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Case Study for Oxalate and its Related Mineral Contents in Selected Fodder Plants in Subtropical and Tropical Regions

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ABSTRACT

A survey of oxalate and its related mineral contents in selected fodder plants was conducted in two regions of subtropical Okinawa, Japan and of tropical Savar and Shahzadpur, Bangladesh. A total of 31 samples were taken from 13 fodder species in Okinawa, Southern part of Japan and of 63 samples from 27 fodder species in Bangladesh. The data of both regions revealed that the majority of fodder plants accumulated lower contents of oxalate than the critical level for toxicity at more than 20 g kg^{-1} DM, while few fodder species (*Pennisetum purpureum* and *Brachiaria mutica*) in Bangladesh and only *Setaria sphacelata* in southern part of Japan reached this critical level. In most of the cases, no relationship was found between oxalate and mineral contents in the plants tested. The results from the present study demonstrate that the oxalate content in tropical fodder species may vary in a wide range, mainly depending on plant species. To be noted is that some fodder species could accumulate oxalate at so high content as might be toxic to ruminants in certain conditions.

Key words: Oxalate, mineral, subtropical, tropical regions, fodder plant

INTRODUCTION

Plants contain a tremendous array of substances that are sometimes poisonous to livestock (Cheeke and Shull, 1985). Oxalate is a common plant component considered to be an antinutrient as well as toxin (Rahman and Kawamura, 2011). It can bind with some mineral nutrients to form insoluble salts which are not absorbed by the intestine. Hence, its content in fodder plants is of great concern for livestock feeding. Rahman *et al.* (2012) suggested that soluble oxalate at a content of 20 g kg^{-1} DM or more can lead to acute toxicosis in ruminants, while insoluble oxalate is not thought to have a harmful effect on the body's metabolism as it seems to pass through the digestive tract (Ward *et al.*, 1979).

Oxalate content is usually higher in tropical plants than temperate plants, suggesting that grown in tropical regions may be high in oxalate. Rahman and Kawamura (2011) reviewed that oxalate content in herbaceous plants depended on many factors including fertilizer management, harvesting practices, season and plant species. For example, oxalate content in *Pennisetum purpureum* variable among seasons, when it was highest (37.7 g kg^{-1} DM) and lowest (17.6 g kg^{-1} DM) in early summer and in late autumn, respectively (Rahman *et al.*, 2006). Browse plants have the potential to remain green even in the dry season to play good sources of dry-season feed for ruminant animals. However, there remains to determine the oxalate content in a range of fodder plants grown in subtropical and tropical regions. Thus, the present study was aimed at measuring the oxalate and its related mineral contents in a wide range of tropical fodder plants that are commonly consumed by ruminant livestock. In this study, Bangladesh (Savar and Shahzadpur) and southern part of Japan (Okinawa) were selected as tropical and subtropical regions, respectively.

MATERIALS AND METHODS

Plant materials: Samples were collected from two sites of subtropical and tropical regions, namely (i) Southern part of Japan (Okinawa at 26°N127°E) and (ii) Bangladesh (Savar at 23°N 90°E and Shahzadpur at 24°N89°E). In Okinawa, a total of 31 plant samples were taken from 13 fodder plant species in February 2010. In Savar and Shahzadpur, a total of 63 plant samples were taken from 27 fodder plant species in September 2010. Stage of plant samples was fixed at the time of maturity when the farmers usually offer to ruminant livestock for feeding in these sites.

In Savar and Shahzadpur, it has been achieved significant success in increasing the animal production (especially milk) by providing training and extension services. Annual minimum temperature of the country (Bangladesh) varies from 8.0-13.4°C and maximum temperature 25.5-36.8°C. The average annual rainfall varies from 1429 to 4338 mm. The 80% of the rainfall occur in Monsoon which covers July to October of the year (BBS, 2002). Okinawa is a subtropical climate, with a relatively high annual average temperature of 23.0°C and precipitation is about 2100 mm.

Sample preparation and chemical analyses: All samples were cut and divided into plant fraction if necessary before drying. The dried samples were milled to pass through a 1 mm screen using a Wiley mill. Samples were analyzed for total and soluble oxalates following the method of Rahman *et al.* (2007). Insoluble oxalate content was estimated as the difference between the total and soluble oxalate contents. The calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) contents in the samples were determined by the flame atomic spectroscopy method after wet digestion with nitric acid and hydrogen peroxide (Laboratory of Agricultural Chemistry, The University of Tokyo, 1978). The correlation coefficient between oxalate and mineral contents in plants was analyzed using SPSS (version 12.0, SPSS Inc., Chicago, IL, USA).

RESULTS

The fodder plants tested were divided into 3 groups based on their soluble oxalate content, namely plants containing over 20 g kg^{-1} DM (group 1, probably toxic as reported by McKenzie *et al.* (1988), 10-20 g kg^{-1} (group 2, probably safe) and less than 10 g kg^{-1} (group 3, safe).

The oxalate content of the plant samples at Okinawa site is given in Table 1. Samples belonging to group 1 included *Setaria sphacelata*; group 2 included *Pennisetum purpureum*, *Cenchrus ciliaris* and *Digitaria decumbens* and group 3 included other 9 plants. *Chloris gayana*, *Saccharum officinarum* and *Leucaena leucocephala* did not show any detectable soluble oxalate. The soluble oxalate content in plant samples ranged from 0 to 29.67 g kg^{-1} DM and total oxalate content ranged from 0 to 32.12 g kg^{-1} DM.

The oxalate content of the plant samples at two sites in Bangladesh is given in Table 2. Samples belonging to group 1 included *Pennisetum purpureum* and *Brachiaria mutica*;

Table 1: Oxalate content (g kg^{-1} DM) of fodder plants in Okinawa, Japan

Common name and fraction of plants	Scientific name	No. of samples	Soluble oxalate	Total oxalate
Group 1				
Setaria	*Setaria sphacelata*	1	29.67	32.12
Group 2				
Buffelgrass	*Cenchrus ciliaris*	1	12.64	13.18
Pangola grass	*Digitaria decumbens*	4	4.68-11.16 (7.28)	3.89-18.37 (13.77)
Napier grass	*Pennisetum purpureum*	7	9.85-19.41 (14.13)	14.92-20.26 (19.64)
Group 3				
Creeping signal grass	*Brachiaria humidicola*	1	9.24	14.42
Para grass	*Brachiaria mutica*	5	5.40-9.84 (7.56)	9.81-17.54 (13.46)
Brachiaria marandu	*Brachiaria* spp.	2	3.83-6.33 (5.08)	9.37-10.14 (9.76)
Rhodes grass	*Chloris gayana*	2	nd	nd-3.91 (3.91)
Giant star grass	*Cynodon aethiopicus*	2	nd-2.35 (2.35)	3.93-4.84 (5.55)
Leucaena leaves	*Leucaena leucocephala*	1	nd	6.99
Guinea grass	*Panicum maximum*	3	3.95-6.42 (5.04)	9.73-15.09 (12.15)
Sugarcane tops	*Saccharum officinarum*	1	nd	1.05
Korean lawn-grass	*Zoysia tenuifolia*	1	2.17	4.38

nd: not detected, Groups 1, 2 and 3 were classified with soluble oxalate content at >20, 10-20 and <10 g kg^{-1} DM, respectively, Mean values are in parenthesis

Table 2: Oxalate content (g kg^{-1} DM) of fodder plants in Savar and Shahzadpur, Bangladesh

Common name and fractions of plants	Scientific name	No. of sample	Soluble oxalate	Total oxalate
Group 1				
Para grass	*Brachiaria mutica*	4	1.78-24.23 (9.76)	6.62-39.62 (29.75)
Napier grass	*Pennisetum purpureum*	15	1.90-31.61 (14.84)	10.04-34.25 (25.46)
Group 2				
Pangola grass	*Digitaria decumbens*	1	15.50	15.50
Rice straw	*Oryza sativa*	3	5.13-14.93 (10.08)	7.52-14.93 (12.48)
Guinea grass	*Panicum maximum*	3	3.06-10.45 (5.91)	4.23-15.88 (11.55)
Sugarcane tops	*Saccharum officinarum*	1	11.82	11.82
Dhaincha leaves	*Sesbania sesban*	3	2.20-15.70 (10.59)	2.20-15.70 (10.59)
Setaria	*Setaria sphacelata*	2	1.65-15.02 (8.33)	17.97-49.15 (33.56)
Vetiver	*Vetiveria zizanioides*	1	14.88	14.88
Group 3				
Star grass	*Aletris farinosa*	1	2.94	2.94
Andropogon	*Andropogon gayanus*	2	2.07-3.59 (2.83)	2.07-3.59 (2.83)
Signal grass	*Brachiaria decumbens*	2	0.99-6.20 (3.59)	5.14-6.20 (7.74)
Ruzi grass	*Brachiaria ruziziensis*	2	0.83-4.44 (2.63)	0.83-10.01 (8.20)
Buffelgrass	*Cenchrus ciliaris*	1	5.96	9.72
Centrosema	*Centrosema pubescens*	1	3.20	16.38
Bermuda grass	*Cynodon dactylon*	3	0.39-9.76 (3.98)	0.39-9.76 (3.98)
German grass	*Echinochloa crus galli*	2	1.46-7.44 (4.45)	1.46-7.44 (4.45)
Water hyacinth	*Eichhornia* spp.	2	4.18-5.12 (4.65)	7.90-21.33 (14.61)
Dumur	*Ficus hispida*	2	2.75-4.24 (3.49)	4.24-6.33 (7.07)
Dhal grass	*Hymenachne amplexicaulis*	1	3.53	3.53
Khesari	*Lathyrus sativus*	1	6.03	8.38
Leucaena leaves	*Leucaena leucocephala*	1	nd	3.77
Cassava leaves	*Manihot esculenta*	1	8.97	13.25
Sajna leaves	*Moringa oleifera*	1	1.56	19.38
Arali	*Panicum repens*	1	5.60	5.60
Plicatulum	*Paspalum plicatulum*	2	5.25-6.03 (5.64)	5.25-8.59 (8.20)
Sorghum	*Sorghum bicolor*	4	nd-5.17 (4.03)	nd-5.17 (4.03)

nd: not detected, Groups 1, 2 and 3 were classified with soluble oxalate content at >20, 10-20 and <10 g kg^{-1} DM, respectively, Mean values are in parenthesis group 2 included *Setaria sphacelata*, *Panicum maximum*, *Digitaria decumbens*, *Vetiveria zizanioides*, *Oryza sativa*, *Sesbania sesban* and *Saccharum officinarum* and group 3 included other 18 plants. *Leucaena leucocephala* did not show any detectable soluble oxalate content. The soluble oxalate content in plant samples ranged from 0 to 31.61 g kg^{-1} DM and total oxalate content ranged from 0-49.15 g kg^{-1} DM.

The mineral concentration of the plant samples at Okinawa site is given in Table 3. The highest contents of K (16.36 g kg^{-1} DM), Na (8.03), Ca (50.99) and Mg (8.92) were observed in *Pennisetum purpureum*, *Setaria sphacelata*, *Leucaena leucocephala* and *Brachiaria* spp. (Marandu), respectively. The mineral content of the plant samples at 2 sites in Bangladesh is given in Table 4. The highest contents of K (65.48 g kg^{-1} DM), Na (7.69), Ca (30.11) and Mg (9.89) were observed in *Eichhornia* spp., *Vetiveria zizanioides*, *Ficus hispida* and *Aletris farinosa*, respectively. Table 5 represents the correlation coefficient between oxalate and mineral contents in the plants. In most of the cases, no relationship was observed between the oxalate and mineral contents in the plants, except for positive correlation between soluble oxalate and K contents in plants growing in Bangladesh.

DISCUSSION

Oxalate binds and forms insoluble compounds with some essential minerals including Ca, iron, zinc and Mg. High oxalate feeds inhibit mineral absorption. For example, Ca can combine with oxalate to form insoluble Ca-oxalate in the intestine, making Ca unavailable for absorption; Ca-oxalate is then excreted in feces. The decrease in serum Ca impairs normal cell membrane function, causing animals to develop muscle tremors and weakness, leading to collapse and eventually death. Acute oxalate poisoning has been reported with the ingestion of *Setaria sphacelata*, a high oxalate-containing plant, by Jones *et al*. (1970). Without adequate knowledge of oxalate content in fodder plants, dietary guidelines could not be established.

The data of present study revealed that the majority of fodder plants commonly consumed by livestock accumulate oxalate much lower content than 20 g kg^{-1} DM. For example,

Table 3: Mineral content (g kg^{-1} DM) of fodder plants in Okinawa, Japan

Common name and fraction of plants	Scientific name	No. of sample	K	Na	Ca	Mg
Group 1						
Setaria	*Setaria sphacelata*	1	10.36	8.03	7.54	5.56
Group 2						
Buffelgrass	*Cenchrus ciliaris*	1	12.14	1.84	6.58	7.80
Pangola grass	*Digitaria decumbens*	4	8.57±1.71	6.02±2.29	8.63±1.26	5.36±1.88
Napier grass	*Pennisetum purpureum*	7	16.36±5.38	1.84±0.34	9.08±3.09	7.17±3.99
Group 3						
Creeping signal grass	*Brachiaria humidicola*	1	5.69	6.22	8.36	7.66
Para grass	*Brachiaria mutica*	5	12.65±4.06	3.23±1.27	7.88±2.16	4.72±1.54
Brachiaria Marandu	*Brachiaria* spp.	2	8.27±0.64	2.16±1.14	12.95±1.47	8.92±0.02
Rhodes grass	*Chloris gayana*	2	9.61±4.70	5.23±1.05	9.61±0.29	3.99±0.21
Giant star grass	*Cynodon aethiopicus*	2	11.52±1.13	1.77±0.20	7.92±0.74	4.22±0.86
Leucaena leaves	*Leucaena leucocephala*	1	5.43	2.12	50.99	8.67
Guinea grass	*Panicum maximum*	3	12.18±2.30	3.25±0.96	10.10±2.61	7.65±1.48
Sugarcane tops	*Saccharum officinarum*	1	8.57	1.66	9.87	2.39
Korean lawn-grass	*Zoysia tenuifolia*	1	9.83	1.71	5.47	4.89

Groups 1, 2 and 3 were classified with soluble oxalate content at >20, 10-20 and <10 g kg^{-1} DM, respectively

Table 4: Mineral content (g kg^{-1} DM) of fodder plants in Savar and Shahzadpur, Bangladesh

Common name and fraction of plants	Scientific name	No. of sample	K	Na	Ca	Mg
Group 1						
Para grass	*Brachiaria mutica*	4	27.19±11.76	3.03±2.27	3.81±1.15	3.04±0.53
Napier grass	*Pennisetum purpureum*	15	34.21±12.68	0.37±0.21	4.77±1.45	3.16±1.07
Group 2						
Pangola grass	*Digitaria decumbens*	1	30.56	5.19	4.55	3.34
Rice straw	*Oryza sativa*	3	23.66±4.38	0.92±0.26	5.53±2.02	2.67±1.13
Guinea grass	*Panicum maximum*	3	26.01±7.44	2.45±3.00	6.31±1.55	3.89±0.70
Sugarcane tops	*Saccharum officinarum*	1	18.39	0.40	1.77	0.94
Dhaincha leaves	*Sesbania sesban*	3	19.57±1.40	0.97±1.04	12.43±2.62	3.47±1.29
Setaria	*Setaria sphacelata*	2	33.05±18.76	4.66±0.63	3.64±0.61	2.73±1.27
Vetiver	*Vetiveria zizanioides*	1	21.53	7.69	8.58	5.70
Group 3						
Star grass	*Aletris farinosa*	1	13.79	0.87	8.23	9.89
Andropogon	*Andropogon gayanus*	2	16.51±6.18	0.26±0.29	6.98±2.59	6.06±2.08
Signal grass	*Brachiaria decumbens*	2	15.38±4.32	0.63±0.30	4.86±1.49	4.48±2.80
Ruzi grass	*Brachiaria ruziziensis*	2	16.75±4.07	0.43±0.04	5.51±2.12	3.81±1.60
Buffelgrass	*Cenchrus ciliaris*	1	12.34	5.55	10.81	5.48
Centrosema	*Centrosema pubescens*	1	14.74	0.69	12.34	5.60
Bermuda grass	*Cynodon dactylon*	3	29.20±15.34	0.41±0.22	3.72±1.29	2.64±1.21
German grass	*Echinochloa crus galli*	2	17.43±8.36	3.04±3.00	6.29±3.33	3.75±0.51
Water hyacinth	*Eichhornia* spp.	2	65.48±7.62	1.03±0.46	14.75±6.53	6.59±0.74
Dumur	*Ficus hispida*	2	32.66±0.37	0.04±0.06	30.11±0.62	9.59±1.95
Dhal grass	*Hymenachne amplexicaulis*	1	42.51	1.91	2.69	2.14
Khesari	*Lathyrus sativus*	1	24.78	1.64	12.03	4.02
Leucaena leaves	*Leucaena leucocephala*	1	19.32	0.51	14.39	3.63
Cassava leaves	*Manihot esculenta*	1	15.38	0.50	11.53	9.85
Sajna leaves	*Moringa oleifera*	1	17.80	0.24	12.41	6.03
Arali	*Panicum repens*	1	12.93	0.68	3.58	3.29
Plicatulum	*Paspalum plicatulum*	2	17.66±3.86	0.23±0.19	7.00±2.37	6.75±5.28
Sorghum	*Sorghum bicolor*	4	26.27±9.71	0.43±0.11	8.34±1.13	5.96±2.02

Groups 1, 2 and 3 were classified with soluble oxalate content at >20, 10-20 and <10 g kg^{-1} DM, respectively

Table 5: Correlation coefficient between oxalate and mineral contents in plants

Type of oxalate	Mineral	Plants in Okinawa	Plants in Bangladesh
Soluble oxalate	K	0.34 ns	0.31*
	Na	0.20 ns	0.04 ns
Insoluble oxalate	Ca	0.19 ns	-0.26 ns
	Mg	0.25 ns	-0.19 ns

ns: Not significant at p>0.05, significant at *p<0.05

Oryza sativa contained up to 14.93 g kg^{-1} DM soluble oxalate. However, some fodder plants (*Pennisetum purpureum*, *Setaria sphacelata* and *Brachiaria mutica*) showed oxalate contents exceeding 20 g kg^{-1} DM. Fodder plants having a lower tendency to accumulate oxalate might be selected for cultivation; otherwise, consumption of high oxalate-containing plants by ruminants should be carefully monitored.

A previous study demonstrated that sheep fed by forage containing high oxalate (13.4 g kg^{-1} DM) had lower blood Ca than those feeding low oxalate (4.7 g kg^{-1} DM) of forage (Rahman *et al.*, 2011). The present results revealed that the formulation of a recommendable ration shall be based not only on the nutrient content of feedstuffs but also on antinutrients as oxalate. *Pennisetum purpureum* and *Brachiaria mutica* of Bangladesh contained high soluble oxalate and low Ca which may cause Ca deficiency in animal. *Setaria* in Okinawa contained plenty of Ca (7.54 g kg^{-1} DM) may be safe for animal feeding despite high soluble oxalate content (29.67 g kg^{-1} DM). The legume plants contained relatively low contents of soluble oxalate, ranging from 0 in *Leucaena leucocephala* to 15.70 g kg^{-1} DM in *Sesbania sesban*. In some regions of Bangladesh, *Leucaena leucocephala* and *Sesbania sesban* are well recognized in wasteland and are used by most livestock farmers as a feed supplement.

Feeding browse plants has become an essential practice in many parts of the tropics, especially in the dry season, when a scarcity of grass and herbaceous legume plants always occurs. *Ficus hispida* is a commonly available fodder tree in Bangladesh and this plant is often used as a feed for ruminants. *Ficus hispida* contained very low content of soluble oxalate (ranging from 2.75-4.24 g kg^{-1} DM) and high content of Ca (30.11 g kg^{-1} DM).

In the previous study, we observed a positive relationship between oxalate and mineral contents in napier grass (Rahman *et al*., 2008). However, no significant correlations between these 2 factors were observed in most of plants tested in this study, suggesting that the relationship between oxalate and mineral contents may vary among plant species. Smith (1972) reported that the amounts of inorganic ions in plants can be varied by altering the nutritional conditions and that the ions maintaining ionic balance in plants may alter the amounts of carboxylic acids (including oxalate).

Several factors are concerned in the accumulation of oxalate in fodder plants. For example, seasons can influence on oxalate accumulation in plants (Singh, 2002; Rahman *et al*., 2006). Singh (2002) reported that the oxalate content in napier grass was found to be 1.5 times higher in June and July than in April, whereas in August the level decreased from 36.0 to 25.6 g kg^{-1} DM. In this study, however, samples were not collected during the peak growth of plants, i.e. summer and rainy seasons, but collected in late winter (for the samples in Okinawa, Japan) and late summer (for the samples in 2 sites of Bangladesh). Therefore, unfavorable season might have caused lowering the oxalate content in this study. Samples were also not harvested at the same stage of maturity that might be affected the oxalate accumulation to some extent, because oxalate levels declined as the harvest interval increased (Rahman *et al*., 2009b).

The oxalate levels of the same grass species we examined in two subtropical and tropical regions were varied and this might be associated with area of origin, although environmental conditions of Bangladesh are more or less similar with southern part of Japan (Okinawa). Moreover, this variation might also be associated with cation uptake, because both N and K application have pronounced effect on oxalate (Rahman and Kawamura, 2011). The order in soluble and insoluble oxalate contents was reversed for *Setaria sphacelata* in Okinawa and Bangladesh and this variation was not clear. However, this result might be partially explained with the findings of Rahman *et al*. (2009a) who reported that Ca supply can affect the soluble/insoluble oxalate ratio in plants. Hence, oxalate level in fodder plants grown in two subtropical and tropical regions could differ due to different fertilizer management.

The results of the present study demonstrate that the oxalate content in fodder plants may vary over a wide range, mainly depending upon the plant species. The majority of fodder plants in both subtropical and tropical regions accumulated low contents of oxalate, while a few fodder plants in some cases could accumulate oxalate up to the potentially toxic level. Dietary Ca should be ingested with the rations to maximize the binding of oxalate in the gut. We hope the data obtained herein can help livestock farmer to take necessary step on the prevention from oxalate toxicity.

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