Innovation in agriculture: plant factories with artificial light

Plant factories with artificial light (PFAL) are used in Japan for commercial production of leaf vegetables. Their annual productivity per unit area is roughly 100-fold that in open fields. PFAL can be built anywhere and in any building, because they use neither solar energy nor natural soil and productivity is not affected by climate or soil fertility. In the near future, PFAL will play an important role in local production and consumption of healthy, safe vegetables and other short-height crops in large cities. The current status of PFAL in Japan is introduced and the principles, characteristics, possibilities, and challenges are discussed below.

Concept of PFAL

A PFAL is a plant production facility consisting of six components: a thermally insulated, airtight warehouse-like opaque structure; four to 20 tiers (layers) equipped with hydroponic culture beds; lighting devices such as fluorescent and LED lamps; air-conditioners with air fans; CO_2 supply unit, nutrient solution supply unit with water pumps; and environment control unit (Figure). High-quality plants are produced without pesticides year round, regardless of weather, by controlling aerial and root-zone environments optimally. Vegetables produced in PFAL are so clean that washing is not needed before cooking or processing. The life span of the vegetables after harvest is more than two-fold longer than that of those produced in a greenhouse.

Commercialization and cost performance of PFAL in Japan

As of March 2012, Japan had 106 PFALs for commercial production of leaf vegetables; that number will increase to over 150 by March 2013. The largest PFAL in Japan produces around 25,000 lettuce heads per day or nine million per year. In addition to PFAL for leaf vegetables, facilities of 15–100 m^2 for commercial seedling production were in use at about 150 different locations in Japan as of October 2012. About 20% of PFAL are profitable, 60% break even, and 20% lose money. Depreciation accounts for roughly 30%, labor 25%, and electricity 20% of total production costs. Initial setup and operating costs are expected to decrease by around 50% within 10 years.

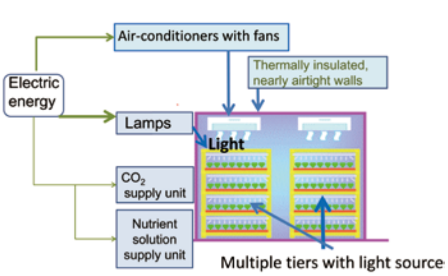

Figure. Main components of PFAL. Most components are mass produced at low cost and suitable for later reuse.

PFAL at Chiba University operated by Mirai Co., Ltd.

A PFAL on the Kashiwa-no-ha campus of Chiba University has been operated commercially since July 2011 by Mirai Co., Ltd. Its total floor area and area for cultivation are 406 m^2 and 356 m^2, respectively, with 10 tiers and nine rows (Photo.). This PFAL produced approximately 3,000 lettuces daily or one million heads annually as of November 2012.

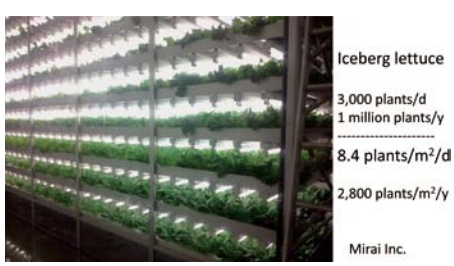

Photo. PFAL on the Kashiwa-no-ha campus (floor area for cultivation: 356 m^2, 10 tiers, 9 rows).

Research in progress

Research has been conducted to reduce the initial and operating costs by producing higher-quality, higher-yielding plants with fewer inputs (electricity, water, fertilizer, labor, etc.) and less emission of environmental pollutants (waste water, garbage, CO_2, etc.). Use of LEDs will soon improve the cost performance of PFAL considerably. Improving the lighting system is an important research subject for expanding PFAL commercialization. Extensive PFAL R&D is underway in the ROC, ROK, and PR China.

Plants suitable for PFAL production

Plants produced in PFAL need to be short because the distance between tiers is around 40 cm for maximum use of air space. For commercial production, plants should grow well at relatively low light intensity and high planting density, and most parts (leaves, stems, roots) should be edible or sell at a high price. These include transplants/seedlings of all kinds, leaf vegetables, herbs, root crops, medicinal plants, miniature ornamentals, and bedding plants. Staples like rice, wheat, and potatoes are not suitable for PFAL production.

Relative annual productivity and sales volume of PFAL

The relative annual productivity of leaf vegetables per unit PFAL area with 10 tiers is roughly 90-fold (= 10 × 2 × 2 × 1.5 × 1.5) and its sales volume is over 100-fold (= 90 × 1.2) compared with open fields (Table).

Table. Estimated relative annual productivity of PFAL per unit area versus open fields.

PFAL compared with open fields	Factor	Multiplication factor
10-fold using10 tiers	10	10
2-fold by shortening the culture period from seeding/transplanting to harvesting by half	2	20
2-fold by extending the annual duration of cultivation to year-round production with virtually no time lost between harvest and next seeding/transplanting	2	40
1.5-fold by increased planting density	1.5	60
1.5-fold by lack of damage due to typhoons, heavy rain and drought, and pest infestations	1.5	90
1.2-fold by improved quality and less loss of fresh produce	1.2	108

Increased demand from the food service industry

Currently, most vegetables and herbs produced in PFAL are sold to the food service industry including home meal-replacement businesses. Costs for hygienic processing are significantly reduced for PFAL-produced vegetables, because no pesticides, dust, or insects are present. PFAL-produced spinach is now used to produce paste for baby food and food for the elderly and hospitalized. In future, PFAL will also produce Chinese chives, Chinese cabbage, and raw materials for pickles and frozen food. PFAL-produced herbs and medicinal plants can be used as food and drink additives, traditional medicines, supplements, cosmetics, etc.

Resource saving with PFAL

Essential resources for photosynthesis in PFAL are light energy, water, CO_2, and inorganic fertilizer. However, electricity is needed to provide light and control the temperature and nutrient solution. These account for around 80%, 15%, and 5%, respectively, of total electricity consumption in the cultivation room. PFAL are well insulated, airtight, and cooled with air-conditioners even in the coldest season because significant amounts of heat are generated by lamps. At night, 30–40% of the lamps remain on to reduce daytime costs for lighting and cooling. About 95% of water vapor evaporated from leaves is collected as condensation on cooling panels of air-conditioners. The condensation is recycled to nutrient solution tanks; the nutrient solution in culture beds and tanks is also recirculated, resulting in minimal water and inorganic fertilizer losses.

PFAL must be airtight because the CO_2 concentration is kept at 1,200–2,000 ppm (three to five times higher than that of outside air) to promote photosynthesis and growth, prevent insects and dust from entering, and minimize the effects of weather. By keeping PFAL airtight, CO_2 supplied for photosynthesis is efficiently absorbed by plants. Energy use efficiency of plants in PFAL is several times higher than in greenhouses and is expected to improve further.

Challenges in PFAL

Future challenges in PFAL include: 1) life cycle assessment; 2) applications in hotels, restaurants, hospitals, schools, community centers, etc.; 3) lighting system and light quality improvement; 4) automation and development of integrated environment control and total management systems; 5) integration with other bioproduction and resource recycling systems; 6) production of medicinal and other functional plants; 7) third-party safety and security evaluations; 8) streamlining outdoor agriculture/protected horticulture, natural energy, and IT; and 9) universal/barrier-free design of PFAL.

Professor Emeritus Toyoki Kozai obtained a PhD in Agricultural Engineering from the University of Tokyo in 1972. He then worked on greenhouse light environments, energy saving, heat pump applications, ventilation, and computer control. His scientific interest subsequently extended to in vitro environments and their control. After serving as president of Chiba University, 2005–2008, Prof. Kozai returned to research at the Center for Environment, Health and Field Sciences, Chiba University, focusing on medicinal plant production. Since 2010, he has been chief-director of the nonprofit Japan Plant Factory Association.