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Selection of Nutrient Solutions and Substrates for Radish(*Raphanus sativus* L. var. *sativus*) Growth[1)]

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20일 무(*Raphanus sativus* L. var. *sativus*)의 수경재배에 적합한 양액 및 배지의 선발

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Abstract

The main objective of this study was to evaluate the effectiveness of nutrient solutions, substrates, and nutrient solution concentrations in substrate culture of radish(*Raphanus sativus* L. var. *sativus*). Cooper's, Hoagland & Arnon's, and Yamazaki's solution were used to determine the most suitable nutrient solution in deep flow culture(DFC). In result, Yamazaki's solution treatment showed better results than Hoagland's and Cooper's solution treatments in leaf length, leaf number, shoot and root fresh weights. Cooper's solution was much worse than others. Root shape index were low as 0.6 in all treatments. The selection of suitable was conducted among 14 kinds of substrates which were used commercially, such as sand, perlite and peatmoss, in substrates culture. Sand was the most proper in radish growth and shortened the growth periods. Sand also showed better results than others in leaf length, leaf number, shoot and root fresh weight. On the contrary, radish growth in peatmoss was the worst. Generally, root shape index was higher in substrate than in DFC. In order to investigate the suitable ionic strength in radish, Yamazaki's solution was treated with EC of 0.5, 1.0, 1.5, and 2.0 mS/cm. Generally radish growth above 1.0mS/cm concentration was good, and the best result was shown in 1.5mS/cm. Vitamin C contents were not significantly different in the roots of radish grown under 1.0mS/cm or more. The highest vitamin C content was shown in 0.5 mS/cm, and so was thiocyanate content. Anthocyanin contents increased with the increase of the ionic strength in nutrient solution. Mineral nutrient contents had no significant statistical differences between the treatments, but potassium content was remarkably high in 1.5mS/cm.

Key words : deep flow culture, thiocyanate, anthocyanin, vitamin C, minerals
키 워 드 : 담액수경, 티오시아네이트, 안토시안, 비타민 C, 무기염류

[1)] 본 연구는 교육부의 농업과학학술연구 조성비(94-농-2)에 의해 수행된 '기상조건 및 생육단계별 수경채소의 배양액조절 시스템 개발' 연구의 일부임.

Introduction

The radish (*Raphanus sativus* L. var. *sativus*) is a member of the Cruciferae family and includes both annual and biennial types. The spring and summer radishes(short season types) are annuals; the winter cultivars require up to 2 months to reach edible stage and may be annual or biennial.

The main criterion for producing high quality radishes is to avoid exposure to hot and drying weather. To remain mild, tender, and visually attractive, the radish must grow rapidly with plenty of moisture. Suitable soils include muck, sand, sandy loams, and clay loams.[19] And the growth of radish was the greatest in nutrient film technique(NFT), followed by water culture, sack culture, and sand culture. The external appearance of it was better with sack culture and sand culture than NFT and water culture.[17]

Radish has not been so widely cultivated in our country, as in foreign countries, but the study of soilless culture to improve growth and quality has not been carried out frequently.

The main objective of this study was to determine the appropriate nutrient solution, substrate, and solution concentration in substrates culture to improve growth and several qualities of radish.

Materials and Methods

This experiment was conducted at greenhouses at Korea University in 1994 to 1995. The tested radish was 'Chukhwan 20 days radish' of Takii Seeds Co.

1. Selection of suitable nutrient solution

This study was conducted by using deep flow culture(DFC) for the purpose of selection of suitable nutrient solution for radish growth.

Cutivation performed from 2 November, 1994 to 4 January, 1995. After the seedlings were grown in the perlite medium for 6 days, they were washed and transported to DFC system. Hardening was carried out during 2 days and then treatment initiated.

DFC system applied to this experiment had four beds and one bed was consisted of four lanes, in which one lane had capacity of 20 –liter nutrient solution. The electrical pump circulated the nutrient solutions at the intervals of 15min per 1hr under a pressure of 1/8 HP at a rate of 2400Lh^{-1} through the root zone of the plants in bed. Nutrient solution treatments in this experiment were Cooper's[5], Hoagland and Arnon's[10], and Yamazaki's[23] solutions (Table 1). Nutrient solutions were exchanged every week. Both acidity and electric conductivity(EC) were not adjusted after supply of nutrient solution into bed.

2. Selection of suitable growing media

Result from experiment 1 in DFC system, radish put in lane was lack of adequate soil pressure in rhizosphere, and then root shape was modified into almost rectangle style. Radish–root shape in DFC system was relative poor, because adequate soil pressure had been lack in rizosphere.

So, experiment 2 was carried out to alleviate its problems of growing crops from 29 May to 24 June, 1995, and the substrates were used commercially available medium, such as sand, perlite, and peatmoss. These substrates were prepared of 14 kinds of substrates, which were sand, perlite, peatmoss, sand:perlite=2:1, sand:perlite=1:1, sand:perlite=1:2, sand:peatmoss=2:1, sand:peatmoss=1:1, sand:peatmoss=1:2, perlite:peatmoss=2:1, perlite:peatmoss=1:1, perlite:peatmoss=1:2, peatmoss:perlite=2:1, sand:perlite:peatmoss=2:1:1, and sand:perlite:peatmoss=1:1:1. Plastic cups of ϕ 8cm, container for substrates, were penetrated (each hole diameter was 4mm) to let root absorb nutrient solution in the lane of DFC system. When the true leaves were initiated, they were transported into DFC system.

Transported seedlings were hardened with 0.25mS/cm of Yamazaki's working solution for 2 days and then grown with 1.0mS/cm of this solution. Nutrient solutions were refreshed once a week during the course of experiment.

3. Determination of suitable ionic strength of nutrient solution

The treatments of nutrient solution concentration were 0.5, 1.0, 1.5, and 2.0mS/cm of Yamazaki's solution contained macronutrients (NO_3^-, NH_4^-, P, K Ca, Mg, and S) and micronutrients(Fe, Mn, Cu, Zn, B, and Mo) (Table 1).

Radish seeds were sown on 21 August, and harvested on 21 September, 1995. The seeds were in plastic cup, and then transported at once. After 1 week, Yamazaki's solution was prepared with 0.5, 1.0, 1.5, and 2.0mS/cm, respectively. Nutrient solutions were exchanged every week during the course of experiment.

Radish growth investigations were performed once a week and measurement items for growth were such as leaf number, leaf length, and leaf width.

4. List of investigation

Investigated items for external appearance were, leaf number, leaf length, leaf width, total fresh weight of aerial parts, root fresh weight, root length, root width, and root shape index. And leaf length, leaf width were measured with the largest leaf, and root shape index(root width divided by root length) was calculated.

For plant quality comparison, mineral (Total−N, P_2O_5, K_2O, CaO, MgO) contents, vitamin C[12], thiocyanate[11,15,16], and anthocyanin[8] contents were analyzed.

Bulk density was measured by Core method. With this method, a cylindrical metal sampler was pressed into the soil to the desired depth and was carefully removed to preserve a known volume of sample as it existed in situation. The sample was dried to 105℃ and weighed. The bulk density was the oven−dry mass of the sample divided by the sample volume. In field moisture capacity, water was added in soil to wet sufficiently. After the drainage was accomplished enough, weighed and measured, water contents were calculated as percentage(v/v) of

Table 1. The macronutrient composition in 3 kinds of nutrient solutions(me/ℓ).

	NO_3−N	NH_4−N	P	K	Ca	Mg	EC(mS/cm)
Cooper's	14.9	0	8.2	8.5	8.4	4.0	2.19
Hoagland & /Arnon's	14.0	1.0	3.0	6.0	8.0	4.0	2.14
Yamazaki's	6.0	0.5	1.5	4.0	2.0	1.0	1.06

dried soil. In case of EC, distilled water 25mℓ added in dried soil, and shaked during 1hr. After that, filtered and measured by EC meter

Results and Discussion

1. Selection of suitable nutrient solution

In Yamazaki's solution treatment, all of external growth measurements were better than others. And, Yamazaki's solution treatment resulted in the highest root width and root length. The growth in Hoagland's solution treatment was worse than Yamazaki's solution. However in case of Cooper's solution treatment, the growth was significantly lower than Yamazaki's and Hoagland's solutions (Table 2).

Especially, root development is the most important growth factor in radish. In shoot and root fresh weight, Yamazaki's solution was better than Hoagland's solution treatments, and was highly better results than Cooper's solution treatment. However, in all of treatments root shape index was poor about 0.6, this meant that all treatments had long root shape.

Cooper's solution treatments showed low tendency of radish growth in DFC.

Reported in many leaf vegetables, plants growth largely depended on nitrogen source. Although Cooper's and Hoagland's solution have two times higher nitrogen concentration than Yamazaki's solution, the growth was relatively poor. This meant that oversupply of nitrogen effected badly on root vegetables development. In conclusion, Yamazaki's solution had adequate nitrogen concentration and other elements for radish growth. And Ota and Yamamoto[18] reported that when radish plants were grown in nutrient solutions that contained ammonium ions(NH_4^-) as the sole source of nitrogen, they grew poorly and accumulated high levels of NH_4^- in their leaves and high concentrations of ammonium ions modified various metabolic pathways. In contrast, plants supplied with 5:1 mixture(NH_4^-:NO_3^-) grew well and did not accumulate ammonium ions. And the leaves received 5mM NH_4^- added 1mM NO_3^- (5:1 mixed−N) exhibited higher activities of glutamine synthetase than those of the NH_4^- fed plants. Activities of ferredoxin−dependent glutamate synthase were higher in the leaves of the 5:1 mixed−N−fed plants than in those of the NH_4^- fed plants after 4 days of water culture. The leaves of the plants fed 5:1 mixed−N contained larger amounts of aspartic acid and glutamic acid than those of the NH_4^-fed plants. The presence of

Table 2. The effects of several nutrient solutions on the growth of radish in DFC system.

Treat.	Leaf length (cm)	Leaf number	Leaf width (cm)	Fresh weight(g)		Root width (cm)	Root length (cm)	Root shape index
				Top	Root			
Copper	15.33b[z]	8.67a	4.33b	5.09c	8.96b	2.38b	3.40b	0.60a
Hoagland	19.33a	9.00a	6.00a	9.52b	13.94a	2.49b	4.09a	0.61a
Yamazaki	21.33a	9.33a	6.43a	11.02a	16.34a	2.78a	4.38a	0.63a

[z] Means separation within columns by Duncan's multiple range test, at the 5% level.

a small amount of nitrate was shown to stimulate the assimilation of ammonium ions and the synthesis of proteins.

Goyal et al.[9] observed that nitrate equivalent to 10% or more of the NH_4^- concentration alleviated the inhibitor effects of NH_4^- on growth and also decreased the NH_4^- content of the plants. In this experiment, the radish growth declinement in Cooper's solution might be caused that it's composition had no NH_4^- contents.

Also, in Hoagland's solution treatment, which contained $NH_4^-:NO_3^-$ of 1:14, it meant that this ratio was worse for the growth of radish than Yamazaki's solution treatment of $NH_4^-:NO_3^-$ of 1:12. Accordingly, the ratio of $NH_4^-:NO_3^-$ in Yamazaki's solution was more proper to radish growth.

In addition, EC of Cooper's and Hoagland's solutions was about 2.0(mS/cm), and Yamazaki's solution about 1.0(mS/cm). In conclusion, the choice of Yamazaki's solution might be recommended for the plant growth and commercial ways.

2. Selection of suitable growing media

The most important function of the root is to absorb water and minerals. At the same time, root also supports plant and contacts with soil(or artificial medium)particles, so in case of root vegetables, physical and chemical properties of soil were very important factor on root growth and thickening of radish. In sole treatment of sand, or mixed treatments with perlite and peatmoss, bulk density showed high results over 1g/cm^3, especially, 1.39g/cm^3 in sand indicated heavy particles On the other hand, other treatments without sand, that is, sole treatment of perlite, peatmoss, and combination of perlite and peatmoss showed low bulk density below 0. 3g/cm^3. Bulk density reflects soil structure well, and exhibits air circulation or water retention capacity, etc. Generally bulk density was high in sand, and low in substrates which had high organic matter contents or desirable aggregates structure.[1,6]

Porosity is closely related with bulk density, and the more bulk density increase the more porosity decrease, the more bulk density decrease the more porosity increase. Because sand had high bulk density, it was regarded that porosity could be low.[2]

Field moisture capacity means soil had maximum moisture contents against gravity. Peatmoss treatment was the greatest about 500%, and sole perlite, mixed with peatmoss treatment showed high value over 100%, therefore these substrates might be have good water retention capacity. In contrast, sole sand, mixed with perlite and peatmoss displayed low field moisture capacity under 50%, and very poor water retention capacity.

Conventional field culture method with sand might be inadequate for radish, because sand has high bulk density, poor aggregates structure, low porosity, and low field moisture capacity, which caused lack of water and nutrient contents for plant.

However, as DFT system supplied sufficient moisture and air circulation for root of each pot, on the contrary, radish growth in sand was accelerated. In peatmoss substrates, too much water contents and oxygen deficit induced absolutely low germination rate and even seedlings revealed soft rot in the crown within a week. In perlite, radish growth was middle between sand and peatmoss. Perlite was not better than sand, but showed a good development relatively, because of high porosity and good drainage. In addition, comparing with water culture, overall substrates culture could produce better commercial products except for several treatments, because substrates could support and pressure to root evenly, so vertical elongation to the gravity could be inhibited.[7] Those rhizospheric barrier might contributed to the horizontal growth of the root. Therefore, the suitable barrier against vertical elongation of root might be essential, and that could make the root almost sphere style.[13,20] In order to investigate soil chemical properties, EC, organic matter contents, phosphorus(P_2O_5), potassium(K), calcium(Ca), magnesium(Mg), and cation exchangeable capacity(CEC) were measured.

All of EC were low under 0.5mS/cm except for perlite:peatmoss=2:1, peatmoss:perlite=2:1, and sole peatmoss treatment of 0.86, 1.41, 1.99(mS/cm), respectively.

Organic matter contents were the highest in peatmoss above 90%, the rest indicated low value under 5%.

Phosphorus in peatmoss indicated the highest value of 158ppm, in sand the lowest contents of 12ppm, and in the rest displayed under 50ppm.

Besides of it, potassium, calcium, and magnesium measured the highest value in peatmoss treatment, respectively.

Cation exchange capacity(CEC) manifests that a fixed soil or colloid matter have total quantity of it, and that is expressed by equivalent.

Almost substrates had low CEC contents below 10(me/100g), except for sole peatmoss or combination of perlite and peatmoss.

According to this analysis, it was showed that there were great differences in chemical properties among substrates. Especially, substrates of sole peatmoss or mixed with two times of peatmoss contained the highest EC, organic matter contents, phosphorus, potassium, calcium, magnesium, and cation exchange capacity. However, despite of these high chemical properties, they were not profitable to radish growth. The reason was that the purpose of using substrates was not nutrient supply to radish, but only to give adequate support and pressure to root growth physically. Because Yamazaki's solution was circulated continuously, and then root absorbed it, differences of chemical properties among substrates were not significant. In addition, EC of peatmoss:perlite=2:1, peatmoss:perlite=1:1, and peatmoss was much higher than 1.0(mS/cm), this result was suggested that those substrates contained Yamazaki's solution had higher EC in themselves, which caused high concentration disorders to the radish.

In conclusion, on the chemical properties of substrate, oversupply of inorganic matter could modify the solution composition. So, in case of substrate culture, it was regarded that chemical analysis of substrate was prerequisite for the treatment of nutrient solution.

In this study, sand had worse chemical properties, lower field moisture capacity, and higher bulk density than other substrates, where these factors influenced on prosperous radish growth. This result agreed with reports by Kim.[14] However, peatmoss could not meet the needs in physical and chemical properties, so it affected the poor growth of radish.

In most of substrates, root fresh weight was between 4g and 6g. Average root width was about 2cm, and root length was uniform between 2cm and 2.5cm. Root shape index was high from 0.8 to 1.0 except for several ones. This value was higher than DFC, non−substrates culture, it meant that substrates culture was more effective than DFC in root

Table 3. The chemicaland physical properties of media in substrates culture.

Treat[z]	EC (mS/cm)	O.M.[y] (%)	P (ppm)	K (me/100g)	Ca (me/100g)	Mg (me/100g)	CEC[x] (me/100g)	Field capacity (%)	Bulk density
S	0.08	1.30	12	0.07	0.96	0.24	1.27	26.49	1.39
S:PL=2:1	0.16	0.78	14	0.28	0.97	0.24	1.49	35.70	1.08
S:PL=1:1	0.21	2.26	16	0.10	0.93	0.33	1.36	43.93	0.82
S:PL=1:2	0.20	2.48	17	0.20	0.89	0.19	1.28	57.22	0.67
PL	0.51	2.30	19	0.13	0.77	0.10	1.00	125.09	0.21
PL:PT=2:1	0.86	14.62	32	0.29	1.41	1.62	11.02	173.69	0.16
PL:PT=1:1	1.13	29.86	29	0.20	1.64	2.12	17.16	177.46	0.14
PL:PT=1:2	1.41	43.20	28	0.23	1.77	2.67	21.17	246.01	0.13
PT	1.99	94.24	158	0.78	2.19	3.25	39.22	480.99	0.09
PT:S=2:1	0.37	9.56	38	0.07	1.21	1.23	8.01	89.53	0.62
PT:S=1:1	0.20	4.12	26	0.03	1.07	0.92	5.32	49.66	0.82
PT:S=1:2	0.13	4.34	12	0.12	0.87	0.55	4.85	54.32	1.04
S:PL:PT=2:1:1	0.15	1.20	89	0.13	1.16	0.56	2.95	42.23	0.86
S:PL:PT=1:1:1	0.25	6.16	30	0.29	1.14	0.85	4.48	65.13	0.63

[z] S:sand, PL:perlite, PT:peatmoss, v:v=volume:volume mixing.

[y] O.M:organic matters.

[x] CEC:cation exchange capacity.

Table 4. The growth of radish on media of substrates culture.

Treat[z]	Leaf length (cm)	Leaf number	Leaf width (cm)	Fresh weight(g)		Root width (cm)	Root length (cm)	Root shape index
				Top	Root			
S	18.27a[y]	5.67a	5.17a	6.79a	5.75a	2.50a	2.73bc	0.91b
S:PL=2:1	15.50b	5.00ab	4.57a	5.86b	5.10b	2.00d	2.33ef	0.86bc
S:PL=1:1	15.70b	5.33ab	4.50a	5.80bc	5.07b	2.00d	2.30ef	0.87b
S:PL=1:2	14.90b	5.00ab	4.67a	5.72bc	5.20b	2.43ab	2.13fg	1.15a
PL	14.63b	4.67ab	4.50a	5.30cd	4.35c	1.93de	2.37ef	0.81bc
PL:PT=2:1	11.86d	3.50cd	3.18a	4.23e	3.27f	1.73ef	2.71bc	0.64d
PL:PT=1:1	5.50e	2.89de	2.36c	2.55f	3.30f	1.63f	1.91g	0.85bc
PL:PT=1:2	4.90e	2.41e	2.23c	2.06f	0.02g	0.11g	1.31h	0.08e
PT	–	–	–	–	–	–	–	–
PT:S=2:1	12.15cd	4.47bc	5.15a	4.14e	3.46ef	2.24bc	2.89ab	0.78bc
PT:S=1:1	13.31c	4.67ab	5.00a	4.93d	3.83de	2.02d	3.14a	0.64d
PT:S=1:2	14.81b	4.97ab	4.93a	4.18e	4.23cd	1.86de	2.39de	0.78bc
S:PL:PT=2:1:1	15.63b	4.67ab	4.67a	4.95d	5.02b	1.97d	2.80b	0.71cd
S:PL:PT=1:1:1	14.99b	5.33ab	4.80a	4.90d	5.02b	2.08cd	2.56cd	0.81bc

[z] See table 3.

[y] Means separation within columns by Duncan's multiple range test, at the 5% level.

thickening growth(Table 4).

When the mineral nutrient contents were analyzed, although their differences are existed between treatments, which had not significant.(Table 5).

These results suggested that substrates culture was more effective method than water culture, because it improved radish growth than water culture, and root shape was also better. Especially, sand had the more rapid growth than other treatments, a lot of yield within the same periods, and high value of leaf length, shoot and root fresh weight, root shape index, relatively, Therefore sand is regarded as the most adequate substrate for the growth of radish in substrates culture (Fig. 1).

Table 5. The mineral contents of radish on media of substrates culture.

Treat.[z]	T-N(%)	P_2O_5(%)	K_2O(%)	CaO(%)	MgO(%)
S	1.96	1.39	23.83	1.55	0.58
S:PL=2:1	2.03	1.19	12.86	1.65	0.53
S:PL=1:1	3.69	1.31	5.25	1.72	0.52
S:PL=1:2	2.12	1.36	15.21	1.48	0.52
PL	2.47	1.32	10.90	1.37	0.53
PL:PT=2:1	2.04	1.48	11.81	1.02	0.44
PL:PT=1:1	1.85	1.35	11.21	1.13	0.54
PT:S=2:1	2.32	1.11	24.24	1.39	0.55
PT:S=1:1	3.53	1.43	11.87	1.40	0.53
PT:S=1:2	2.40	1.52	9.12	1.32	0.54
S:PL:PT=2:1:1	1.99	1.27	10.92	1.45	0.52
S:PL:PT=1:1:1	2.32	1.35	10.68	1.31	0.51
Hydro.	2.38	1.31	11.80	1.53	0.52

[z] See table 3.

Table 6. The effects of Yamazaki's nutrient solution concentrations on the growth of radish in substrate culture.

Treat.	Leaf length (cm)	Leaf number	Leaf width (cm)	Fresh weight(g)		Root width (cm)	Root length (cm)	Root shape (cm)
				Top	Root			
0.5	13.40c[z]	6.33a	3.80b	3.65b	8.08c	2.13c	3.30b	0.69a
1.0	17.63b	6.00a	5.80a	7.12a	13.28b	2.37bc	4.63a	0.51b
1.5	19.67a	6.33a	6.17a	7.96a	15.32a	2.63a	4.53a	0.58ab
2.0	18.43ab	7.33a	5.60a	7.65a	14.80a	2.53ab	4.67a	0.56ab

[z] Means separation within columns by Duncan's multiple range test, at the 5% level.

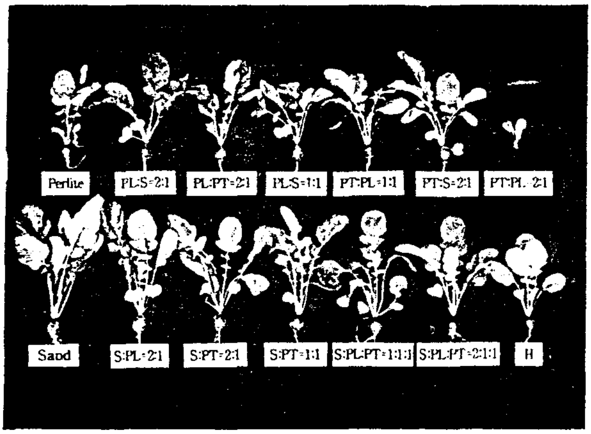

Fig. 1. The appearance of radish(*Raphanus sativus* L. var. *sativus*) according to several nutrient solutions at 22 days after planting.

3. Determination of suitable ionic strength of nutrient solution

This study was conducted to know the growth and quality of radish influenced by modified Yamazaki's solution at different 4 concentrations. The nutrient treatments were 0.5, 1.0, 1.5, and 2.0mS/cm, respectively.

The high values in leaf length, leaf width, shoot and root fresh weights were obtained over 1.0 mS/cm concentration solutions and particularly radish growth in 1.5mS/cm concentration was the higher than 1.0 and 2.0mS/cm concentration solution treatments. But apparent growth reduction caused by the 0.5mS/cm was found[4,21](Table 6).

In mineral nutrient contents, total nitrogen was low with 1.42% in 0.5mS/cm, and there were no significant differences between other treatments. Phosphorus(P_2O_5) had the same tendency with nitrogen. However, in case of potassium(K_2O), it was highest value in 1.5mS/cm with 13.39% and lowest in 0.5mS/cm with 5.57%.

Because in this experiment potassium content was highest in 1.5mS/cm, higher assimilation products by photosynthesis caused better root growth in 1.5mS/cm.

And potassium made the root have high osmotic pressure which caused better root growth by high water uptake. Because the amount of nutrient uptake was strongly affected by water uptake. That is, absorption of nutrient increased with increasing water absorption. Contents of calcium(CaO) and magnesium(MgO) were not revealed significant statistical differences between treatments(Fig. 2).

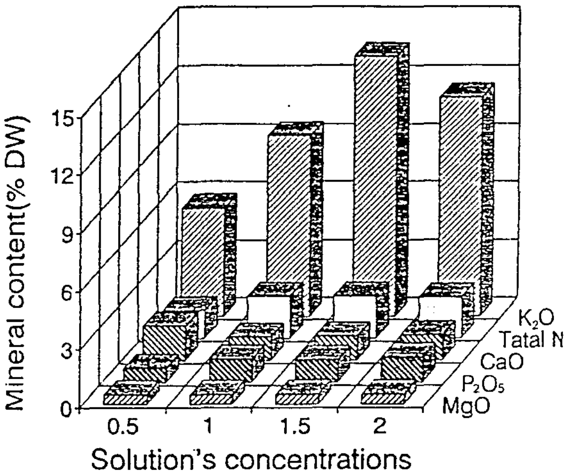

Fig. 2. The effects of Yamazaki nutrient solution concentrations(mS/cm) on the mineral contents of radish.

In vitamin C contents, among roots of radish grown above 1.0mS/cm, it's contents had not significantly differences, but it was the highest in 0.5mS/cm. Because it has negative correlation between root vitamin C content and root size (Fig. 3).

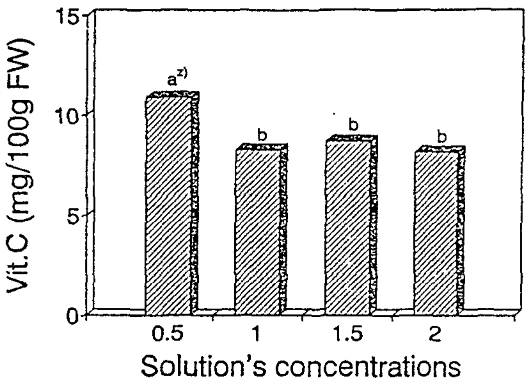

Fig. 3. The effects of Yamazaki nutrient solution concentrations(mS/cm) on the vitamin C contents of radish.
z) Means separation within columns by Duncan's multiple range test, at the 5% level.

Thiocyanate contents had same tendency with vitamin C.[3] This result meant that thiocyanate contents were centralized at root excessively in 0.5mS/cm by poor root environment, but best growth in 1.5mS/cm showed an opposite effects(Fig. 4).

In case of anthocyanin contents, they were increased with increasing the ionic strength of nutrient solution except being grown in 0.5mS/cm. The reason was that radish grown in 0.5mS/cm had been exposed to inadequate rhizospheric environment, which caused poor growth and low water contents. So, the anthocyanin contents value in the treatment of 0.5mS/cm, calculated by fresh weight basis, was the higher than others. Generally, anthocyanin in plants was also concentrated under the stress condition(Fig. 5).

Usually radish is used in salad, so it is required that high nutritive value and low pungency, such as high vitamin C and low thiocyanate contents may be ideal quality condition. Therefore radish in 1.5mS/cm could be the most adequate quality.

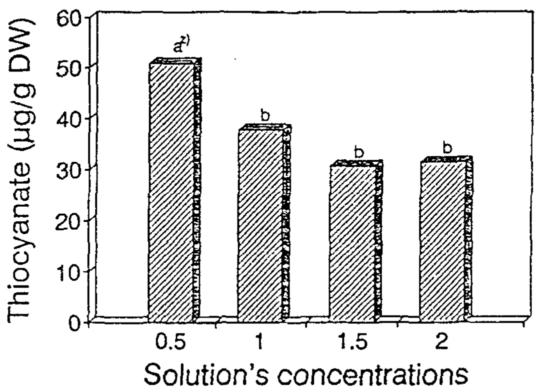

Fig. 4. The effects of Yamazaki nutrient solution concentrations(mS/cm) on the thiocyanate contents of radish.
z) Means separation within columns by Duncan's multiple range test, at the 5% level.

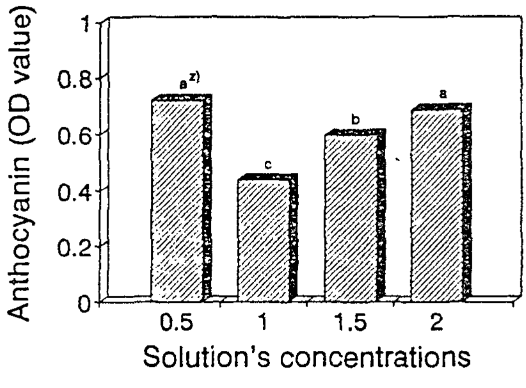

Fig. 5. The effects of Yamazaki nutrient solution concentrations(mS/cm) on the anthocyanin contents of radish.
z) Means separation within columns by Duncan's multiple range test, at the 5% level.

Only in 0.5mS/cm was measured rapid decrease of growth in all measurements; leaf number, leaf length, leaf width, and fresh weight(shoot and root). The better growth was obtained from the solution up to 1.5 ionic concentration solutions; to 1.5 ionic strength, growth was increased, but more than that reduced slowly.[22]

So, 1.5mS/cm concentration of Yamazaki's solution in sand culture was regarded as best ionic solution strength with good growth, high vitamin C contents, and low thiocyanate contents.

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적 요

본 실험은 양액의 종류와 배지의 종류, 그리고 양액의 농도가 20일 무의 생육과 몇가지 품질에 미치는 영향을 알아보고자 실시하였다. 20일 무의 양액재배시 적절한 양액의 구명을 위하여 기존의 Cooper, Hoagland, Yamazaki양액의 비교실험을 실시한 결과, Yamazaki양액이 엽장, 엽수, 지상부와 지하부 생체중 등 전반적으로 Hoagland와 Cooper 양액보다 좋은 결과를 나타내었다. 근형지수는 모든 처리구에서 약 0.66으로 비교적 낮은 수치를 보였다. 14가지 조합의 배지를 이용하여 고형배지경을 실시하였다. 그 결과 모래 배지가 가장 균일하고도 좋은 생육의 20일 무를 배출하였고, 피트모스는 반대의 생육을 생육을 보였다. 근형지수의 경우 전반적으로 고형배지경이 순수수경재배보다 높은 수치를 나타내었다. Yamazaki 양액의 적정농도 수준을 구명을 위하여 모래를 배지로 하여 20일 무의 생육과 품질을 비교 조사한 결과, 1.0mS/cm 이상의 농도에서는 전반적으로 20일 무의 생육이 좋았으며, 특히 1.5mS/cm가 가장 좋은 생육을 보였다. 비타민 C의 함량과 티오시아네이트 함량은 1.0mS/cm이상의 처리구에서는 현저한 차이가 없었으나, 0.5mS/cm는 상당히 높은 수치를 보였다. 또한 무기물 함량의 경우는 모든 처리구에서 통계적 유의성이 없었으나, 칼륨이 1.5mS/cm에서 비교적 높은 함량을 나타내었다.