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Water treatment in enhancing germination and seedling elongation of leafy vegetable in soilless culture

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Abstract

Growing crops in soilless culture under protected cultivation can be considered as the most complex production system available today. In this study, tap water of Kochi, Japan, was treated with two different kinds of condensed natural waters and granular ceramics applied in the germination test with leafy vegetable seeds of komatsuna (*Brassica rapa L.* nothovar) to focus the treatment effects on it. The natural waters refereed as α(alpha) and ω(omega) were employed in different treatments with Kochi tap water. In each treated water, pH increased linearly at every hour interval; simultaneously ORP (oxidation reduction potential) increased largely at the initial hour immediately after the treatments and then decreased sharply. Using treated and untreated waters, germination trial was conducted with komatsuna seeds in soilless culture. The germination percentage and early growth of komatsuna seedlings were significantly higher in applying ω-treated Kochi tap water (T_4) compared to other treatments. By performing this treatment (T_4), the values of pH and ORP changed to a range of suitable levels (pH 7.20, ORP 225 mV) for plant growth and the presence of Ca^{2+} and Mg^{2+} might be the reason for better germination and seedling elongation in komatsuna. Addition of ω type natural water (T_4) could be used for controlling irrigation water quality on the growth and germination of komatsuna seedlings.

Key words: Ca^{2+}, Mg^{2+}, Na^+, K^+, pH, ORP, natural water, tap water, ceramics, soilless culture, water quality, early growth, komatsuna.

Introduction

Increasing pollution, urbanization and industrialization has lead to a growing threat to water quality in rivers and lakes. Water resources development should not only ensure water supply in the right quantity at the right time but also ensure that the water is of good quality. While drinking water must meet stringent quality standards, water quality is also important for agricultural, industrial and other uses [1]. The problem of water shortage and water quality becomes more and more important year-by-year, for consumption increasing and good water availability reduction. The activities that need elevated water amount, like the cultivation of ornamental and horticultural crops, suffer from this situation and, consequently, new solutions have to be introduced to rationalize water consumption, avoiding water shortage periods and water quality worsening [2].

Soilless culture may assure, if correctly managed, higher yields, better quality and better hygienic-sanitary characteristics of the product. These are important aspects for leafy vegetables [3]. Soilless cultivation is now normally used in protected culture in different countries, since the productive process increases both growing rhythm and yield quantity and quality. Soilless cultivation can also contribute to overcome problems related to exhausted soil, soil disinfection and salinity [4]. In fact, the presence of soil-borne pathogens at the start of the crop, as well as the decline of the soil fertility due to its continual cultivation for the same or a related crop species, represent significant limitations to soil-based cultures [5]. Soilless cultivation systems are peculiar in their ability to provide simultaneously optimum levels of both oxygen and water to the roots. A further advantage of soilless systems over soil-based cultures is a more precise control of nutrition and more efficient use of water and fertilizers[6]. Importantly, soilless culture systems can improve yield and product quality [7, 8]. There is a definite need for new technologies to simplify soilless systems, suitable for different farming systems and environmental conditions. Seed germination is among all physiological processes one of the most sensitive to stresses [9].

In this study, granular ceramics having electrical charges on their surfaces and Kochi tap water with natural water treatments were used in the germination test of komatsuna (*Brassica rapa L.* nothovar), which is found everywhere in Japan as a highly nutritious leafy vegetable. Two different natural waters (commercial names α and ω) collected from Kochi prefecture, were used for treatment of Kochi tap water. Natural water is a complex and heterogeneous in nature with different quality parameters, such as pH, oxidation-reduction potential (ORP) and concentrations of cations Ca^{2+} and Mg^{2+}, which might affect germination and seedling elongation. The objective of this investigation was to study the effect of water quality on growth of komatsuna seedlings.

Materials and Methods

Tap water was used as the main growing media in germination of komatsuna seeds, the other two natural waters, i.e. α and ω type waters, were applied as treatment materials. The tap water was taken from the Monobe campus of Kochi University (Kochi tap water) originated from ground water; α and ω waters were collected from different places of Shimanto layer in Kochi prefecture originated from very old rocks i.e. α water from soil rocks and ω water from chart type rocks (Tables 1 and 3). Treatment material used in this experiment was also granular ceramics, 2 to 3 mm in diameter, made by using the powder of Quartz Porphyry sintering at 1200°C [10], and natural soil was used as a bonding agent. Moh's hardness of granular ceramics is 6.8.

Treatments and preparation of water samples: Four different kinds of water samples were prepared which referred as Kochi tap water (T_1), through ceramics passed Kochi tap water (T_2), α-treated Kochi tap water (T_3) and ω-treated Kochi tap water (T_4). T_1 was prepared by collection of water from the circulating pipe of Kochi University in Monobe campus. T_2 was prepared in passing tap water for once through fluidized ceramics; about 3 L of Kochi tap water taken into a water tank was passed for one time through a system of fluidized granular ceramics in a water treatment apparatus. With a magnetic pump, water flow was directed from lower to upper side so that the ceramics should be fluidized by which water was passed through the fluidization layer, and the flow rate could be controlled at 12 L/minute with a valve. In preparing T_3, 400 mL Kochi tap water was placed in a 500 mL volumetric flask, and then 1.0 mL α type natural water was poured into this flask, shaken slightly and kept for a while. For making T_4, 400 mL Kochi tap water was put into a 500 mL volumetric flask as above, and 1.0 mL ω type natural water was added to the tap water and kept for a while after shaking.

Germination test of komatsuna seeds: Twenty seeds were placed on pre-moistened germination paper in Petri dish with a diameter of 90 mm. All treated and untreated water samples were added to pre-moisten the seeds at the volume of 5 mL. Then the Petri dishes were kept in growth chambers (incubator: BITEC-400, Shimadzu) at a temperature of 25°C. The germination test was performed for the period over 4-days from its sowing time and the seedling elongation was measured. The whole examination was conducted in triplicate.

Analysis: Water samples were analyzed at a constant temperature of 25°C. Immediately after preparing of each sample, the pH and oxidation-reduction potential (ORP) were measured with pH meter (PHL-10 DKK) and ORP meter (PHL-10 DKK) respectively. Na^+, K^+, Ca^{2+} and Mg^{2+} ion concentrations of water samples were determined through a paper chromatographer (IA-100).

Average values with standard deviations of the two parameters (pH and ORP) were measured for each treatment (Tables 1 and 2). The average length of komatsuna seedlings (root + shoot) was calculated at the end of 4-days experiment. The data in Tables 5 and 6 are the means and statistical differences of seedling elongation subjected to Duncan's multiple range test at P= 0.05.

Results and Discussion

Characteristics of water samples: Table 1 shows pH and ORP in Kochi tap water, α water and ω water and Table 2 exposes the values of same parameters in Kochi tap water at control and different treatment sections. In the control, Kochi tap water pH and ORP values were 6.88 and 338 mV, and after treatments pH values increased but ORP decreased rapidly except in the case of α -treated water (T_3). At α - treated Kochi tap water, pH (7.08) increased significantly while ORP (465 mV) did not change significantly. After addition of ω water to the tap water, pH and ORP changed significantly.

Table 1. Acidity and oxidation-reduction potential (ORP) of Kochi tap water, α and ω type natural water.

Water type	pH	ORP (mV)
Kochi tap water	6.88 (0.02)	338 (4)
α water	5.60 (0.03)	271 (3)
ω water	5.51 (0.01)	238 (2)

Temperature 25°; each value indicates the average of three samples with standard deviation in parentheses.

Table 2. Acidity and oxidation-reduction potential (ORP) of Kochi tap water in different treatments: T_1 Kochi tap water (raw)/control; T_2 ceramics-treated Kochi tap water; T_3 α -treated Kochi tap water; T_4 ω -treated Kochi tap water.

Treatment	pH	ORP (mV)
T_1/Control	6.88 (0.03)	338(5)
T_2	6.98 (0.02)	266 (3)
T_3	7.08 (0.04)	465 (4)
T_4	7.20 (0.01)	225 (2)

Temperature 25°; Each value indicates the average of three samples with standard deviation in parentheses.

Ion concentration in Kochi tap water was low for K^+ (1.20 mg/L) and Mg^{2+} (1.55 mg/L), high for Ca^{2+} (18.90 mg/L) and moderate for Na^+ (5.65 mg/L) (Table 3). Magnesium and calcium were absent in α water while present in ω water (Mg^{2+} 0.12 mg/L; Ca^{2+} 0.09 mg/L); on the other hand Na^+ was measured zero in both cases. Table 4 shows insignificant changes in ion concentrations after ceramics treatment (T_2) and α treatment (T_3) sections. This tendency is in accordance with the observations of Tamura et al. [11] and also agrees with the results of Azad et al. [12]. Mg^{2+} and Ca^{2+} ion concentrations were higher after ω treatment (T_4).

Table 3. Cation concentrations of Kochi tap water, α and ω type natural water.

	mg/L			
Water type	Na^+	K^+	Mg^{2+}	Ca^{2+}
Kochi tap water	5.65	1.20	1.55	18.90
α water	0.00	0.01	0.00	0.00
ω water	0.00	0.00	0.12	0.09

Measured temperature: 25°; Each value indicates the average of three samples

Changes of pH and ORP in water samples

Changes of pH: After preparing all water samples, the initial values of pH in Kochi tap water (T_1), ceramics-treated tap water (T_2), α-treated water (T_3) and ω-treated water (T_4) were 6.88, 6.99, 7.07 and 7.20 respectively. Fig. 1 shows the gradually increasing values of pH in different treatments and elapsing at a certain period of time it was not changed significantly. After one hour interval, pH increased evenly only in Treatment T_4, unlikely in Treatments T_1, T_2 and T_3. In each treatment, pH increased linearly up to a certain period and the increments in different treatments followed the increasing order of $T_4 > T_3 > T_1 > T_2$.

In ceramics-treated Kochi tap water (T_2), the increasing rate of pH value was very low, and the total change after 6 hours was 0.11 pH-units, and thereafter the change was negligible. After passing the first one hour time in Treatment T_3 the increased value of pH was 7.10 and it rose to 7.41 at the end of the sixth hour. The changes of pH became slower and negligible after seventh hour. Within these periods the total increase was about 0.36 pH units. With Treatment T_4, the increment of pH value was very small at the end of the first one hour interval (0.02), then it increased significantly up to the 10^{th} hour. A remarkable difference, at about 0.40, was observed in the increment of pH value between the first and the 10^{th} hour.

Changes of ORP: The ORP (Fig. 2) indicated increasing and decreasing trend in different treatments. The primary ORP values of Kochi tap water (T_1), ceramics-treated tap water (T_2), α-treated water (T_3) and ω- treated water (T_4) were 338, 270, 450 and 225 mV. The values of ORP increased rapidly only at the end of the first one hour of interval in all treatments and the values remained between the levels of 400-500 mV, then declined gradually from the 2nd hour of experimental period. The decreasing rate of values in each treatment was not so much different, and the decrements followed the order of T_4>T_3>T_2>T_1 up to a certain time. At the end of treatment periods, the declining tendency of ORP appeared to be slower or steady.

With Treatment T_4, the values of ORP began to change at a significant range in the end of the 3rd hour and continued evenly at the last period of the treatment time. The value (200-300 mV) is accepted for well growth of plants in agriculture according to the results of Matsuo et al. [13]. Similar trend was observed in Treatments T_2 and T_3 at the 7th and 5th hours respectively, but not in the case of control (T_1). In Treatment T_4, the ORP values attributed to the optimum level very quickly and remained for longer duration of time than in the other treatments (Fig. 2).

Influence on germination and growth of komatsuna: Table 5 shows the germination rate of komatsuna seeds in different treatments. Treatment effects on germination were assessed by determining germination percentages in each day and the total germination at 4 days from the beginning of the trial. After 1 (24 hours) day from the beginning of the trial, Treatment T_4 had more than 25% of germinated seeds while all other treatments had germination percentage lower than 20%. Beyond 60% of seeds had germinated after 2 days from the beginning of the trial in Treatment T_4. With the same treatment, more than 85% of seeds were germinated after 3 days, which is significantly different with the other treatments. The highest germination rate after 4 days, greater than 95%, was also recorded in Treatment T_4 with pH 7.20 and ORP 225 mV. The lowest values, less than 75% were found in Treatment T_3 with pH 7.08 and ORP 465 mV. The total germination percentage was significantly different in Treatment T_4 compared to control and other treatments. After starting the examination, the germination percentage in Treatment T_4 was always significantly higher than in the other treatments. It seems that the general germination percentage was influenced by pH and ORP of the treatment solution.

The average growth of komatsuna seedlings germinated over 4-days period is shown in Table 6. Using the tap water of Kochi without treatment, the average length of komatsuna seedlings was 25.1 mm. At the end of Treatments T_2 and T_3 the differences of seedling length (T_2 = 26.2 mm, T_3 = 26.0 mm) were not remarkable. In T_4 (ω-treated Kochi tap water), the length was higher (31.4 mm) than in the other treatments.

Figs 3 and 4 showed the trends in the growth of komatsuna seedlings due to the assumed effects of pH and ORP in treated Kochi tap water. The greatest seedling growth (31.4 mm) was at pH 7.20 and ORP 225 mV. These values are suitable for plant growth, because accepted values of pH and ORP for agriculture are 6.0-8.5 and 200-300 mV respectively [11-13].

In ω-treated water the concentrations of Ca^{2+} and Mg^{2+} were higher and seemed to be the reason for the enhancement of early growth of seedlings in Treatment T_4. The amount of Ca^{2+} in the rooting medium was sufficient for short-term growth and thus satisfied an essential intrinsic requirement [15]. Previous studies indicated that Mg^{2+} resembles Ca^{2+} in some respects [16]. Na^+ is an

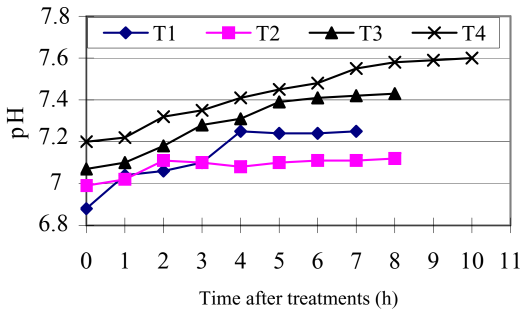

Figure 1. pH values of Kochi tap water with different treatments after different periods; T_1, Kochi tap water; T_2, One pass ceramic-treated Kochi tap water; T_3, α-treated Kochi tap water; T_4, ω-treated Kochi tap water.

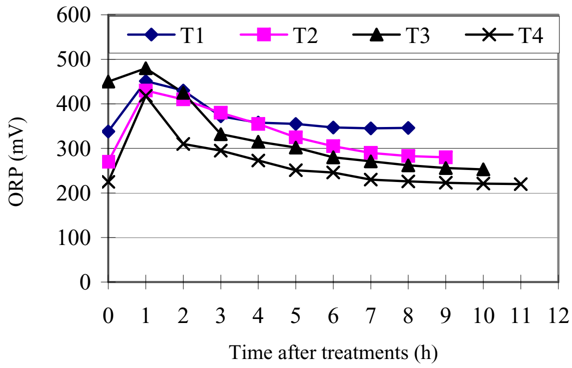

Figure 2. ORP values of Kochi tap water with different treatments in different periods; T_1, T_2, T_3 and T_4 explained in Fig.1.

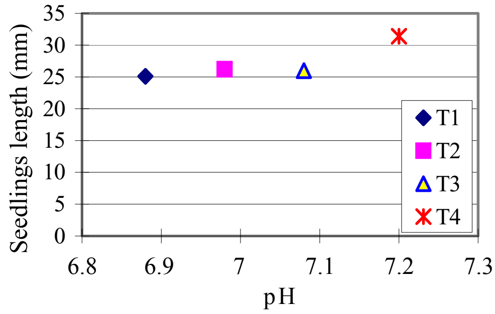

Figure 3. Effects of pH on the seedlings length of komatsuna in different treated Kochi tap water.

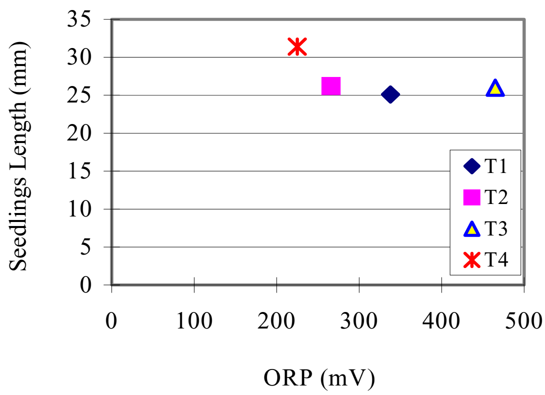

Figure 4. Effects of ORP on the seedlings length of komatsuna in different treated Kochi tap water.

Table 4. Cation concentrations of Kochi tap water in Treatments T_1, T_2, T_3 and T_4 (explained in Table 2).

	mg/L			
Treatment	Na^+	K^+	Mg^{2+}	Ca^{2+}
T_1/Control	5.65	1.20	1.55	18.90
T_2	5.54	1.21	1.57	18.91
T_3	5.65	1.23	1.55	18.90
T_4	5.60	1.18	1.67	19.06

Table 5. Germination rate after days of seeding on Petri dishes in incubator.

Treatment	Days after seeding			
	1	2	3	4
	Mean germination rate (%)			
T_1/Control	18.3	40.5	67.2	72.6
T_2	19.5	44.4	71.5	76.2
T_3	19.3	41.1	70.2	74.5
T_4	28.0**	60.5**	85.3**	95.1**

** Mean values are significantly different from the control according to Duncan's multiple range test at P = 0.01 (1%)

Table 6. Comparison of average seedling length in komatsuna using different treatments with Kochi tap water: T_1, T_2, T_3, and T_4 explained in Table 2.

Treatment	Seedling elongation (mm)
T_1/Control	25.1^{ab}
T_2	26.2^{ab}
T_3	26.0^{ab}
T_4	31.4^{ac}

Note: Means (from 60 samples) followed by different letters are significantly different according to Duncan's multiple range test at P = 0.05 (5%)

intrinsic toxicant, if it achieves large concentrations in the cytoplasm [15]. Increase in the Ca^{2+} content of the rooting medium can reduce the concentration of cytoplasmic Na^+, but it cannot increase water potential [17, 18].

Conclusions

It was shown that pH and ORP in treatment solutions were not fixed in value up to a certain period of time. In each treatment, pH increased linearly at every hour interval; on the other hand, ORP increased at a high rate in the initial hour and then declined quickly. The pH increased and ORP decreased in the course of time and after a certain period, the changes were not significant.

In the germination test, the germination percentages and the vigor of the early growth of komatsuna seedlings were higher in treatment T_4 compared to the other treatments. By using ω- treated water (T_4), pH and ORP were changed to an optimum level (pH 7.20 and ORP 225 mV), and sufficient content of Ca^{2+} and Mg^{2+} ions might be the reason for better germination rate and the seedling elongation.

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