha^{-1}), SP-36 (200 kg ha^{-1}), and KCl (100 kg ha^{-1}) were among the fertilizers used. Manure was used as the basal fertilizer at a rate of 25 kg $plot^{-1}$. The land was then divided into 3m x 4m plots with a 40 cm distance between the experimental plots, and planting holes were dug with a drill. Sorghum seeds were planted in groups of 3-4 per planting hole. On 21 days after planting, thinning was completed, leaving only one plant per planting hole.

The next fertilization was applied twice, with 150 kg ha^{-1} Urea, 200 kg ha^{-1} SP-36, 100 kg ha^{-1} KCl applied ten days after planting, and 150 kg ha^{-1} Urea applied 30 days after planting. The fertilizers were applied to specific areas. Watering was done twice, once when the plant entered the generative phase and once when leaving the generative phase. Watering primarily aimed to meet the plants needs and was influenced by the climatic conditions at the planting time. Harvesting was done when the sweet sorghum was ready for harvest, as indicated by a change in color, hardening of the seeds, and more than 50% of the leaves had dried. A machete or sickle was used for harvesting. The panicle and stem parts of the plant were separated and examined separately.

Variable observations of morphological and agronomical traits were based on the sweet sorghum characterization guideline released by the Protection of Plant Varieties and Farmers Rights Authority (PPV & FRA) (Hariprasanna 2015). Table 2 shows a detailed visual assessment. In addition, data on four additional characteristics were collected (single plant yield (g), stem sugar (% brix), sorghum biomass (g), and percentage of leaf Cd uptake). The Atomic Absorption Spectrophotometer method was used to determine the amount of cadmium in leaves and soil. The obtained data were then calculated using the following formula:

$$Leaf\ Cd\ uptake = \frac{Cleaf}{Csoil} \times 100$$

Where: Cleaf and Csoil represent the Cd levels in the leaf organs and soil, respectively.

Data analysis

The observed morphological characteristic value was converted into scores to assess the level of diversity on sweet sorghum released by the Protection of Plant Varieties and Farmers Rights Authority (PPV & FRA) (Hariprasanna 2015) and dendrogram analysis by NTSys Software. For agronomical characteristics, analysis of variance (ANOVA) was performed, followed by the Duncan Multiple Range Test (DMRT) 95% of confidence level (Gomez and Gomez 1995). Pearson coefficient correlation was calculated by SAS 9.0 software.

RESULTS AND DISCUSSION

Morphological characteristics

Morphological characterization was recorded from six varieties of sorghum in cadmium-contaminated paddy fields. Morphological characteristics to distinguish among the six varieties on one site used thirty-one morphological characteristics of seedling stages, plant stages (vegetative and maturity), and seeds maturity, based on the Guideline for the DUS test of sorghum. The qualitative characteristics for distinguishing the six varieties are presented in Table 3.

The anthocyanin coloration of coleoptile indicated that the six varieties were classified into two states: yellowish green 50% and grayish purple 50% (Table 4). Super-1, Suri-3 and Hitam had grayish purple coleoptile, and Samurai-1, Numbu and Kawali showed yellowish green color (Table 3). Most varieties had 66,67% colorless leaf sheaths, while 33,33% variety had colored leaf sheaths. Leaf midribs were classified into two groups: white midrib 50% and yellowish-green midrib 50%. Leaf midrib coloration varied, starting from white, yellowish white, yellowish green, and brown; white and yellowish green were the most common midrib colors. (Trikoesoemaningtyas et al. 2018). The majority of the varieties had very early (<56 days) panicle emergence (50% frequency of expression); 16.67% variety showed early (56-65 days), and 33.33% variety was observed in medium (76-85 days) panicle emergence (Tables 3 and 4). Panicle emergence is affected by environmental factors rather than genetic factors, i.e. sunlight intensity speeds up panicle emergence (Mengistu et al. 2020; Gano et al. 2021). In addition to the Indonesian Agency for Agricultural Research and Development, the Ministry of Agriculture of the Republic of Indonesia reported (unpublished data) that panicle emergence is categorized into five groups, namely panicle emergence <50 days (very early/short); at 51-60 day (early/short); at 61-70 day (medium) and at >80 days (long/late). However, our study reported that the varieties with very early flowering and early flowering had low single-plant yields (Table 5).

All varieties showed the absence of yellow coloration of flag leaf midrib. While, the observation of lemma arista formation revealed that 83.33% varieties did not show, only 16.67% showed lemma arista formation. The stigma anthocyanin coloration revealed that zero percent varieties showed colored stigma. 66.67% varieties showed the presence of yellow coloration of the stigma, while 33.33% varieties showed the absence (Table 4). Anthocyanin causes coloration in flowers and fruits (Eryılmaz 2006), and it plays an important role in protecting plants against abiotic and biotic stress (Jeon et al. 2020).

Length of the flower were classified into two sizes: 83.3% varieties showed a medium-sized and 16.7% variety showed very long-sized 16.7%. Color of dry anthers revealed that 83.3% had dry orange anthers and 16.7% showed orange-red (Table 4). Martiwi et al. (2020); Sri

Subalakhshmi et al. (2021) reported the same variation of dry anther characteristics. The observation of the glume color revealed four different colors: 50% varieties had grayish yellow glume, 16.7% had grayish red, 16.7% had grayish orange, and 16.7% had grayish purple glume.

The panicle density of 66.7% varieties were semi loose density, while 16.7% semi compact and 16.7% had very loose of the panicle density. Panicle shape is the main distinguishing characteristic of sorghum genotypes. According to DUS (Durrishahwar et al. 2012; Hariprasanna 2018), the panicle shape of sorghum can be distinguished by considering the position of its widest part, whether it is symmetrical, broader in the upper part, broader in the lower part, and pyramidal. The study results showed that, in the cadmium-contaminated land, 50% varieties had symmetrical panicles, 33.3% varieties had panicles broader in the upper part and 16.7% had a pyramidal shape.

The length of the glumes was categorized as very short, short, medium and very long glumes. The result showed that 33.3% varieties had medium-sized glumes, 16.7% had very short-sized glumes, 33.3% varieties had short glumes, 16.7% had very long-sized glumes (Table 4). This characteristic is beneficial for certain sorghum varieties to prevent birds from eating grains (Martiwi et al. 2020). In addition, glume length is related to threshability (Vki et al. 2021). The threshability of the studied sorghum genotypes was grouped into two categories: 83.3% of partly threshable and 16.7% of difficult to thresh, with most types falling within the partly threshable category (Table 4).

The caryopsis color was classified into grayish orange and grayish white. The observation showed that 66.7% varieties had grayish orange color and 33.3% had grayish white color. (Table 4). In addition, the color of caryopsis is related to anthocyanin content which is related to antioxidant activity (Choi et al. 2019). Meanwhile, the grain shape was reviewed from the dorsal and profile views. From the dorsal view, grain shapes were classified into three categories, i.e., narrow elliptical shape 16.7%, elliptical 33.3% and circular 50%. Super-1, Samurai-1 dan Numbu had a circular shape, Suri-3 had an elliptical shape, and Hitam had a narrow elliptical shape (Table 3). From the profile view, the grain shapes were classified into elliptical and circular shapes: 83.3% varieties had elliptical shapes, and 16.7% had circular shapes. The size of germ was classified into two sizes. The observation showed that 50% varieties showed medium-sized germs, and 50% varieties showed large germs. The endosperm texture wa classified into four categories, i.e 16.7% variety had fully farinaceous endosperm; 33.3% varieties had ¾ vitreous endosperm, 33.3% varieties had half vitreous endosperm, and 16.7% variety had ¾ farinaceous endosperm (Table 4).

Regarding the color of vitreous albumen, the varieties were classified into three, i.e., grayish-yellow, grayish-orange, and grayish-purple. The result showed that 16.7% variety had the grayish-orange color of vitreous albumen, 33.3% varieties showed grayish-yellow, and 50% varieties showed the grayish-purple color of vitreous albumen. The lustrous grain showed that 83.3% varieties were recorded to have lustrous grain after threshing, and 16.7% variety had non-lustrous grain. The present study also revealed that all the genotypes were distinct and had different characteristics (Table 4). Observations regarding the morphological characters, especially the qualitative characters of sorghum, have never been carried out. There are very few references available, especially the detailed morphology of the varieties used in this test, so the results of this study can be used as a reference for other studies related to the morphology of sorghum in cadmium-stressed soil conditions.

Agronomic characteristics

An essential indicator of plant growth is plant height. Plant height in the R1 phase was measured from the soil surface to the tip of the plant when the plant began to flower, while the plant height in the R5 phase was measured from the soil surface to the tip of the plant when the panicle started to have filled grains. The study revealed that Super-1, Samurai-1, and Kawali were tall and notably different varieties (Table 5). Hitam, a short sorghum variety, significantly differed from Suri-3 and Numbu. The examined varieties had a particular capacity to react to their surroundings. Tall plants are an important genetic resource for feed production (Birhan et al. 2020), while short plants have been recognized as a key characteristic for drought tolerance (Seyoum et al. 2019).

The results of the stem diameter measurement showed that Samurai-1 had the largest stem diameter, while Hitam had the smallest stem diameter and significantly differed from other varieties. Besides being important in biofuel production, the size of the stem diameter is also an indicator of plant stem strength that can support the formation of sturdy plants resistant to laying down. This is reinforced by research by Kong et al. (2020), showing that plant height and thick and sturdy stem diameter are important in biofuel production. Sorghum genotypes with a large stem diameter will have a stronger ability to support the plant's height and will not fall over easily. A small stem diameter causes sorghum plants to fall over more easily, thus reducing plant productivity. The stress level and changes in the Cd environment can directly lower root activity, impede the uptake of water and mineral nutrients, and impact the growth of the upper part of the plant by reducing plant height and leaf area (Zhu et al. 2021).

The observed morphological characteristics of the flowers included the length of the stigma and the length of the anther. The results showed that Suri-3 had the longest stigma and significantly differed from the other five varieties. Meanwhile, Suri-3, Numbu, Kawali and Hitam had the longest anther (Table 5). The panicle characteristics were observed quantitatively, including panicle length without peduncle and panicle branch length. Hitam had the longest panicle and significantly differed from the other five varieties. All the varieties showed insignificant differences in terms of panicle branch length (Table 5). The length of the panicle neck visible above the leaf sheath showed that Hitam had longer than the other five varieties (Table 5).

The 1000-grain weight differed significantly among the tested varieties. Numbu produced the highest 1000-grain weight, while Hitam had the lowest 1000-grain weight

(Table 5). According to Winata et al. (2015), 1000-grain weight is determined by the size of the seeds, which is controlled by genetic factors. Numbu produced the highest seed production and was noticeably different following the 1000-grain weight. Hitam produced the lowest seed yield. Hitam's low panicle density and somewhat uncommon panicle form contributed to its low seed yield (Table 5).

Stem sugar content was also included as a quantitative character. Typically, sorghum stems contain sugar molecules that can be used as bioethanol source materials (Pabendon et al. 2012). The stem sugar content of Kawali and Samurai-1 was substantially higher than that of the other four varieties. Hitam produced the lowest stem sugar concentration (Table 5). Plant fresh weight was measured by weighing the fresh plant crown weight. Samurai-1 produced the highest yield and a substantial difference in plant fresh weight. Hitam had the lowest plant fresh weight, while Super-1, Numbu, and Kawali produced the same yields (Table 5).

The morphological and agronomic characteristics of six sorghum varieties were characterized in this experiment. Qualitative and quantitative morphological and agronomic characteristics were distinguished. According to Sinha and Kumaravadivel (2016), qualitative characteristics are more commonly used as identifiers for a variety because they are encoded by monogenic genes, which means that environmental influences have little impact. Qualitative traits have a discontinuous phenotypic distribution and are easily recognized. In contrast, quantitative traits have a continuous phenotypic distribution and are controlled by many genes, each influencing the trait being expressed.

Table 3. Characterization of six sorghum varieties based on characteristics given in guidelines of PPV&FRA for DUS testing in sorghum

Variety and characteristics	Cadmium-contaminated paddy field					
	Super-1	**Samurai-1**	**Suri-3**	**Numbu**	**Kawali**	**Hitam**
SAC	Grayish purple	Yellowish green	Grayish purple	Yellowish green	Yellowish green	Grayish purple
LSAC	Absent	Absent	Present	Absent	Absent	Absent
LMC	White	Yellowish green	White	Yellowish green	Yellowish green	White
DPM	Very early	Early	Very early	Medium	Medium	Very early
PHF	Medium	Medium	Medium	Medium	Medium	Short
FLYC	Absent	Absent	Absent	Absent	Absent	Absent
LAF	Absent	Absent	Absent	Absent	Absent	Present
STAC	Absent	Absent	Absent	Absent	Absent	Absent
STYC	Absent	Present	Present	Present	Absent	Present
STL	Medium	Medium	Long	Medium	Medium	Medium
FWPLF	Medium	Medium	Medium	Medium	Medium	Very long
AL	Medium	Medium	Medium	Medium	Medium	Medium
AC	Orange	Red orange	Orange	Orange	Orange	Orange
GC	Grayish yellow	Grayish orange	Grayish red	Grayish yellow	Grayish yellow	Grayish purple
PH	Medium	Medium	Short	Short	Medium	Short
SD	Small	Medium	Small	Small	Small	Small
LBL	Long	Long	Long	Long	Long	Long
LBW	Broad	Very broad	Broad	Broad	Very broad	Medium
PLB	Medium	Medium	Medium	Medium	Medium	Long
PLWP	Medium	Medium	Medium	Medium	Medium	Very long
PDM	Semi-compact	Semi-loose	Semi-loose	Semi-loose	Semi-loose	Very loose
PS	Symmetrical	Symmetrical	Symmetrical	Panicle broader in the upper part	Panicle broader in the upper part	Pyramidal
NPVAS	Short	Very short	Short	Medium	Medium	Very long
GL	Medium	Short	Medium	Medium	Medium	Very long
CC	Grayish orange	Yellowish white	Grayish orange	Yellowish white	Grayish orange	Grayish orange
GSDV	Circular	Circular	Elliptical	Circular	Elliptical	Narrow elliptical
THR	Partly threshable	Partly threshable	Partly threshable	Partly threshable	Partly threshable	Difficult thresh
TGW	Medium	Medium	Low	High	Medium	Low
GSPV	Elliptical	Elliptical	Elliptical	Circular	Elliptical	Elliptical
GSMG	Large	Medium	Medium	Large	Medium	Large
GTE	¾ farinaceous	¾ vitreous	Fully farinaceous	Half vitreous	Half vitreous	¾ vitreous
GCVA	Grayed purple	Grayish yellow	Grayish purple	Grayish yellow	Grayish orange	Grayish purple
GLU	Lustrous	Non-lustrous	Lustrous	Lustrous	Lustrous	Lustrous

Note: SAC: Seedling Anthocyanin Coloration of coleoptile, LSAC: Leaf Sheath Anthocyanin Coloration, LMC: Leaf Midrib Color, DPM: Days of Panicle Emergence, PHF/PH R1: Plant Height at R1 phase, FLYC: Flag Leaf midrib Yellow Coloration, LAF: Lemma Arista Formation, STAC: Stigma Anthocyanin Coloration, STYC: Stigma Yellow Coloration, STL: Stigma Length, FWPLF: Flower With Pedicel: Length of Flower, AL: Anther Length, AC: Anther Color of the dry anther, GC: Glume Color, PH R5: Plant Height at R5 phase (cm), SD: Stem Diameter, LBL: Leaf Blade Length, LBW: Leaf Blade Width, PLWP: Panicle Length Without Peduncle, PLB: Panicle Length of Branches, PDM: Panicle Density at Maturity, PS: Panicle Shape, NPVAS: Neck of Panicle Visible length Above Sheath, GL: Glume Length, color of caryopsis, GSDV: Grain Shape in Dorsal View, THR: Threshability, TGW: Thousand-Grain Weight, GSPV: Grain Shape in Profile View, GSMG: Grain Shape of the Mark of Germ, GTE: Grain Texture of Endosperm, GCVA: Grain Color of Vitreous Albumen, GLU: Grain Luster

Table 4. Distribution of qualitative characteristics among six varieties of sweet sorghum

Characteristics	Frequency of expression
Seedling anthocyanin coloration of coleoptile	Yellowish green (50.0), Grayish purple (50.0)
Leaf sheath anthocyanin coloration	Yellowish green (50.0), Grayish purple (50.0)
Leaf: midrib color	White (50.0), Yellowish green (50.0)
Time of panicle emergence	Very early (66.7), Early (16.7), Medium (16.7)
Yellow coloration of flag leaf midrib	Absent (66.7), Present (33.3)
Lemma: Arista formation	Absent (66.7), Present (33.3)
Stigma anthocyanin coloration	Absent (66.7), Present (33.3)
Stigma yellow coloration	Absent (33.3), Present (66.7)
Flower with pedicel:length of flower	Medium (83.3), Very long (16.7)
Color of dry anthers	Yellowish orange (16.7), Orange (50.0), Red orange (33.3)
Glume color	Yellowish white (33.3), Grayish yellow (16.7), Grayish red (33.3), Grayish purple (16.7)
Panicle density	Very loose (16.7), Semi loose (16.7), Semi compact (33.3), Compact (33.3)
Panicle shape	Panicle broader in upper part (16.7), Symmetrical (33.3), Panicle broader in lower part (33.3), Pyramidal (16.7)
Glume length	Short (16.7), Medium (66.7), Very long (16.7)
Threshability score	Partly threshable (83.3), Difficult to thresh (16.7)
Caryopsis color after threshing	White (16.7), Yellowish white (16.7), Yellowish orange (33.3), Grayish orange (33.3)
Grain shape in dorsal view	Narrow elliptical (16.7), Elliptical (33.3), Circular (50.0)
Grain shape in profile view	Elliptical (50.0), Circular (50.0)
Size of mark of germ	Medium (50.0), Large (50.0)
Endosperm texture	¾ vitreous (16.7), Half vitreous (16.7), ¾ farinaceous (16.7), Fully farinaceous (50.0)
Color of vitreous albumen	Grayish yellow (33.3), Grayish orange (16.7), Grayish purple (50.0)
Grain lustre	Non-lustrous (16.7), Lustrous (83.3)

Note: Values in parenthesis donate percentage values

Table 5. Agronomical characteristics of six sorghum varieties

Variety	Agronomical characteristics													
	PH R1	PH R5	SD	LBL	LBW	STL	AL	PLWP	PLB	NPVAS	TGW	SPY	SC	PFW
Super-1	200.35^{a}	222.77^{a}	15.07^{b}	78.26^{a}	6.78^{b}	1.75^{c}	2.95^{b}	25.28^{b}	9.88^{a}	5.55^{c}	32.75^{c}	63.74^{b}	11.75^{bc}	340.23^{b}
Samurai-1	176.74^{b}	207.52^{a}	20.77^{a}	74.19^{a}	8.92^{a}	1.95^{bc}	2.98^{b}	22.72^{b}	7.88^{a}	5.00^{c}	35.09^{b}	62.42^{b}	15.13^{a}	574.17^{a}
Suri-3	145.56^{c}	172.96^{b}	10.35^{c}	71.17^{a}	6.55^{b}	3.00^{a}	4.00^{a}	23.35^{b}	6.79^{a}	6.62^{c}	25.35^{d}	47.60^{c}	10.75^{c}	203.24^{c}
Numbu	142.97^{c}	170.29^{b}	12.27^{c}	$67{,}19^{a}$	6.81^{b}	1.90^{bc}	3.93^{a}	23.43^{b}	7.42^{a}	11.00^{b}	$39{,}04^{a}$	81.83^{a}	12.00^{b}	323.83^{b}
Kawali	190.72^{ab}	216.98^{a}	14.49^{b}	75.33^{a}	8.11^{a}	2.00^{b}	4.00^{a}	25.17^{b}	7.92^{a}	12.75^{b}	31.04^{c}	62.16^{b}	14.63^{a}	361.92^{b}
Hitam	100.77^{d}	132.84^{c}	7.93^{c}	76.96^{a}	4.94^{c}	1.85^{bc}	3.90^{a}	44.35^{a}	10.29^{a}	22.13^{a}	19.24^{e}	33.97^{d}	7.50^{d}	112.51^{d}
CV (%)	8.84	7.68	26.42	12.38	11.29	7.06	2.14	11.17	40.67	13.47	1.72	2.04	5.68	12.04

Note: the values in the same column with different letters were significantly different at $p<0.05$, PH R1: Plant Height at R1 phase (cm), PH R5: Plant Height at R5 phase (cm), SD: Stem Diameter (mm), LBL: Leaf Blade Length (cm), LBW: Leaf Blade Width (cm), STL: Stigma Length (mm), AL: Anther Length (mm), PLWP: Panicle Length Without Peduncle (cm), PLB: Panicle Length of Branches (cm), NPVAS: Neck of Panicle Visible length Above Sheath (cm), TGW: Thousand-Grain Weight (g), SPY: Single Plant Yield (g), SC: Sugar Content (% sugar brix), PFW: Plant Fresh Weight (g)

Growth and production are affected by the performance of sorghum varieties. Six sorghum varieties in this study grew normally based on the description of varieties (Table 1). That implies plant growth is not directly affected by soil cadmium contamination. However, all the varieties in contaminated soil showed diverse morphological responses; this can occur due to growth retardation by cadmium. According to several studies, cadmium is a non-essential metal whose presence is toxic to plants; even at low concentrations, it impacts soil biology and plants (Zhu et al. 2021), and decreases nutrient uptake and assimilation (Guo et al. 2018). These are very important in plant growth, maturity, and flowering. The correlation Table 6, illustrates the closeness of the relationship between quantitative characteristics in this study. Therefore, to identify plants as phytoremediators, several characteristics that influence the components of fresh biomass must be considered. Characteristics with a significant positive correlation with yield characteristics can be used as phytoremediator plant selection criteria.

Plant fresh weight was positively and significantly correlated with plant height in phase-1, plant height in phase-5, stem diameter, leaf width, thousand-grain weight, and stem sugar content (Table 6). According to these findings, an increase in plant height in phase-1, plant height in phase-5, stem diameter, 1000-grain weight, and single plant yield is followed by an increase in fresh plant weight. Tall plants also have a higher biomass. In this study, the Super-1, Samurai-1, and Kawali had significantly higher plant heights than Suri-3, Numbu, and Hitam (Table 5). The tested varieties had unique abilities to respond to their surroundings. Sorghum of short variety is more stresstolerant (Birhan et al. 2020), whereas sorghum of a relatively tall variety has great potential as animal feed (Seyoum et al. 2019). Considering the flowering time as a measure of adaptation to the growing environment in this study, Kawali could adapt to the environment and maintain good growth performance. In this study, cadmium-contaminated fields reduced plant height by 24.93% for Suri-3 and 11% for Hitam. More than 25 $mgkg^{-1}$ Cd stress inhibited chlorophyll synthesis and caused a significant decrease in root activity during the plant growth stage. According to Da-lin et al. (2011), roots and leaves have a supply-demand relationship concerning water and inorganic nutrients. Cd stress can directly reduce root activity, inhibit water and mineral nutrient absorption, and affect upper plant growth by reducing plant height and leaf area (Zhu et al. 2021).

Samurai-1 had the largest stem diameter, while Hitam had the smallest stem diameter and was the most distinct from the others (Table 5). Aside from being important in biofuel production, stem diameter is also an indicator of plant stem strength, which can support the formation of sturdy plants with lodging resistance. This is supported by research by Kong et al. (2020), who found that plant height and thick and sturdy stem diameter are important factors in biofuel production. Sorghum with a large stem diameter will be able to support the plant's height and will not fall over easily. On the other hand, a small stem diameter reduces plant productivity. The leaf width categories in the varieties observed in this study were broad, medium, and very broad. Post hoc DMRT test revealed that Samurai-1 and Kawali had significantly broader leaves than the other four varieties (Table 5). According to Xiao-Ping et al. (2011), the gene controlling the leaf length is located on chromosomes 6 and 10 and has an overdominant effect. The gene that determines leaf width is found on chromosomes 1, 6, and 4, acting in dominant, incomplete dominant, and additive manners. Leaf width and length are proportional to leaf area. Increased leaf area can improve solar radiation interception for photosynthesis (Widyaningtias et al. 2020). Samurai-1 and Kawali are two varieties with very broad leaves. That demonstrates the leaf area of the two varieties was relatively larger than the other four varieties, allowing them to increase photosynthetic efficiency while having a high crown performance, large stem diameter, and thick leaves.

The 1000-grain weight, had a significant result between varieties. Unlike Super-1, Samurai-1, Suri-3, Kawali, and Hitam, Numbu produced the highest 1000-grain weight. Hitam, on the other hand, had the lowest 1000-grain weight. The 1000-grain weight relates to determining the harvest age at which the seeds reach physiological maturity, producing seeds with maximum filling. High-quality seeds are inseparable from viability and vigor, where seeds are harvested just when they reach physiological maturity. One of the factors causing the difference in weight is the endosperm content of the seeds. The determination of 1000 seed weights determine the productivity of varieties that can adapt to the growing environment.

Numbu had the highest seed yield per plant, significantly different from Super-1, Samurai-1 and Kawali. Hitam produced the lowest number of seeds per plot. The low panicle density, shape, and 1000-grain weight support this (Table 5).

Stem sugar was included in the quantitative observations as another crop yield. Samurai-1 and Kawali produced significantly sweeter stem sugar than other varieties. Hitam had the lowest stem sugar content (Table 5). Varieties with sweeter stems of sugar have great potential as bioethanol feedstock.

Samurai-1 produced the highest yield and had the greatest difference in plant fresh weight. Super-1, Numbu, and Kawali were the same, while Hitam had a low plant fresh weight (Table 5). There is a difference in fresh biomass production due to the difference in plant height of the varieties. The correlation analysis showed that fresh biomass was highly correlated with plant height, stem diameter, and leaf width (Table 6). This correlation indicates that the taller the plant, the wider the diameter of the stem and leaves, and the higher the fresh biomass.

Table 6. Pearson correlation coefficient among 14 morphological characteristics

Characteristics	PHR1	PHR5	SD	LLB	LWB	STL	AL	PLWP	PLB	NPVAS	TGW	SPY	SC	PFW
PH R1	1.00													
PH R5	**0.97***	1.00												
SD	**0.42***	0.33	1.00											
LBL	-0.05	-0.07	-0.13	1.00										
LBW	0.31	0.29	**0.64***	0.32	1.00									
STL	-0.22	-0.25	-0.03	-0.28	-0.01	1.00								
AL	**-0.48***	**-0.47***	-0.37	-0.17	-0.23	**0.62***	1.00							
PLWP	-0.38	**-0.39***	**-0.41***	**0.43***	**-0.42***	-0.31	0.14	1.00						
PLB	0.25	0.20	0.13	0.19	0.15	-0.21	-0.23	0.21	1.00					
NPVAS	-0.528	**-0.52***	**-0.40***	0.22	-0.35	-0.20	**0.52***	**0.70***	-0.13	1.00				
TGW	**0.83***	**0.83***	**0.58***	-0.29	**0.45***	-0.22	-0.36	**-0.58***	0.08	**-0.44***	1.00			
SPY	**0.63***	**0.61***	0.06	-0.25	0.06	-0.07	0.03	-0.26	-0.01	-0.22	**0.57***	1.00		
SC	0.36	0.36	**0.78***	-0.08	**0.79***	-0.08	-0.30	**-0.48***	0.24	**-0.45***	**0.59***	0.12	1.00	
PFW	**0.53***	**0.52***	**0.76***	0.04	**0.79***	-0.22	**-0.50***	-0.48	0.27	**-0.50***	**0.65***	0.13	**0.89***	1.00

Note: PH R1: Plant Height at R1 phase (cm), PH R5: Plant Height at R5 phase (cm), SD: Stem Diameter (mm), LBL: Leaf Blade Length (cm), LBW: Leaf Blade Width (cm), STL: Stigma Length (mm), AL: Anther Length (mm), PLWP: Panicle Length Without Peduncle (cm), PLB: Panicle Length of Branches (cm), NPVAS: Neck of Panicle Visible length Above Sheath (cm), TGW: Thousand-Grain Weight (g), SPY: Single Plant Yield (g), SC: Sugar Content (% Brix), PFW: Plant Fresh Weight (g)

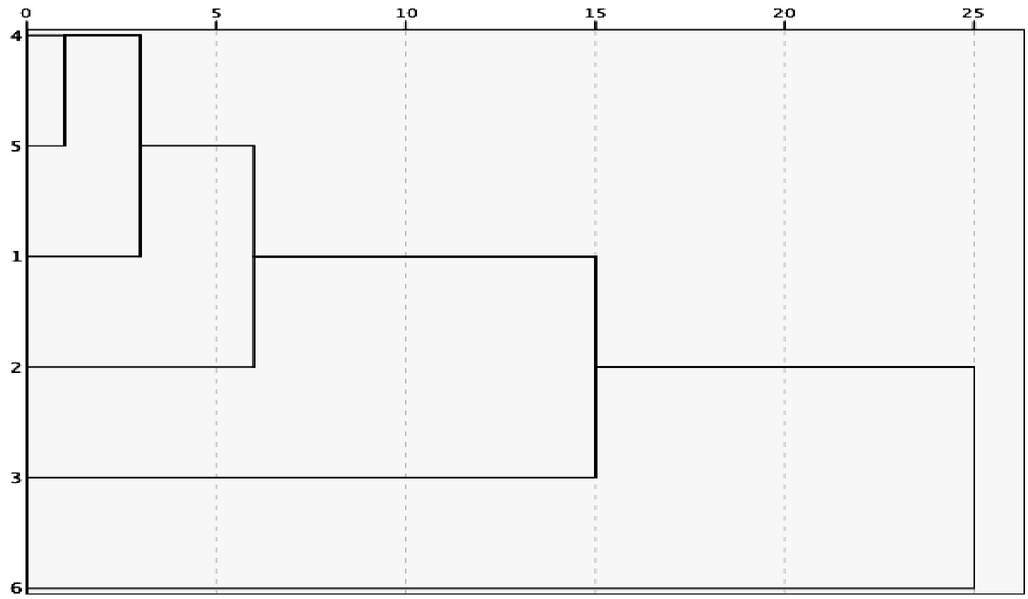

Figure 2. Dendogram of six varieties of sorghum. where: 1: Super-1, 2: Samurai-1, 3: Suri-3, 4: Numbu, 5: Kawali, 6: Hitam

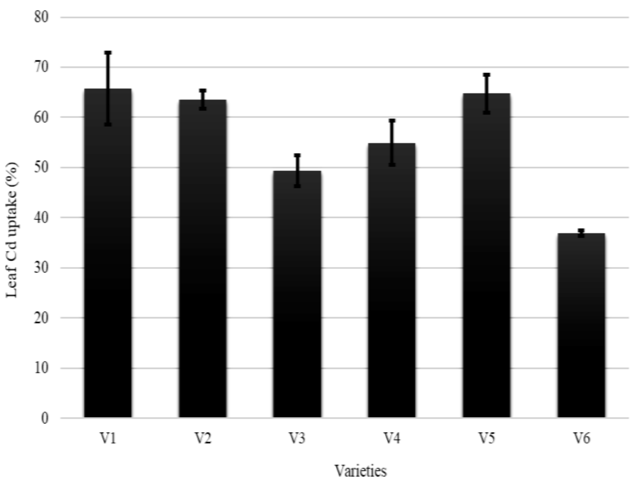

Figure 3. Leaf Cd uptake (%)

The six varieties were categorized into three groups based on 22 qualitative traits according to DUS morphological characteristics (Hariprasanna 2018). Group 1, panicle emergence time: very early (Super-1, Suri-3, Numbu and Hitam); plant height: long (Super-1), medium (Suri-3), short (Numbu and Hitam); panicle shape: broader at the top (Numbu), symmetrical (Super1 and Suri3), pyramidal (Hitam); caryopsis colors: white (Super-1), grayish orange (Suri-3 and Hitam), yellowish orange (Numbu). Group 2, time of panicle emergence: early (Samurai-1); plant height: medium (Samurai-1); panicle shape: broader at the bottom (Samurai-1); caryopsis color: yellowish orange (Samurai-1). Group 3, time of panicle emergence: medium (Kawali); plant height: medium (Kawali); panicle shape: broader at the bottom (Kawali); caryopsis color: yellowish white (Kawali). Compared to Suri-3 and Hitam, Super-1, Samurai-1, Numbu, and Kawali showed improved morphological traits.

The investigation was furthered by employing the SPSS software to generate a kinship dendrogram with a genetic similarity coefficient (Figure 2). All the sorghum varieties tested tended to cluster based on morphological characteristics. The smaller the genetic similarity coefficient (close to 0), the more distant the kinship relationship, or the greater the genetic distance (close to 1), the greater the characteristic diversity.

The efficiency of metal extraction is determined by the potential for biomass production and concentration in shoots (Huang et al. 2020). Furthermore, differences in Cd uptake in sorghum leaf organs were discovered in the six different sorghum varieties. Based on the percentage of Cd heavy metal composition, the results of this study indicated that approximately 36.97-65.70% of cadmium was stored in the leaves (Figure.3). The leaf organs of Super-1, Kawali, and Samurai-1 contained more than 60% of the content, while Hitam contained the least. This is because Super-1, Kawali, and Samurai-1 had larger leaf surface areas, allowing more plant cell walls to absorb ions (Hasanah et al. 2021). However, the leaf Cd composition of Super-1, Samurai-1, and Kawali showed higher leaf Cd uptake than Numbu, Suri-3, and Hitam.

There were significant differences in quantitative traits such as plant height, stem diameter, leaf blade width, stigma length, anther length, panicle length without peduncle, neck of panicle visible length above sheath, thousand-grain weight, single plant yield, sugar content and plant fresh weight. The quantitative morphological response analysis results of the six sorghum varieties showed that cadmium induced morphological disturbances in the tested sorghum varieties (Table 5). The six sorghum varieties were classified as adaptive until the end of the observation. Most morphological traits in sorghum are linked to one or more economically important traits and will aid in selecting high-yielding sorghum genotypes (Mufumbo et al. 2022). Plants suitable for phytoremediation must have several characteristics, including the capability of accumulating heavy metals above ground, tolerance to metal accumulation, fast growth and high biomass, branched root system, and ease of harvest (Eapen and D'Souza 2005; Sarma 2011; Muro-González et al. 2020), easy cultivation and quick harvest (Takahashi et al. 2021), not consumed by humans (Jia et al. 2016; Martiwi et al. 2020; Muro-González et al. 2020), has rejection of herbivores to avoid contamination of the food chain (Huang et al. 2020), has several economic interests (Abdel-Sabour et al. 2000; Almodares and Darany 2006; Angelova et al. 2011; Liu et al. 2020; Saleem et al. 2020). Futhermore, the six varieties were able to adapt to cadmium-contaminated land. Super-1 had an advantage in plant height, while, Samurai-1 had a tall plant, a large stem diameter, and a broad leaf blade, thus having the highest biomass compared to the other five varieties. Meanwhile, Kawali had a tall plant and a broad leaf blade, and Numbu had the highest 1000-grain weight compared to the other five varieties. In addition, varieties with many plant characteristics also have a high biomass. Plants can have added value as phytoremediators if they are not consumed by humans or used as animal feed, in addition to having high biomass for accumulating heavy metals.

In conclusion, using sweet sorghum as a phytoremediator the characters' quantity and quality determines the potential of fresh biomass, stem sugar content and Cd uptake. Unlike the Super-1, Samurai-1 and Kawali varieties, none of the varieties tested had advantages for the three characters at once. Numbu has a high potential for fresh biomass with high stem sugar content but lower Cd uptake. However, Numbu has the advantage of having the highest weight of 1000 seeds, so Numbu is more appropriate for food and feed. The results of this study provide information related to the morphological characters of six varieties of sorghum grown in cadmium-contaminated land, which can be used as literacy in their development as raw materials for food, feed, and bioethanol. This case can be a consideration in the better selection of varieties as heavy metal phytoremediators. This study's results could also be used as a reference for further research regarding the distribution and amount of metal absorption in sorghum organs that are in an acceptable range by this plant.

ACKNOWLEDGEMENTS

The authors would like to thank the National Research and Innovation Agency, the Ministry of Research and Technology for funding this research with contract number 221.1/UN27.22/HK.07.00/2021.

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