Development of New Agriculture and Aquaculture Technology Using Fine Bubbles

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Abstract— Fine bubbles of sizes less than 100 µm dia., are capable to efficiently increase dissolved oxygen level in the water or so when air is introduced into encapsulated gas in fine bubbles. For that reason, its remarkable availability is expected for agriculture and aquaculture.

However, it is required to properly coordinate properties of fine bubbles suitable for agriculture and aquaculture in order to obtain sufficient effects and availability. So far, fine bubble technology development has been continuously made in the current studies to take advantage of fine bubble properties based on actual usage of fine bubbles in such industries. As a result, it has revealed to be potentially effective, and needs to widely develop versatile usage of fine bubbles by identifying the system configuration and precautions of fine bubble usage in the agriculture and aquaculture.

Keywords— Fine bubble, agriculture, aquaculture

I. INTRODUCTION

In recent years, it has been defined by International Organization for Standardization (ISO) that microscopic bubbles with sizes less than 100 µm dia., shall be collectively called as fine bubbles. Fine bubbles obtained by micronizing gas were found to have a specific nature different from those of air bubbles with sizes of millimeter and centimeter level usually seen in daily life.

For example, since multiple fine bubbles with the same total volume as a single air bubble of centimeter size level can have significantly larger total surface area, they can drastically enhance not only chemical reactions, but also physical absorption, and substance transport at gas-liquid interfaces. In addition, they can improve dissolution efficiency of encapsulated gas by their huge total surface area.

In consideration of their acquired properties together with such industrial advantages as well as high environmental affinity and safety, which were obtained by combination of air and water, fine bubbles have begun to be developed for various applications [1]. In particular, high availability for versatile applications in agriculture and aquaculture is expected due to its excellent capability to efficiently increase dissolved oxygen level when air is introduced into encapsulated gas in fine bubbles.

In order to obtain such effects and usefulness, however, it is required to properly coordinate the properties of fine bubbles suitable for usage in agriculture and aquaculture. In this study, the research of agriculture and aquaculture technology development utilizing the property of the fine bubble is discussed.

Since fine bubbles include microbubbles and ultrafine bubbles (nanobubbles) which have different properties, in some cases it is difficult to separately evaluate each effect in environmental water being used for agriculture and aquaculture, and thus, the combined effect of both is shown in this study.

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II. DEVELOPMENT OF APPLICATION IN AGRICULTURE

A. *Utilization for watering*

Plants absorb water and nutrients from around the roots. Therefore, growth of plants is significantly impeded unless the roots are grown healthily, even if they are cultivated at temperature, humidity and light quantity as well as carbon dioxide concentration which are appropriate for their growth, unless the roots are grown healthily.

Cells in the vicinity of tip of the roots divide actively for growth where respiratory activity, i.e. oxygen demand is high, and it is known that respiration rate of roots is actually lowered along with decrease in dissolved oxygen level of nutrient solution. In addition, absorption of nutrients also decreases according to the respiration rate if oxygen supply to roots is insufficient due to reduction in dissolved oxygen level of nutrient solution.

In an examination to investigate difference in nutrient absorption between aeration and non-aeration conditions using Arnon Hoagland solution, one of nutrient solutions, absorption of constituents such as potassium, nitrate-nitrogen, phosphorus, calcium and magnesium decreased by about 30 % under non-aeration condition than aeration condition.

It is understood to be necessary for growth of roots to supply sufficient oxygen for keeping activity of the roots. Therefore, oxygen quantity around the roots is kept in general by enhancing aeration property of the soil using tilling and soil amendment material, however, oxygen supply from the atmosphere cannot be expected much because the roots are soaked in the nutrient solution in case of clay-rich soil and nutriculture.

Furthermore, it is required to pay attention to where water is pumped up. Table I shows dissolved oxygen levels of environmental water which are used for watering in Kochi prefecture, Japan. According to the table, dissolved oxygen level is often significantly lower in ground water and lake water compared with river water in which the level has reached almost saturation value. Such conditions unfavorable for cultivation may be generated simultaneously in some cases and for example, young ginger is cultivated in clay-rich soil using ground water in Haruno-cho, Kochi prefecture.

Then, introducing a fine bubble generator which can be attached on a watering pipe at this agricultural field (Swirl flow type: Two fine bubble groups were confirmed by about 1.4×10^8 mL^{-1} at around 200 nm (ultrafine bubble) and by 7.6×10^4 mL^{-1} at around 2 μm (microbubble)), an effect of increase in yield has been obtained by about 109 % (total weight) as a result of comparison of experiment section established by increasing dissolved oxygen level of watering with control section.

Effect of increase in yield (about by 109 % compared with control section) has been also obtained in other item, Zingiber mioga. Even though it is possible to secure certain level of dissolved oxygen by aeration with a common diffuser tube, it becomes impossible for such diffuser tube to sufficiently respond to growing watering amount as the planting area becomes larger. Fine bubble can work as a solution for such problem.

Furthermore, in consideration of an aspect of metabolism, cytokine and gibberellin which are hormones necessary for growth are produced at the roots over biosynthesis, but these useful hormones may decrease when oxygen supply to the roots run short of and growth inhibition is caused by abscisic acid and ethylene that increased instead of them.

As oxygen supply around the roots is also necessary from this perspective, increase in amount of synthesis of useful cytokine was recognized by using fine bubble water in an experimental system using tomatoes [2].

TABLE I

DISSOLVED OXYGEN LEVEL OF ENVIRONMENTAL WATER USED FOR WATERING IN KOCHI PREFECTURE

Environmental water	Point of water collection	Dissolved oxygen level (%)
River water	A	103.0
	B	98.0
Ground water	A	68.6
	B	59.6
	C	74.6
Lake water	Upper layer	57.8
	Medium layer	56.3
	Lower layer	1.1

Growth of plant is mainly classified into two types, i.e. trophic growth to strengthen itself by creating stems and leaves and generative growth to provide descendants with flowers and fruits. These processes are closely interrelated with each other and if any of the two processes became dominant, growth in the other process deteriorates.

For example, a strong process of trophic growth may cause unsuccessful bearing or poor growth of fruit. In other words, it is required to shift the process to generative growth in order to harvest fruits. Therefore, it is important to determine appropriate timing to reduce watering amount as well as to stop fine bubble introduction since high concentration of dissolved oxygen generally tends to intensify orientation toward trophic growth.

However, there is individual know-how for each item regarding these judgements including the timing. Results of examinations of the know-hows under various conditions performed by introducing fine bubble to actual melon farm fields showed increase in yield (by about 114% compared with control section) as well as in sugar content.

As described above, dissolved oxygen of watering is important for growth of plants and there are various cautions at actual fields. One of them is consumption of dissolved oxygen by a biofilm in the piping. Therefore, it is required to cope with such problem by regular cleaning of inside the piping.

B. Effects of watering use except for dissolved oxygen: Concentration of nutrients

In relation to usage of fine bubble for watering, it is expected to be effective for local nutrient concentration of nutrient solution to be added in the watering other than for dissolved oxygen. It is a result of utilization of a property of fine bubble [3] that it has negative charge when it is within a neutral range. It also means that concentration of positive ion nutrients occurs at around fine bubbles with negative charge.

In addition, stability is kept more securely for fine bubble by attaching to something to drift than drifting alone in a solution. Actually, such a state is observed that a large amount of fine bubbles are attached to the roots [4] is observed in a nutriculture as shown in Fig. 1.

From these factors, high concentration of nutrients is expected at around the roots during nutriculture.

Spinach was cultivated in a nutriculture under a condition of nutrient solution (Otsuka House prescription A) diluted to 1/10 by setting up a fine bubble section with a constant dissolved oxygen level and an aeration section with a diffuser tube.

As a result, fine bubble section showed the same level of growth state as that of control section (aeration treatment was performed for ordinary amount of nutrient solution) as shown by a picture on Fig. 2 [4].

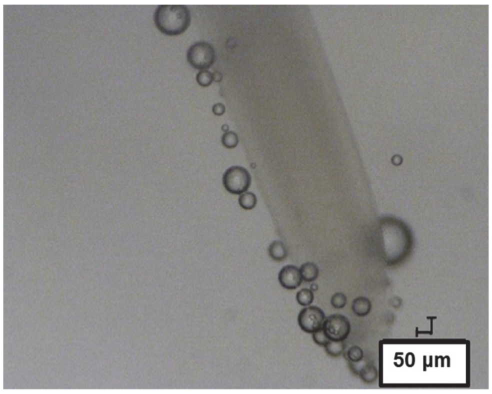

Fig. 1. Fine bubbles absorbed to the roots.

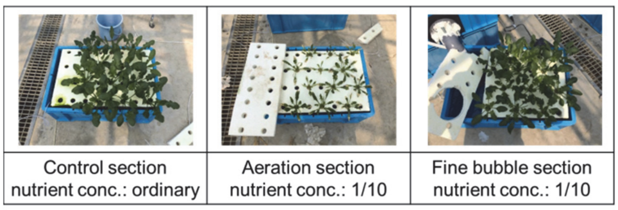

Fig. 2. Fine bubble's effect on spinach nutriculture.

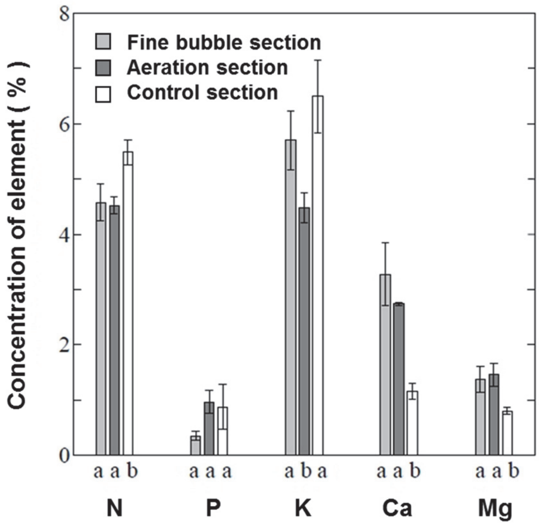

Fig. 3. Amount of elements contained in above-ground part of spinach. (The letters a and b in the figure indicate test results by Tukey method with significance level of 5% and different and same interval between the letters means existence and non-existence of significant difference, respectively.)

Moreover, as a result of quantitative elemental analysis of upper part of cultivation medium in the same experiment, almost the same amount of potassium (K^+) (amount absorbed from the nutrient solution) was observed in both fine bubble section and control section with 1/10 of nutrient solution amount, whereas reduction in the amount of potassium was observed in aeration section with the same amount of nutrient solution as shown in Fig. 3, recognizing growth inhibition by lack of K^+ in the same section. It is considered that concentration of K^+ around fine bubbles absorbed to the roots by negative charge of fine bubbles may have suppressed decrease of the absorption amount [4].

When soy bean seedlings were soaked in a nutrient solution treated with fine bubbles while adding sodium (Na^+), cesium (Cs^+) and phosphorous (P^-) labelled by radioisotope, it has been also reported to support the experiment result that amount of Na^+ and Cs^+ absorbed by soy beans increased at both above-ground and underground parts than the control section but absorption of P^- was inhibited [5].

The previous results may be supported in consideration of a fact that sodium and cesium are cation (positive charge) while phosphoric acid is anion (negative charge).

C. Quality preservation using carbon dioxide fine bubble

It is known that bacteria are killed off under an environment with high concentration of carbon dioxide. This mechanism is considered to be associated with changes in various functions of cellular membrane under coexistence of carbon dioxide as well as enhancement and suppression of intracellular enzyme synthesis capability [6].

While rotting of foods is generally caused by oxidation by atmospheric air and absorbed bacteria and antioxidants are added in order to prevent it, carbon dioxide fine bubble is considered to effectively work for oxidation prevention and inhibition of bacteria proliferation.

Among gingers that Kochi prefecture accounts for the largest amount of crop in Japan (in 2014), young ginger in bright red is highly evaluated and distributed to Tokyo area. The bright red color of young ginger, however, gradually changes into black due to oxidation and absorbed bacteria and they are discarded in a week or so. Soaking young gingers in a carbon dioxide fine bubble solution for about 30 minutes to be cut into a size of 1 cm^3 and culturing absorbed bacteria, their proliferation was suppressed by carbon dioxide fine bubble treatment compared with control section.

As a result of actual examination of rotten stem ratio based on a benchmark of change in colors after carbon dioxide fine bubble treatment of young ginger, reduced rotten stem ratio was recognized compared with control section as shown in Fig. 4. Therefore, extension of product value is expected by carbon dioxide fine bubble treatment.

Even though pH may shift to acidic property range upon introducing carbon dioxide, suppression of proliferation was not recognized in a system based on buffer solution adjusted to the same pH level as the water after fine bubble treatment.

Moreover, suppression of proliferation was recognized by fine bubbles with introduced nitrogen but the effect was slight compared with that of carbon dioxide system.

Thus, with expectation of value added by introduction of carbon dioxide fine bubble, study on utilization of fine bubble for food products sector has been in progress.

III. Development of Application in Aquaculture

A. Technology to recover from dysoxic environment

Since fine bubble which contains air may generate high oxygen dissolution ratio, there are many application examples of fine bubbles for aquafarming sites where dissolved oxygen may be depleted [7]. For example, it has been introduced to

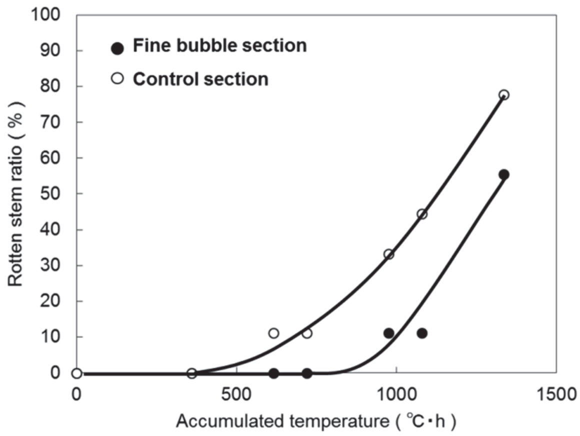

Fig. 4. Relationship between rotten stem ratio and accumulated temperature in young ginger. (Accumulated temperature is expressed by temperature and time, for example, in case of storage for 5 hours at 20℃ after 3 hours of storage at 15℃, it is expressed by 145℃ time according to a formula of 15℃× 3 hours ＋ 20℃×5 hours. In general, rotten ratio increases along with accumulated temperature. Therefore, rotten ratio may decrease as long as low temperature is kept because the ratio is obtained by multiplying term of temperature.)

chemical bathing (Fig. 5) in marine culture. In seawater culture, parasites called as *Benedenia seriolae* attached to the skin of yellowtails, in particular, may cause cultured fishes to be weakened.

Therefore, parasites are eliminated by forcing cultured fishes with attached parasites enter into an enclosed environment prepared by mixing an agent for eliminating parasites (this operation is called as chemical bathing). During this operation, certain amount of cultured fishes may die due to the dysoxic state (oxygen deficiency) in some cases because a large amount of cultured fishes are kept in such enclosed environment.

Alternatively, if chemical bathing time was shortened for preventing oxygen deficiency it may cause insufficient elimination of parasites resulting in increased workload by shortened chemical bathing cycle. Therefore, air fine bubble has been introduced to avoid oxygen deficiency during the chemical bathing work.

Variation of dissolved oxygen level during the operation in Fig. 5 is shown in Fig. 6. In case of control section, dissolved oxygen level within the chemical bathing environment continuously decreased causing death of fishes (around 5% of the total number) seemingly due to oxygen deficiency.

In a case with fine bubble introduced, however, the initial level of dissolved oxygen was kept until completion of the work causing no death of fishes due to oxygen deficiency.

Such reduction in dissolved oxygen level is also observed during feeding. The reduction in dissolved oxygen level is

Fig. 5. Chemical bathing in marine culture.

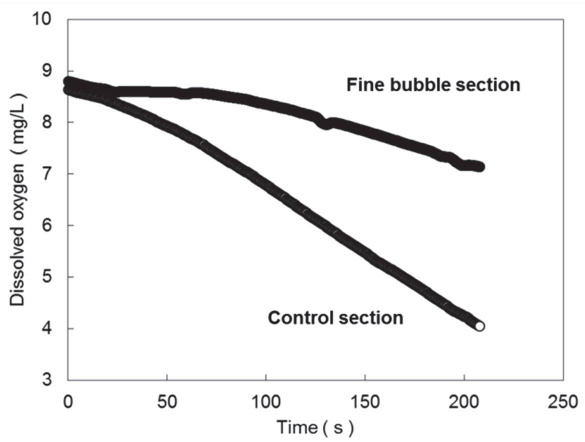

Fig. 6. Variation behavior of dissolved oxygen during chemical bathing work.

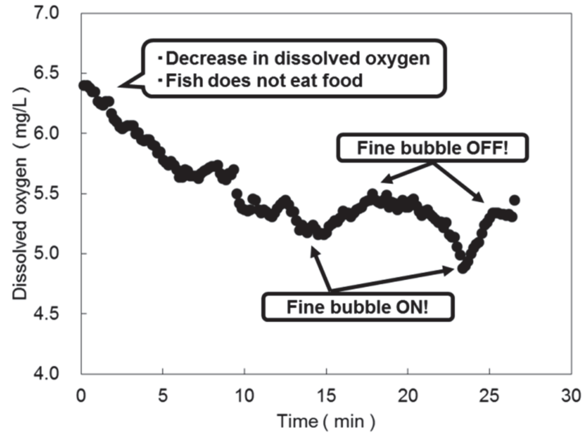

Fig. 7. Transition of dissolved oxygen level during feeding in great amberjack culture tank.

caused by activities of cultured fishes during feeding resulting in poor appetite for the feeds due to a mild oxygen deficiency and leading to deterioration in metabolism. As it is important to secure dissolved oxygen, in particular, during growth stage from young to adult fish [8], early recovery of the dissolved oxygen level is desired.

As a transition of dissolved oxygen level during feeding in an actual great amberjack culture tank, effect of fine bubbles at the time of introduction is shown in Fig. 7. Reduction in dissolved oxygen level at the time of feeding was relieved by introducing fine bubbles as shown in the figure.

As a result of actual introduction of fine bubble to aquafarming of juvenile yellowtails as a preventive technology for reduction in dissolved oxygen caused by feeding, caudal furca length, weight and feeding amount were significantly larger in fine bubble section compared with control section.

B. *Securement of dissolved oxygen level of water at high temperature*

Saturation value of dissolved oxygen level decreases along with rise in water temperature. Therefore, aeration has a significantly important meaning in case of high-temperature water.

Besides, when it comes to bonito fishing which is quite popular in Kochi prefecture, because fishing places at distant seas are often located at near equator areas with high water temperature, such a problematic case may occur that anchovies to be used as feeds, in particular, cannot survive in the high-temperature water due to oxygen deficiency. When the fine bubble was introduced as a solution for it, reduction in number of dead fishes was observed as shown in Fig. 8.

Thus, it is possible to develop fine bubble with reliability as a technology for securing dissolved oxygen which is crucial also in aquaculture. Supply of fine bubble may not have extremely adverse impact on cultured fishes, however, in consideration of the fact that some stress and gas disease (oxygen entered into the blood through gills is broken free and turned into air bubble) were observed in cultured red sea bream due to excessive feeding, it is important to build up a system capable of adjusting feeding amount and removing bubbles.

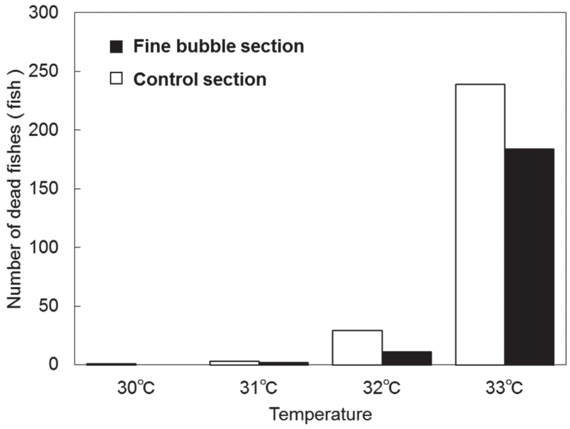

Fig. 8. Number of anchovies died from high temperature water.

IV. Conclusion

Fine bubble has begun to spread as a technology to secure dissolved oxygen which is important in agriculture and aquaculture.

However, it is important to understand that dissolved oxygen is consumed by biofilms in the watering piping in agriculture and that gas diseases are concerned in aquaculture. Further development of fine bubble is expected in the agriculture and aquaculture in the future by establishing a system to cope with such items and properly taking advantage of other properties of fine bubble for the industries.

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