Effect of Supplemental Irrigation on Reducing Cyanide Content of Cassava Variety Kasetsart 50

Johazel Hular-Bograd¹, Ed Sarobol^{1*}, Chareinsak Rojanaridpiched¹ and Klanarong Sriroth²

ABSTRACT

Cassava's cyanogenic potential, exacerbated during drought, remains a challenge to optimizing its production and consumption. This research investigated how supplemental irrigation during the dry season could reduce the cyanide content in the highly-cyanogenic cassava variety Kasetsart 50 (KU50). KU50 stakes were planted in May 2009 at Khao Hin Son Research Station, Inseechandrastitya Institute for Crop Research and Development, Kasetsart University, Chachoengsao province. A split-plot in a randomized complete block design was used, with three harvest periods (6, 9, 12 mth after planting; MAP) as main plots, three irrigation treatments (T0, rain-fed only; T1, 30mm.mth⁻¹, split into three applications; and T2, 60mm.mth⁻¹, split into three applications) as subplots, and four field replications. Root samples harvested at 6, 9 and 12 MAP were analyzed for total cyanide, non-glucosidic cyanide (NGC), and bound cyanide contents in the whole root, peel and parenchyma.

Roots harvested at 9 MAP had the lowest bound and total cyanide, and the highest starch content. T2 yielded the lowest NGC, bound and total cyanide, and the highest starch content. Thus, irrigating with 60mm and harvesting at 9 MAP produced the lowest cyanogenic content and highest starch percentage in cassava roots. No significant effect was observed on the number of bulking roots, the plant height and plant top weight. However, supplemental irrigation significantly (P < 0.05) increased the starch content and root yield, but reduced the protein content.

Keywords: Kasetsart 50, cyanide, irrigation, harvest period, starch

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), also known as *tapioca, manioc, mandioca, yucca, kamoteng-kahoy, and kayu* in different parts of the world, is a perennial, starchy, tropical root crop originating in Brazil (Howeler, 1985) and is cultivated in over 90 countries in Africa, Latin America, the Caribbean and Asia, providing food and livelihood to over 500 million people (Teles, 2002). In Thailand, cassava is a cash crop and a primary export commodity utilized as a raw material in various food and non-food industries. Its high-starch content is excellent for feeds and ethanol fuel production (LDD, 2005).

Cassava's reputation of hardiness and ability to thrive on marginal land has exponentially increased its popularity as an agronomic crop. However, in spite of its drought-tolerance, cassava needs water especially during the critical stages

¹ Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.

² Cassava Starch Technology Research Unit (CSTRU), Kasetsart University, Bangkok 10900, Thailand.

^{*} Corresponding author, e-mail: agred@ku.ac.th

of root initiation and tuberization (Cock *et al.*, 1979). A water deficit during this period can reduce root yield from 32 to 60% (Porto, 1993), with the severity depending on the duration of the water deficit and on the sensitivity of the plant growth stage to water stress (Santisopasri *et al.*, 2000). It is also under such drought conditions that cassava's cyanogenic potential is exacerbated (Sriroth *et al.*, 2001), making it toxic and potentially lethal for animal and human consumption if inadequately processed.

All breeds of cassava contain cyanide (HCN) at varying levels and varying degrees of potency (Alves, 1998). Cyanogenic plants (such as bamboo shoots, lima beans, almonds, among others) contain cyanogenic glycosides (CG) that have been suggested to be a plant defense mechanism (Sayre et al., 1998). When the cassava root is ruptured during harvest or maceration, CG (mainly linamarin) comes in contact with and is hydrolyzed by a beta-glucosidase (linamarase), yielding a ketone (acetone cyanohydrin), which spontaneously or enzymatically decomposes into free hydrogen cyanide (HCN) (Bradbury, 2002). Cassava cultivars with a cyanide content less than 100 mg.kg⁻¹ of fresh weight (FW) are called "sweet" varieties, while those with 100-500 mg.kg⁻¹ FW are known as "bitter" varieties (Wheatley and Chuzel, 1993). Generally, sweet cassava is safe to eat after peeling and thorough cooking. However, detoxifying bitter cassava roots requires extensive processing involving peeling, grating, pressing and drying for several days (Chotineeranat et al., 2006). A lack of knowledge and unfortunate circumstances, such as war and famine in impoverished communities make proper detoxification of cassava roots difficult or impossible. During droughts, cassava-associated cyanide poisoning is rampant in poor countries where cassava is a staple diet. In the Philippines, incidents of cassava cyanide-poisoning and fatalities have been reported (CNN, 2005). The Food and Agriculture Organization (FAO, 2006) has reported that the acute lethal dose of hydrogen cyanide for humans is 0.5 to 3.5 mg.kg⁻¹ of body weight. For an adult, consumption of 50–100 mg, or 2 mmol of HCN equivalents within 24 hr can be fatal. Children are particularly at risk of cyanide-poisoning because of their smaller body size. Among the detrimental effects related to cyanide-accumulation in the body are acute cyanide intoxication, tropical ataxic neuropathy (TAN), iodine deficiency/goiter, irreversible paralysis called Konzo, and death (Teles, 2002).

A number of studies observed the impact of water stress on the root cyanide content, the only non-starch component significantly affected by growth and harvest conditions (Santisopasri *et al.*, 2000; Sriroth *et al.*, 2001). Chotineeranat *et al.* (2006) showed that the cyanide content in water-stressed plants harvested at 6 and 8 mth after planting, (MAP), with 96.6–253.8 and 70.3–119.1 μ g.g⁻¹, respectively, was higher compared with unstressed plants harvested at 10 and 12 MAP, with 99.7–284.9 and 7.5–34.3 μ g.g⁻¹, respectively. These findings confirm the HCN concentration in the roots during drought and how a water deficit retards the transport mechanism of essential minerals for plant growth (CIAT, 1989).

Samutthong *et al.* (2007) studied how supplemental irrigation during the drought season increases the growth and yield of Huay Bong 60 in Chachoengsao province in eastern Thailand. Using different irrigation volumes (30 mm, 45 mm, 60 mm) and varying the frequency of application (once, twice, thrice per month), Samutthong concluded that if water is not a limiting factor, irrigating at 60mm.mth⁻¹ (split into three applications of 20 mm) guarantees the highest yield, harvest index and maximum net income.

The present research investigated how supplemental irrigation during the dry season could reduce the cyanide content in highlycyanogenic Kasetsart 50 (KU50) cassava roots.

MATERIALS AND METHODS

Planting material

KU50 was used as the test cultivar because of its economic significance, popularity and high cyanide content, with total HCN of $1,427.2 \pm$ 481.6 mg HCN per kg dry weight in fresh roots harvested at 6 MAP (Chotineeranat *et al.*, 2006). Weeding by hand-pulling and Paraquat application (450 cc.rai⁻¹) were done 1 mth before planting. In May 2009, KU50 stakes were vertically planted at 1×1 m spacing. At 1 MAP, NPK fertilizer (15:7:18) was applied at the recommended rate of 50 kg.rai⁻¹. Glyphosate (250cc.rai⁻¹) was initially sprayed during September 2009 and again at later growth stages when necessary.

Field experiment

The experiment was conducted at the Khao Hin Son Research Station, Inseechandrastitya Institute for Crop Research and Development, Kasetsart University, Chachoengsao province, from May 2009 to May 2010. A split-plot in randomized complete block design was used with four replications, with the harvest period, (HP; 6, 9, 12 mth) as the main plot, and irrigation treatments, (IT; T0 = control, rain-fed only; T1 = 30mm. mth⁻¹, split into three applications of 10 mm; and T2 = 60mm.mth⁻¹, split into three applications of 20 mm) as subplots. There were 48 plots, with each plot having dimensions of 12 × 5 m.

Soil sampling and soil analysis

Soil sampling and analysis were carried out at the beginning of the experiment to detect mineral and micronutrient deficiencies. The Soil Science Department Laboratory of Kasetsart University in Bangkhen conducted the analysis, which entailed air-drying, refining/grinding, and screening 500 g of soil obtained from the experimental site. Results showed that the soil type was moderately drained, loamy sand, with pH 4.6, low organic matter and very low potassium.

Monthly data and harvest data collection

Plant heights were measured monthly for 12 mth. The yield, number of roots, number of bulking roots, weight of leaves and stock, and starch content using the Reimann scale, were recorded at every harvest. In the laboratory, the cyanide content in the whole roots, in peel and in parenchyma, and the physico-chemical properties of cassava starch (moisture content, starch content, protein, ash and fat percentage) were measured at every harvest.

Treatment implementation and timing

Supplemental irrigation via a sprinkler system started in November 2009, at 6 MAP. Treatments T0, T1 and T2 were administered thrice, every 10th, 20th and 30th day of the month, at 10mm and 20mm per time for T2 and T3, respectively. Using a drip pan method for field plot sprinkle irrigation, and through several trials and adjustments of the sprinkler mechanism, irrigation at 10 and 20 mm rates was completed in 30 and 60 min, respectively.

Harvesting

Root samples were harvested at 6, 9 and 12 MAP, with laboratory analysis of the cyanide content conducted within 24 hr of harvest to minimize free-HCN volatilization and post-harvest spoilage of roots.

Laboratory analysis for cyanide content Sample extraction

Standard procedures for fresh cassava root sample extraction were followed. Fifty grams of diced root were homogenized in 160 mL of extraction medium for 2 min. Using an extra 20 mL of extraction medium, the homogenate was washed on to a glass-fiber filter (Whatman GFA), and the extract was collected under vacuum.

Assay procedure

Whole root, peel and parenchyma were separately assayed for NGC and for total cyanide

content. Assay results were used to compute the amount of bound cyanide. Free cyanide was not determined due to the difficulty in measuring this highly-volatile cyanogen component that was present in minute amounts. Cyanogens were assayed in duplicate using the following formats.

Total cyanide assay

A 0.1 mL aliquot of extract was added to 0.4 mL pH 7.0 buffer A in a stoppered test tube, to which the linamarase preparation (0.1 mL) was added. After 15 min incubation at 30° C, 0.2 M NaOH (0.6 mL) was added, followed by Buffer A (2.8 mL; pH 6.0). Aliquots were assayed by a colorimetric procedure.

NGC assay

Extract (0.1mL) was first mixed with 0.4mL pH 4.0 Buffer A, and an excess of 0.2 M NaOh (0.6 mL) was added. After 5 min it was diluted with a further 2.9 mL of buffer A (pH 4.0), after which aliquots were assayed colorimetrically.

Colorimetric procedure

Chloramine-T reagent (0.2 mL; 0.5% w/v) was added to 4 mL buffered extract in a stoppered Quickfit test tube and mixed well. Tubes were placed in an ice water bath for 5 min, after which pyridine/pyrazolone reagent (0.8 mL) was added in a fume cupboard. After 90 min, the absorbance at 620 nm was determined. Duplicate analyses were performed and blanks containing extraction medium were run for each analysis.

Statistical analysis

Field and laboratory data were analyzed using the SPSS computer package (Version 17.0.1, SPSS Inc., Chicago, USA). The general linear model (GLM) univariate analysis test for betweensubjects effect was used to analyze variance (ANOVA), Duncan and Turkey HSD was used for post-hoc analysis, and means were separated using the 5% level of significance.

RESULTS

In whole roots, the results showed that the harvest period had a significant reducing effect on NGC. While the difference in means for bound and total cyanide was not statistically significant, closer inspection of the laboratory data showed that there was an observable decline from 6 MAP to 9 MAP, but an increase from 9 MAP to 12 MAP. In peel, the harvest period had a strong inverse correlation with cyanide content. Table 1 shows NGC, bound and total cyanide in peel significantly declined with root age. In parenchyma, bound cyanide was lowest at 9 MAP and highest at 12 MAP. While not statistically significant, the laboratory data showed a considerable increase in total cyanide content from 9 MAP to 12 MAP (from 560.3 ± 75.5 to 873.8 ± 190.9 mg HCN per kg dry weight).

The effect of irrigation treatments on cvanide content cannot be isolated from the harvest period, thus the interaction $IT \times HP$ was analyzed on NGC, bound and total cyanide in whole roots, in peel and in parenchyma. Tests between subject effects confirmed the significance of the interaction (P < 0.05). In whole roots, the bound and total cyanide content were lowest at 9 MAP, while bound cyanide was highest at 12 MAP. T2 yielded the lowest NGC, bound and total cyanide, but T1 produced the highest overall cyanide content, albeit not significantly different from T0. For the $IT \times HP$ interaction effect on cyanide in whole roots, Figure 1 shows that irrigating with T2 and harvesting at 9 MAP yielded the lowest NGC and bound cyanide.

In parenchyma, roots harvested at 9 MAP had the lowest bound and total cyanide content, with harvest at 12 MAP having the highest. The reducing effect of supplemental irrigation on the cyanide content was most evident at 9 MAP, when T2 yielded the lowest NGC, bound and total cyanide, compared with T1 and T0 which were not statistically different (Table 2).

Root part	Harvest period	NGC	Bound cyanide	Total cyanide		
	(months after	(mg HCN.kg ⁻¹ dry	(mg HCN.kg ⁻¹ dry	(mg HCN.kg ⁻¹ dry		
	planting)	weight)	weight)	weight)		
Peel	6	169.2 ± 19.8	2397.1 ± 403.1	2566.3 ± 397.9		
	9	259.8 ± 123.1	1726.0 ± 195.7	1985.7 ± 300.3		
	12	$96.6~\pm~39.4$	1265.2 ± 357.4	1361.8 ± 351.3		
	Significance	0.00	0.00	0.00		
	(<i>P</i> < 0.05)					
Parenchyma	6	102.9 ± 17.6	513.2 ± 107.2	616.2 ± 123.9		
	9	99.1 ± 3.0	461.2 ± 73.5	560.3 ± 75.5		
	12	60.6 ± 13.0	813.3 ± 185.2	873.8 ± 190.9		
	Significance	n.s.	0.05	n.s.		
	(<i>P</i> < 0.05)					
Whole root	6	113.8 ± 17.0	761.9 ± 115.2	1477.7 ± 314.9		
	9	$132.8~\pm~24.8$	691.1 ± 44.4	1023.2 ± 179.7		
	12	$80.9~\pm~12.9$	884.5 ± 197.1	950.3 ± 81.7		
	Significance	0.039	n.s.	n.s.		
	(<i>P</i> < 0.05)					

Table 1Effect of harvest period at 6, 9, 12 mth after planting on non-glucosidic cyanide (NGC), bound
and total cyanide content in cassava peel, parenchyma and whole root.

Data are means \pm SD of three laboratory determinations.

NGC = Non-glucosidic cyanide.

n.s. = Not significant.



Figure 1 Non-glucosidic cyanide (NGC), bound and total cyanide (HCN) content in KU50 whole roots subjected to irrigation treatments (T0, rain-fed only; T1, 30mm.mth⁻¹, split into three applications; and T2, 60mm.mth⁻¹, split into three applications) at harvest periods 6, 9 and 12 mth after planting.

Table 2	Non-glucosidic cyanide (NGC), bound and total cyanide content in KU50 parenchyma subjected
	to irrigation treatments (T0, rain-fed only; T1, 30mm.mth ⁻¹ , split into three applications; and
	T2, 60mm.mth ⁻¹ , split into three applications), harvested at 6, 9 and 12 mth after planting.

Harvest period	Treatment	NGC	Bound cyanide	Total cyanide		
(months after		(mg HCN/kg dry	(mg HCN/kg dry	(mg HCN/kg dry		
planting)		weight)	weight)	weight)		
6	Т0	102.9 ± 17.6	513.2 ± 107.2	616.2 ± 123.9		
	T1	80.9 ± 14.2	512.9 ± 80.5	593.9 ± 67.2		
	T2	$72.6~\pm~2.0$	549.9 ± 93.5	626.6 ± 93.7		
9	Т0	99.1 ± 3.0	461.2 ± 73.5	560.3 ± 75.5		
	T1	116.6 ± 17.5	560.0 ± 153.3	676.6 ± 168.2		
	T2	81.9 ± 12.2	364.8 ± 35.1	446.7 ± 31.9		
12	Т0	60.6 ± 13.0	813.3 ± 185.2	873.8 ± 190.9		
	T1	78.9 ± 17.5	677.9 ± 114.0	756.8 ± 128.1		
	T2	53.9 ± 15.8	$677.2 ~\pm~ 28.3$	731.1 ± 40.6		

Data are means \pm SD of three laboratory determinations.

NGC = Non-glucosidic cyanide.

The results of the effect of harvest period (6, 9, 12 MAP) on yield, harvest index and starch chemical properties of KU50 whole root (Table 3) show that plant age has a very strong (P < 0.01) positive correlation with and a significant (P < 0.05) positive impact on plant height, weight of leaves and stem, and root yield. Hence, the highest root yield and biomass was attained at 12 MAP.

However, the starch content was highest at 9 MAP (P < 0.05), while the number of bulking roots showed no real correlation with HP. Fat content had a low (P < 0.05) positive correlation, while the ash and protein contents had no real correlation to HP, although the raw data showed a slight increase in these properties over the three harvests.

Table 3 Plant height, top weight, root yield, number of bulking roots, starch, moisture, ash, fat andprotein content in KU50 whole roots harvested at 6, 9 and 12 mth after planting.

r · · · ·							1				
	HP	PLT HT ^a	TOP WT ^a	YIELD ^a	No. RTS ^a	RSta ^a	MC ^b	LSta ^b	ASH ^b	FAT ^b	PRO ^b
		(cm)	(t.rai ⁻¹)	(t.rai ⁻¹)	(per plot)	(%)	(%)	(%)	(%)	(%)	(%)
	6	165.69	2.43	5.05	165.5	27.89	59.17	84.17	1.92	0.28	1.73
	9	192.49	2.41	5.67	146.4	29.44	60.76	84.31	1.97	0.31	1.70
	12	252.13	3.87	9.80	157.4	25.47	64.15	77.17	1.97	0.41	1.55
	x	203.43	2.90	6.84	156.4	27.60	61.36	81.88	1.96	0.33	1.66
	LSD										
(P < 0.05)	38.23	0.84	2.33	n.s.	2.26	3.43	3.79	n.s.	0.13	n.s.

HP = Harvest period; PLT HT = Plant height; TOP WT = top weight; No. RTS = Number of bulking roots per plot; RSta = Starch content measured by Reimann Scale; MC = Moisture content; LSta = Starch content determined in laboratory; ASH = ash percentage; FAT = fat percentage; PRO = Protein content.

^a = Data represent means of four field replicates.

n.s. = Not significant.

b = Data represent means of three laboratory determinations.

The analysis of the effect of irrigation treatments showed that only root yield, starch content, moisture content and protein were statistically significant (P < 0.05). Higher supplemental irrigation yielded a significant (P < 0.05) increase in starch content, but a highly significant (P < 0.01) decrease in protein content. In the interaction effect of harvest period and irrigation treatment (HP \times IT), bound and total cyanide content for parenchyma were lowest at 9 MAP, and highest at 12 MAP. The same trend was observed in whole roots, with 9 MAP yielding the lowest bound and total cyanide contents. In peel, the bound and total cyanide showed a steady decline over time, with 6 MAP having the highest means and 12 MAP the lowest.

DISCUSSION

To determine the accurate effect of harvest period on the cyanide content and other crop growth components, other factors must be kept constant. As past and prevailing environmental factors such as monthly rainfall could not be kept constant throughout the experiment, it was necessary to use data from the control treatment (T0; N=36) to compare the means for analyzing the effect of harvest period. The results showed that HP had a significant (P < 0.05) effect on NGC. However, a significant effect of HP on bound and total cyanide could not be established, presumably due to the wide variations in cyanide content among whole roots, peel and parenchyma.

To properly measure the total moisture received by the plant during the research period, total rainfall within the vicinity of the research plots was recorded. Figure 2 shows the total amount of water available to the plants, with total monthly rainfall plus supplemental irrigation, which commenced on November 2009.

The high starch content at 6 MAP is to be expected, as harvest immediately followed the major rainy season that contributed to high water availability for the roots, reaffirming the assessment



Figure 2 Total monthly rainfall and supplemental irrigation on the trial area from April 2009 to May 2010 in Khao Hin Son district, Chachoengsao province, eastern Thailand.

by Sriroth (2001) that environmental conditions, especially water availability, during early plant development and immediately before harvest, strongly influence the production efficiency of cassava, including the yield and starch quality. The high positive correlation between water treatments and starch content (significant at the 95% level for Reimann scale data, and at the 90% level for laboratory data) reaffirmed that water availability markedly impacts root productivity as well as starch quality (Sriroth *et al.*, 1999; Sriroth *et al.*, 2001; Chotineeranat *et al.*, 2006).

While the results showed that increasing irrigation also increases the starch content percentage in the roots, water treatment appeared to have no significant effect on root yield, and yield components (plant height and plant weight), except for the number of bulking roots, which showed a low (significant at 90%) positive correlation to water treatments.

The decline in total cyanide content over the three harvests was most readily apparent for T2 and T0, with values showing a decrease over time. It would seem that the change in the cyanide concentration appears to be due to dilution by an increase in DW rather than as a result of a decrease in its synthesis. Moreover, peel had three times more total HCN than parenchyma; while roots harvested at 6 MAP had the highest total HCN, but at 9 and 12 MAP were not statistically different.

CONCLUSION

Cassava's reputation as a droughttolerant crop is irrefutable. However, the cyanide content in cassava, which is exacerbated in periods of drought, impacts the economics of its production and safety of consumption. The results of this study showed that for total cyanide, bound cyanide, and NGC, roots harvested at 9 MAP contained the lowest levels of cyanide. In terms of irrigation treatments, roots subjected to T2 (60 mm) yielded the lowest cyanogen content, while T1 (30 mm) yielded the highest mean cyanogen content.

With all factors being equal, the highest water volume, T2, was expected to cause the greatest reduction in the cyanide-content of peel, parenchyma and whole roots, with T1 having a median effect and T0 (control) having the least impact. While this was not always the case (with T1 yielding the highest overall cyanogen content, albeit not significantly different from T0), these results would imply that perhaps water volume treatments (30 and 60 mm.mth⁻¹) used in this study were not sufficiently high to effect a significant reduction in the cyanogenic potential in the root samples. Furthermore, while the reduction effect of supplemental irrigation was only statistically significant (P < 0.05) for the NGC content in whole roots, peel and parenchyma, closer inspection of the laboratory data revealed observably lower cyanide content at 9 and 12 MAP when more water was used. Supplemental irrigation significantly (P < 0.05) increased the starch content and the number of bulking roots, although it did not significantly affect root yield, plant height and plant top weight. The protein content was significantly (P < 0.01) reduced by supplemental irrigation, thus corroborating reports (Howeler, 1985; Wheatley and Chuzel, 1993; Sriroth et al., 1999; Sriroth et al., 2001; Chotineeranat et al., 2006) that drought stress induces the expression of proteins that are directly or indirectly related to the plant's adaptive response to drought. Thus, in the absence of drought, such water stress-related proteins were not expressed. As was expected and proven in the results, the more mature the plant was at harvest, the higher the dry matter accumulation was in the storage roots as well as in the leaves and stems. Hence, the highest root yield and biomass were attained at 12 MAP. Conversely, the starch content percentage did not improve with age. The starch content was at its maximum at 9 MAP, coinciding with the late drought period, and then declined towards 12 MAP.

In conclusion, administering an ample supply of water, particularly during the dry season, should mitigate the cyanogenic potential of cassava roots. If the economic gains outweigh the cost of irrigation, the rate of 60 mm.mth⁻¹ or higher is recommended, along with selecting and planting a suitable cassava cultivar that must be a low-cyanide variety if being planted for food. Moreover, it is recommended to harvest the roots at 9 MAP, when the bound and total cyanide content in the parenchyma and whole roots are lowest, and the starch content is at its highest.

ACKNOWLEDGEMENT

The researcher extends her gratitude to Mr. Noppasool Samutthong of Khao Hin Son Research Station and Dr. Sunee Chotineeranat and the Cassava Starch Technology Research Unit (CSTRU) for assistance, supervision and the use of facilities.

LITERATURE CITED

- Alves, A.A.C. 1998. Physiological and Developmental Changes in Cassava (Manihot esculenta Crantz) under Water Deficit. PhD. dissertation. Cornell University, Ithaca, New York.
- Bradbury, J.H. 2002. Cassava's nasty after-taste. **Spore CTA** 97: 6–7.
- Chotineeranat, S., T. Suwansichon, P. Chompreeda, K. Piyachomkwan, V. Vichukit, K. Sriroth and V. Haruthaithanasan. 2006. Effect of root ages in the quality of low- cyanide cassava flour from Kasetsart 50. Kasetsart J. (Nat. Sci.) 40: 694–701.
- CIAT. 1989. **Annual Report for 1989.** Agroecological Studies Unit. Cali, Colombia. 656 pp.
- CNN. 2005. Food Poisoning Kills 25 Children. [Available from: http://www.asiafinest. com/forum/index.php?showtopic=31560].

[Accessed: 9 March 2005].

- Cock, J.H., D. Franklin, G. Sandoval and P. Juri. 1979. The ideal cassava plant for maximum yield. **Crop Sci.** 19: 271–279.
- FoodandAgricultureOrganization.2006. FAO 2006 Database. [Available from:: http://apps.fao. org/cgi-bin/nph-db.pl?subset=agriculture]. [Accessed: 19 September 2010].
- Howeler, R.H. 1985. Mineral nutrition and fertilization of cassava. *In* Cassava: Research, Production and Utilization. UNDP-CIAT Cassava Program, Cali, Colombia. pp. 249–320.
- LDD 2005. Royal New Theory: Agricultural Land Management. Land Development Department, Bangkok. [Available from: http:// www.ldd.go.th/EFiles_html/ main% 20page/ Ea0400.htm]. [Accessed: 29 May 2010].
- Porto, M.C.M. 1993. Production hints: Selection and propagation of cassava planting materials.
 Trop. Root Tuber Crops Bull. 7: 3–4.
- Samutthong, N., E. Sarobol, V. Vichukit and S. Thongpae. 2007. Effects of amount and rate of watering on cassava growth and yield potential, pp.75–82. *In* Proceedings of the 45th Kasetsart University Annual Conference, Bangkok, Thailand, 30 January–2 February 2007. Subject: Plants 2007.
- Santisopasri, V., K. Kurotjanawong, S. Chotineeranat, K. Piyachomkwan, K. Sriroth and C.G. Oates. 2000. Impact of water stress on yield and quality of cassava starch. Ind. Crop. Prod. 13: 115–129.
- Sayre, R.T., W.L.B. White, D.I. Arias-Garzon and J.M.T. McMahon. 1998. Cyanogenesis in cassava - the role of hydroxynitrile-lyase in root cyanide production. **Plant Physiol.** 116(4): 1219–1225.
- Sriroth, K., S. Wanlaphathit, K. Piyachomkwan and C.G. Oates. 1999. Improved cassava starch granule stability in the presence of sulphur dioxide. Starch/Stärke 50(11–12): 466–473.

- Sriroth, K., K. Piyachomkwan, V. Santisopasri and C.G. Oates. 2001. Environmental conditions during root development: drought constraint on cassava starch quality. **Euphytica** 120: 95–101.
- Teles, F.F. 2002. Chronic poisoning by hydrogen cyanide in cassava and its prevention in Africa and Latin America. **Food Nutr. Bull.** 23(4): 407–412.
- Wheatley, C.C. and G. Chuzel. 1993. Cassava: The nature of the tuber and use as a raw material, pp.734–743. *In* R. Macrae, R.K. Robinson and M.J. Sadler, (eds.). Encyclopedia of Food Science, Food Technology, and Nutrition. Academic Press, San Diego, California.