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Effect of Potassium Level on Quality traits of Indonesian Potato Tubers

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Abstract—The rate of K_2O can affect yield and process-grade tubers of potato (*Solanum tuberosum L.*). The Indonesian cultivars Tenggo and Krespo were examined for effects of K_2O level on selected quality traits. Both new cultivars are intended for processing purposes. The result showed that dry matter, K, Mg and Mn contents were not affected by K_2O supply. Citric acid content of cultivar Tenggo increased up to 2.64 mg 100 g^{-1} Dry Matter due to application of 100 kg ha^{-1} K_2O, whereas ascorbic and chlorogenic acid contents were not affected by K_2O level. Malic and fumaric acid in cultivar Krespo, and tartaric and fumaric acids in cultivar Tenggo increased due to application of 100 kg ha^{-1} of K_2O. Regarding the oxidative potential no differences between the cultivars were found.

***Keywords*—– Solanum tuberosum, potassium fertilization, organic acids, oxidative potential, tubers' quality**

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INTRODUCTION

Potato (*Solanum tuberosum L.*) is a good source of carbohydrates, protein, vitamin C, fiber, minerals and it is low in fat (Navarre et al., 2009). One important factor during cultivation influencing tuber yield and quality is an adequate and balanced fertilizer supply. Responses of potato to fertilizer rate vary with location, cultivar, application time, and rate and type of fertilizer (Vander Zaag, 1981). Among the major nutrients, potassium (K) is required in high amounts due to its important role on plant physiology. K contributes to many aspects, for example it stimulates enzyme activities, promotes protein synthesis, improves photosynthesis, supports on osmoregulation, regulates opening and closure of stomata and participate on nutrients translocation (Marschner, 1995; Mengel, 2007). With regard to these functions, an adequate supply of K in the potato plant dictates improvements of tubers quality, such as increasing total yield and yield of processed-grade tubers, decreasing blackspot susceptibility and hollow heart, improving processing properties and chips color (Imas and Bansal, 1999; McNabnay et al., 1999), as well as increasing plant resistance to disease, pathogens and environmental stresses (Roemheld and Kirkby, 2010). K plays an important role in tuber yield and quality due to its high mobility in plant tissues (Mengel and Kirkby, 2001).

Indonesia is the highest potato producer in South-east Asia (FAO, 2012a), but depends on imports to fulfill demand of processing tubers (FAO, 2012b; Fuglie et al., 2003). Demand for processing tubers cannot be meet by local producers because approximately 90% of total cultivated area in Indonesia produces tubers for the fresh market (Fuglie et al., 2006).

In 2005,cvs. Tenggo and Krespo, which have superior quality, were released. However, there needs to be more information on quality of tubers of these cultivars produced with varying amounts of fertilizer. This project was undertaken to study the effect of different K levels on selected quality traits of the cvs. Tenggo and Krespo.

MATERIALS AND METHODS

Cultivation

The soil is andisol at Serang highland, Purbalingga district, Central Java, Indonesia, at an altitude of 1,300 m above sea level. Prior to planting, the land was cleared and the soil tilled and turned to a 30 cm depth by hoe. A week before establishment, 10 Mt•ha^{-1} of manure was applied, followed by application of 300 kg•ha^{-1} of N; 300 kg•ha^{-1} of P_2O_5 and 0, 50, 100, and 150 kg•ha^{-1} of K_2O at planting. The micronutrients Fe, Mn, Cu, Co and B were applied to leaves every 7 days starting 20 days after planting as foliar fertilizer. All activities conformed to local cultivation practices except for levels of K_2O fertilizer. Tubers were planted in ridges with a row spacing of 80 × 30 cm, with 3 replications for each cultivar.

Sampling

Yield was determined immediately after manual harvest with care to avoid damage to tubers. Tuber size distribution was classified based on diameter according to Indonesian National Standard. Process grade tubers were 3 to <7 cm size. Culls were <3 and >7 cm. After conditioning for about 24 hrs at room temperature, dry matter was measured from the fresh tubers. The rest of samples were peeled and then freeze-dried for further analysis. All of analysis were determined in triplicate.

Chemicals

All chemicals were from Merck (Darmstadt, Germany), KMF, Roth, and VWR Germany. Water used for extraction and high performance liquid chromatography (HPLC) analysis was generated by Millipore (Milli-Q, Q-Gard 2, Eschborn, Germany). The citric, malic, tartaric, fumaric, ascorbic, 5-caffeoylquinic, and gallic acid standards were from Sigma Aldrich (Seelze, Germany).

Dry matter content

Tubers were washed, sliced into small dices, and homogenized using a mixer (Kenwood FP 180, New Line, Havant, England). Ten-g of pulp was transferred to a Petri dish and preheated in an oven (Memmert ULM 400, Germany) at 60°C for 15 hrs and then at 105°C for 3 hrs (Winiger and Ludwig, 1974).

Potassium (K), magnesium (Mg), and manganese (Mn) contents

Samples were digested in a microwave oven (Abu Samra et al., 1975). A 0.2 g freeze-dried sample was treated with 4 mL of 65% HNO_3 in a Teflon vessel which was placed in a metal holder and screwed to a carrousel. Samples were digested in a microwave oven at 175°C for 13 hrs. Digested samples were transferred to a 10 mL volumetric flask. The digestive extract was kept in scintillation vessels at room temperature. K, Mg and Mn contents were determined by Atomic Absorption Spectral photometry/AAS (Unicam M series, Cambridge, England) (Sulaiman, 2005).

Organic acids

Tartaric, malic, citric, and fumaric acids were identified and quantified using HPLC (Bushway et al., 1984). Briefly, 1 g of freeze-dried sample was mixed with 18 mL of distilled water and stirred for 15 min. Then, 0.5 mL of Carrez I solution and 0.5 mL of Carrez II solution were added and the solution again stirred for 5 min and subsequently 6 mL of distilled water added. Samples were filtered through filter paper no. 615 ¼ Ø 150 mm (Macherey-Nagel, Dueren, Germany) and the supernatant stored at -20°C. Samples were thawed at room temperature before analysis, following which samples were filtered through injection filter 0.45 μm PTFE membrane and measured using HPLC.

Ascorbic acid

Ascorbic acid in fresh tubers was measured by an iodometric method (Peller, 1998). Briefly, 10 mL of potato slurry was placed in a 100 mL volumetric flask and distilled water added to the mark. Mixes were centrifuged at 10,000 rpm. Five-mL of the supernatant was collected and placed in an Erlenmeyer flask. Then, 2 mL of 1% starch solution and 20 mL distilled water were added. Titration was performed using 0.01 N standardized iodine solution.

Chlorogenic acid

Chlorogenic acid was measured according to Griffiths et al. (1992). A 100 mg freeze-dried sample was suspended in 2 mL aqueous solution containing 0.17 M urea and 0.1 M acetic acid. Then, 1 mL of distilled water was added and the solution mixed using a vortex (Assistant Reamix 2789, Heppenheim, Germany) for 15 sec. and 1 mL of 0.14 M sodium nitrite was immediately added. After 2 min, 1 mL of 0.5 M sodium hydroxide was added. The suspension was centrifuged at 10,000 rpm. An aliquot of the supernatant was transferred to a cuvette and the absorbance measured at 510 nm. Standards of known concentration (50 to 400 mg•L^{-1}) were prepared from 5-caffeoylquinic acid.

Oxidative potential

In a beaker, 1 g of freeze-dried sample was added to 10 mL of 0.05 M phosphate buffer (Scharlau, Sentmenat, Spain) at pH 6.5. The mixture was homogenized using an ultra-turrax (IKA T 18 B, Staufen, Germany) and oxidized at room temperature for 24 hrs. The mix was filtered using filter paper no. 615 ¼ Ø 150 mm (Macherey-Nagel) and centrifuged at 12,000 rpm for 10 min (Du Pont Instruments, Sorvall RC-5B, Wuppertal, Germany). A spectrophotometer (Hewlett Packard 8453, Waldbronn, Germany) was used to measure absorbance at 475 nm (McNabnay et al., 1999).

Statistical Analysis

Data were subjected to analysis of variance using SPPS (ver. 13, Armonk, New York). If interactions were significant they were used to explain results. If interactions were not significant means were separated with Least Significant Difference.

Results and Discussions

Soil characteristics are presented in Table 1. It is classified as silt loam soil with pH 6.5 and K content is 0.24%. Average yields for cv. Tenggo and cv. Krespo were 12.23 and 13.21 Mt•ha^{-1}, respectively. The percent of process-grades tubers of cv. Tenggo and cv. Krespo were 48.16 and 49.56%, respectively. Percent of processed grade tubers in both cultivars due to treatment were not different. The average percent of cultivar dry matter contents were 19.92% (cv. Tenggo) and 22.13% (cv. Krespo) (Table 2).

Table 1. Soil characteristics

Parameter	Unit	Value
Texture		
Sand	%	31.26
Silt	%	50.58
Clay	%	18.16
Texture Class		Silt loam
pH (H_2O)		6.50
pH (KCl)		5.73
Total N	%	0.40
Organic C	%	4.53
Organic Matter	%	7.81
C/N ratio		11.39
Total P_2O_5	%	0.30
Total K_2O	%	0.24
Exchangeable K	me %	0.34
Total Ca	%	0.12
Exchangeable Ca	me %	1.64
Total Mg	%	0.10
Exchangeable Mg	me %	0.42
CEC	me %	19.36

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Table 2. Yield, processed grade, and dry matter content of the tubers

K_2O application	Tenggo				Krespo			
	Yield $Mt \cdot ha^{-1}$	NPG (%)	PG (%)	DM (%)	Yield $Mt \cdot ha^{-1}$	NPG (%)	PG (%)	DM (%)
0 kg ha^{-1}	11.58	54.54	45.46	20.46	13.25	51.81	48.19	23.21
50 kg ha^{-1}	12.09	51.52	48.48	19.97	13.26	50.46	49.54	21.78
100 kg ha^{-1}	12.40	50.89	49.11	19.11	12.79	51.59	48.41	22.10
150 kg ha^{-1}	12.87	50.48	49.52	20.15	13.56	47.90	52.10	21.41

NPG: non-processed grade; PG: processed grade; DM: dry matter
The data are presented as mean ± standard deviation.

Table 3. K, Mg and Mn contents of the tubers (mg kg^{-1} DM)

K_2O application	K		Mg		Mn	
	Tenggo	Krespo	Tenggo	Krespo	Tenggo	Krespo
0 kg ha^{-1}	2027.25 ± 26	1786.08 ± 188	111.85 ± 1	108.10 ± 1	0.98 ± 0.12	1.08 ± 0.10
50 kg ha^{-1}	2115.83 ± 315	1915.41 ± 59	106.15 ± 10	121.05 ± 22	0.93 ±0.21	1.01 ± 0.08
100 kg ha^{-1}	2152.91 ± 133	1863.16 ± 118	111.36 ± 2	121.70 ± 19	0.89 ± 0.07	1.02 ± 0.06
150 kg ha^{-1}	2000.25 ± 85	1859.58 ± 116	101.88 ± 7	108.96 ± 6	0.89 ± 0.03	0.95 ± 0.08

The data are presented as mean ± standard deviation.

Table 4. Organic acids content of the tubers (g 100 g^{-1} DM)

K_2O application	Citric Acid		Malic acid		Tartaric acid		Fumaric acid	
	Tenggo	Krespo	Tenggo	Krespo	Tenggo	Krespo	Tenggo	Krespo
0 kg ha^{-1}	2.59 ± 0.2^{a}	2.41 ± 0.4^{a}	0.49 ± 0.03^{a}	0.84 ± 0.23^{abc}	1.15 ± 0.06^{abc}	1.25 ± 0.05^{a}	0.02 ± 0.003^{a}	0.008 ± 0.001^{ab}
50 kg ha^{-1}	2.63 ± 0.3^{a}	2.34 ± 0.1^{a}	0.56 ± 0.04^{a}	0.64 ± 0.24^{b}	1.07 ± 0.06^{b}	1.11 ± 0.05^{a}	0.02 ± 0.008^{a}	0.006 ± 0.002^{a}
100 kg ha^{-1}	3.56 ± 0.5^{b}	2.39 ± 0.3^{a}	0.65 ± 0.19^{a}	1.02 ± 0.21^{c}	1.27 ± 0.11^{c}	1.27 ± 0.05^{a}	0.03 ± 0.006^{b}	0.012 ± 0.001^{c}
150 kg ha^{-1}	2.44 ± 0.1^{a}	2.25 ± 0.1^{a}	0.48 ± 0.05^{a}	0.85 ± 0.02^{abc}	1.21 ± 0.09^{abc}	1.05 ± 0.12^{a}	0.02 ± 0.002^{a}	0.011 ± 0.001^{bc}

* value in column followed by the same letter are not significantly different ($p<0.05$).

Table 5. Ascorbic acid and chlorogenic acid contents of the tubers

K_2O application	Ascorbic acid (mg 100 g^{-1} FM)		Chlorogenic acid (mg 100 g^{-1} DM)	
	Tenggo	Krespo	Tenggo	Krespo
0 kg ha^{-1}	17.01 ± 2.69	17.01 ± 2.69	5.15 ± 0.65	5.11 ± 0.53
50 kg ha^{-1}	17.01 ± 4.43	17.60 ± 4.66	5.11 ± 0.82	5.85 ± 1.44
100 kg ha^{-1}	14.08 ± 1.76	19.94 ± 3.66	4.14 ± 1.24	4.20 ± 1.05
150 kg ha^{-1}	16.42 ± 3.66	18.18 ± 1.02	4.85 ± 1.09	6.06 ± 0.71

The data are presented as mean ± standard deviation.

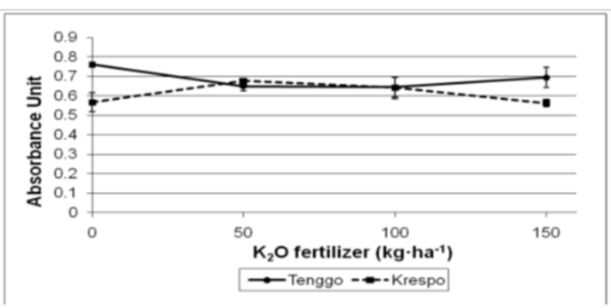

Figure 1. Oxidative potential of potato tubers cultivar Tenggo and Krespo depending on potassium fertilizer level
The data are presented as mean ± standard deviation.

Analysis of variance indicated that fertilizer level affected citric, malic, tartaric and fumaric acid contents.

The interaction between varieties and fertilizer level were not significant except for oxidative potential.

K content of cv. Tenggo (2074.06 mg•kg^{-1}DM) was higher compared to cv. Krespo (1856.06 mg•kg^{-1} DM). Mg and Mn contents of cv. Krespo (1.02 mg•kg^{-1} DM and 114.95 mg•kg^{-1} DM, respectively) were higher than cv. Tenggo (0.9 and 107.81 mg•kg^{-1} DM, respectively) as presented in Table 3.

Organic acids content of tubers showed different pattern. Citric acid content of cv. Tenggo increased due to application of K_2O fertilizer up to 100 kg ha^{-1}. Increasing fertilizer to 150 kg ha^{-1} decreased citric acid content. There was no difference in citric acid content between cultivars. Similar patterns was obtained for other organic acids. Increasing fertilizer level to 150 kg ha^{-1} resulted in decreased organic acids content (Table 4). There were no differences in malic acid content of cv. Tenggo and tartaric acid content of cv. Krespo.

Average content of ascorbic acid and chlorogenic acid of Krespo (18.19 mg 100 g^{-1} FM and 5.31 mg 100 g^{-1} DM, respectively) were higher compared to Tenggo (16.13 mg 100 g^{-1} FM and 4.81 mg 100 g^{-1} DM, respectively) as presented in Table 5.

The oxidative potential of Tenggo was higher compared to Krespo (Figure 1). Due to application of 150 kg ha^{-1} K_2O, cv. Krespo had the lowest oxidative potential. Tubers with the highest oxidative potential were from cv. Tenggo without K_2O treatment.

K is an essential nutrient because it is required for many metabolic processes and its role cannot be substituted by other nutrients (Westermann, 2005). In this research K_2SO_4 was used as source of K_2O. The findings agree with Stark et al. (2004) and Kumar et al. (2007) that K can increase yield, the proportion of process-grade tubers, and tuber and chips quality. Bansal and Trehan (2011) reported that K fertilizer application increases tuber size but not numbers. It can increase yield by increasing numbers and yield of large sized tubers. Moreover, Singh et al. (2010) reported that application of 100 kg ha^{-1} K_2O fertilizer increased numbers as well as yield of large (>75g) and medium-large (50-75g) tubers which increased overall tuber yield and marketable yield. Our research was conducted in different soil condition, potatoes variety, source of K fertilizer and levels of fertilizer application compared to previous work. Although the quantity of yield was similar, addition of K_2SO_4 fertilizer can increase numbers of process grade tubers. Therefore K_2O can be proposed to obtain higher proportion of processed grade tubers.

Dry matter is essential for processing and corresponds to texture in chips and French fries (Kita, 2002). High dry matter content is preferable to produce desired crisp texture; low dry matter content in tubers results in low chips yield and soggy texture because of excessive oil absorption during and/or after frying. Dry matter contents of cvs. Tenggo and Krespo ranged between 19.11 and 20.46%. This result indicates that different level of K application did not significantly influence dry matter content (Table 2). A higher rate of K fertilizer does not guarantee improvement in several parameters of tuber quality (Davenport and Bentley, 2001; Abdelgadir et al., 2003; Kavvadias et al., 2012). However, K_2SO_4 increases dry matter content of tubers (Westermann et al., 1994; Khan et al., 2010).The lower dry matter limit for processing purposes is 18.2% (Mosley and Chase, 1993) or 20% (Kirkman, 2007). Therefore, dry matter content of cvs. Tenggo and Krespo were above limits of tolerance for chips production (Table 2). Both cultivars have the potential for use for processing purposes.

There were no differences in tuber K, Mg and Mn contents of both cultivars (Table 3). Tubers are a rich source of K which can be explained by K being a nutrient with high mobility required by potatoes during vegetative growth, tuber initiation, tubers bulking and maturation periods (Stark et al., 2004). Plants remove K from soil, and it is accumulated in the tubers. High levels of K can reduce Mg concentration due to competition for uptake by plant roots (Mengel, 2007). Mg, a relatively mobile element, binds atoms within the chlorophyll molecule and activates many enzymes (Marschner, 1995). Mn activates several enzymes and activates ribonucleic acid polymerase and contributes to lipid metabolism (Campbell and Nable, 1998). Low Mn levels in cvs. Tenggo and Krespo tubers could be due to its low mobility in the phloem (Kaerenlampi and White, 2009) with only a small portion of Mn in leaves transported to tubers.

Organic acids are important in determining pH level of potato tubers (Wichrowska et al., 2009). Citric acid reduces after-cooking darkening in tubers, because of its ability to bind to iron forming a colorless complex (Griffiths et al., 1992). Organic acids content of tuber, including malic, tartaric and fumaric, are important due to their effect on quality of chips produced. In this research, organic acids content was slightly influenced by different level of K fertilization (Table 4). Even though organic acids are found at low concentration in tubers, they can still contribute to minimizing the browning reaction by lowering the pH (Belitz et al., 2009). There were no significant effects found on chlorogenic and ascorbic acid contents of both cultivars (Table 5). In potato tubers, chlorogenic acid contributes to after-cooking darkening, caused by formation of ferri-dichlorogenic acid if processed tubers are exposed to air (Wang-Pruski and Nowak, 2004). Tubers with a low chlorogenic to citric acid ratio are required to minimize after-cooking darkening and oxidative potential. Contrary to this result Hamouz et al. (2010) found a negative correlation between K fertilizer application and chlorogenic acid content, with higher levels of K fertilizer reducing chlorogenic acids content of tubers.

Because of the relatively high amount of ascorbic acid, both cultivars can be potential sources of vitamin C (Table 5). This result contradicts Trehan et al. (2009) who found that application of K fertilizer increased ascorbic acid concentration in tubers. Khan et al. (2010) concluded application of K fertilizer at an appropriate concentration enhances ascorbic acid content; doses lower or higher than optimum are unfavorable for ascorbic acid formation in tubers. Ascorbic acid in tubers plays an important role in decreasing oxidative potential in tubers (Delgado et al.,

2001) and minimizes enzymatic reactions by decreasing pH (Werij et al., 2007).

The blackspot index test is commonly used method to measure blackspot susceptibility. However, in this research, oxidative potential was used to determine blackspot susceptibility because limited numbers of tuber were available for measurement. Oxidative potential is correlated with blackspot index (Wulkow, 2009). The oxidative potential of cvs. Tenggo and Krespo from all treatments were higher than 0.5 (Figure 1). As comparison, the oxidative potential of potato tuber cvs. Satina (moderately resistant) and Sandra (moderately susceptible) were about 0.25 and 0.45, respectively (Delgado et al., 2001). Therefore,the oxidative potential of cvs. Tenggo and Krespo were relatively high. A higher oxidative potential corresponds to higher sensitivity to mechanical damage.

CONCLUSIONS

Application of K_2O fertilizer at 150 kg ha^{-1} has the tendency to increase yield, percent of process grade tubers, and organic acids content of cultivars Tenggo and Krespo. Even though, there is no significant effect of potassium application, the high dry matter content of both cultivars makes them suitable for processing purposes.

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