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Growth Response of *Sorghum bicolor* Cultivars to Trivalent Chromium Stress

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Abstract

One of heavy metal pollutants in the soil that can be absorbed by the sorghum is chromium (Cr). The study was conducted to determine the growth response of Cr^{3+} stress of sorghum cultivars. Two chemical compounds Cr^{3+} and 3 level concentrations were exposed to sorghum cultivars. The research was conducted in two separate experiments i.e. during seed germination and early seedling development stages. The parameters measured were radicle/root length, seedling length, fresh weight, dry weight, and stress tolerance index (STI) value. The results showed that Cr^{3+} either in form of $CrCl_3$ or $KCr(SO_4)_2$ significantly reduced the seedling growth of sorghum cultivars. The growth responses of sorghum cultivars toward Cr^{3+} stress showed differences both on stage of the germination and early seedling. Based on the average of STI value, four sorghum cultivars (Badik, Keris, Keris M3 and Numbu) were classified as very strong tolerant, 4 cultivars (Hegari, Mandau, Sangkur and Gambela) were categorized as moderate tolerant, two cultivars (UPCA and Selayer) were weak tolerant, and 2 cultivars (Kawali and Batari) were sensitive ones, under stress condition of Cr^{3+}.The results of this study are expected to provide the scientific basis of the physiological and tolerance responses of sorghum cultivars toward Cr^{3+} stress condition.

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INTRODUCTION

Sorghum (*Sorghum bicolor*) is a multipurpose crop grown for food, animal feed, and industrial purposes. Sorghum belongs to Poaceae family and a C4 plant that usually grows under hot and dry conditions. It is considered as more tolerant to many stresses, including heat, drought, salinity and flooding, compared to other cereal crops (Bibi et al., 2012; Naim et al., 2012; Hefny et al., 2013; Menezes et al., 2014).

Besides affected by stresses of temperature, salinity, and drought, the productivity of sorghum plants is also influenced by the heavy metal stress. Sorghum can be exposed to heavy metals through the use of fertilizers containing heavy metals or the use of solid or liquid industrial waste containing Cr as fertilizer as well as the irrigation water (Yadav, 2010; Francis, 2000). One of heavy metal pollutants in the soil that can be absorbed by the sorghum is chromium (Cr).

Chromium (Cr) is chemically unique compared to other heavy metals. Different level of oxidation of Cr, especially trivalent (Cr^{3+}) and hexavalent (Cr^{6+}), is found in their mobility, solubility, reactivity, availability, and toxicity. Cr in soil is found in the oxidation state ranging from Cr^{2+} to Cr^{6+}. The trivalent and hexavalent oxidation state are the most stable (Zayed & Terry, 2003). Cr^{6+} and Cr^{3+} show differences in its solubility, availability, mobility, reactivity, toxicity and the physical and chemical properties (Njoku & Nweeze, 2009). Cr can be either beneficial or toxic to animals and humans, depending on its oxidation state and concentrations (Zayed et al. 1998). Cr^{3+} is less toxic compared to Cr^{6+} and has toxicity 10 - 100 times lower than Cr^{6+} (Kim et al., 2002; Yu & Gu, 2007). Cr^{3+} is considered to be a trace element essential for the proper functioning of living organisms. At low concentrations, nutritionally Cr^{3+} is an essential component of a balanced human and animal diet for preventing adverse effects in the metabolism of glucose (Katz & Salem, 1994; Anderson, 1997). However, Cr^{3+} at increased concentrations can interfere with several metabolic processes because of its high capability to coordinate various organic compounds resulting in inhibition of some metalloenzyme systems (Zayed et al. 1998). Cr^{3+} is an essential nutrient in plant metabolism, e.g., synthesis of amino and nucleic acids.

The toxic effect of Cr^{3+} on the plant had been studied and reported. The toxic effect of Cr^{3+} in the form $CrCl_3$ had been reported on *Vigna radiata* (Karuppanapandian et al., 2006), *Lycopersicon esculentum* (Henriquez, 2010), *Cucumis melo* (Akinci & Akinci, 2010), *Leersia hexandra* (Liu et al., 2011), and *Salix matzudana* (Yu & Gu 2007; Zhang et al., 2009). Toxicity of Cr^{3+} in the form of $KCr(SO_4)_2.12H_2O$ had been reported on *Allium cepa*, *Urtica dioica*, *Brassica napus*, and *Zea mays* (Liu & Kottke, 2003; Shams et al., 2010).

Revathi et al. (2011), reported that sorghum was classified as one kind of accumulator plants of heavy metals. Growth response of various cultivars of sorghum in Indonesia toward stress of heavy metals, especially Cr has not been reported widely. Agustina et al. (2010), reported the adaptability of four sorghum cultivars, B-69 and B-75 cultivars were sensitive toward aluminum (Al) stress, while Numbu and ZH30-29-07 cultivars were tolerant toward Al stress.

The present study was conducted to determine the growth response and level tolerance toward Cr^{3+} stress of twelve sorghum cultivars on stages of seed germination and early seedling growth. Two chemical compounds Cr^{3+} ($CrCl_3.6H_2O$ and $KCr(SO_4)_2.12H_2O$) and 3 level concentrations (0, 50, and 500 mg Cr/l) were exposed to twelve sorghum cultivars. The growth response measured include radicle/root length, seedling length, fresh weight and dry weight. Stress tolerance index (STI) value was used to classify the level of tolerance of sorghum cultivars to Cr^{3+} stress.

METHODS

This research experiment used the randomized block design with three treatment factors. The first and second factors were the treatment of chemical compound and the level concentration of trivalent chromium (Cr^{3+}). The third factor was the treatment of sorghum cultivars.

Plant material and culture condition

Twelve cultivars of sorghum were used in this study. Ten cultivars (i.e. UPCA, Badik, Keris, Keris M3, Hegari Genjah, Sangkur, Mandau, Gambela, Batari and Selayer) were obtained from Indonesian Center for Agricultural Biotechnology and Genetic Resources (Bogor) and two cultivars (i.e. Numbu and Kawali) from Indonesian Cereals Research Institute (Maros). These cultivars was used in Cr^{3+} stress treatment consisted of 2 chemical compounds ($CrCl_3.6H_2O$ and $KCr(SO_4)_2.12H_2O$) and 3 level concentrations (0, 50, and 500 mg Cr/l). The research was conducted in two separate experiments i.e. at seed germination and early seedling development stages. The experiments of germination and early seedling growth were done hydroponically in Hoagland solution with the composition as used by Zayed et al., (1998) as follows (mg / l): 606.6 KNO_3 ; Ca (NO_3) $2.5H_2O$ 1270; NaCl 58.4; KH_2PO_4 272.2; $MgSO_4.7H_2O$ 492.8; $MnCl_2$ 1.158; $ZnSO_4$ 0.123; H_3BO_3 2.86; $CuSO_4.5H_2O$ 0.08, H_2MoO_4 0.017 and Fe-EDTA 5.0. Each of these cultivars had the same opportunity to received two chemical compounds and three levels of Cr^{3+} concentrations, therefore, there were 72 units of treatment with the combination of three factors, either during the research of seed germination or early seedling development stage. Each unit of treatment was done with four replications.

Germination experiments and measured parameters

Before germinated, twelve cultivars of sorghum seeds were sterilized with commercial bleaching solution containing 0.5% sodium hypochlorite (NaClO), and then washed with distilled water. Ten uniform sized seeds of each sorghum cultivar were selected and sown at equal distance in 90 mm Petridishes containing a double layer of paper straw as four replications, and were moistened with 20 ml of Hoagland medium (control), 50 and 500 mg/l Cr test solution (as $CrCl_3.6H_2O$ and $KCr(SO_4)_2$) in Hoagland solution. The Petridishes were kept moist by 5 ml of test solution added regularly every day. The Seeds were considered germinated once the radicle emerged 2 mm, out of the seeds (Akinci & Akinci, 2010). Seven-day-old seedlings were used to determined seedling growth parameters. The seedlings then were taken out from each Petri dish of different concentration and measured their seedling growth (radicle length and seedling length), fresh weight and dry weight. The seedlings were dried in the oven at 80°C for three days and the dry weight of the seedlings was recorded.

Early seedling experiments and measured parameters

Twenty seeds from each sorghum cultivars were sterilized with commercial bleaching solution containing 0.5% sodium hypochloride (NaClO) for 10 minutes and then were washed with distilled water. The seeds were sown in 90 mm Petridishes containing a double layer of paper straw moistened with distilled water and were allowed to germinate for seven days. Five seedlings (seven-day-old) that grow uniformly were selected for each cultivar of sorghum, and were grown in plastic cups (200 ml) which have contained sterile river sand (250 mg). The treatment of Cr^{3+} (as $CrCl_3.6H_2O$ and $KCr(SO_4)_2$) was given at 3 level concentrations i.e. 0, 50 and 500 mg Cr/l. Cr^{3+} treatments were mixed with Hoagland solution full strength, and added to seedlings from each treatment Cr^{3+} by 50 ml in the beginning, and add 10 ml every day for 7 days. Seedlings without exposure to Cr^{3+} were used as control groups. Each treatment was done with five replications. After seven days of the experiment, root length, seedling length, and fresh weight of seedlings (treated Cr^{3+} and control) were measured. After dried for three days at 80°C in the oven, the dry weight of seedlings was obtained.

Determination of level tolerance

The determination of tolerance level was based on the comparison of the mean value of STI cultivars and standard deviation. The value selection criteria used was STI (Stress Tolerance Index) as described by Fernandez that used by Hosseini et al. (2012), with the following formula STI = $(Yp + Ys)/(\bar{y}p)^2$ which denotes the average value of cultivar non Cr^{3+} stresses condition. Ys is the yield of cultivar under Cr^{3+} stress condition, Yp the yield of cultivar under non Cr^{3+} stress condition (control), and $\bar{y}p$ the mean yield of all

Table 1. Tolerance level based on the comparison of the mean value of STI cultivars and standard deviation (Purwani and Marjani, 2009; Nanang et al., 2014)

Tolerance Level	Criteria
VT (Very strong tolerant)	if ***STI cultivars*** > average value of STI all cultivars + standard deviation
ST (Strong tolerant)	average value of STI all cultivars + standard deviation < *STI cultivars* > the average value of STI all cultivars + ½ standard deviation
M (Moderate tolerant)	the average value of STI all cultivars + ½ standard deviation < *STI cultivars* > the average value of STI all cultivars - ½ standard deviation
WT (Weak tolerant)	the average value of STI all cultivars - ½ standard deviation < *STI cultivars* > the average value of STI all cultivars - standard deviation
S (Sensitive)	if *STI cultivars* < the average value of STI all cultivars - standard deviation

cultivars under non Cr^{3+} stress condition. The radicle length, seedling length, fresh weight, and dry weight that was measured in experiments of germination and early seedling growth, was used to determine the value of STI. This tolerance level was adopted from Purwani & Marjani (2009) as following (Table 1):

Statistical analysis of data

The data obtained were analyzed by using analysis of variance and the differences between means treatments were compared by Duncan's multiple range test at $p < 0.05$. Ward's minimum variance cluster analysis with STI values parameters on the experiment of germination and early seedling simultaneously to evaluate the Cr^{3+} tolerance facilitates the ranking of Cr^{3+} tolerance of sorghum cultivars.

RESULT AND DISCUSSION

The result of analysis of variance showed that cultivar, $CrCl_3$, and interaction of $CrCl_3$ treatment and cultivar providing a noticeable effect on growth parameters of seedling on germination experiment. The interaction effects of cultivars and $CrCl_3$ concentrations on radicle length ($F= 6.17$, $df= 22$, $\alpha= 0.01$), seedling length ($F= 5.12$, $df= 22$, $\alpha= 0.01$), fresh weight ($F= 4.35$, $df= 22$, $\alpha= 0.01$) and dry weight ($F= 4.35$, $df = 22$, $\alpha= 0.01$) were found to be significant at the stage of seed germination. Peralta et al. (2001), reported that seed germination is the first physiological process affected by chromium (Cr), the ability of seed to germinate and growth in a medium containing Cr would be indicative of its level of tolerance to this metal. Mei et al. (2002), reported that ten plant species that have been documented having a high accumulation potential for Cr and/or other heavy metals showed different tolerance response toward $CrCl_3$. Seedling of eight plant species survived (90-100%) after two weeks germinated in the nutrient solution with 1.0 mM $CrCl_3$ while seedling of two plant species had no survivor.

Based on the result in Table 2 and 3, all the growth parameters of seedling (radicle length, seedling length, fresh weight and dry weight) demonstrated the considerable range and variability among twelve sorghum cultivars under control and $CrCl_3$ stress. The growth of seedling of sorghum cultivars was significantly affected by all $CrCl_3$ treatments. Table 2 indicated that the radicle length and length of seedling decreased with an increase of $CrCl_3$ concentration and degree of reduction varied with the $CrCl_3$ concentration and cultivars of sorghum. The highest average of percentage reduction was noted for the length of radicle (60.0%) and seedling length (47.5%) due to $CrCl_3$ stress (500 mg Cr/l). The highest percentage reduction in length of radicle and seedling was observed on cultivar Hegari i.e. 89.6% and 73.8%, respectively under stress condition of 500 mg/l $CrCl_3$. At 500 mg Cr/l, the lowest percentage reduction in length of radicle and length of seedling was observed on cultivars

Table 2. The length of radicle and seedling of each sorghum cultivar under stress condition of $CrCl_3$ on germination experiment

Treatments	Radicle length (cm)			Seedling length (cm)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	6.78^{h-l}	5.76^{k-n}	2.83^{p-s}	15.11^{d-g}	14.66^{d-h}	8.56^{k-n}
Badik	8.74^{f-i}	8.72^{f-i}	3.05^{p-s}	17.85^{b-e}	18.08^{b-d}	10.70^{i-k}
Keris	8.91^{f-h}	8.16^{g-j}	4.97^{l-p}	19.43^{b-c}	16.71^{c-f}	14.13^{e-i}
Keris M3	14.72^{b}	16.67^{a}	5.68^{k-n}	24.99^{a}	27.78^{a}	12.21^{g-j}
Hegari	10.48^{d-f}	6.64^{i-m}	1.09^{s}	19.37^{b-c}	14.88^{d-g}	5.07^{n}
Sangkur	6.70^{i-l}	5.47^{l-o}	3.44^{o-r}	14.99^{d-g}	12.98^{f-j}	9.37^{j-m}
Mandau	12.13^{c-d}	12.25^{c-d}	8.24^{g-j}	21.29^{b}	20.70^{b}	15.41^{d-g}
Numbu	9.74^{e-g}	4.47^{m-q}	1.71^{r-s}	20.97^{b}	12.84^{g-j}	7.03^{l-n}
Gambela	8.89^{f-h}	5.36^{l-o}	2.69^{q-s}	21.07^{b}	14.45^{d-h}	7.53^{k-n}
Kawali	4.93^{l-p}	2.28^{r-s}	2.40^{q-s}	11.11^{h-k}	6.08^{m-n}	6.68^{l-n}
Selayer	10.00^{e-g}	7.81^{g-k}	3.61^{n-r}	20.14^{b-c}	17.05^{c-e}	10.70^{i-k}
Batari	12.95^{b-c}	11.15^{c-e}	6.11^{j-m}	20.79^{b}	15.76^{d-g}	10.12^{j-l}

Means followed by the same letter(s) within treatment are not significantly different at $\alpha=0.05$ using DMRT.

Mandau and Keris, i.e. 32.1% and 27.3%, respectively. The different response of cultivars indicated that there was a lot of variabilities in sorghum for $CrCl_3$ tolerance at the stage of germination.

Similar to the elongation of radicle and seedling, the weight of seedling (fresh and dry) also decreased with an increase of $CrCl_3$ concentration (Table 3). There were significant differences between cultivars regarding fresh and dry weight. Increasing $CrCl_3$ treatments resulted in significant decreased in seedling weights (fresh and dry). The degree of percentage reduction varied with the $CrCl_3$ concentration and cultivars of sorghum. The low $CrCl_3$ treatment (50 mg Cr/l) reduced fresh and dry weights of seedling lesser than high $CrCl_3$ treatment (500 mg Cr/l). The highest average of percentage reduction was noted for fresh weight (32.8%) and dry weight (37.4%) due to $CrCl_3$ stress (500 mg Cr/l). The lowest percentage reduction in fresh and dry weights of seedling was observed on cultivars Sangkur and UPCA, i.e. 15.0% and 11.8%, respectively, at the treatment solution with 500 mg $CrCl_3$/l. Meanwhile, at 500 mg Cr/l, the highest percentage reduction of fresh and dry weights was observed on cultivars Gambela (50.9%) and Selayer (74.1%).

Analysis of variance showed that interaction between $KCr(SO_4)_2$ treatment and cultivars caused a significant effect (α=0.01) on radicle length (F= 3.91, df= 22, α= 0.01), seedling length (F= 3.40, df= 22, α= 0.01), fresh weight (F= 4.28, df= 22, α= 0.01) and dry weight (F= 7.85, df = 22, α= 0.01) at germination experiment. This result indicated that the seedling growth (elongation and biomass) at germination stage of sorghum cultivars were adversely affected by all $KCr(SO_4)_2$ treatments.

Similar to the effect of $CrCl_3$ treatments, all the growth parameters of seedling (radicle length, seedling length, fresh weight and dry weight) also affected by $KCr(SO_4)_2$ treatments. The growth parameters of seedling (radicle length, seedling length, fresh weight and dry weight) demonstrated the considerable range and variability among twelve sorghum cultivars under control and $KCr(SO_4)_2$ stress. The mean growth parameters of all tested cultivars were lower than controls. DMRT result showed that, all growth parameters (radicle length, seedling length, fresh weight and dry weight) of twelve cultivars at 0 mg/l $KCr(SO_4)_2$ was significantly different (α=0.05) from treatments of 50 and 500 mg/l $KCr(SO_4)_2$ (Table 4 and 5).

In general, the growth parameters i.e. radicle length, seedling length, fresh weight and dry weight of all seedling cultivars sorghum decreased with increasing concentration of $KCr(SO_4)_2$. The percentage reduction of growth parameters varied with the $KCr(SO_4)_2$ concentration and cultivars sorghum. The high concentration of $KCr(SO_4)_2$ (500 mg Cr/l) reduced fresh and dry weights of seedling higher compared to the treatment of low concentration (50 mg Cr/l).

The highest average of percentage reduction was noted for the length of radicle (53.9%),

Table 3. The fresh and dry weights of seedling of each sorghum cultivar under stress condition of $CrCl_3$ on germination experiment

Treatments	Fresh weight (g)			Dry weight (g)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	1.455^{e-g}	1.335^{f-j}	1.055^{k-n}	0.085^{f-l}	0.083^{g-l}	0.075^{i-m}
Badik	1.389^{e-i}	1.615^{c-e}	1.077^{k-n}	0.115^{b-e}	0.136^{a-b}	0.072^{j-m}
Keris	1.422^{e-h}	1.204^{h-l}	1.061^{k-n}	0.133^{a-c}	0.081^{g-l}	0.092^{e-j}
Keris M3	1.879^{a-b}	1.717^{b-d}	1.147^{i-m}	0.109^{c-g}	0.130^{a-d}	0.079^{g-l}
Hegari	1.224^{g-k}	0.939^{m-o}	0.644^{q-r}	0.105^{d-h}	0.047^{m-o}	0.035^{n-p}
Sangkur	1.131^{j-n}	1.121^{j-n}	0.961^{l-o}	0.086^{e-k}	0.077^{h-l}	0.073^{i-m}
Mandau	1.942^{a-b}	1.967^{a}	1.498^{d-f}	0.154^{a}	0.136^{a-b}	0.114^{b-e}
Numbu	1.966^{a}	1.503^{d-f}	1.042^{k-n}	0.112^{b-f}	0.088^{e-j}	0.077^{h-l}
Gambela	1.823^{a-c}	1.241^{g-k}	0.895^{m-p}	0.131^{a-c}	0.101^{e-i}	0.086^{e-k}
Kawali	0.884^{n-q}	0.735^{o-r}	0.671^{p-r}	0.038^{n-p}	0.031^{o-p}	0.021^{p}
Selayer	1.258^{f-k}	1.271^{f-k}	0.739^{o-r}	0.081^{g-l}	0.068^{j-m}	0.021^{p}
Batari	0.907^{m-p}	0.646^{q-r}	0.633^{r}	0.055^{l-o}	0.035^{o-p}	0.028^{o-p}

Means followed by the same letter(s) within treatment are not significantly different at α=0.05 using DMRT.

seedling length (42.5%), fresh weight (31.5%) and dry weight (45.9%) under stress condition of 500 mg/l $KCr(SO_4)_2$. The results suggested that radicle length was greatest affected by $KCr(SO_4)_2$ stress compared to other growth parameters. Meanwhile, the fresh weight of seedling was least affected by $KCr(SO_4)_2$ stress at germination experiment.

Among sorghum cultivars that were tested, the highest percentage reduction of radicle and seedling lengths was observed on cultivars Numbu and Mandau, i.e. 79.5% and 63.2%, respectively under stress condition of 500 mg/l $KCr(SO_4)_2$. While the highest percentage reduction of fresh and dry weights was observed on Mandau (49.4%) and Batari (78.2%), respectively under stress condition of 500 mg/l $KCr(SO_4)_2$. The lowest percentage reduction of radicle length,

Table 4. The length of radicle and seedling of each sorghum cultivar under stress condition of $KCr(SO_4)_2$ on germination experiment

Treatments	Radicle length (cm)			Seedling length (cm)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	$6.78^{f\text{-}h}$	$4.85^{h\text{-}k}$	$3.02^{j\text{-}l}$	$15.11^{d\text{-}h}$	$12.36^{h\text{-}m}$	$8.22^{n\text{-}p}$
Badik	$8.74^{d\text{-}g}$	$8.16^{e\text{-}g}$	$4.97^{h\text{-}j}$	$17.85^{b\text{-}e}$	$16.71^{c\text{-}g}$	$14.13^{f\text{-}k}$
Keris	$8.91^{d\text{-}f}$	$5.51^{h\text{-}i}$	2.57^{l}	$19.43^{b\text{-}c}$	$14.41^{f\text{-}k}$	$9.19^{m\text{-}p}$
Keris M3	14.72^{a}	$8.34^{d\text{-}g}$	5.80^{h}	24.99^{a}	$17.99^{b\text{-}e}$	$12.80^{h\text{-}l}$
Hegari	$10.48^{c\text{-}d}$	$8.61^{d\text{-}g}$	$5.07^{h\text{-}j}$	$19.37^{b\text{-}c}$	$17.19^{c\text{-}f}$	$11.01^{k\text{-}o}$
Sangkur	$6.70^{f\text{-}h}$	$3.44^{i\text{-}l}$	2.54^{l}	$14.99^{d\text{-}i}$	$11.40^{i\text{-}n}$	6.95^{p}
Mandau	$12.13^{b\text{-}c}$	$6.74^{f\text{-}h}$	$2.70^{k\text{-}l}$	21.29^{b}	$14.71^{e\text{-}j}$	$7.84^{o\text{-}p}$
Numbu	$9.74^{d\text{-}e}$	$5.03^{h\text{-}j}$	2.00^{l}	20.97^{b}	$14.30^{f\text{-}k}$	$8.03^{n\text{-}p}$
Gambela	$8.89^{d\text{-}f}$	$6.84^{f\text{-}h}$	$5.08^{h\text{-}j}$	21.07^{b}	$18.45^{b\text{-}d}$	$14.38^{f\text{-}k}$
Kawali	$4.93^{h\text{-}k}$	$3.12^{j\text{-}l}$	$3.08^{j\text{-}l}$	$11.11^{j\text{-}o}$	$9.33^{l\text{-}p}$	$7.76^{o\text{-}p}$
Selayer	$10.00^{d\text{-}e}$	$5.40^{h\text{-}i}$	$6.58^{g\text{-}h}$	$20.14^{b\text{-}c}$	$12.03^{h\text{-}m}$	$15.56^{d\text{-}h}$
Batari	$12.95^{a\text{-}b}$	$9.19^{d\text{-}e}$	$8.97^{d\text{-}f}$	20.79^{b}	$14.70^{e\text{-}j}$	$13.24^{g\text{-}k}$

Means followed by the same letter(s) within treatment are not significantly different at α=0.05 using DMRT.

Table 5. The fresh and dry weights of seedling of each sorghum cultivar under stress condition of $KCr(SO_4)_2$ on germination experiment

Treatments	Fresh weight (g)			Dry weight (g)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	$1.455^{c\text{-}d}$	$1.473^{c\text{-}d}$	$0.902^{j\text{-}n}$	$0.085^{d\text{-}i}$	$0.057^{i\text{-}l}$	0.035^{l}
Badik	$1.389^{c\text{-}e}$	$1.204^{d\text{-}i}$	$1.061^{g\text{-}m}$	$0.115^{b\text{-}d}$	$0.081^{e\text{-}j}$	$0.092^{d\text{-}g}$
Keris	$1.422^{c\text{-}e}$	$1.075^{g\text{-}m}$	0.726^{n}	$0.133^{a\text{-}c}$	$0.094^{d\text{-}g}$	$0.051^{j\text{-}l}$
Keris M3	1.879^{a}	$1.239^{d\text{-}i}$	$1.115^{f\text{-}l}$	$0.109^{c\text{-}e}$	$0.086^{d\text{-}h}$	$0.099^{d\text{-}f}$
Hegari	$1.224^{d\text{-}i}$	$1.171^{e\text{-}j}$	$0.881^{k\text{-}n}$	$0.105^{d\text{-}f}$	$0.077^{f\text{-}j}$	$0.046^{k\text{-}l}$
Sangkur	$1.131^{f\text{-}k}$	$1.063^{g\text{-}m}$	$0.824^{m\text{-}n}$	$0.086^{d\text{-}h}$	$0.077^{f\text{-}j}$	$0.058^{i\text{-}l}$
Mandau	1.942^{a}	$1.620^{b\text{-}c}$	$0.983^{h\text{-}n}$	0.154^{a}	$0.138^{a\text{-}b}$	$0.090^{d\text{-}g}$
Numbu	1.966^{a}	1.924^{a}	$1.201^{d\text{-}i}$	$0.114^{b\text{-}d}$	$0.096^{d\text{-}g}$	$0.055^{j\text{-}l}$
Gambela	$1.823^{a\text{-}b}$	$1.388^{c\text{-}f}$	$1.310^{d\text{-}g}$	$0.131^{a\text{-}c}$	0.151^{a}	$0.067^{g\text{-}k}$
Kawali	$0.884^{k\text{-}n}$	0.778^{n}	0.777^{n}	0.038^{l}	$0.028^{n\text{-}m}$	$0.023^{n\text{-}m}$
Selayer	$1.258^{d\text{-}h}$	$0.836^{l\text{-}n}$	$0.973^{i\text{-}n}$	$0.081^{e\text{-}j}$	0.036^{l}	0.038^{l}
Batari	$0.907^{j\text{-}n}$	$0.824^{m\text{-}n}$	0.721^{n}	$0.055^{j\text{-}l}$	0.041^{l}	0.012^{m}

Means followed by the same letter(s) within treatment are not significantly different at α=0.05 using DMRT.

seedling length, fresh weight and dry weight was observed on Batari (30.7%), Selayer (22.7%), Kawali (12.1%), and Keris M3 (9.2%), under stress condition of 500 mg/l $KCr(SO_4)_2$.

At low concentration treatment (50 mg/l), Cr^{3+} ($CrCl_3$ and $KCr(SO_4)_2$) increased the four growth parameters on several cultivars i.e. Badik, Mandau, Keris M3, Selayer, UPCA and Gambela. The results indicated that in some cultivars of sorghum, Cr^{3+} has a role in improving the growth of plants. Several beneficial effects in term of yield by applying chromium was reported in oat, barley, cucumber, and grape (Samantaray et al., 1998).

The response of twelve cultivars sorghum toward stresses of $CrCl_3$ and $KCr(SO_4)_2$ also observed at the early seedling growth stage. The experiment was conducted to observe the effect of $CrCl_3$ and $KCr(SO_4)_2$ on the seedling growth of sorghum cultivars. The results of analysis variance showed that the interaction between $CrCl_3$ and cultivars treatment was significantly affected by growth parameters of seedling i.e. root length ($F= 4.25$, $df= 22$, $\alpha= 0.01$), seedling length ($F= 6.86$, $df= 22$, $\alpha= 0.01$), fresh weight ($F= 6.73$, $df= 22$, $\alpha= 0.01$) and dry weight ($F= 6.13$, $df= 22$, $\alpha= 0.01$) at early seedling growth experiment.

The results obtained indicate that increasing $CrCl_3$ concentration caused decreased elongation of root and seedling (Table 6) and weight of seedling (Table 7) as compared to controls. At the early seedling stage, the percentage reduction in root length, seedling length, fresh weight and dry weight clearly demonstrated genetic variation in growth responses toward stresses of Cr^{3+} among sorghum cultivars. Significant differences observed in length of root and seedling, and also fresh and dry weight between sorghum cultivars, and these parameters were inhibited by $CrCl_3$ stress. Under stress condition of 500 mg/l $CrCl_3$, the highest average of percentage reduction was noted for the length of the root (31.4%), seedling length (33.5%), fresh weight (69.6%) and dry weight (44.6%). These result indicated that the seedling weight (fresh and dry weight) was greater affected by $CrCl_3$ treatments compared to the length of the root and length of the seedling.

Significant genotypic variation was recorded with $CrCl_3$ treatments. High variability existed for growth parameters in the seedling. It was observed that among 12 cultivars, under high concentration of $CrCl_3$ (500 mg /l), the highest percentage reduction of root and seedling lengths was observed on cultivars Selayer and Batari, i.e. 47.8% and 53.4%, respectively. Meanwhile, the highest percentage reduction of fresh and dry weights was observed on Gambela (85.6%) and Batari (64.3%). Under stress condition of 500 mg/l $CrCl_3$, the lowest percentage reduction of radicle length, seedling length, and dry weight was observed on Kawali i.e. 1.9%, 14.9%, 19.4.1%, respectively, and fresh weight in UPCA (35.3%).

At low concentration of $CrCl_3$ (50 mg/l), some cultivars showed an increase in seedling growth, i.e., on cultivar Gambela, Kawali and

Table 6. The length of radicle and seedling of each sorghum cultivar under stress condition of $CrCl_3$ on early seedling growth experiment

Treatments	Root length (cm)			Seedling length (cm)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	$15.41^{f\text{-}i}$	$13.00^{j\text{-}n}$	$11.40^{n\text{-}p}$	$39.45^{h\text{-}j}$	$35.64^{j\text{-}l}$	$32.34^{l\text{-}m}$
Badik	$19.48^{b\text{-}c}$	$17.46^{c\text{-}f}$	$12.84^{k\text{-}n}$	53.09^{a}	$51.74^{a\text{-}b}$	$36.32^{j\text{-}l}$
Keris	$18.75^{b\text{-}d}$	$15.24^{f\text{-}j}$	$12.38^{l\text{-}o}$	$48.31^{b\text{-}d}$	$42.28^{g\text{-}h}$	$32.94^{k\text{-}m}$
Keris M3	20.62^{b}	$17.78^{c\text{-}e}$	$15.58^{e\text{-}i}$	$50.91^{a\text{-}c}$	$47.74^{c\text{-}e}$	$36.70^{j\text{-}k}$
Hegari	$17.31^{c\text{-}f}$	$11.34^{n\text{-}p}$	$10.50^{o\text{-}p}$	$48.71^{b\text{-}d}$	$39.46^{h\text{-}j}$	$29.44^{m\text{-}n}$
Sangkur	$16.09^{e\text{-}h}$	$13.48^{i\text{-}n}$	$11.56^{n\text{-}p}$	$43.42^{f\text{-}g}$	$36.96^{j\text{-}k}$	$27.28^{n\text{-}o}$
Mandau	$14.16^{h\text{-}m}$	$12.02^{m\text{-}p}$	$7.94^{q\text{-}r}$	$35.73^{m\text{-}n}$	$30.78^{j\text{-}l}$	23.30^{p}
Numbu	$19.21^{b\text{-}c}$	$16.08^{e\text{-}h}$	$14.76^{g\text{-}k}$	$52.03^{a\text{-}b}$	$39.32^{h\text{-}j}$	$33.08^{k\text{-}m}$
Gambela	$16.68^{d\text{-}g}$	$19.42^{b\text{-}c}$	$12.02^{m\text{-}p}$	$43.88^{e\text{-}g}$	$47.46^{c\text{-}e}$	$30.62^{m\text{-}n}$
Kawali	20.62^{b}	23.42^{a}	20.22^{b}	$44.98^{d\text{-}g}$	$46.52^{d\text{-}f}$	$38.28^{i\text{-}j}$
Selayer	$14.56^{g\text{-}l}$	$12.40^{l\text{-}o}$	7.60^{r}	$44.31^{e\text{-}g}$	$41.06^{g\text{-}i}$	$24.04^{o\text{-}p}$
Batari	$9.80^{p\text{-}q}$	$7.04^{r\text{-}s}$	5.26^{s}	$33.15^{k\text{-}m}$	20.60^{p}	15.46^{q}

Means followed by the same letter(s) within treatment are not significantly different at $\alpha=0.05$ using DMRT.

Selayer. The treatment of 0.5 ppm chromium as chromium sulfate reported stimulating growth in the hydroponic experiment with maize. The maize growth was inhibited at 5 ppm and strongly inhibited at 50 ppm (Gardea –Torresday et al., 2004). The low Cr^{3+} concentration was also reported promoting plant growth, and stimulating chlorophyll synthesis and photosynthetic activity.

The effects of interaction between treatments of $KCr(SO_4)_2$ and cultivars, on root length (F= 3.14, df= 22, α= 0.01), seedling length (F= 3.77, df= 22, α= 0.01), fresh weight (F= 2.48, df= 22, α= 0.01) and dry weight (F= 3.31, df= 22, α= 0.01) at the stage of early seedling growth were found significant (α=0.01). The average length and weight of seedlings showed decrease depending on the increasing $KCr(SO_4)_2$ concentrations.

The DMRT result showed that all seedling growth parameters of twelve cultivars at 0 mg/l $KCr(SO_4)_2$ was significantly different (α=0.05) from treatments of 50 and 500 mg/l $KCr(SO_4)_2$ (Table 8 and 9) on the early seedling experiment. Similar to the effect of $KCr(SO_4)_2$ at germination experiment, the seedling growth parameters (elongation and weight) of cultivars sorghum decreased with an increase of $KCr(SO_4)_2$ concentration, at the early seedling experiment. The percentage reduction of growth parameters varied with $KCr(SO_4)_2$ concentration and cultivars sorghum. The low concentration of $KCr(SO_4)_2$ (50 mg Cr/l) reduced seedling growth lesser compared to the treatment of high concentration (500 mg Cr/l).

Under stress condition of 500 mg/l $KCr(SO_4)_2$, the highest average of percentage reduction was noted for root length (28.6%), seedling length (26.1%), fresh weight (41.1%) and dry weight (27.8%). The results suggested that fresh weight was the greatest affected by $KCr(SO_4)_2$ stress compared to other growth parameters. Meanwhile, the seedling length was least affected by $KCr(SO_4)_2$ stress at the early seedling experiment.

The interaction effect between cultivars and $KCr(SO_4)_2$ treatments showed significant variation among cultivars on seedling growth parameters. Among sorghum cultivars that were tested, under stress condition of 500 mg/l $KCr(SO_4)_2$, there were three cultivars recorded to have percentage reduction of growth seedling greater than 50%, i.e. Kawali, Selayer and Batari. The lowest percentage reduction of seedling length and fresh weight was observed on Numbu i.e., 3.6%, and 0.9 %, respectively, at the treatment of 500 mg/l $KCr(SO_4)_2$. At high concentration $KCr(SO_4)_2$, Numbu cultivar recorded to have an increasing dry weight 10.5% as compared to the control treatment. Badik cultivar had the lowest percentage reduction of root length compared to other cultivars, i.e. 7.7%, at high concentration $KCr(SO_4)_2$. Similar to the effect of $CrCl_3$, at low concentration treatment of $KCr(SO_4)_2$, several cultivars also showed an increasing seedling growth, i.e. on Badik, Keris, Hegari, Numbu, Sangkur, and Mandau.

Based on the experimental results at the stage of germination and early seedling growth

Table 7. The fresh and dry weights of seedling of each sorghum cultivar under stress condition of $CrCl_3$ on early seedling growth experiment

Treatments	Fresh weight (g)			Dry weight (g)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	0.329^{g-j}	0.310^{h-k}	0.213^{l-n}	0.038^{g-i}	0.037^{g-j}	0.031^{i-l}
Badik	0.538^{a-b}	0.360^{e-j}	0.097^{o-q}	0.058^{b}	0.040^{f-i}	0.024^{l-m}
Keris	0.560^{a}	0.371^{e-i}	0.112^{o-q}	0.059^{a-b}	0.044^{e-h}	0.024^{l-m}
Keris M3	0.422^{d-f}	0.412^{d-g}	0.187^{m-o}	0.045^{d-g}	0.045^{d-g}	0.034^{i-k}
Hegari	0.522^{a-c}	0.470^{b-d}	0.149^{m-p}	0.053^{b-d}	0.050^{b-e}	0.028^{j-m}
Sangkur	0.466^{b-d}	0.279^{i-l}	0.132^{n-q}	0.049^{c-f}	0.031^{i-l}	0.021^{m-n}
Mandau	0.305^{h-k}	0.235^{k-m}	0.081^{p-q}	0.035^{h-j}	0.030^{i-l}	0.021^{m-n}
Numbu	0.569^{a}	0.281^{i-l}	0.141^{n-p}	0.057^{b-c}	0.034^{i-l}	0.025^{k-m}
Gambela	0.472^{b-d}	0.451^{b-e}	0.068^{p-q}	0.053^{b-d}	0.067^{a}	0.031^{i-l}
Kawali	0.327^{g-j}	0.337^{f-j}	0.179^{m-o}	0.031^{i-l}	0.034^{i-l}	0.025^{k-m}
Selayer	0.434^{c-e}	0.396^{d-h}	0.100^{o-q}	0.039^{g-i}	0.040^{f-i}	0.020^{m-n}
Batari	0.277^{j-l}	0.107^{o-q}	0.048^{q}	0.028^{j-m}	0.015^{n-o}	0.010^{o}

Means followed by the same letter(s) within treatment are not significantly different at α=0.05 using DMRT.

indicated that the treatment $CrCl_3$ and $KCr(SO_4)_2$ providing a similar effect on the growth of twelve sorghum cultivars that were tested. The Cr^{3+} treatment, either in the form of $CrCl_3$ or $KCr(SO_4)_2$ reduced the seedling growth of all sorghum cultivars that were tested (Figure 1).

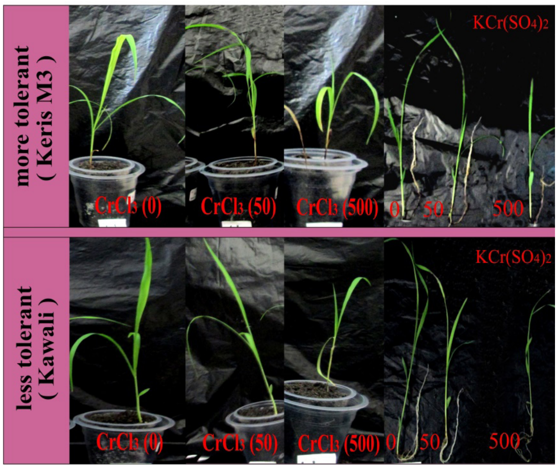

Figure 1. Seedling growth of sorghum cultivar more tolerant (above) and less tolerant (below)

The growth response of sorghum cultivars toward Cr^{3+} stresses showed differences both on the stage of the germination and early seedling growth. Tigabu et al. (2013), reported that germination and seedling characteristics were the most viable criteria used for selecting tolerant plants because the final plant stand of a crop primarily depends on seedling characteristics. Sharma et al. (2013) also reported that seed germination and early seedling growth were the two critical stage in the life cycle of a crop. According to Rani et al. (2012), the preventative effect of heavy metals on the germination of crops was a major limiting factor for plants stability in contaminated soil by heavy metals. The stage of germination was the most important phase due to its direct effect on initial plants establishment.

The growth response to environmental stresses at the germination stage had been widely reported on cereal plant species. The growth response of cereal plants cultivar to salinity stress at germination stage had been reported on *Sorghum bicolor* (Rani et al., 2012), *Triticum aestivum* (El-Hendawy et al., 2005), *Hordeum vulgare* (Bagci & Yilmaz, 2003), and *Oryza sativa* (Roslim et al., 2015). In addition to the stress salinity, the growth response of cereal crops to the stress of heavy metals in the phase of germination had also been widely reported. The effect of chromium hexavalent (Cr^{6+}) stresses at seedling growth responses of cereal crops had been reported on *Oryza sativa* (Gyawali & Lekhak, 2006), *Triticum aestivum* (Datta et al., 2011), and *Sorghum bicolor* (Kasmiyati et al., 2015). Shaw & Rout (2002), reported that plants respond differently to different heavy metals. The toxicity of heavy metals varied depending on the genotypes, age and developmental stages of plants.

At the stage of germination, the length of root was the growth parameters of sorghum cultivars that were the most affected by trivalent chromium stresses ($CrCl_3$ and $KCr(SO_4)_2$). These results indicated that the root was the most sensitive organ to Cr^{3+} stresses. In contrast to the

Table 8. The length of root and seedling of each sorghum cultivar under stress condition of $KCr(SO_4)_2$ on early seedling growth experiment

Treatments	Radicle length (cm)			Seedling length (cm)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	15.41^{e-i}	12.60^{i-m}	9.84^{l-n}	39.45^{j-l}	38.92^{j-m}	31.36^{n-o}
Badik	19.48^{a-c}	22.28^{a}	17.98^{b-g}	53.09^{a-c}	57.86^{a}	47.36^{c-h}
Keris	18.75^{b-e}	20.30^{a-b}	15.34^{e-i}	48.31^{c-h}	49.46^{b-g}	40.16^{j-l}
Keris M3	20.62^{a-b}	17.22^{b-h}	14.34^{g-j}	50.91^{b-e}	46.40^{d-i}	41.10^{i-l}
Hegari	17.31^{b-h}	22.34^{a}	15.64^{d-i}	48.71^{c-h}	53.34^{a-c}	42.76^{h-k}
Sangkur	16.09^{c-i}	14.12^{h-k}	11.68^{i-n}	43.42^{g-k}	39.64^{j-l}	31.98^{n-o}
Mandau	14.16^{h-k}	14.84^{f-j}	12.94^{i-l}	35.73^{l-n}	32.06^{n-o}	28.16^{o-p}
Numbu	19.21^{a-d}	18.28^{b-f}	16.10^{c-i}	52.03^{a-d}	55.46^{a-b}	50.16^{b-f}
Gambela	16.68^{c-h}	15.86^{d-i}	10.50^{l-n}	43.88^{f-k}	38.06^{k-m}	29.94^{n-o}
Kawali	20.62^{a-b}	12.62^{i-m}	9.16^{m-n}	44.98^{e-j}	39.40^{j-l}	22.56^{p}
Selayer	14.56^{g-j}	10.72^{k-n}	9.10^{m-n}	44.31^{f-k}	30.22^{n-o}	24.06^{p}
Batari	9.80^{l-n}	8.30^{n}	4.10^{o}	33.15^{m-o}	27.00^{o-p}	14.80^{q}

Means followed by the same letter(s) within treatment are not significantly different at $\alpha=0.05$ using DMRT.

results of experiments on germination, seedling growth parameter of sorghum cultivars that were mostly affected by stress Cr^{3+} ($CrCl_3$ and $KCr(SO_4)_2$) was fresh weight, at early seedling growth experiments. According to Hagemeyer (1999), roots that directly interacted with nutrient and toxic elements, were generally more sensitive than other tissue of plants. Wani et al. (2012), also reported that the root of the various plants including cereals was the first organ that was directly exposed to metal in soil and hence was the target of stressor molecules including heavy metals. Diwan et al. (2010) used the root growth as an important parameter in classifying heavy metal tolerance. Therefore, tolerance degrees of the cultivars in the germination stage were also evaluated by looking at the length root reduction. Roslim et al. (2015) reported that the seedling roots growth was the best parameter to study the salt tolerance in rice. According to the seedling roots growth, Indragiri was the salt tolerant rice variety, Amat Candu was the salt moderate rice variety, and IR64, Sadani, Yamin, and Solok were the salt-sensitive rice varieties.

The reduction in seedling length and biomass that were observed in sorghum cultivars that caused by Cr^{3+} stresses indicated that chromium was toxic to seedling growth and biomass production. According to Shanker et al. (2005), the reduction in length and biomass of seedling that was caused by inhibition of roots growth had an impact in reducing the distribution of nutrients and water toward shoots of plants. Chromium that was transported to the aerial part of the plant also had a direct effect on the cellular metabolism of shoots thus reducing seedling length.

Stress tolerance index (STI) and its standard deviation were used to classify the level of tolerance to Cr^{3+} stress ($CrCl_3$ and $KCr(SO_4)_2$). The radicle length, seedling length, fresh weight, and dry weight that were measured in experiments of germination and early seedling growth were used to determine the value of STI. Determining the level of plant tolerance to environmental stress using STI values was described by Fernandez (1992). It had been suggested that high tolerance to environmental stress was correlated with high STI. Selection based on STI will result in cultivars with higher stress tolerance, and yield potential will be selected (Hosseini et al., 2012)

Based on the result in Table 10, it was indicated that there was variation in the values of STI between cultivars of sorghum, either on the experiment of germination or early seedling growth. The tolerance level and STI value of cultivars sorghum during germination stage differed from the early seedling growth. It had been reported that for the most crops, the stress tolerance at one developmental phase was significantly different from the other phases. Therefore, the sensitivity or tolerance to stress should be evaluated in three different developmental phases i.e. germination, vegetative growth, and generative growth.

The results also showed that there were differences in the effects of chemical compound Cr^{3+} on STI values and tolerance level of sorghum

Table 9. The fresh and dry weights of seedling of each sorghum cultivar under stress condition of $KCr(SO_4)_2$ on early seedling growth experiment

Treatments	Fresh weight (g)			Dry weight (g)		
	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l	0 mg Cr/l	50 mg Cr/l	500 mg Cr/l
UPCA	$0.329^{f\text{-}k}$	$0.323^{f\text{-}l}$	$0.210^{j\text{-}n}$	$0.038^{g\text{-}j}$	$0.036^{g\text{-}k}$	$0.029^{i\text{-}m}$
Badik	$0.538^{b\text{-}e}$	0.754^{a}	$0.437^{c\text{-}h}$	$0.058^{c\text{-}e}$	0.087^{a}	$0.066^{b\text{-}c}$
Keris	$0.560^{b\text{-}d}$	$0.643^{a\text{-}b}$	$0.409^{e\text{-}i}$	$0.059^{c\text{-}d}$	$0.065^{b\text{-}c}$	$0.053^{c\text{-}f}$
Keris M3	$0.422^{d\text{-}i}$	$0.309^{h\text{-}l}$	$0.227^{j\text{-}n}$	$0.045^{d\text{-}h}$	$0.032^{h\text{-}l}$	$0.028^{i\text{-}m}$
Hegari	$0.522^{b\text{-}e}$	$0.573^{b\text{-}c}$	$0.347^{f\text{-}j}$	$0.053^{c\text{-}f}$	$0.058^{c\text{-}e}$	$0.042^{f\text{-}h}$
Sangkur	$0.466^{c\text{-}g}$	$0.469^{c\text{-}g}$	$0.318^{g\text{-}l}$	$0.048^{d\text{-}g}$	$0.053^{c\text{-}f}$	$0.044^{e\text{-}h}$
Mandau	$0.305^{h\text{-}l}$	$0.217^{j\text{-}n}$	$0.177^{l\text{-}n}$	$0.035^{g\text{-}k}$	$0.027^{j\text{-}m}$	$0.023^{k\text{-}n}$
Numbu	$0.569^{b\text{-}d}$	0.749^{a}	$0.564^{b\text{-}d}$	$0.057^{c\text{-}e}$	$0.076^{a\text{-}b}$	0.063^{c}
Gambela	$0.472^{c\text{-}f}$	$0.354^{f\text{-}j}$	$0.248^{j\text{-}m}$	$0.053^{c\text{-}f}$	$0.036^{g\text{-}k}$	$0.029^{i\text{-}m}$
Kawali	$0.327^{f\text{-}l}$	$0.321^{g\text{-}l}$	$0.117^{m\text{-}n}$	$0.031^{h\text{-}l}$	$0.030^{i\text{-}l}$	$0.015^{m\text{-}n}$
Selayer	$0.434^{c\text{-}h}$	$0.195^{k\text{-}n}$	$0.102^{m\text{-}n}$	$0.039^{g\text{-}j}$	$0.018^{l\text{-}n}$	0.012^{n}
Batari	$0.277^{i\text{-}l}$	$0.193^{k\text{-}n}$	0.088^{n}	$0.028^{i\text{-}m}$	$0.022^{k\text{-}n}$	0.012^{n}

Means followed by the same letter(s) within treatment are not significantly different at α=0.05 using DMRT.

cultivars, at the stage of germination and early seedling growth. At germination experiment, two sorghum cultivars i.e. Keris M3 and Mandau had high STI value and classified as very strong tolerant cultivar to $CrCl_3$ stress. Eight cultivars (UPCA, Badik, Keris, Hegari, Sangkur, Numbu, Gambela, Selayer, and Batari) were classified as moderate to $CrCl_3$ stress. Meanwhile, Kawali that had the lowest STI value was classified as weak tolerant cultivar to $CrCl_3$ stress. Twelve cultivars sorghum showed variation in STI values and tolerance level to $KCr(SO_4)_2$ stress. Three cultivars sorghum had high STI value and were classified as very strong tolerant cultivar i.e. Keris M3, Mandau and Gambela; two cultivars were recorded to have STI value lower compared to other cultivar and classified as weak tolerant cultivars (Kawali and Sangkur). The other cultivars (seven cultivars i.e. UPCA, Badik, Keris, Hegari, Numbu, Gambela, Selayer, and Batari) were classified as moderat tolerant ones to $KCr(SO_4)_2$ stress.

At the early seedling experiment, two cultivars were classified as a very strong tolerant cultivar (Gambela) and a weak tolerant one (Batari) because Gambela had the highest STI values and Batari had the lowest under $CrCl_3$ stress condition. The other sorghum cultivars that were tested (UPCA, Badik, Keris, Keris M3, Hegari, Numbu, Sangkur, Mandau, Kawali, and Selayer) were classified as moderat tolerant cultivars to $CrCl_3$ stress. Cr^{3+} in the form of $KCr(SO_4)_2$ showed more toxic effects on sorghum cultivars at early seedling growth, compared to $CrCl_3$. Under condition of stress $KCr(SO_4)_2$, among sorghum cultivars were noted that three cultivars were classified as very strong tolerant cultivars (Badik and Numbu) and a strong tolerant one (Keris), five cultivars (UPCA, Keris M3, Hegari, Sangkur, and Gambela) were clasified as moderat tolerant, and four cultivars (Mandau, Kawali, Selayer and Batari) were classified as weak tolerant ones. Based on the average of STI values of 12 sorghum cultivars under condition of Cr^{3+} stresses ($CrCl_3$ and $KCr(SO_4)_2$) at two stages of plant growth (germination and early seedling) showed that there were four sorghum cultivars (Badik, Keris, Keris M3 and Numbu) that were classified as very strong tolerant cultivars, 4 cultivars (Hegari, Mandau, Sangkur and Gambela) as moderate tolerant, two cultivars (UPCA and Selayer) as weak tolerant, and 2 cultivars (Kawali and Batari) as sensitive ones (Figure 2).

Plant species or cultivars within species differ widely in a tolerance ability to metal, and mechanism of tolerance helped to maintain growth even in the presence of potentially toxic metal concentration (Clemens, 2006). The metal tolerance refers to any individual which can with-

Table 10. Tolerance level based on STI value of each sorghum cultivar under Cr^{3+} stress condition at stages of germination and early seedling growth

Treatments	Germination Stage				Early Seedling Growth Stage			
	$CrCl_3$	Tolerance level	$KCr(SO_4)_2$	Tolerance level	$CrCl_3$	Tolerance level	$KCr(SO_4)_2$	Tolerance level
UPCA	0.737	MT	0.676	MT	0.726	MT	0.714	MT
Badik	0.887	MT	0.767	MT	0.832	MT	1.635	VT
Keris	0.920	MT	0.780	MT	0.868	MT	1.449	ST
Keris M3	1.280	VT	1.036	ST	0.884	MT	0.791	MT
Hegari	0.663	MT	0.790	MT	0.907	MT	1.181	MT
Sangkur	0.703	MT	0.645	WT	0.710	MT	1.024	MT
Mandau	1.218	VT	0.934	ST	0.599	MT	0.628	WT
Numbu	0.798	MT	0.845	MT	0.830	MT	1.653	VT
Gambela	0.838	MT	1.017	ST	0.946	ST	0.855	MT
Kawali	0.528	WT	0.569	WT	0.688	MT	0.612	WT
Selayer	0.769	MT	0.769	MT	0.701	MT	0.547	WT
Batari	0.677	MT	0.702	MT	0.456	WT	0.509	WT
Average of STI	0.835		0.794		0.762		0.968	
Standard deviation	0.348		0.268		0.335		0.593	

VT=very strong, tolerant, ST= strong tolerant, MT= moderate tolerant, WT= weak tolerant stand greater amounts of toxicity than its immediate relatives of normal condition. The tolerance capacity of metal in plants, may be due to the certain inherited potentiality of the seed. The tolerant cultivars had an integrated complex of adaptations to cope with a range of various types and concentrations of metals. According to Samantaray et al. (1998), the physiological mechanism of Cr tolerance in different of plant species and cultivars can be controlled by different genes through the different biochemical pathway. The Cr-tolerant cultivars or plant species must be able to prevent the absorption of excess Cr or to detoxify the Cr that had been absorbed.

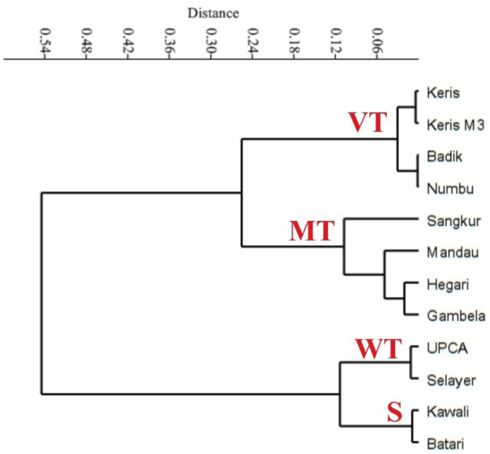

Figure 2. Cluster analysis of sorghum cultivar under Cr^{3+} stress at germination and early seedling stage using Ward's minimum variance method. VT=very strong tolerant, MT= moderate tolerant, WT= weak tolerant, S= sensitive

The results of this study are expected to provide the scientific basis of the physiological and tolerance responses of sorghum cultivars toward Cr^{3+} stress condition. The tolerant sorghum cultivars that obtained are expected to be developed as an agent of phytoremediation in environments contaminated by Cr^{3+}.

CONCLUSION

The growth responses (root length, seedling length, fresh and dry weight) of twelve sorghum cultivars toward Cr^{3+} ($CrCl_3$ and $KCr(SO_4)_2$) stresses showed differences both on the stage of the germination and early seedling growth. The length of root and fresh weight of twelve sorghum cultivars were the growth parameters that were the most affected by trivalent chromium stresses ($CrCl_3$ and $KCr(SO_4)_2$) at the germination and early seedling growth, respectively. The Cr^{3+} treatment, either in the form of $CrCl_3$ or $KCr(SO_4)_2$ reduced the seedling growth of all sorghum cultivars that were tested. At high concentrations of Cr^{3+}, the decreasing of seedling growth was greater than at low Cr^{3+} concentrations. Several sorghum cultivars were recorded to have increasing growth responses, at low concentration treatment of $CrCl_3$ (Gambela, Kawali, and Selayer) and $KCr(SO_4)_2$ (Badik, Keris, Hegari, Numbu, Sangkur, and Mandau). Based on the average of STI values, four sorghum cultivars were classified as very strong tolerant cultivars (Badik, Keris, Keris M3 and Numbu), 4 cultivars were categorized as moderate, tolerant cultivars (Hegari, Mandau, Sangkur and Gambela), two cultivars were under weak tolerant cultivar classification (UPCA and Selayer), and 2 cultivars were classified as sensitive ones (Kawali and Batari), under stress condition of Cr^{3+}, and at stages of germination and early seedling growth.

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