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An Aquaponic System with Hydroponic Culture of Sweet Potato and Tilapia Culture

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Authors' contributions

This work was carried out in collaboration among all authors. Author AFMS designed the study, implemented research activities, performed the statistical analysis, wrote the protocol, and wrote the first and modified drafts of the manuscript. Author HH helped during the implementation of the study and statistical analysis and author YK finalized the design of the study, helped during implementation of the research and finalized the manuscript and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

An integrated system with a hydroponic culture of sweet potato and tilapia culture was assessed as a new combination in aquaponics to investigate its potential and productivity. The first experiment was conducted inside a glasshouse using plastic tanks as water reservoirs to compare the growth and development of two sweet potato (*Ipomoea batatas* (L.) Lam.) varieties Beniazuma and purple sweet lord using hydroballs, granular plastics, cut rockwool, and rockwool blocks as supporting materials in hydroponic culture. The supporting material was placed inside plastic pots. Greater growth and development of the storage roots of sweet potatoes in both varieties were obtained in hydroballs. In the second experiment, four sweet potato varieties, Kokei 14, Suioh, Beniazuma, and Elegant summer, with hydroballs as the supporting material, were examined hydroponically with an integrated culture of tilapia fish in the pond. Two ponds were 7.7 m and 5.3 m, in length and width, respectively, and water depth was maintained at 0.38 cm. Styrofoam boxes with holes on the bottom side were used to culture sweet potato on the water surface. Nylon net containers filled with hydroballs were placed in the Styrofoam boxes. The variety Kokei 14 produced the greatest fresh

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and dry weights of storage roots and percent harvest index in both ponds, with and without fish. The number and diameter of the storage roots of Kokei 14 were higher. Tilapia fish were cultured in one of the two ponds and fed artificial feed. The average length and weight of tilapia fishes increased to 10 cm and 188 g, respectively, 143 days after culturing, and those were 1.8 and 6.9 times, respectively, greater than at the start. The integrated culture of sweet potato hydroponically on the water surface and tilapia in pond water increases the food production in a limited space and profitable.

Keywords: Ipomoea batatas; tilapia fish; hydroponic cultivation; integrated culture; supporting materials.

1. INTRODUCTION

Concerns have arisen over the stable supply of food and water resources owing to the recent growth in the global population. Therefore, there is an urgent need to develop production technologies that effectively utilize water resources and provide a steady food supply. This study examined aquaponics, a biological production system combining hydroponics and fish farming, which has attracted attention in recent years as a resource recycling production system.

Integrated fish and vegetable production technologies are more profitable than rice production, and adopting these technologies has improved the micronutrient status of members of implementing households through better dietary quality in Bangladesh [1]. An integrated culture of fish and vegetables resulted in significantly higher annual net cash flow than farming fish and vegetables separately [2]. Vegetable production with the integration of tilapia fish in aquaponic systems showed good biomass production and economic returns [3].

Aquaponics can effectively utilize water and nutrients [4]. Sharing water between hydroponics and aquaculture systems allows plants to use fertilizer components derived from fish excrement for growth. Therefore, food can be produced with less water, while reusing nutrients and converting waste into high-value resources. Aquaponics is an important biological production system in areas with limited water and fertilizer resources. As an extreme example, an integrated culture system of crops or vegetables with fish will be an essential component of a controlled ecological life support system (CELSS) in space because it is likely to play an important role in regenerative systems for producing crops, vegetables, and fish to increase food and dietary energy for long-term human stay in space [5].

Sweet potatoes grown hydroponically yielded higher per plant under controlled environmental conditions using modified nutrient film techniques [6] and in a box culture system with an air space above a nutrient solution layer [7,8] in comparison with the yield when grown conventionally under field conditions. The hydroponic technique for crop production has mainly been used in the absence of adequate soil, water resources, or proper climatic conditions. Previous studies on the hydroponic cultivation of sweet potatoes have been carried out mainly under greenhouse and growth chamber conditions.

In the box culture system developed by Uewada [7] and Uewada et al. [8], sweet potatoes were grown in plastic boxes (inside measurements 0.4 m × 0.7 m × 0.32 m high) containing a nutrient solution at the bottom. The upper and middle portions of the sweet potato root system developed as storage roots in the aerial spaces above the nutrient solution layer, whereas the lower part of the root system developed as absorbing roots in the nutrient solution layer. The results obtained with this system suggested that storage roots could be developed in the aerial spaces even if the absorbing roots were submerged in the solution. Although storage roots can grow in blank aerial spaces, large-scale production using this method is neither possible nor economically profitable. However, large-scale production of crops at low cost cannot be achieved under these conditions. The selection of appropriate supporting materials is necessary for hydroponically large-scale production of sweet potatoes. Hydroballs were selected as the supporting materials to achieve greater growth and yield of hydroponically grown sweet potatoes under glasshouse conditions. The possibility of culturing sweet potato hydroponically using hydroballs as supporting material with an integrated culture of tilapia fish in pond water was examined to enhance food production.

2. MATERIALS AND METHODS

2.1 Selection of Suitable Supporting Material for Hydroponic Cultivation of Sweet Potato (Exp. 1)

The experiment was conducted inside the glasshouse using plastic tanks (118 × 77 × 45 cm high) as water reservoirs from the middle of June to early October. A plastic plate table with a height of 30 cm was placed inside the water reservoir tank. Plastic-rooting pots containing different supporting materials were placed on a plastic plate table. In the experiment, four supporting materials (hydroballs, granular plastics, cutrockwool, and rockwool blocks) and two sweet potato varieties (Beniazuma and Purple sweet lord) were cultured using the hydroponic method. The hydroballs were made with clay soils well mixed with a small proportion of sand in the range of 5 to 6.5 mm in diameter following the same preparation method of bricks but not as strong burning as for brick preparation. The diameter of the granular plastics was 3.5 mm in diameter. The individual pieces of the cut rockwool were approximately 12 mm ×10 mm ×10 mm. The rockwool blocks were approximately 86 mm ×68 mm ×200 mm in height. The supporting materials were placed inside plastic rooting pots (100×80×220 mm). Some holes were made in pots' lower surface and side walls to ease the nutrient solution's entry inside the rooting pots and to grow the absorbing roots outside the rooting pots to absorb water and nutrients from the nutrient solution. Vine cutting of sweet potatoes with seven nodes and five leaves was performed in the supporting materials in each rooting pot. The tip of the vine cuttings was removed during planting. Two lower nodes of vine cuttings were inserted into the supporting material during the planting. The nutrient solution depth was maintained at three-fourths of the rooting pot height from the lower surface for two weeks after planting. After that, the nutrition solution depth gradually decreased and remained constant at one-fourth of the rooting pot height from the bottom three weeks after planting and maintained the same depth of nutrient solution throughout the growing period. The leaf number was kept constant throughout the growing period by removing newly growing shoots. Two and a half months after planting, one to two leaves from the lower side of the vines died because of senescence. Harvesting of sweet potato plants was done three months after planting.

2.2 Integrated Culture of Sweet Potato and Tilapia Fish (Exp. 2)

The experiment was conducted at the experimental farm of the Osaka Metropolitan University, Japan, from mid-June to early October. Two ponds were used to conduct the experiment using the hydroponic method of sweet potato cultivation. The length and breadth of each pond were 7.7 m and 5.3 m, respectively, and water depth was maintained at 0.38 cm throughout the culture period. The soil surfaces inside the ponds were covered with three-layered polyethylene sheets to avoid leaching water loss from the ponds. Styrofoam boxes (42×32×25 cm high) were used to culture sweet potato in the pond (Fig. 1).

A B

Fig. 1. Sweetpotato plants with boxes floating on water (A) and box with plants in nylon nets (B)

Holes were made on the lower side of the boxes to insert the water inside the boxes and come out of the growing non-storage absorbing roots into the water to absorb nutrients from the water. Four chambers were created inside each Styrofoam box. One nylon net container, filled with approximately 2 kg of dry hydroballs, was placed in each chamber. After pouring the hydroballs in the nylon net containers, two-layered black polyethylene bags were used to cover the nylon net containers to protect the penetration of light inside the nylon net containing hydroballs. Three nodes of a rooted transplant (ca. 13 g fresh weight) of sweet potato were inserted into the hydroballs of each nylon container at planting. Four varieties of sweet potato, namely, Kokei 14, Suioh, Beniazuma, and Elegant summer, were cultured on the surface of pond water. Fertilizers were applied twice during the growth period. First, fertilizers were applied inside the Styrofoam boxes in perforated non-degradable small bags for 35 days after planting. One month after the first fertilizer application, a nutrient solution was applied to the hydroballs. The insects were controlled mechanically by hand, without using insecticides. Sweet potatoes were harvested 105 days after planting.

Two hundred tilapia fish were cultured in one of the two ponds and fed 30 g of artificial dry feed per day. The fish also ate growing non-storage roots that came out through the bottom holes of the Styrofoam boxes and microalgae. Tilapia were cultured for 143 d in pond water. The initial average length and weight of the tilapia fingerlings were 12 cm and 32 g, respectively, at the start of the culture. After the fish were harvested, 87 fish were sampled and their lengths and weights were measured and separated into numbers according to length and weight categories.

2.3 Experimental Design and Data Analysis

The sweet potato experiments conducted at the glasshouse to select the appropriate supporting materials and on the water surface to compare the growth and yield of sweet potato using different varieties in ponds with or without fish were laid out in a randomized block design with four replications. Duncan's multiple range test was used to compare the growth characteristics and yield of sweet potato using different supporting materials and two varieties of sweet potato inside the glasshouse and on the water surface with four varieties of sweet potato and two ponds, after an ANOVA test. Mean differences in the parameters in the treatments were compared using Duncan's multiple range test at a 5% level of significance. The numbers of tilapia fish were separated into different length and weight categories, as shown in Figures. The mean length and weight of the sampled tilapia were also calculated.

3. RESULTS AND DISCUSSION

Exp. 1. Growth performance of sweet potato grown hydroponically with different supporting materials Sweet potato's main edible part (i.e., storage roots) showed greater growth and development in hydroballs than the other supporting materials in both Beniazuma and Purple sweet lord varieties (Table 1). In contrast, the non-edible parts (i.e., stems, leaves, and non-storage roots) showed relatively less growth and development in hydroballs than the other supporting materials. Fresh and dry weights of storage roots in Beniazuma were approximately 2.4 times greater in hydroballs than in cut rockwool, and in purple sweet lord, they were approximately 5.1 times greater in hydroballs than in granular plastics.

The number of storage roots was 1.5 times greater in the hydroballs than in the rockwool block in both varieties. The length of storage roots in Beniazuma was 1.3 times greater in hydroballs than in granular plastics, and that in purple sweet lord was 1.9 times greater in hydroballs than in cut rockwool. The diameter of storage roots in Beniazuma was 3.5 times greater in hydroballs than in cut rockwool, and that in purple sweet lord was 2.1 times greater in hydroballs than in granular plastics. In most cases, the non-edible parts of sweet potato plants showed greater growth in granular plastics, cut rockwool, and rockwool blocks in both varieties than in the hydroballs (Table 2). Although lower and medium growth of plants was obtained in hydroballs, the storage root growth was greater in hydroballs than in the other supporting materials in both varieties. The percent harvest index in Beniazuma was 2.2 times greater in hydroballs than in cut rockwool, and that in purple sweet lord was 6.1 times greater in hydroballs than in granular plastics (Table 3). The shoot root ratio was greater in cut rockwool, rockwool blocks, and granular plastics than in hydroballs. The greater growth and development of storage roots in hydroballs may be due to proper aeration, looseness, and the provision of an optimum amount of water for the normal growth and development of sweet potato. The hydroballs contained sufficient water for the normal growth and development of storage roots and whole plants because the hydroballs were made with clay soils mixed with a small proportion of sandy soils. Hydroballs also have capillary action to provide optimum moisture for greater plant growth.

The lower growth and development of storage roots in granular plastics may owing to the lack of sufficient water for plants as the low water retention ability and lower capillary action of granular plastics, may restrict the growth and development of storage roots. Water-saturated conditions in cut rockwool may limit the growth of storage roots. Greater hardness and water saturation in rockwool blocks may have a more detrimental effect on the normal growth and development of storage roots. However, in most cases, relatively greater growth of non-storage roots and aboveground parts was obtained in the granular plastics, cut rockwool, and rockwool blocks than in the hydroballs. Similar results were obtained by Islam et al. [9] in modified hydroponic cultivation of sweet potato in wet lowland field conditions with porous plastic tubes placed inside the soil ridges for aeration inside the ridges. The dry weight of storage roots in the aerated treatment was four times greater than that in the normal soil ridges under wet soil conditions; however, the dry weight of non-storage roots was greater in normal soil ridges than in aerated ridges. From this experiment, hydroballs were selected as the appropriate material for use in the hydroponic culture of sweet potatoes to obtain a greater yield.

Exp. 2. Growth performance of sweet potato grown hydroponically with integrated culture of tilapia fish in a pond

The growth and development of the storage roots of sweet potatoes in hydroponic culture were satisfactory, although there were variations among the different varieties and in ponds with or without fish (Fig 2).

Kokei 14 produced the highest fresh and dry weights of storage roots in ponds, either with or without fish (Table 4). Fresh and dry weights of storage roots were 2.4 times greater in Kokei 14 than in Beniazuma in the pond with fish and those were 3.1 times greater in Kokei 14 than in Elegant summer in the pond without fish. Fresh and dry weights of non-storage roots were greater for each variety in the pond without fish than in the pond without fish. A greater number and diameter of storage roots were also obtained in the Kokei 14 variety in both ponds. The diameter was 1.4 and 1.8 times greater in the pond with fish and without fish, respectively, in Kokei 14 than in Elegant summer. Fresh and dry weights of the whole plant were 2.2 times greater in Kokei 14 than in Beniazuma in the pond with fish and approximately 2.4 times greater in Kokei 14 than in Elegant summer in the pond without fish (Table 5).

The percent harvest index was greater in the Kokei 14 variety in both ponds than in the other varieties (Table 6). Mortley et al. [10] reported that the harvest index ranged from 31 to 82% among sweet potato genotypes developed for hydroponic systems in greenhouses using the nutrient film technique (NFT). In the present study, the harvest index ranged from 64 (Elegant summer) to 82% (Kokei 14). The shoot-root ratio was greater in Beniazuma, Elegant summer, and Suioh ponds than in Kokei 14 ponds with or without fish. In the hydroponic cultivation method, Suioh, Beniazuma, and Elegant summers showed poor growth and development of aboveground and subground parts and, consequently, the whole plant. This may be due to the susceptibility of these varieties to water-saturated conditions. A greater shoot-root ratio was obtained in the Beniazuma and Elegant summers. Fresh and dry weights of non-storage roots were greater in the pond without fish than in the pond with fish because the non-storage roots that came out through the bottom holes of the boxes in the pond with fish were eaten by fish.

The average length and weight of tilapia fish 143 days after culturing in the pond with integrated hydroponic cultivation of sweet potato increased to 10 cm (12 cm at start and 22 cm at harvest) and 188 g (32 g at start and 220 g at harvest), respectively, and was 1.8 and 6.8 times greater, respectively, at the start of culture (Fig. 2). The highest number of fishes was obtained in the 20.1 to 22.0 cm length category followed by 22.1 to 24.0 cm, 18.1 to 20.0 cm, 24.1 to 26.0 cm and the lowest was in the 26.1 to 28.0 cm and 16.1 to 18.0 cm categories (Fig. 3). The highest number of fishes was obtained in the 191 to 210 g weight category followed by 211 to 230 g, 231 to 250 g, 171 to 190 g, 251 to 270 g, and the lowest was in the 151 to 170 g and 271 to 290 g categories (Fig. 4).

Table 1. Weights of storage roots, non-storage roots and characteristics of sweet potato grown in different supporting materials in hydroponic cultivation (Exp. 1)

Varieties	Supporting materials	Weight of storage roots (g plant^{-1})		Weight of non-storage roots (g plant^{-1})		Characteristics of storage roots		
		Fresh	Dry	Fresh	Dry	Number plant^{-1}	Length (mm)	Diameter (mm)
Beniazuma	Hydroballs	14.6b	2.5a	31.2b	4.8a	4.3a	173a	14.0ab
	Granular plastics	9.5c	1.6c	39.3a	5.3a	3.3b	133c	7.2c
	Cut rockwool	5.6e	1.2d	29.1b	5.5a	3.5b	140b	4.3d
	Rockwool block	8.8c	2.3b	33.8b	4.9a	2.8c	153ab	11.8b
Purple sweet lord	Hydroballs	19.0a	2.7a	34.0b	2.1c	4.5a	148b	16.9a
	Granular plastics	4.0e	0.5e	43.4a	3.8b	2.8c	117d	8.0c
	Cut rockwool	12.2bc	1.9c	41.0a	2.9b	3.5b	77e	13.8ab
	Rockwool block	7.2d	1.3d	22.7c	1.4d	2.8c	129c	11.8b
Analysis of variance								
Varieties (V)		*	*	*	**	NS	**	**
Rooting media (M)		*	*	*	**	*	*	*
V × M		*	*	*	**	NS	*	*

*In each column, the figures with different letter(s) indicate a significant difference at the 5% level by Duncan's Multiple Range Test; Analysis of variances was applied for 8 treatments; 2 varieties and 4 supporting materials (Rooting media); * and ** indicate significant at 5% and 1% levels, respectively; NS indicates non-significant*

Table 2. Weights of above-ground parts, sub-ground parts, and whole-plant of sweet potato grown in different supporting materials in hydroponic cultivation (Exp. 1)

Varieties	Supporting materials	Weight of above-ground part (g plant^{-1})		Weight of sub-ground part (g plant^{-1})		Weight of whole-plant (g plant^{-1})	
		Fresh	Dry	Fresh	Dry	Fresh	Dry
Beniazuma	Hydroballs	39.7bc	6.6b	45.8b	7.3a	85.4bc	13.9b
	Granular plastics	52.8a	7.3b	48.8a	6.9ab	101.6a	14.2b
	Cut rockwool	47.1ab	8.1a	34.7c	6.9ab	81.7c	14.9b
	Rockwool block	55.0a	9.7a	42.6b	7.2a	97.6b	16.9a
Purple sweet lord	Hydroballs	33.7c	3.7cd	53.0a	4.8c	86.7b	8.5c
	Granular plastics	39.8bc	4.5c	47.4b	4.2c	87.2b	8.7c
	Cut rockwool	40.6bc	3.7cd	53.2a	4.9c	93.7b	8.6c
	Rockwool block	34.2c	2.8d	29.8c	2.7d	64.0c	5.6d
Analysis of variance							
Varieties (V)		**	**	*	**	*	**
Rooting media (M)		*	*	*	*	*	*
V × M		*	*	*	*	*	*

*In each column, the figures with different letter(s) indicate a significant difference at the 5% level by Duncan's Multiple Range Test; Analysis of variances was applied for 8 treatments; 2 varieties and 4 supporting materials (Rooting media); * and ** indicate significant at 5% and 1% levels, respectively*

Table 3. Weights of stems and leaves, percent harvest index and the shoot-root ratio of sweet potato grown in different supporting materials in hydroponic cultivation (Exp. 1)

Varieties	Supporting materials	Weight of stems (g plant^{-1})		Weight of leaves (g plant^{-1})		Harvest index^{X} (%)	Shoot-root ratio^{Y}
		Fresh	Dry	Fresh	Dry		
Beniazuma	Hydroballs	30.1b	4.3b	9.6c	2.4b	18.1b	0.9b
	Granular plastics	34.7ab	4.2b	18.0a	3.1a	11.4b	1.1ab
	Cut rockwool	37.2a	5.4a	9.9c	2.7b	8.3c	1.2a
	Rockwool block	38.1a	6.0a	16.9a	3.6a	13.4b	1.3a
Purple sweet lord	Hydroballs	23.7c	2.5c	10.0bc	1.2c	31.3a	0.8c
	Granular plastics	29.2b	3.1bc	10.6bc	1.4c	5.1c	1.1ab
	Cut rockwool	27.9b	2.3c	12.7b	1.4c	22.5b	0.8c
	Rockwool block	23.6c	1.9c	10.7bc	0.9d	23.3b	1.0b
Analysis of variance							
Varieties (V)		**	**	*	**	**	*
Rooting media (M)		*	*	*	**	**	*
V × M		*	*	*	**	**	*

*^{X}: (Storage roots dry weight / whole-plant dry weight) × 100; ^{Y}: Above-ground dry weight / sub-ground dry weight; In each column, the figures with different letter(s) indicate a significant difference at the 5% level by Duncan's Multiple Range Test; Analysis of variances was applied for 8 treatments; 2 varieties and 4 supporting materials (Rooting media); * and ** indicate significant at 5% and 1% levels, respectively*

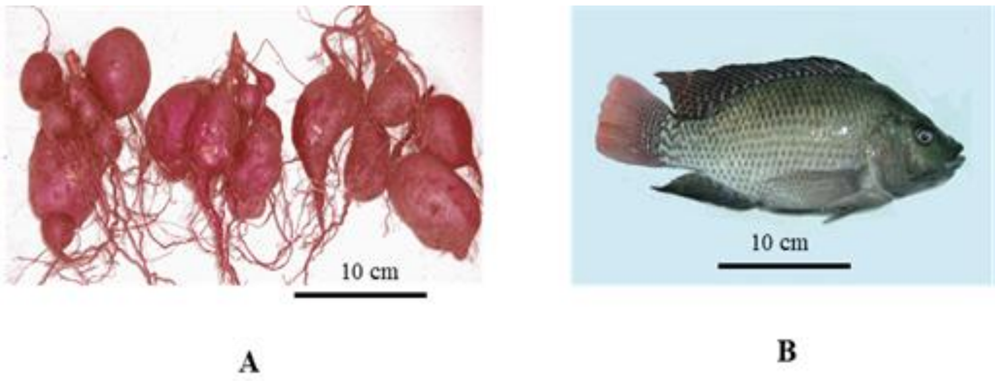

Fig. 2. Storage roots of sweet potato (A) and tilapia fish at harvest (B)

Table 4. Weights of storage and non-storage roots, and characteristics of storage roots of sweet potato grown hydroponically on the water surface with an integrated culture of tilapia fish in the pond water (Exp. 2)

Ponds	Varieties	Weight of storage roots (g plant^{-1})		Weight of non-storage roots (g plant^{-1})		Characteristics of storage roots		
		Fresh	Dry	Fresh	Dry	Number plant^{-1}	Length (mm)	Diameter (mm)
With fish	Kokei 14	364.8a	102.1a	58.8c	6.4b	6.1a	113b	54.7a
	Suioh	165.9c	49.5c	57.5c	6.3b	5.6a	88c	43.7b
	Beniazuma	151.8c	41.7d	18.3d	2.6d	3.5b	113b	45.2b
	Elegant summer	223.1b	58.7c	68.2c	5.6c	6.1a	131a	37.9c
Without fish	Kokei 14	339.0a	82.9b	104.4a	9.1a	5.8a	97c	60.5a
	Suioh	244.3b	75.9b	85.4b	7.5ab	5.8a	106b	48.4b
	Beniazuma	164.9c	40.0d	75.5b	8.0a	4.3b	116b	47.3b
	Elegant summer	108.5d	26.7e	63.3c	5.8c	5.3a	93c	33.2c
Analysis of variance								
Ponds (P)		*	*	**	**	NS	*	NS
Varieties (V)		*	*	**	**	*	*	*
P × V		*	*	**	*	NS	*	NS

In each column, the figures with different letter(s) indicate a significant difference at the 5% level by Duncan's multiple range test*; Analysis of variances was applied for 8 treatments; 2 ponds and 4 varieties; * and ** indicate significant at 5% and 1% levels, respectively; NS indicates non-significant.*

Table 5. Weights of above-ground, sub-ground, and whole-plant of sweet potato grown hydroponically on the water surface with an integrated culture of tilapia fish in the pond water (Exp. 2)

Ponds	Varieties	Weight of above-ground part (g plant^{-1})		Weight of sub-ground part (g plant^{-1})		Weight of whole-plant (g plant^{-1})	
		Fresh	Dry	Fresh	Dry	Fresh	Dry
With fish	Kokei 14	73.4a	16.0a	423.6a	108.5a	497.0a	124.5a
	Suioh	54.4c	11.8b	223.4d	55.8c	277.8c	67.6d
	Beniazuma	54.1c	10.8b	170.1e	44.3d	224.2d	55.1d
	Elegant summer	81.4a	14.8a	291.3c	64.3c	372.7b	79.1c
Without fish	Kokei 14	53.6c	10.7b	443.4a	92.0b	497.0a	102.7b
	Suioh	67.3b	12.3b	329.7b	83.4b	397.0b	95.7b
	Beniazuma	55.7c	10.7b	240.4d	48.0d	296.1c	58.7d
	Elegant summer	41.4d	7.7c	171.8e	32.5e	213.2d	40.2e
Analysis of variance							
Ponds (P)		*	*	*	*	*	*
Varieties (V)		*	*	**	**	**	**
P × V		*	*	*	*	*	*

In each column, the figures with different letter(s) indicate a significant difference at the 5% level by Duncan's multiple range test*; Analysis of variances was applied for 8 treatments; 2 ponds and 4 varieties; * and ** indicate significant at 5% and 1% levels, respectively*

Table 6. Weights of stems and leaves, percent harvest index and the shoot-root ratio of sweet potato grown hydroponically on the water surface with an integrated culture of tilapia fish in the pond water (Exp. 2)

Ponds	Varieties	Weight of stems ($g\ plant^{-1}$)		Weight of leaves ($g\ plant^{-1}$)		Leaf number $plant^{-1}$	Harvest $index^{X}$ (%)	Shoot-root $ratio^{Y}$
		Fresh	Dry	Fresh	Dry			
With fish	Kokei 14	57.6a	12.9a	15.8b	3.1b	40.1a	82.0a	0.15b
	Suioh	41.3b	8.4b	13.1bc	3.4b	30.6b	73.2b	0.21a
	Beniazuma	38.4b	7.6b	15.7b	3.2b	35.8ab	75.7b	0.24a
	Elegant summer	58.3a	10.5ab	23.1a	4.3a	34.8ab	74.2b	0.23a
Without fish	Kokei 14	40.8b	8.2b	12.8bc	2.5c	23.5c	80.7a	0.12b
	Suioh	56.2a	10.3ab	11.1c	2.0c	22.8c	79.3a	0.15b
	Beniazuma	40.6b	7.9b	15.1b	2.8b	26.5bc	68.1c	0.22a
	Elegant summer	30.7c	5.9c	10.7c	1.8c	23.5c	66.4c	0.24a
Analysis of variance								
Ponds (P)		*	*	*	*	**	NS	NS
Varieties (V)		*	*	*	*	*	*	*
P × V		*	*	*	*	*	NS	NS

[X]: (Storage roots dry weight / whole-plant dry weight) × 100; [Y] : Above-ground dry weight / sub-ground dry weight; In each column, the figures with different letter(s) indicate a significant difference at the 5% level by Duncan's multiple range test*; Analysis of variances was applied for 8 treatments; 2 ponds and 4 varieties; * and ** indicate significant at 5% and 1% levels, respectively; NS indicates non-significant*

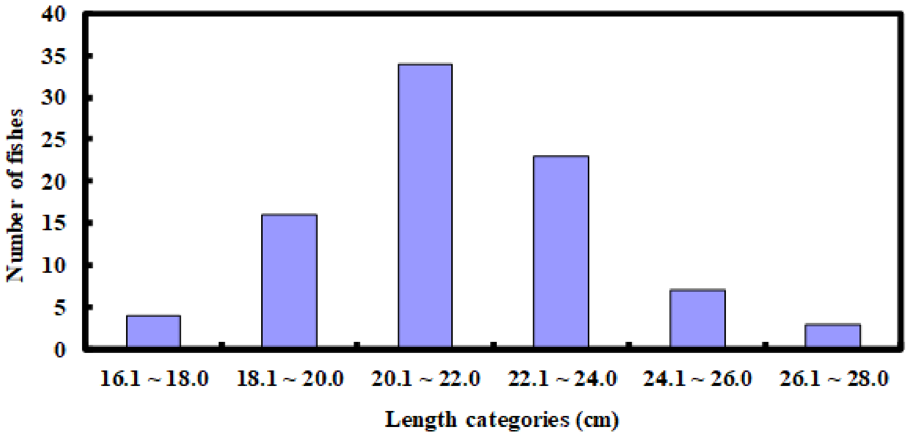

Fig. 3. Number of tilapia fish in different length categories

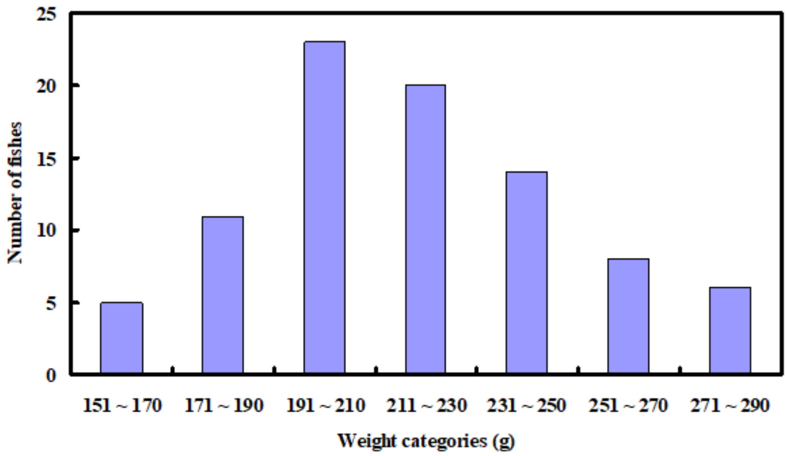

Fig. 4. Number of tilapia fish in different weight categories

Tilapia fish can be grown in ponds with the integration of hydroponically grown vegetables or field crops through artificial feeding, growing plankton, and fish can eat the roots and other parts of the plants. Fish excretes also enrich the water with nutrients that can be absorbed by plants. In an integrated culture system with fish and vegetables resulted in 3 and 2.5 times greater than that of the culture of fish alone and farming of non-integrated vegetables, respectively (Limbu, 2016). In the present system, sweet potato plants and fish can be grown symbiotically in an integrated culture system through mutual benefits in hydroponic cultivation.

4. CONCLUSION

Sweet potatoes can be cultured on water surfaces and lowland wet fields using the hydroponic method. The culture of indigenous fish in water can be combined with hydroponic cultivation of sweet potato to enhance food production in a limited space. The integrated culture method developed in this study is also applicable to other vegetable crops.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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