Rice Research: Open Access

Yamori et al., J Rice Res 2014, 2:1
http://dx.doi.org/10.4172/jrr.1000119

Review Article · Open Access

Feasibility Study of Rice Growth in Plant Factories

Wataru Yamori[1,2]*, Geng Zhang[1], Michiko Takagaki[1] and Toru Maruo[1]

[1]*Center for Environment, Health and Field Sciences, Chiba University, Japan*
[2]*Japan Science and Technology Agency (JST), Japan*

Abstract

Global food production will need to increase more than 50% before 2050 to satisfy the food demands of an increasing human population. To solve this food crisis, an increase in rice production will be necessary as rice is especially vital for the nutrition of much of the population in many countries. One solution to the future food shortage worldwide would be to cultivate crops in places where plants to do typically grow (e.g., desert and Antarctic). The technology for "plant factories", a new facility to grow plants under a controlled environment that would enable high yield and high quality production year-round, is progressing. Through the computer-based, automated control of environmental conditions for optimal rice growth, the external environmental conditions would have little effect on the plants growing inside the plant factory. In the near future, the plant factory could play an important role in areas where field productions are difficult or impossible. Moreover, since producing biopharmaceuticals in plants through genetic engineering technologies has many economic and qualitative benefits, the trial to produce useful materials in transgenic plants is examined in the plant factory. Transgenic plants might therefore expand the usefulness of plant factories. In this review article, feasibility of rice growth in plant factories is summarized.

Keywords: Rice; Plant factory; Greenhouse; Transgenic; Cultivation

Introduction

Food production is fundamental to our existence. Over the past half century, the rapid growth of the global world population is astounding and it is likely to plateau at some 9 billion people by the middle of this century [1]. Since the overgrowth of population presents a threat to the continued existence of humanity, a great increase in the food supply is demanded for the enlarging population. Additionally, environmental problems such as climate change and the water crisis are constraints for future global food production. The excessive growth of populations, environmental pollution and resource shortages are major reasons leading to the scarcity of food. Therefore, to meet the projected demands of increasing population and consumption, we must roughly double food supplies in the next few decades [2]. Rice is especially vital for the nutrition of much of the population in Asia, as well as in Latin America and Africa. It is central to the food security of over half the world's population. Developing countries account for 95% of the total rice production, with China and India alone responsible for nearly half of the world's output. The largest consumers are China with about 30% of the world's consumption and India with about 25%. In order to solve the crisis of food, an increase in rice production will be necessary.

In recent years, the technology of protected horticulture has been developed. In the Netherlands and other parts of Europe this technology has seen increases in yield from tomato plants grown in greenhouses that use sunlight but control all other environmental conditions (hereafter referred to as a plant factory with sun light). Plant factories using sunlight for plant growth can get high yield productions year-round, as well as high quality produce of high nutritive value by controlling the nutrient solution with hydroponic cultivation and soilless systems. On the other hand, the technology of plant factories using artificial light is in progress in Asia, especially in Japan [3]. Plant factories using artificial light in Japan have been already used for the commercial production of leafy vegetables. Using the plant factory with artificial light, high quality pesticide-free plants are produced all year-round owing to the optimal control of the aerial and root-zone environments. The annual sales volume per unit land area of plant factories is roughly 100-fold that of open fields. Plant factories with artificial light can be built in any location and in any building, since it needs neither solar energy nor natural soil. So, its productivity is independent of the outside climate and soil fertility. In the near future, plant factories with artificial light could provide the possibility to expand food production into areas where crop plants cannot currently grow (e.g., desert, Antarctic, and highly-polluted areas).

Three Types of Plant Factory and their Characteristics

The concept of a plant factory has not yet been fixed definitively. A plant factory is a new facility to grow plants under a controlled environment and is able to get high yield and high quality productions year-round. Through the computer-based, automated control of conditions for optimal plant growth, including the environmental factors of temperature, light, CO_2 concentration and nutrient source, a plant factory is a labor-saving food production technology where crops inside the facility would be largely unaffected by the weather. Plant factories are mainly categorized into three types based on their characteristics: i) plant factories with sunlight, ii) plant factories with sunlight and supplemental light, and iii) plant factories with fully artificial light (Figure 1).

i) Plant factories with sunlight (typical Dutch type greenhouse)

This is a system that uses sunlight without supplemental lighting. Generally speaking, the solar lighting system is considered to be an advanced greenhouse. This type of plant factory is installed with a CO_2 gas supply, thermal screen, shading curtain and heat pump to optimize

***Corresponding author:** Wataru Yamori, Center for Environment, Health and Field Sciences, Chiba University, Japan, Tel & Fax: +81-4-7137-8114; E-mail: wataru.yamori@chiba-u.jp

Received January 01, 2014; **Accepted** January 30, 2014; **Published** February 03, 2014

Citation: Yamori W, Zhang G, Takagaki M, Maruo T (2014) Feasibility Study of Rice Growth in Plant Factories. J Rice Res 2: 119. doi: 10.4172/jrr.1000119

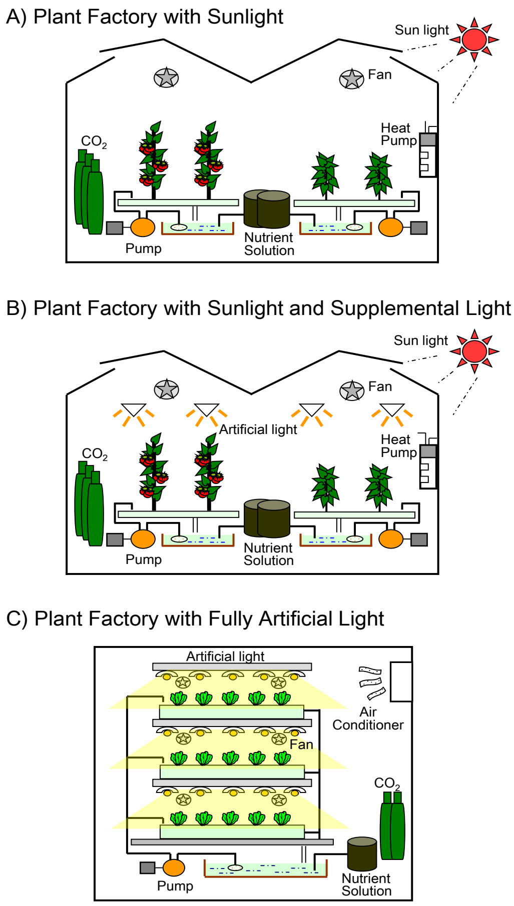


Figure 1: Three types of plant factories, Plant factories are mainly categorized into three types: A) plant factories with sunlight (typical Dutch type greenhouse), B) plant factories with sunlight and supplemental light, and C) plant factories with fully artificial light.

photosynthesis, plant growth, and the development of flowers and fruit. This system does not have fully closed environment. So, great care has been exercised in preventing their infiltration by external insects, for example, by surrounding entry points with insect screens. Since this type of plant factory does not use supplemental sunlight, its light energy costs are low, compared with other two plant factories.

ii) Plant factories with sunlight and supplemental light

This is a system that operates using sunlight, but when there is a shortfall in the amount of light (e.g., rainy season and winter), artificial light sources are used to supplement the light and prevent any delay in growth and reduction in quality, as well as to regulate the timing of flowering. High pressure sodium lamps, and recently LED light sources, would be the main light source in plant factories with sunlight and supplemental light. These plant factories do not differ in external appearance from a plant factory with sunlight.

iii) Plant factories with fully artificial light

This system does not use any sunlight and has a closed environment. In plant factories with fully artificial light, all factors such as light, nutrients, humidity, CO_2 concentration and temperature are electrically controlled for optimal plant growth, and fluorescent lamps and LEDs are the main lighting source [3,4]. Higher rates of plant productivity are possible, and it can be described as a factory-like production system. In systems that barely require any light, such as mushroom cultivation systems, the advantages of fully artificial light plant factories can be demonstrated to their greatest effect. In cultivations that do require light, such as leaf vegetable cultivation, the electricity expenses would be high as plant growth is dependent on light. Nevertheless, since the outside environment has no influence on the plant growth, plants can be grown under greater environmental control year-round, even in regions where field production is difficult or impossible. Moreover, it is possible to grow transgenic plants in this factory since the facility is a closed environment and thus it will reduce the risk of gene flow compared to the field-grown alternative. Since no agricultural chemicals need to be used in closed facilities, because pests and diseases can be kept outside, the plants can be eaten without washing because of the higher security and safety during the production.

The standard system for these plant factories includes (1) temperature and humidity control, (2) hydroponic culture beds, (3) nutrient solution control (solution temperature, electrical conductivity (EC), pH and dissolved oxygen), and (4) CO_2 concentrations, and/or (5) light source control depending on the plant factory. Control of these environmental elements is performed by using fixed set points, and correctly determining the importance of each set point is a form of expertise. It is also feasible to perform process control involving the automatic regulation of set points in a time sequence to match individual growth stages. Technical issues that warrant attention include the control of feedback to temperature and humidity control, control of feed-forward to the control of solution and of elements including CO_2 concentration, and program control for light source control. Moreover, all plant factories can reduce water consumption via a circulation system with hydroponic cultivation and soilless systems. Merits and demerits of plant factories are summarized in Table 1, in terms of yield, quality, cultivation technology, risk management, resources, labor and cost.

In plant factories with fully artificial light, leafy vegetables (e.g., lettuce, mustard, spinach and herbs) have been grown, that require relatively low light (e.g., approximately 200 μmol m^{-2} s^{-1}) for growth. On the other hand, in plant factories with sunlight as well as plant factories with sunlight and supplemental light, tomato and strawberry, both of which require relatively high light (e.g., approximately 800 μmol m^{-2} s^{-1} and 600 μmol m^{-2} s^{-1}, respectively), have been grown as well as leaf vegetables.

Feasibility Study of Rice Growth in Plant Factory

Sufficient light intensity and appropriate temperature is needed for healthy rice growth. The light saturation point of the photosynthetic rate has been shown to be approximately 800 ~ 1000 μmol m^{-2} s^{-1} at 25°C [5]. When such high light cannot be reached in a growth chamber, rice plants tend to show elongation and a lower fertility rate. The optimal temperature for growth also differs depending on the growth stage (Table 2) [6]. It has been reported that the optimal temperature for the photosynthetic rate in rice leaves is approximately 30°C [7,8]. Generally speaking, it has been considered that the optimal temperature for rice growth can range from 25-30°C and for rice ripening can range from 20-25°C with several degrees difference between day and night.

In general paddy fields, it takes approximately 120 days from sowing to harvesting, and rice can only be grown from spring to autumn once every year. In plant factories with sunlight and supplemental light, rice could be grown more than 2 ~ 3 times per year, even in winter. On

Merit
* The yield aspect → Maximization of production per unit area (e.g., multi-shelf system and transplanting system depending on plant size) → Increases in annual yield via the improvement of plant growth by environmental control → Year-round or extended growing seasons irrespective of region and season → No damage from monocropping with hydroponic cultivation and soilless systems → Flexible changes in production of crop species → Can grow plants in regions where field production is difficult or impossible
* The risk management
→ Stable production unaffected by abnormal weather (e.g., high and low temp.) and disasters (e.g., long rain, typhoon, snowfall) → Easy to make an annual contract with supermarkets and restaurants because of the stable and planned production → Can select the plant characteristics with high-yielding and superior taste rather than with higher stress tolerance
* The quality side
→ Can produce pesticide-free vegetables (in a closed facility) → Can cultivate and utilize transgenic plants (in a closed facility) → Can produce vegetables with high nutritive value by control of the nutrient solution → Can create a long shelf life because of the low viable bacterial cell number → Can produce vegetables with same size, shape, taste and nutritive value under stable production
* The labor
→ Standardization of cultivation techniques for light work, as well as safe and easy work → A physically handicapped person and/or Elderly people can work → Can work without harm on the rainy days and at night → Easy labor savings and automation for cultivation techniques → Can employ for 1 year contracts on employment period → Can reduce and spread out the busy farming season
* The resources
→ Can reduce water consumption → Can reduce environmental burden via a circulation system for nutrient solutions
Demerit
* The cost aspect
→ Higher construction cost
→ Higher cost of facilities for lighting (e.g., LED) and environmental control system (e.g., air conditioner)
→ Higher running cost, especially for electricity bill for lighting and air conditioner
* The crop variation aspect
→ The crop species is limited to leaf vegetables
* The cultivation technology
→ Crops are annihilated once pathogenic bacteria contaminate the hydroponic system
→ Pollination by plant hormone manually and/or the use of pollinator (e.g., bumblebee) is needed
→ Unwholesome chemicals (e.g., nitrate nitrogen) are accumulated in crops under poor nutrient management in hydroponic system
* The management
→ Higher knowledge needed for successful control of plant factory
→ Computerized environmental control is complex and still not perfected
* The resources
→ Higher energy use for running environmental control system (e.g., lighting and air conditioner)

Table 1: Merits and demerits of plant factories.

the other hand, in plant factories with fully artificial light where light irradiance and growth temperature can be highly regulated, it would take approximately 90 days from the transplanting of rice seedlings to harvesting (Figure 2). Therefore, it would be possible to grow rice 4 ~ 5 times per year, leading to a large increase in rice production per unit area. At present, crops including rice and wheat are rarely grown in plant factories with fully artificial light, because of the plant height and the long harvesting time, and thus it would be unprofitable. In the next section, the preferred type of rice plant factories with fully artificial light is summarized.

i) Method for rearing rice seedling

Since seedling growth is easily influenced by environmental conditions, the use of artificial light for seedling growth would be adopted rapidly. A closed production system, which is called Nae-Terasu ("seedling-terrace"; Mitsubishi Plastics Agri Dream Co., Ltd.), has been used to produce high-quality seedlings. The main advantage to using Nae-Terasu for seedling growth is the ability to regulate environmental conditions easily and precisely, since it can automatically control light environment (e.g., light intensity, light wavelength, direction of light, day-length), temperature, humidity, air flow, CO_2 concentration, water and nutrient solution.

Using Nae-Terasu water consumption for plant growth can be highly reduced because of 1) the circulation system for hydroponic cultivation and soilless systems, and 2) the collection and re-use of water, which plants transpired, via the cooling coil of the air conditioner. Moreover, the consumption of chemical fertilizer can be minimized, and it is possible to prevent the discharge of fertilizer to the outside because of the hydroponic circulation system. In these systems, it is easy to prevent invasion of pests and pathogenic microorganisms making it possible to grow plants pesticide-free. In addition, Nae-Terasu have a lower production cost since the multi-shelf system has a more available space for seedling growth compared to on-site areas of the facility. Since seedlings need relatively low light for their growth, the energy use of

Citation: Yamori W, Zhang G, Takagaki M, Maruo T (2014) Feasibility Study of Rice Growth in Plant Factories. J Rice Res 2: 119. doi: 10.4172/jrr.1000119

	Critical temperature[a]		
Growth stage	Low (°C)	High (°C)	Optimal (°C)
Germination	10	45	20-35
Seedling emergence & establishment	12-13	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Initiation of panicles primordia	15	-	-
Panicle differentiation	15-20	38	-
Anthesis	22	35	30-33
Ripening	12-18	30	20-25

The data is adapted from Yoshida (1981) [6]
[a]Refers to daily mean temperature except for germination

Table 2: Response of rice plants to varying temperatures at different growth stages. The critically low and high temperatures, normally below 20°C and above 30°C, vary from one growth stage to another. These critical temperatures differ according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant. There is usually an optimal temperature for different physiological processes and these vary to some degree with variety. Therefore, the results of an experiment depend on the variety used and on whether the range of temperatures studied is above or below the optimum.

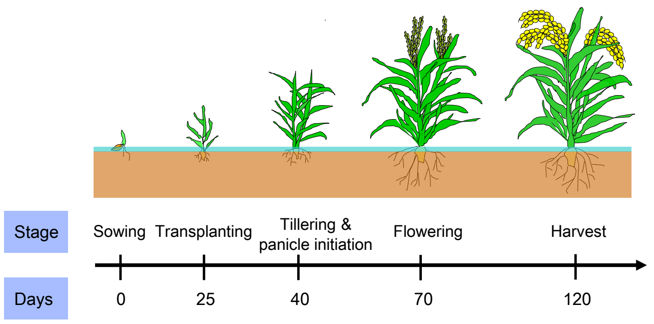


Figure 2: Rice growth. It takes approximately 120 days from sowing seeds to harvesting in general paddy fields. On the other hand, if we transfer rice seedlings at 25 days after seed germination into a plant factory with fully artificial light, it takes approximately 90 days from transplanting of rice seedling to harvesting. Therefore, it would be possible to grow rice 4 ~ 5 times per year.

lighting and air conditioning due to the heat can be suppressed.

ii) Method for rearing mature rice

When rice plants are cultivated in plant factories, we do not have to worry about seasons. Moreover, it is possible to create an ideal environment to bring out the maximal production in plants since the environmental conditions (e.g., light, temperature, and humidity) can be effectively controlled in the plant factory.

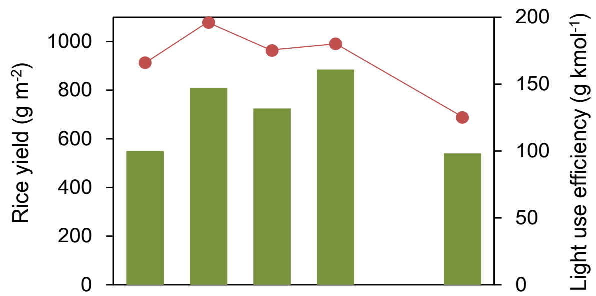
Effects of light intensity, temperature and plant density on rice yield have been examined (Figure 3) [9]. Rice was grown for 28 days after sowing in a seedling-growth room, then transferred to an environmentally controlled chamber and further grown until harvest for approximately 95 days. Light use efficiency, evaluated from rice yield divided by irradiated light energy, was 34~58% greater in the plant factory than in the paddy field. As a result, rice yield in the plant factory is improved up to 65% compared to the paddy field. This experiment indicates that it is possible to grow rice at least 3 ~ 4 times per year with this system and annual production can be approximately 5 times greater than the paddy field.

The sophisticated artificial lighting system makes use of several different types of lighting: LEDs, fluorescent bulbs, and high pressure sodium lights. The wavelengths and intensity of the lights can be controlled to provide the optimal environment for the type of plant that is being grown. The system can even mimic the bright summer sun, allowing crops like rice and corn, which require strong light and thus were difficult to grow in conventional factories, to be cultivated. Particularly, improvements of LED lights are progressing rapidly, and high outputs have been realized. A LED panel unit which achieves the output of more than a PPFD of 1000 μmol m^{-2} s^{-1} has been marketed, and it is now possible to grow rice by LED light. High intensity discharge lamp could not irradiate plants at short-distance, but LED light can. Therefore, LED lights are needed for the development of a rice plant factory which has a multi-shelf rice cultivation system. Moreover, as it is possible to irradiate a combination of light of the singular wavelengths with LED light, we can optimize wavelength control, pulse irradiation of LED light and so on, depending on the growth stage of the rice. Thus, it is highly possible to achieve production levels greatly surpassing anything achieved to date.

One important technology in a plant factory is space-use technology to effectively utilize the space. This automatically regulates furrow spacing by taking into account the increase in the plant size as it grows. In addition, there are several important objectives that need to be achieved by the plant factory: to be able to automize the rice production, plant factories will be equipped with many machine systems, including seeders, transplant carriers, transplanters, pest control machines, harvesters, graders, and packing machines. Fully automatic and intelligent technology (involving the greater use of robots) may be considered as the next step to be taken for these machine systems.

New Effective Means for Rice Growth in Plant Factories

It would soon be possible to set up an efficient cultivation system



Light intensity (μmol m^{-2} s^{-1})	800	1000	1000	1200		Paddy Field
Rice density (Number m^{-2})	120	90	120	120		
Integral of light (kmol m^{-2})	3.3	4.1	4.1	4.9		4.3
Averaged air temp. (ºC)	25	25	25	25		24

Figure 3: Effects of light intensity, temperature and plant density on rice yield, adopted from Nakajima (2012) [9]. Rice plants were grown for 28 days after sowing seeds, then transferred into an environmentally controlled chamber and grown until their harvest. Rice yield as well as light use efficiency which is calculated from rice yield divided by irradiated light energy are shown in the figure. Light intensity (PPFD, μmol m^{-2} s^{-1}), rice density (number m^{-2}), integral of light intensity (kmol m^{-2}) and the averaged air temperature for plant growth (°C) are also summarized.

for the Rice Plant Factory with fully artificial light. Is it possible to run a Rice Plant Factory with operating income? It would be difficult to run a plant factory using general rice varieties, even if the rice yield per unit area can be greatly improved. As stated above, it takes a long time until harvest and also the use of current multi-shelf systems is unavailable due to the higher plant height. As a result, the running cost, especially for electricity and air conditioning, is expected to be high, and thus unprofitable. Therefore, to grow rice in plant factories would be difficult, unless rice has the specific benefit for its quality. An effective means for growing rice in plant factories would be to cultivate and utilize transgenic rice plants with high specific protein content via genetic engineering technologies. It is now possible to establish a plant based platform to grow transgenic rice. The most common type of genetic modification involves boosting the resistance of crops to pests and disease, but it is now also possible to use the technology to develop new drugs and treat genetic disorders since the technology makes it possible to obtain cultivars with precisely the desired characters.

Biopharmaceuticals have traditionally been produced using a variety of transgenic systems, including cultured mammalian cells, bacteria and fungi [10-12]. Producing therapeutic proteins in plants has many economic and qualitative benefits, including reduced health risks from pathogen contamination, comparatively high yields and production in seeds or other storage organs [11]. Trials to produce useful products in genetically-modified plants have been done [13-17], with some already commercialized. It has been called 'molecular farming'.

Nicotiana tabacum has been widely used as a model expression system to produce recombinant pharmaceuticals in plants. Proteins can achieve high expression levels due to the high copy-number of transgenes per cell. It has been reported that an expression level of up to 30% of total soluble protein for an animal vaccine can be produced in transgenic tobacco plants [18]. Other plants have also been used, including rice [11,19,20], wheat [20], maize [21] and oilseed rape [22-24], since it is considered that full-scale commercial production could involve grain and oilseed crops. The production of vaccines, antibodies and biopharmaceuticals in transgenic plants has been summarized in a previous review article [14]. Recently, in Japan, the National Institute of Advanced Industrial Science and Technology (AIST) plant factory grows strawberries that have been implanted with canine interferon genes and uses these specially modified strawberries to manufacture a treatment for canine periodontal disease for dogs (http://www.aist.go.jp/index_en.html). Every step of the production processes, from growing transgenic plants to processing them into drugs, can be completed within a closed plant factory on the same site. In addition to strawberries, the factory has also succeeded in growing a number of other promising transgenic plants, including potatoes that express a vaccine against avian influenza, and rice and tobacco plants that express a cholera vaccine.

Production in cereal crop seeds has already been demonstrated to increase the yield of recombinant proteins based on the established expression system using a strong seed-specific promoter, codon optimization, and a specific host reducing storage proteins and depositing into protein bodies [25-27]. Furthermore, protein productions in rice seeds have the additional benefit of high biomass yield with a minimal risk of outcrossing. In addition, recombinant proteins produced in seeds become desiccated and could remain intact for long periods [20,28-30], making seeds a convenient method of storing, distributing, and administering biopharmaceuticals and vaccines [20,28]. Rice is commonly eaten in grain form without first being pulverized. This would make it easy to control intake, as with medicines in pill form. In addition, in places where rice is eaten as a staple, it is possible to ensure regular intake. Ordinarily, vaccines would be administered by injection, but oral administration of pills is easier and less stressful to animals and it is cheaper too, since no needles or other medical appliances are needed. The oral or other mucosal vaccinations appear to have fewer side effects than vaccines administered by injection [31,32]. Moreover, plants are potentially a cheap source of recombinant products [28,29,33]. It has been estimated that the cost of producing recombinant proteins in plants could be 10 to 50 fold lower than producing the same protein by *Escherichia coli* fermentation [34]. Therefore, transgenic plants are an ideal platform for the production of high value recombinant proteins, such as pharmaceuticals, vaccines and antibodies [35-37]. Thus, the use of transgenic plants in the plant factory can expand further possibilities and choices to utilize the plant factory with fully artificial light.

Strides for Success to Run a Plant Factory

There are some concerns to running a plant factory (see, demerits of plant factories in Table 1). The present main issues have been summarized below.

i) High initial investment and running cost

A lot of money needs expended on the construction of the plant factory and the supporting facilities (i.e., installations of LEDs, the hydroponic system and the environmental control system). Moreover, electric consumption is another serious problem during plant production. In a plant factory, the major electric consumption elements are lighting (e.g., LEDs) and air conditioning (e.g., heat pumps), although both LEDs and heat pumps are required during the whole growth period of plants. To realize a cost reduction for the construction and the supporting facilities will be necessary.

ii) Space constraint for rice plant growth

Rice plants can grow to 1.0 - 1.8 m tall depending on the variety and region. Nowadays, a plant factory is used for vegetables production, especially for leafy vegetables since they are short and compact, which can be easy to manage and harvest. A multi-shelf system is the staple cultivation system for vegetables in plant factories. Cultivating rice in a plant factory will face the challenge of space limitations.

iii) Optimization of plant growth conditions

Plant factories are the optimal platform for plant cultivation. The intelligent environmental control in the plant factory will offer an opportunity for rice to grow fast and enrich a specific protein by regulating the combination of light (intensity, wavelength and day-length), temperature, humidity, CO_2 concentration and nutrients.

iv) New rice breeding for cultivation in Plant factories

The environmental conditions in plant factories are much different from those in the paddy field, can be well optimized for plant growth, and there should be no pests and diseases. Therefore, there is no need to hold disease resistance, insect resistance and environmental stress tolerance for heat, cold or drought stress, as plants have been traditionally selectively bred for. So, new rice breeding for growth in plant factories will be necessary.

Since various environmental conditions can be highly regulated in the plant factory, it has been considered that various potential abilities of the plant can be exploited, leading to greater crop yield. The use of transgenic plants in the plant factory can further expand the possibilities and choices to utilize plant factories. As rice can be successfully cultivated in hydroponics, in the near future it will be possible to produce hydroponic rice in plant factories without the limitations of space and environment, and increase rice quality and productivity at the same time. It is expected that new industrial developments for the production of pharmaceutical products via genetically-modified plants and/or any material production will make full use of plant factories.

Acknowledgement

This research was supported by the Japan Science and Technology Agency, PRESTO (to W.Y.) and by a grant from the Japan Society for the Promotion of Science (Scientific Research No. 25891005 to W.Y.).

References

1. Godfray HC, Beddington JR, Crute IR, Haddad L, Lawrence D, et al. (2010) Food security: the challenge of feeding 9 billion people. Science 327: 812-818.
2. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, et al. (2011) Solutions for a cultivated planet. Nature 478: 337-342.
3. Kozai (2013) Plant factory in Japan - current situation and perspectives. Chronica Horticulturae 53: 8-11.
4. Moon A, Lee S, Kim K (2012) Design of a Component-based Plant Factory Management Platform. The Fourth International Conferences on Advanced Service Computing: 24-28.
5. Makino A, Nakano H, Mae T (1994) Responses of Ribulose-1,5-Bisphosphate Carboxylase, Cytochrome f, and Sucrose Synthesis Enzymes in Rice Leaves to Leaf Nitrogen and Their Relationships to Photosynthesis. Plant Physiol 105: 173-179.
6. Yoshida S (1981) Fundamentals of rice crop science. IRRI, Los IRRI, Los Banos, Philippines, Pp69-84.
7. Yamori W, Noguchi K, Hikosaka K, Terashima I (2010) Phenotypic plasticity in photosynthetic temperature acclimation among crop species with different cold tolerances. Plant Physiol 152: 388-399.
8. Yamori W, Noguchi K, Hikosaka K, Terashima I (2009) Cold-tolerant crop species have greater temperature homeostasis of leaf respiration and photosynthesis than cold-sensitive species. Plant Cell Physiol 50: 203-215.
9. Nakajima (2012) Rice plant factory with artificial light. In Agri-Photonics II Advances in Plant Factories with LED Lighting CMC Publishing Co. Ltd 161-168.
10. Ma JK, Vine ND (1999) Plant expression systems for the production of vaccines. Curr Top Microbiol Immunol 236: 275-292.
11. Ganz PR, Dudani AK, Tackaberry ES, Sardana R, Sauder C et al. (1996) Expression of human blood proteins in transgenic plants: the cytokine GM-CSF as a model protein. In Transgenic plants: a production system for industrial and pharmaceutical proteins. Pp 281–297.
12. Pen J, Meran RL (1996) Comparison of host systems for the production of recombinant proteins. In Transgenic plants: a production system for industrial and pharmaceutical proteins. Pp 149-167.
13. Daniell H, Streatfield SJ, Wycoff K (2001) Medical molecular farming: production of antibodies, biopharmaceuticals and edible vaccines in plants. Trends Plant Sci 6: 219-226.
14. Giddings G, Allison G, Brooks D, Carter A (2000) Transgenic plants as factories for biopharmaceuticals. Nat Biotechnol 18: 1151-1155.
15. Tacket CO (2005) Plant-derived vaccines against diarrheal diseases. Vaccine 23: 1866-1869.
16. Walmsley AM, Arntzen CJ (2003) Plant cell factories and mucosal vaccines. Curr Opin Biotechnol 14: 145-150.
17. Horn ME, Woodard SL, Howard JA (2004) Plant molecular farming: systems and products. Plant Cell Rep 22: 711-720.
18. Molina A, Hervas-Stubbs S, Daniell H, Mingo-Castel AM, Veramendi J (2004) Highyield expression of a viral peptide animal vaccine in transgenic tobacco chloroplasts. Plant Biotechnology Journal 2: 141-153.
19. Burkhardt PK, Beyer P, Wunn J, Klöti A, Armstrong GA, et al. (1997) Transgenic rice (Oryza sativa) endosperm expressing daffodil (Narcissus pseudonarcissus) phytoene synthase accumulates phytoene, a key intermediate of provitamin a biosynthesis. Plant J 11: 1071-1078.
20. Stöger E, Vaquero C, Torres E, Sack M, Nicholson L, et al. (2000) Cereal crops as viable production and storage systems for pharmaceutical scFv antibodies. Plant Mol Biol 42: 583-590.
21. Zhong GY, Peterson D, Delaney DE, Bailey M, Witcher DR, et al. (1999) Commercial production of aprotinin in transgenic maize seeds. Mol. Breeding 5: 345-356.
22. Boothe JG, Parmenter DL, Saponja JA (1997) Molecular farming in plants: oilseeds as vehicles for the production of pharmaceutical proteins. Drug Develop Res 42: 172-181.
23. Goddijn OJM, Pen J (1995) Plants as bioreactors. Trends Biotechnol 13: 379-387.
24. Vandekerckhove J, VanDamme J, VanLijsebettens M, Botterman J, DeBlock M, et al. (1989) Enkephalins produced in transgenic plants using modified 2S storage proteins. Bio/Technology 7: 929-932.
25. Stoger E, Ma JK, Fischer R, Christou P (2005) Sowing the seeds of success: pharmaceutical proteins from plants. Curr Opin Biotechnol 16: 167-173.
26. Lau OS, Sun SS (2009) Plant seeds as bioreactors for recombinant protein production. Biotechnol Adv 27: 1015-1022.
27. Kawakatsu T, Takaiwa F (2010) Cereal seed storage protein synthesis: fundamental processes for recombinant protein production in cereal grains. Plant Biotechnol J 8: 939-953.
28. Whitelam GC (1995) The production of recombinant proteins in plants. J Sci Food Agric 68: 1-9.
29. Moloney MM (1995) Molecular farming in plants: achievements and prospects. Biotechnol Eng 9: 3-9.
30. Nochi T, Takagi H, Yuki Y, Yang L, Masumura T, et al. (2007) Rice-based mucosal vaccine as a global strategy for cold-chain- and needle-free vaccination. Proc Natl Acad Sci U S A 104: 10986-10991.
31. Kim HD, Cao Y, Kong FK, Van Kampen KR, Lewis TL, et al. (2005) Induction of a Th2 immune response by co-administration of recombinant adenovirus vectors encoding amyloid beta-protein and GM-CSF. Vaccine 23: 2977-2986.
32. Ishii-Katsuno R, Nakajima A, Katsuno T, Nojima J, Futai E, et al. (2010) Reduction of amyloid beta-peptide accumulation in Tg2576 transgenic mice by oral vaccination. Biochem Biophys Res Commun 399: 593-599.
33. Parmenter DL, Boothe JG, van Rooijen GJ, Yeung EC, Moloney MM (1995) Production of biologically active hirudin in plant seeds using oleosin partitioning. Plant Mol Biol 29: 1167-1180.
34. Kusnadi AR, Nikolov ZL, Howard JA (1997) Production of recombinant proteins in transgenic plants: Practical considerations. Biotechnol Bioeng 56: 473-484.
35. Daniell H, Singh ND, Mason H, Streatfield SJ (2009) Plant-made vaccine antigens and biopharmaceuticals. Trends Plant Sci 14: 669-679.
36. Sharma AK, Sharma MK (2009) Plants as bioreactors: Recent developments and emerging opportunities. Biotechnol Adv 27: 811-832.
37. Tiwari S, Verma PC, Singh PK, Tuli R (2009) Plants as bioreactors for the production of vaccine antigens. Biotechnol Adv 27: 449-467.

Citation: Yamori W, Zhang G, Takagaki M, Maruo T (2014) Feasibility Study of Rice Growth in Plant Factories. J Rice Res 2: 119. doi: 10.4172/jrr.1000119