Chapter 5

Cultivation Methods for Leafy Vegetables and Tomatoes with Low Potassium Content for Dialysis Patients and the Change of those Qualities

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71306

Abstract

It is recommended that kidney disease patients receiving dialysis have limited potassium intake including intake of vegetables with high potassium content. Dialysis patients cannot absorb other nutrients contained in vegetables. To solve these problems, methods of cultivating vegetables with low potassium contents as compared to normal vegetables were studied. In leafy vegetables, the potassium contents were reduced as much with 60–70% by the cultivation without potassium applications during the latter half of the growth period compared with the controls, with no change in plant growth. In tomato, the potassium content in the potassium-restricted group was also reduced to 50–89% of the control. There was no change in the fresh weight per fruit of the tomatoes; however, the total yield was reduced. In this chapter, we introduce the researches of the cultivation method for leafy vegetables and tomatoes with low potassium content while still maintaining normal plant growth. Furthermore, the changes of the contents in minerals, ascorbic acid, and sugar in low potassium vegetables were reported.

Keywords: ascorbic acid, dialysis patients, leafy vegetable, potassium, sodium, tomato, soil-less culture

1. Introduction

In the year 2010, the number of dialysis patients worldwide was approximately 2.16 million [1]. Because the symptoms of kidney disease are subtle, and one of the most significant primary diseases in kidney disease is diabetes, it is estimated that tens of thousands to several million people have a preliminary stage of kidney disease [2]; this suggests a further increase in dialysis patients. By 2030, this figure will project to more than double to 5.439 million, with the largest growth in Asia [1]. Because dialysis patients have dysfunctional potassium excretion mechanisms, there is a possibility of them suffering from serious electrocardiographic abnormalities and heart failure due to hyperkalemia [3]. Therefore, disturbances in plasma potassium concentration, most commonly hyperkalemia, remain a constant threat to the health of dialysis patients [4]. Potassium intake must be restricted in dialysis patients. Because the vegetables that we generally eat contain high levels of potassium [5], dialysis patients should not eat raw vegetables, they should have them boiled or leached in water to remove excess potassium [6, 7]. Although potassium content is partially reduced by these methods, the degree of reduction is limited. In addition, other important minerals and vitamins get eluted and disassembled by these methods. Furthermore, many dietary fibers are included in vegetables, but a dietary fiber becomes lacking in it because vegetables intake are limited as for the kidney disease dialysis patient. As a result, it is reported that the difference in dietary fiber intake of the chronic kidney disease patient (CKD) including the dialysis patient is related to the inflammatory reaction (C-reactivity protein) and death rate [8]. There are many disadvantages by limiting vegetables intake.

It is believed that vegetables cultivated to contain lower potassium levels are beneficial for dialysis patients as compared to those cultivated by the general method. The former allows patients to eat raw vegetables in moderation. The potassium content in these vegetables can be reduced even further by boiling or leaching in water.

On the other hand, potassium is an essential macronutrient for plant growth [9]. Potassium plays a significant physiological role in the metabolism of substances within a cell such as the maintenance of protoplasmic structure and pH levels [10], and the compatible solutes required for osmotic adjustment [11]. Therefore, it is expected that limited supply of potassium will inhibit plant growth. Therefore, it is important to investigate the amount to which the potassium levels can be reduced while still maintaining the optimum levels for plant growth.

The objective of this chapter is to introduce the researches of the cultivation method for leafy vegetables and tomatoes with low potassium content for dialysis patients who are restricted potassium intake, while still maintaining normal plant growth. Furthermore, the changes of the contents in minerals, ascorbic acid, and sugar in low potassium vegetables were reported.

2. Examination of the cultivation method of vegetables with low potassium content and changes of that quality

2.1. Examination of the cultivation method of the spinach with the low potassium content

Ogawa et al. [12] examined the effective cultivation method of the spinach (*Spinacia oleracea* L.), which had high potassium content. Spinach grown hydroponically received one of two treatments:

1. Cultivation with reduced potassium applications throughout the growth period.
2. Cultivation without potassium applications during the latter half of the growth period.

2.1.1. Cultivation with reduced potassium applications throughout the growth period

During the cultivation period, spinach was cultivated at potassium concentration of 1/2 (1/2 K treatment), 1/4 (1/4 K treatment), and 1/8 (1/8 K treatment) of the control. The influence that a difference of the potassium concentration in water culture medium gave the potassium content at the harvest (**Figure 1**). There was no significant difference in 1/2 K treatment and the 1/4 K treatment than control, but the potassium content significantly decreased in 1/8 K treatment. Potassium content was 7.97 mg per 1 g of fresh weight in the control, but it was 5.45 mg in the 1/8 K treatment, and it decreased by 32%.

Fresh weight, the number of leaves, water content, and the SPAD value, which shows chlorophyll content, in each treatment at the harvest are shown in **Table 1**. There was no significant difference at the time of a harvest in fresh weight and the number of leaves by the treatments that had lower potassium concentration than a control. The water content showed 94.0% in 1/2 K treatment and slightly increased compared with a control. However, there was not the significant difference in other treatment. The SPAD value was significantly lower in 1/2 K treatment than a control and was significantly high in 1/8 K treatment.

Table 2 shows the content of magnesium, calcium, sodium, sulfur, copper, iron, manganese, and zinc in the harvest. The content of the major element except sulfur increased by the treatment that had low potassium concentration. Sodium contents increased conspicuously. Sodium content was 828 μg per 1 g of fresh weight in the 1/8 K treatment, which had the lowest potassium concentration and was 12.7-fold of the control.

2.1.2. Cultivation without potassium applications during the latter half of the growth period

Spinach plants that were grown hydroponically received one of three treatments:

1. Treatment not to include potassium in water culture medium for 1 week before the harvest (1W0K treatment)

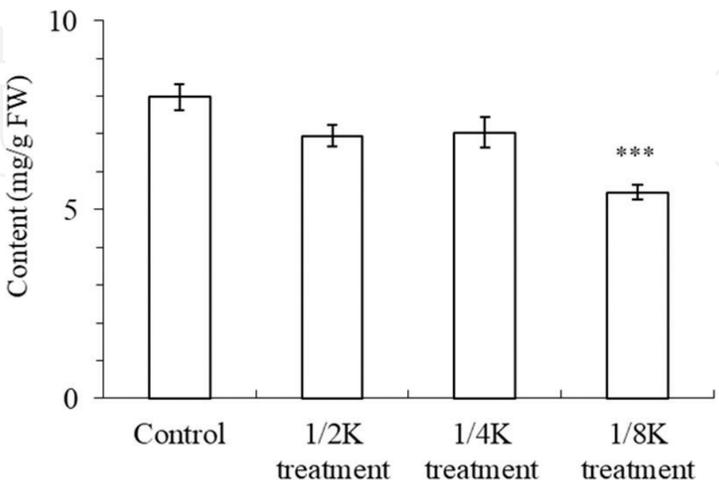

Figure 1. Changes in potassium contents at the harvest by the cultivation with reduced potassium applications throughout the growth period. Each value shows the mean ± standard error (n = 5). *** represents statistical significance at $p < 0.001$ compared with control by t-test. (From Ogawa et al. (12)).

	Control	1/2K treatment		1/4K treatment		1/8K treatment	
Fresh weight (g/plant)	15.1 ± 2.0	25.9 ± 4.7	NS	22.6 ± 4.6	NS	18.9 ± 3.2	NS
Leaf number par plant	14.4 ± 0.9	13.2 ± 1.1	NS	13.4 ± 1.6	NS	13.6 ± 1.0	NS
Water content (%)	92.9 ± 0.2	94.0 ± 0.2	**	93.4 ± 0.4	NS	93.2 ± 0.2	NS
SPAD value	43.5 ± 1.5	38.3 ± 0.6	**	42.0 ± 1.5	NS	48.0 ± 0.8	**

Each value shows the mean ± standard error (n = 5).
**Represents statistical significance at $p<0.01$ compared with control. NS, not significant by *t*-test. (From Ogawa et al. [12]).

Table 1. Changes in fresh weight, leaf number, water content and SPAD value at the harvest by the cultivation with reduced potassium applications through the growth period.

	Control	1/2K treatment		1/4K treatment		1/8K treatment	
Calcium	331 ± 29.2	308 ± 23.7	NS	375 ± 30.6	NS	528 ± 44.9	**
Magnesium	371 ± 8.6	325 ± 18.9	NS	462 ± 28.9	*	465 ± 25.2	**
Sodium	65.2 ± 2.8	108 ± 6.5	***	648 ± 82.9	***	828 ± 57.1	***
Sulfur	337 ± 5.3	289 ± 10.4	**	356 ± 37.4	NS	340 ± 13.4	NS
Copper	0.5 ± 0.03	0.4 ± 0.02	**	0.4 ± 0.06	NS	0.4 ± 0.02	*
Iron	6.4 ± 0.19	4.7 ± 0.23	***	7.3 ± 1.14	NS	7.4 ± 0.51	NS
Manganese	13.5 ± 1.78	10.5 ± 0.50	NS	12.2 ± 1.90	NS	13.8 ± 0.84	NS
Zinc	4.5 ± 0.18	2.3 ± 0.13	***	3.5 ± 0.52	NS	3.4 ± 0.32	*

Each value shows the mean ± standard error (n = 5).
*, ** and *** represent statistical significance at $p<0.05$, *0.01* and *0.001* compared with control, respectively. NS, not significant by *t*-test. (From Ogawa et al. [12]).

Table 2. Changes in mineral contents per fresh weight (μg/g FW) at the harvest by the cultivation with reduced potassium applications through the growth period.

2. Treatment to reduce potassium concentration to 1/4 of the control before 2 weeks of the harvest and not to include potassium before 1 week (1 W1/4 K treatment)
3. Treatment do not include potassium in water culture medium for 2 weeks before the harvest (2W0K treatment)

The potassium content significantly decreased in comparison with a control in each treatment (**Figure 2**). The potassium content was 4.79, 3.61, and 1.71 mg per 1 g of fresh weight in 1W0K treatment, 1 W1/4 K treatment, and 2W0K treatment, respectively. They had

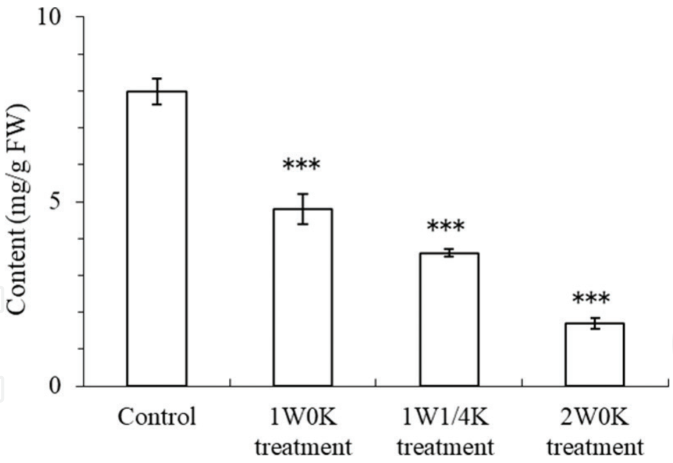

Figure 2. Changes in potassium contents at the harvest by the cultivation without potassium applications during the latter half of the growth period. Each value shows the mean ± standard error (n = 5). *** represents statistical significance at $p < 0.001$ compared with control by *t*-test. (From Ogawa et al. (12)).

lower 40, 55, and 79% than a control in 1W0K treatment, 1 W1/4 K treatment, and 2W0K treatment, respectively.

Fresh weight, the number of leaves, water content, and the SPAD value in each treatment at the harvest are shown in **Table 3**. There was no significant difference at the time of a harvest in fresh weight, the number of leaves, and the SPAD value by the low potassium treatments. The water content showed 94.3% in 1W0K treatment and slightly increased compared with a control. However, there was no significant difference than a control by other treatment.

Table 4 shows the content of magnesium, calcium, sodium, sulfur, copper, iron, manganese, and zinc in the harvest. The content of the major element except sulfur increased by the low potassium treatments. Sodium contents increased conspicuously. Sodium content was 1646 μg per 1 g of fresh weight in the 2W0K treatment, which had the lowest potassium concentration and was 25.3-fold of the control.

From these results, it was revealed that we could reduce potassium more effectively without inhibiting growth by the cultivation method with no potassium applications during the latter half of the growth period.

2.2. Adaptation of the cultivation method for other leafy vegetables

Using a result concerned with the spinach [12], cultivation to reduce potassium without inhibiting growth was investigated in red leaf lettuce (*Lactuca sativa* L. var. *crispa*), asparagus lettuce (*Lactuca sativa* L. var. *angustana*), and komatsuna (*Brassica rapa* L. var. *perviridis*) [13].

Table 5 shows the changes in the ion content in the three leafy vegetables at harvest for each treatment. The potassium contents of red leaf lettuce, asparagus lettuce, and komatsuna in the control group were 3634, 3709, and 4226 μg per 1 g of fresh weight, respectively, and those in the potassium-restricted group were 1026, 1545, and 1315 μg, respectively. These values

	Control	1W0K treatment		1W1/4K treatment		s2W0K treatment	
Fresh weight (g/plant)	15.1 ± 2.0	23.3 ± 5.3	NS	14.8 ± 2.5	NS	15.8 ± 2.3	NS
Leaf number par plant	14.4 ± 0.9	14.5 ± 1.4	NS	14.2 ± 1.2	NS	14.0 ± 0.3	NS
Water content (%)	92.9 ± 0.2	94.3 ± 0.2	**	93.3 ± 0.2	NS	93.1 ± 0.3	NS
SPAD value	43.5 ± 1.5	42.4 ± 1.2	NS	44.0 ± 1.2	NS	43.7 ± 1.3	NS

Each value shows the mean ± standard error (n = 5).

**represents statistical significance at *p<0.01* compared with control. NS, not significant by *t*-test. (From Ogawa et al. [12])

Table 3. Changes in fresh weight, leaf number, water content and SPAD value at the harvest by the cultivation with no potassium applications after the halfway point of the growth period.

	Control	1W0K treatment		1W1/4K treatment		2W0K treatment	
Calcium	331 ± 29.2	566 ± 39.8	**	712 ± 68.2	***	767 ± 40.4	***
Magnesium	371 ± 8.6	408 ± 32.6	NS	424 ± 53.7	NS	475 ± 17.1	***
Sodium	65 ± 2.8	983 ± 26.5	***	1357 ± 35.8	***	1646 ± 124.7	***
Sulfur	337 ± 5.3	270 ± 23.7	*	300 ± 15.8	NS	348 ± 7.1	NS
Copper	0.5 ± 0.03	0.4 ± 0.03	**	0.5 ± 0.03	NS	0.5 ± 0.05	NS
Iron	6.4 ± 0.19	5.8 ± 0.93	NS	6.0 ± 0.52	NS	7.5 ± 0.24	**
Manganese	13.5 ± 1.78	12.6 ± 1.03	NS	13.8 ± 0.70	NS	19.1 ± 0.91	*
Zinc	4.5 ± 0.18	2.3 ± 0.21	***	2.1 ± 0.11	***	2.4 ± 0.06	***

Each value shows the mean ± standard error (n = 5).

*, ** and *** represent statistical significance at *p<0.05*, *0.01* and *0.001* compared with control, respectively. NS, not significant by *t*-test. (From Ogawa et al. [12]).

Table 4. Changes in mineral contents per fresh weight (μg/g FW) at the harvest by the cultivation with no potassium applications after the halfway point of the growth period.

	Red leaf lettuce			Asparagus lettuce			Komatsuna		
	Control	Potassium restricted		Control	Potassium restricted		Control	Potassium restricted	
Potassium	3634 ± 146	1026 ± 48	*	3709 ± 230	1545 ± 90	*	4226 ± 192	1315 ± 36	*
Calcium	373 ± 17	364 ± 12	NS	316 ± 20	287 ± 11	NS	1349 ± 71	1406 ± 59	NS
Magnesium	375 ± 15	492 ± 15	*	206 ± 13	299 ± 12	*	377 ± 24	416 ± 20	NS
Sodium	77 ± 11	1031 ± 55	*	38 ± 2	477 ± 37	*	139 ± 11	1692 ± 60	*

Each value shows the mean ± standard error (n = 8).

*Represents statistical significance at *p<0.05* compared with control. NS, not significant by *t*-test. (From Ogawa et al. [13])

Table 5. Changes in potassium, calcium, magnesium and sodium contents (μg/g FW) of red leaf lettuce, asparagus lettuce and komatsuna at the harvest as affected by potassium-restricted treatment.

represent a significant reduction in potassium levels: 28, 42, and 31% of the control, respectively. The sodium content in all plants and the magnesium contents in the red leaf lettuce and asparagus lettuce were increased significantly when the potassium supply was restricted. Particularly, the sodium content was markedly increased. The sodium contents in red leaf lettuce, asparagus lettuce, and komatsuna in the control group were 77, 38, and 139 μg per 1 g of fresh weight, respectively, while those in the potassium-restricted group were 1031, 477, and 1692 μg, respectively. This represents a 13.4-fold, a 12.6-fold, and a 12.2-fold, respectively, increase as compared with the control group.

Table 6 shows fresh weight, dry weight, and water content at harvest for each treatment group. For all plants, there was no significant difference in these measurements as compared with the control group. These results showed that there was no change in the plant growth, despite the potassium restriction.

Despite the reduction of potassium supply, plant growth was maintained and some other ion contents were increased. One of the roles of potassium ion is to adjust osmotic potential. Therefore, the number of moles of potassium, sodium, magnesium, and calcium ions per fresh weight was calculated to show the total number of moles of these ions (**Figure 3**). The number of moles of sodium and magnesium ions was greater in the potassium-restricted group for all plants. However, the total number of moles in the potassium-restricted group was 83 and 71% of that of the control group in red leaf lettuce and asparagus lettuce, respectively. For komatsuna, the total number of moles in the potassium-restricted group was 98% of that of the control group.

2.3. Examination of the cultivation method of the tomato with low potassium content

Tomatoes (*Solanum lycopersicum* L.) were grown hydroponically under two different potassium-restricted treatments [13].

1. Treatment not to include potassium in water culture medium after the first fruit developed at the first truss (0 K treatment).

	Red leaf lettuce			**Asparagus lettuce**			**Komatsuna**		
	Control	**Potassium restricted**		**Control**	**Potassium restricted**		**Control**	**Potassium restricted**	
Fresh weight (g)	53.9 ± 4.1	50.3 ± 4.3	NS	39.8 ± 4.6	40.6 ± 3.2	NS	176.1 ± 22.0	178.4 ± 11.1	NS
Dry weight (g)	3.4 ± 0.2	3.1 ± 0.3	NS	1.7 ± 0.3	1.6 ± 0.2	NS	10.4 ± 1.5	10.2 ± 0.6	NS
Water content (%)	93.7 ± 0.2	93.8 ± 0.2	NS	95.7 ± 0.2	96.0 ± 0.2	NS	94.1 ± 0.2	94.3 ± 0.2	NS

Each value shows the mean ± standard error (n = 8).
NS, not significant compared with control by *t*-test. (From Ogawa et al. [13])

Table 6. Changes in fresh weight, dry weight and water content of red leaf lettuce, asparagus lettuce and komatsuna at the harvest as affected by potassium restricted treatment.

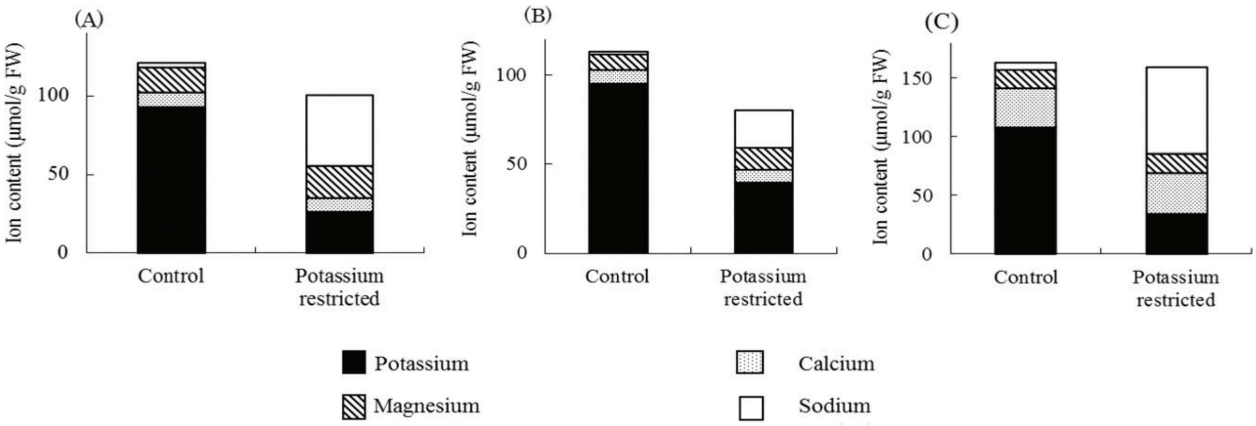

Figure 3. Changes in total ion contents of potassium, calcium, magnesium, and sodium in red leaf lettuce (A), asparagus lettuce (B) and komatsuna (C) at the harvest as affected by potassium-restricted treatment. (from Ogawa et al. [13]).

2. Treatment in a water culture medium alternated every week with and without potassium after the first fruit developed at the first truss (1W0K treatment).

Table 7 shows the changes in ion content in tomatoes at harvest in each treatment group. The potassium contents in the potassium-restricted groups (1W0K and 0 K treatments) in all trusses were reduced significantly when compared with the control. The potassium content of the control group was 1551–2126 μg per 1 g of fresh weight in each truss. On the other hand, the potassium contents were 1382–1645 μg in the 1W0K treatment group and 790–1335 μg in the 0 K treatment group. The percentages were 74–89% and 45–73% of the control group for the 1W0K and 0 K treatment groups. In the fifth truss of the 0 K treatment group, no fruit was harvested by the growth inhibition due to the potassium-restricted treatment.

Calcium and magnesium content was affected slightly by the treatment with potassium restriction (**Table 7**). The calcium content was significantly higher than that in the control group in the third truss of 1W0K treatment and in the first truss of 0 K treatment. The magnesium content was significantly higher than that in the control group in the fifth truss of 1W0K treatment and in the first and the second trusses of 0 K treatment. On the other hand, the sodium content was drastically increased by the treatment with potassium restriction. The sodium contents were 60–106 μg in the 1W0K treatment group and 88–179 μg in the 0 K treatment group. The percentages were 128–200% and 187–332% of the control group in the 1W0K and 0 K treatment groups.

Fresh weight of fruits and the total number of fruits harvested were not affected significantly by the two treatments with potassium restriction, except for the fourth and the fifth truss of the 0 K treatment group (**Table 7**). In the fourth truss of the 0 K treatment group, fresh weight and the total number of fruit were significantly lower than that in the control group. In the 1W0K treatment group, the fresh weight in the fourth truss and the number of fruits in the second truss were higher than that in the control group. Overall, the total fruit yield was not significantly changed by the two treatments with potassium restriction, except for the fourth and the fifth trusses in the 0 K treatment group.

Soluble solids content and water content were affected by the treatment with potassium restriction (**Table 7**). Compared to that in the control group, the soluble solids content was

	Truss	1st		2nd		3rd		4th		5th	
Fresh weight (g/fruit)	Control	39.9 ± 1.7	a	40.8 ± 2.0	a	44.3 ± 2.1	a	45.5 ± 2.0	b	46.3 ± 2.0	a
	1W0K	39.5 ± 2.1	a	42.7 ± 1.7	a	50.3 ± 1.7	a	49.8 ± 2.0	a	51.5 ± 1.8	a
	0K	42.7 ± 1.8	a	43.6 ± 2.4	a	48.5 ± 3.2	a	34.9 ± 2.7	c		
Number of fruit	Control	13.0 ± 1.5	a	13.0 ± 1.0	a	11.7 ± 0.9	a	13.3 ± 1.8	a	9.3 ± 0.7	a
	1W0K	11.3 ± 0.3	a	16.7 ± 0.3	b	12.7 ± 0.7	a	10.0 ± 1.0	ab	9.3 ± 0.9	a
	0K	10.7 ± 0.7	a	10.7 ± 0.3	a	7.0 ± 2.0	a	5.3 ± 0.9	b		
Soluble Solids Content (%)	Control	6.9 ± 0.1	a	6.6 ± 0.1	a	6.5 ± 0.1	a	6.2 ± 0.1	a	5.6 ± 0.1	a
	1W0K	6.7 ± 0.1	a	6.4 ± 0.1	a	6.2 ± 0.1	a	5.5 ± 0.1	b	5.2 ± 0.1	b
	0K	6.7 ± 0.1	a	6.6 ± 0.1	a	5.8 ± 0.2	b	4.9 ± 0.3	c		
Potassium (μg/g FW)	Control	1825 ± 35.0	a	2013 ± 57.3	a	2126 ± 77.9	a	1747 ± 37.7	a	1551 ± 22.6	a
	1W0K	1429 ± 26.2	b	1489 ± 27.2	b	1645 ± 48.1	b	1458 ± 39.7	b	1382 ± 22.7	b
	0K	1335 ± 26.5	b	1155 ± 33.2	c	1072 ± 48.2	c	790 ± 47.5	c		
Calcium (μg/g FW)	Control	36.8 ± 3.5	b	59.0 ± 16.2	ab	58.1 ± 7.0	b	74.4 ± 4.4	a	61.3 ± 3.7	a
	1W0K	47.9 ± 3.9	b	53.1 ± 7.7	b	107.9 ± 5.0	a	84.3 ± 3.8	a	64.0 ± 5.7	a
	0K	61.8 ± 3.4	a	95.7 ± 9.2	a	80.6 ± 6.7	b	90.0 ± 8.3	a		
Magnesium (μg/g FW)	Control	75.1 ± 2.7	b	97.5 ± 2.7	b	100.8 ± 3.2	a	98.7 ± 3.5	a	89.0 ± 2.2	b
	1W0K	77.4 ± 3.1	ab	95.4 ± 2.2	b	107.2 ± 2.5	a	96.7 ± 2.0	a	96.9 ± 2.2	a
	0K	84.8 ± 2.3	a	111.9 ± 2.7	a	109.5 ± 4.5	a	95.1 ± 4.9	a		
Sodium (μg/g FW)	Control	46.9 ± 5.6	b	34.6 ± 9.6	c	57.3 ± 5.6	c	75.3 ± 3.2	c	16.9 ± 2.2	b
	1W0K	59.9 ± 3.5	b	69.4 ± 3.8	b	99.5 ± 8.6	b	106.3 ± 4.4	b	32.3 ± 2.3	a
	0K	87.5 ± 6.7	a	114.9 ± 4.5	a	179.0 ± 11.5	a	160.3 ± 13.0	a		

Each value shows the mean ± standard error. Means followed by the common letters under each trust were not significantly different according to the multiple test of Tukey ($p<0.05$). In the 5th truss of 0K treatment, no fruit were harvested. (From Ogawa et al. [13])

Table 7. Changes in fresh weight, number of fruit, soluble solids content and the contents of potassium calcium, magnesium and sodium contents of tomato at the harvest as affected by potassium-restricted treatment.

significantly lower in the fourth and the fifth trusses of the 1W0K treatment group and in the third and the fourth trusses of the 0 K treatment group. Water content was significantly higher than that in the control in the second to the fifth trusses of the 1W0K treatment group and in the second to the fourth trusses of the 0 K treatment group.

2.4. Elucidation of a change of the ascorbic acid content under the low potassium condition and the mechanism

Ogawa et al. [14] hypothesized that a higher ascorbic acid content results when glucose content, in the form of an ascorbate matrix, increases in a plant. It has been suggested that glucose content increases by osmoregulation when lettuce and spinach are grown hydroponically

	Red leaf lettuce			Asparagus lettuce			Komatsuna			Spinach		
	Control	Potassium restricted		Control	Potassium restricted		Control	Potassium restricted		Control	Potassium restricted	
Vitamin C content (μmol/g FW)	1.05 ± 0.31	0.94 ± 0.22	NS	0.20 ± 0.03	0.38 ± 0.04	*	0.29 ± 0.04	0.44 ± 0.02	*	0.80 ± 0.12	1.16 ± 0.10	*
Glucose content (μmol/g FW)	10.01 ± 1.31	39.86 ± 6.26	**	6.02 ± 1.39	5.75 ± 1.24	NS	3.29 ± 0.44	5.58 ± 0.85	*	2.96 ± 0.23	8.28 ± 1.46	**
GLDH activity (nmol/min mg protein)	49.10 ± 4.26	40.70 ± 6.40	NS	32.56 ± 5.39	25.98 ± 5.66	NS	13.74 ± 3.01	30.25 ± 4.49	*	17.88 ± 1.87	32.54 ± 4.36	*

Each value shows the mean ± standard error (n = 5).

* and ** represent statistical significance at $p<0.05$ and *0.01* compared with control, respectively. NS, not significant by *t*-test. (From Ogawa et al. [14])

Table 8. Changes in vitamin C content, glucose content and GLDH activity of red leaf lettuce, green leaf lettuce, frilly lettuce and spinach at the harvest as affected by potassium-restricted treatment.

without potassium during the latter half of their growth period. The relationship among ascorbic acid content, glucose content, and the activity of L-galactono-γ-lactone dehydrogenase (EC 1.3.2.3; GLDH) was investigated in red leaf lettuce (*Lactuca sativa* L.), green leaf lettuce (*Lactuca sativa* L.), frilly lettuce (*Lactuca sativa* L.), and spinach (*Spinacia oleracea* L.) by using a cultivation method that involves potassium restriction [14].

In frilly lettuce, the ascorbic acid level with potassium restriction treatment was 1.5 times higher than that in the control (**Table 8**). At this time, glucose content and the GLDH activity with potassium restriction treatment were 1.7 and 2.2 times higher than those in the control, respectively. Similarly, in spinach, ascorbic acid content, glucose content, and GLDH activity with potassium restriction treatment were 1.4, 2.4, and 1.8 times higher than those in the control, respectively. In green lettuce, the ascorbic acid level with potassium restriction treatment was 1.5 times higher than that in the control, although glucose content and GLDH activity did not change. In red leaf lettuce, ascorbic acid content and GLDH activity did not change with potassium restriction treatment, although glucose content increased significantly.

3. Discussion

Potassium content was successfully reduced in leafy vegetables, with no significant change in fresh weight when using the hydroponic method in which potassium was applied in the early period and not applied during the last 7–10 days before harvest (**Figure 2** and **Table 5**). The potassium content for the "no potassium" group was 30–40% of the control group. Furthermore, the potassium content in tomato was reduced significantly by the 1W0K and 0 K treatments with no decrease in fresh weight per fruit (**Table 7**). It was reported that despite the presence of very low potassium concentrations in the culture medium, the amount of potassium in the plant tissues was sufficient to sustain the plant vegetative growth [15].

The total fruit yield of tomatoes decreased in the upper truss of the 0 K treatment group. The soluble solids content was decreased significantly, and the water content was increased significantly in the upper truss of the "no potassium" group (**Table 7**). It has been reported that potassium deficiency can reduce stomatal aperture, thereby impairing CO_2 fixation, disrupting the conversion of light energy to chemical energy, and the phloem export of photosynthates from the source to sink organs [16]. It was believed that we should use the technique by the low node-order pinching and high-density planting when you cultivated a low potassium tomato.

When potassium content was reduced drastically, sodium and magnesium contents were increased significantly in leafy vegetables (**Tables 2**, **4**, and **5**) and tomatoes (**Table 7**). It is suggested that the increments of these ions compensated for the potassium reduction. The presence of sodium and magnesium ions is important in alleviating the effects of potassium deficiency. It is suggested that the increase in sodium and magnesium concentrations occurred in response to the decrease in potassium [17, 18]. Potassium ions and magnesium ions have similar roles in osmotic adjustment, enzyme activation, and cellular pH control [19]. It was reported that the absorption of magnesium was increased when the amount of potassium fertilization was reduced in soybeans [20]. Sodium ions could replace potassium ion in nonspecific physiological and biochemical functions [21]. It was reported that substituting 20% NaCl for 20% KCl showed no significant effects on plant growth in spinach grown in sand culture [22]. In this study, the total number of moles in potassium-restricted treatments was lower than those in control, and the decline in potassium ions was not explained sufficiently by the increase in the other three ions in red leaf lettuce, asparagus lettuce (**Figure 3**), and tomato (data not shown). It was reported that other solutes, for example sugars and amino acids, contribute to osmotic adjustment [11]. It is considered that the absence of normal potassium levels resulted in an increase in the concentration of these solutes.

The concentration of sodium increased with the reduction in potassium concentration. An increase in sodium intake is not advisable for dialysis patients because it leads to hyperpiesia and edema. It is necessary to evaluate the benefits of the reduction of potassium against the risks of the increase of sodium intake for dialysis patients whose potassium intake should be restricted to 1500–2000 mg per day [23] and NaCl (equivalent to 2000–3200 mg sodium) intake should be restricted 5000–8000 mg per day. Therefore, sodium intake must be limited to 1.3–1.6-fold of potassium intake. The potassium content per 1 g fresh weight of spinach, red leaf lettuce, asparagus lettuce, and komatsuna in the potassium-restricted groups reduced by 6.26, 2.90, 2.17, and 2.69 mg compared with the control group, respectively (**Figure 2** and **Table 5**), while the sodium contents increased by 1.58, 0.95, 0.44, and 1.66 mg, respectively (**Tables 4** and **5**). Therefore, the reduction of potassium was greater than the increase in sodium in each plant. In addition, potassium intake can only be determined by a patient's diet. Consequently, eating food with low potassium content is an effective way to limit the potassium intake. On the other hand, limiting the amount of salt used is a more effective way of reducing sodium intake than concentrating only on eating foods with low sodium content. We conclude that the benefits of reducing the intake of potassium are greater than the risks of increasing the intake of sodium.

The increase in glucose content in frilly lettuce and spinach for osmoregulation during potassium restriction treatment supports our hypothesis and resulted in elevated ascorbic acid levels (**Table 8**). A significant association between glucose content and ascorbic acid content in tomato under a salt stress condition has been previously reported [24]. It was reported that exogenous glucose treatment increased the ascorbic acid content in rice roots [25]. The increase in ascorbic acid content by potassium restriction was accompanied by an increase in GHLD activity (**Table 8**). Previous studies showed that ascorbic acid accumulates when GHDL is upregulated [26, 27]. Therefore, the increase in ascorbic acid content observed in this study may be attributable to the accumulation of the ascorbate matrix and the upregulation of GHDL during potassium restriction.

Glucose content and GLDH activity did not change with potassium restriction in green lettuce, although the level of ascorbic acid increased (**Table 8**). These findings suggest that an indicator induced an increase in the level of metabolites from glucose to ascorbic acid. It was reported that ascorbic acid content increased when exogenous galactonolactone was introduced [25]. In wheat, ascorbic acid contents change without increasing its GHDL activity [28]. These results support the results that ascorbic acid content increased without changes in glucose levels and GLDH activity.

Glucose content increased with potassium restriction in red reef lettuce, although GLDH activity and ascorbic acid content remained the same. These results suggest that glucose is also used by other metabolic systems such as the glycolytic pathway and the synthesis pathways for cellulose and starch.

4. Conclusion

In this chapter, the author demonstrated a cultivation method to reduce the potassium content in leafy vegetables without causing significant potassium deficiency symptoms. Potassium content was also successfully reduced in tomatoes, with no significant change in the fresh weight per fruit, although the total yield was reduced. Furthermore, the author showed the changes of minerals and the ascorbic acid content and the mechanism. These results will contribute to an improvement in the dietary quality of dialysis patients.

Acknowledgements

This study was partially supported by the Core Research for Evolutionary Science and Technology project, Japan Science and Technology Agency (Grant number JPMJCR15O4).

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