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URBAN AG NEWS

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URBAN AG NEWS

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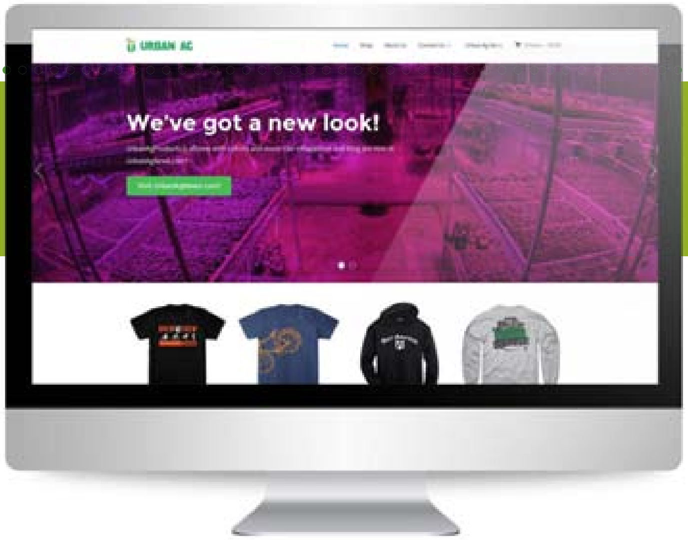

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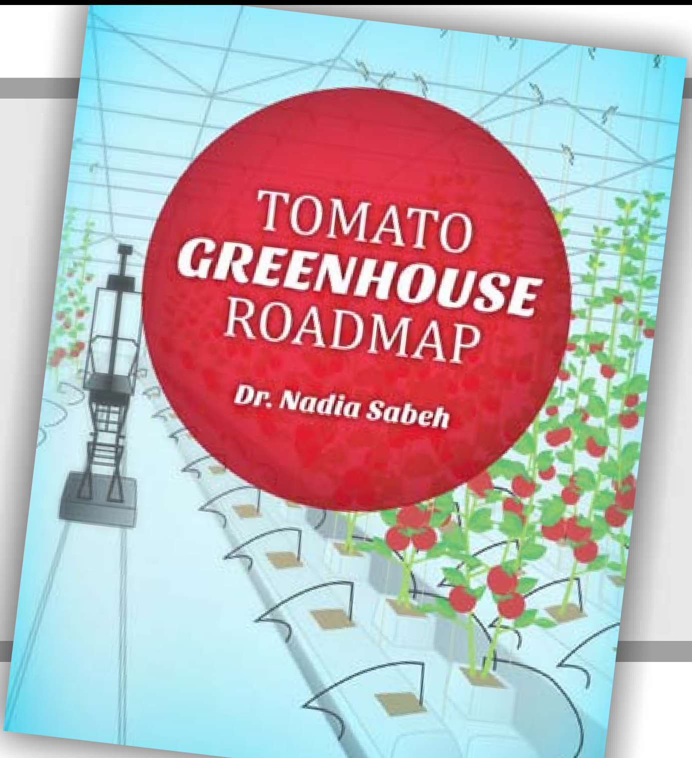
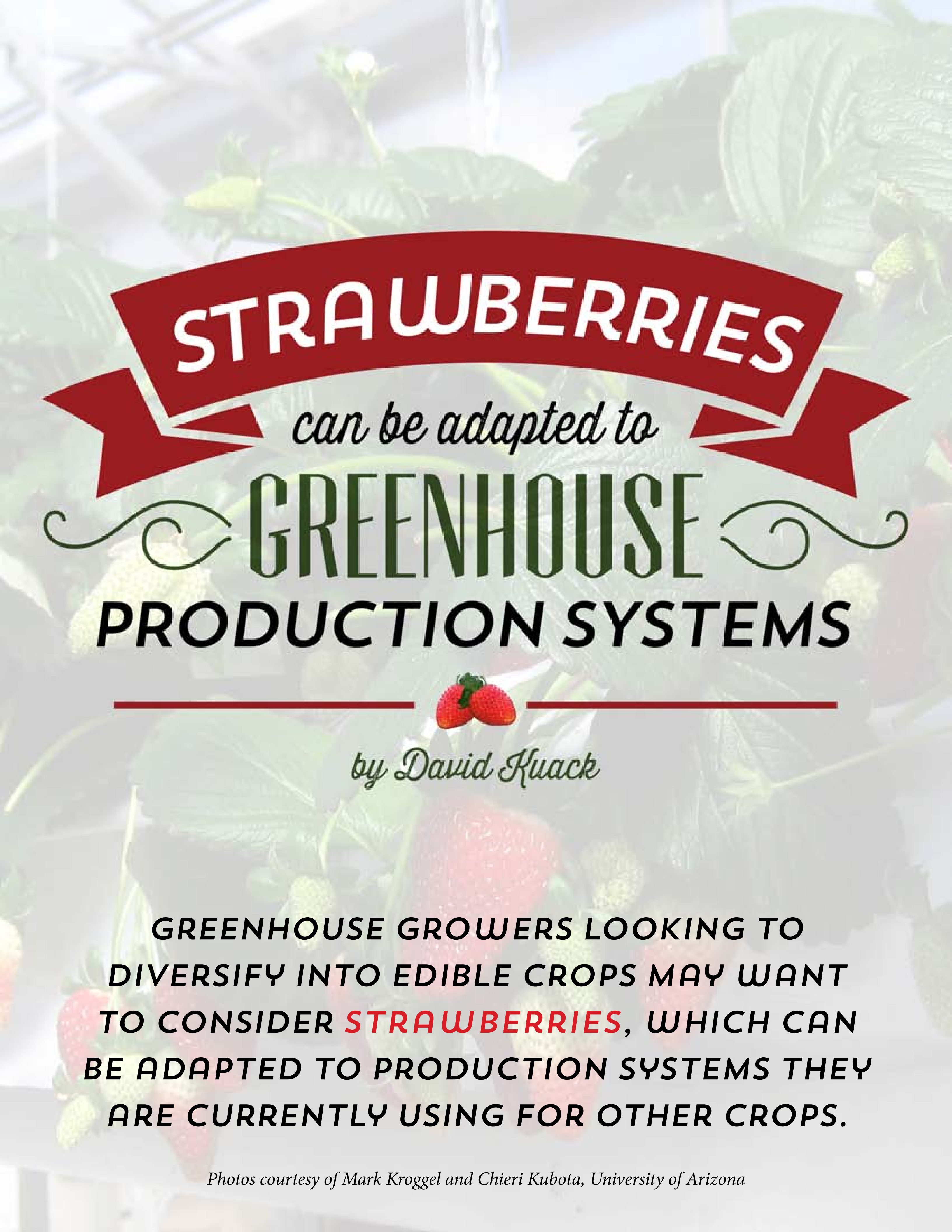




STRAWBERRIES can be adapted to GREENHOUSE PRODUCTION SYSTEMS

by David Kuack

GREENHOUSE GROWERS LOOKING TO DIVERSIFY INTO EDIBLE CROPS MAY WANT TO CONSIDER STRAWBERRIES, WHICH CAN BE ADAPTED TO PRODUCTION SYSTEMS THEY ARE CURRENTLY USING FOR OTHER CROPS.

Photos courtesy of Mark Kroggel and Chieri Kubota, University of Arizona

Greenhouse growers looking to diversify their product mix with a fall to spring edible crop might want to consider strawberries.

"There is still a pretty big hole in the strawberry supply chain for November, December and January," said University of Arizona research specialist Mark Kroggel. "In Arizona, we can produce good quality strawberries in greenhouses from October through April. The best greenhouse strawberry yields occur during March and April.

"Off-season greenhouse strawberry production is trying to accomplish two things: Fill a void in the local supply. And more importantly, produce a premium product. Greenhouse strawberries are going to be better tasting than the field-grown strawberries consumers find in grocery stores at this time of year. Consumers should be willing to pay a premium price for these highly flavored greenhouse berries."

USE EXISTING PRODUCTION SYSTEMS

Kroggel said one of the advantages of growing greenhouse strawberries is they can be adapted to existing production systems.

"Growers should use their existing production systems and try to make them work," he said. "They are familiar with how their systems work. This also helps to minimize investment costs.

"In most cases, strawberries are going to be different than anything else that growers have produced before. But strawberries are adaptable to all types of growing systems. Growers need to start with what they have so that they can learn as much as they can about the plants. They need to become familiar with how strawberries grow. That's going to take a couple of years. Then if growers want to switch to a different, more expensive production system designed for strawberries, they can."

TEMPERATURE CONTROL IS CRITICAL

Strawberries grown in greenhouses prefer day temperatures below 77ºF (25ºC), which Kroggel said is a temperature that works for many food crops. The ideal temperature range for strawberries is 65ºF-77ºF (18ºC -24ºC).

"The temperature shouldn't go much above 77ºF because higher temperatures can negatively affect growth," he said. "Night temperature is much more important for strawberries. We try to maintain night temperatures between 50ºF-54ºF (10ºC-12ºC). Being able to maintain the temperature below 59ºF (15ºC) at night is critical for strawberries because higher night temperatures result in lower quality due to respiration in the fruit.

"If greenhouses cannot be cooled to 59ºF or lower at night, fruit quality is going to be drastically affected. Primarily the acidity will be too high, the Brix (sugar content) will be too low and the surface of the fruit will

ONE OF THE ADVANTAGES OF GROWING GREENHOUSE STRAWBERRIES IS THEY CAN BE ADAPTED TO EXISTING PRODUCTION SYSTEMS.

be off. The strawberry starts to get mealy or soft. The texture, sweetness and acidity are all affected by the temperature."

Kroggel said greenhouse strawberries are typically grown in the United States from the fall through the spring. He said most growers wouldn't be producing strawberries in a greenhouse during the summer because of the competition from field-grown crops.

"There are greenhouse growers in Europe who produce strawberries year-round, but they have a climate that is more amenable to that type of production," he said. "Day temperatures are less important than night temperatures in regards to fruit quality.

"We can grow a crop later in the spring when the outside day temperature can reach 95ºF-100ºF, but because of the low humidity in Arizona, we can still cool the greenhouse temperature to 75ºF during the day and 59ºF or cooler at night. We can maintain the fruit quality. In most U.S. locations, growers should be able to maintain the required cooler night temperature during the fall to spring period."

ENSURING ADEQUATE LIGHT LEVELS

Kroggel said growers interested in producing greenhouse strawberries should be able to provide a minimum daily light integral (DLI) of 12 moles per square meter per day inside the greenhouse.

"Light levels below 12 moles are most likely too low for strawberries," he said. "The big difference between a fruiting crop and an ornamental flowering crop is that fruit is expensive for the plant to produce. It takes a lot of energy to produce a strawberry or tomato. Ornamental plants can produce leaves and flowers under lower light conditions. Growers in areas that don't receive 12 moles of light from November through February are going to produce a minimal yield of fruit. With reduced light and photosynthetic activity, the plants cannot support as many fruit."

Growers in high light areas like Arizona also need to be concerned about too much light. Kroggel said growers should try to keep light levels below 25 moles per square meter per day.

“We have seen some plant stress when the light level starts to reach 30 moles per day in March,” he said. “That’s when we start to shade the greenhouses.”

HUMIDITY CONTROL TO PREVENT DISEASE, TIPBURN

Kroggel said if the greenhouse humidity level is 85 percent or higher during the day and night, foliar diseases including powdery mildew and Botrytis on the fruit, can occur.

“In those parts of the country where the greenhouses are closed at night there can be a problem of high humidity,” he said. “If it’s too cold, heating can lower the humidity. Venting during the day to allow outside air to enter the greenhouse helps to lower the humidity. That’s standard practice and normal day time humidity is usually manageable.”

If the greenhouse humidity is high, the plant canopy can remain wet if there is not adequate air flow. Kroggel said the horizontal airflow fans in the university’s strawberry greenhouses run continuously and help keep the canopy dry. Because of Arizona’s low humidity levels, he said fog has to be used in the greenhouses at night during certain times of the year to raise the humidity in order to prevent tipburn on strawberries.

“We prevent leaf and calyx tipburn by humidifying at night,” he said. “We try to maintain 95 percent humidity inside the plant canopy for three hours at night. Typically that creates a high enough night humidity to prevent tipburn, but is not a long enough time to promote disease.”

Tipburn in strawberry is caused by calcium deficiency just like in poinsettias and lettuce. Kroggel said strawberry tipburn occurs very early in the leaf and calyx development stage.

“When a leaf is developing, if there isn’t sufficient calcium then leaf tipburn has already occurred before the leaf emerges,” he said. “During the day when transpiration in the plant is high, calcium is moving into the mature leaves and not into the growing tip.”

For plants with a mild case of tipburn, Kroggel said there is probably not going to be much effect on photosynthesis. In severe cases, tipburn could impact the fruit.

“If the tipburn is mild and is not on all the leaves, it is probably not affecting photosynthesis that much,” he said. “If the tipburn is severe, then the area of

Strawberries are adaptable to all types of greenhouse growing systems, including troughs, containers and even hanging baskets.

ONCE DORMANT STRAWBERRY RUNNERS HAVE BEEN PLANTED AND PRODUCE SIX LEAVES, PLANTS SHOULD HAVE A GOOD ROOT SYSTEM AND ENOUGH FOLIAGE TO SUPPORT FLOWER PRODUCTION.

JUNE-BEARING STRAWBERRY VARIETIES REQUIRE SHORT DAYS IN ORDER TO INITIATE FLOWERING. EVER-BEARING VARIETIES PREFER LONGER DAYS AND SUPPLEMENTAL LIGHTING HELPS TO PROMOTE FLOWERING.

photosynthetic activity is being impaired. Over half the leaves may not be working properly.

"If tipburn occurs on the calyx of the fruit, then most consumers are not going to want to purchase the fruit. The fruit itself might be beautiful, but most consumers won't buy it because of the calyx burn. Similar to ornamental plants, a grower is impairing his ability to market the fruit if there is calyx burn."

PHOTOPERIOD CONTROL

Kroggel said like poinsettias and chrysanthemums, strawberries respond to short day conditions. These plants, called June-bearing types, require short days in order to initiate flowering.

"We are growing both June-bearing and ever-bearing strawberry varieties," he said. "Ever-bearing varieties prefer longer days and lighting helps to promote flowering."

Kroggel said 12-13 hours of day light are likely short enough to initiate flowering in most U.S. June-bearing varieties.

"For winter production, if a grower is planting June-bearing varieties in August, by the time the plants start growing and

UNIVERSITY OF ARIZONA RESEARCH SPECIALIST MARK KROGGEL SAID OFF-SEASON GREENHOUSE STRAWBERRY PRODUCTION IS TRYING TO FILL A VOID IN THE LOCAL SUPPLY AND PRODUCE A PREMIUM PRODUCT.

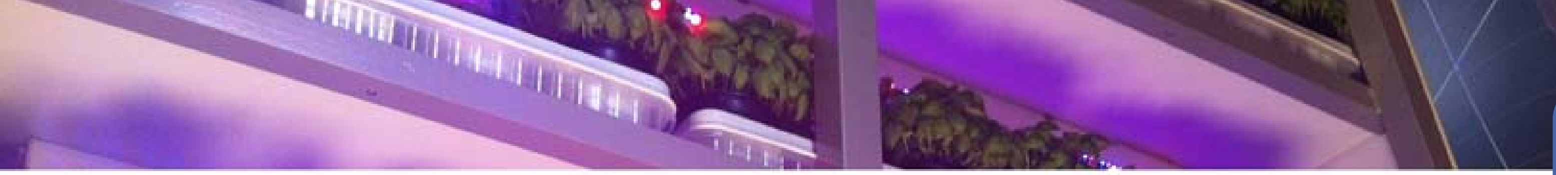
developing there will be 12 hours of light and the plants will begin to initiate flowers," he said. "Then the plants start to fruit naturally because the days are getting shorter. From the time flower initiation occurs until flowers appear takes about a month. From flowers to fruit is about a month. If plants initiate flowers in late September, the fruit should be ready to harvest in December."

Kroggel said in some parts of the world greenhouse strawberry growers provide short day treatments to ensure the plants initiate flowering and produce fruit. Some strawberry growers can pull black cloth just like ornamental plant growers do with poinsettias and mums as long as the temperature under the cloth doesn't get too high. Other growers use temperature-controlled growth chambers to provide short days.

"We do use photoperiodic lighting on ever-bearing varieties to promote flowering because winter days are too short," he said. "Ever-bearing varieties prefer longer days and the lighting helps promote flowering. We use T5 fluorescent lights to do photoperiodic lighting, but we don't do any supplemental lighting. About 3 micromoles per square meter per second at the canopy level is a sufficient amount of light."

For more: Mark Kroggel, University of Arizona, College of Agriculture and Life Sciences, The School of Plant Sciences, Tucson, Ariz.; (520) 626-3928; kroggel@email.arizona.edu. For more information on greenhouse strawberry production: Hydroponic Strawberry Information Website, http://www.cals.arizona.edu/strawberry; Sustainable Hydroponic and Soilless Strawberry Production Systems, https://www.youtube.com/user/sustainablehydro.

David Kuack is a freelance technical writer in Fort Worth, Texas; dkuack@gmail.com.



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LED LIGHTING AT DELISCIOUS

Part of a Dutch television broadcast on Roy Delissen, a greenhouse lettuce grower in the Netherlands who is using LED interlighting to grow his crops.

A NEW INDUSTRY BORN FROM DISASTER

These vegetables have been cultivated
in a good growing environment

A Japanese sustainable hydroponic farming facility uses 99 percent less water than conventional farming.

CHINA'S INDOOR AGRICULTURE INDUSTRY

1/4 OF CHINA'S VEGETABLES COME FROM INDOOR FARMS

They produce **170mn metric tons** of vegetables a year.

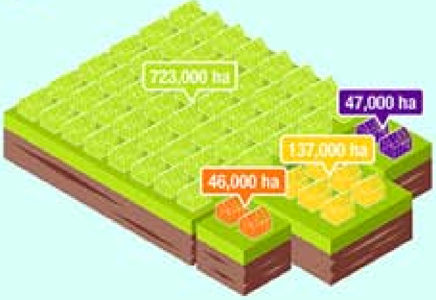
170,000,000 Metric Tons

GREENHOUSES PRODUCE VEGETABLES, MUSHROOMS, FRUIT AND HORTICULTURE SEEDLINGS

Most popular veggies:

Area under greenhouse cultivation from 2006 Indoor Agriculture Census (most recent available):

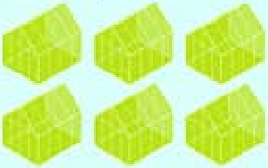
- 🟩 VEGETABLES
- 🟪 HORTICULTURE SEEDLINGS
- 🟨 FRUITS
- 🟧 EDIBLE FUNGI

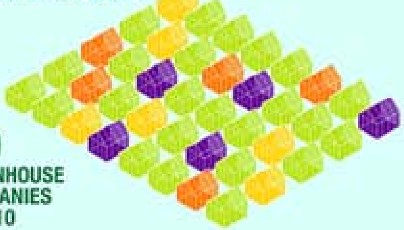


THE INDOOR AGRICULTURE INDUSTRY IS SEEING FAST GROWTH

China had only **5-6 greenhouse companies** in the 1980s, but had nearly **400** by 2010.

5–6 GREENHOUSE COMPANIES in the 1980s

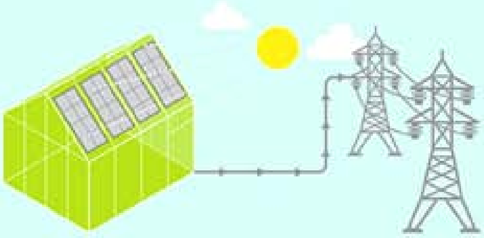




400 GREENHOUSE COMPANIES by 2010

CHINA'S GREENHOUSES ARE GETTING LARGER AND MORE TECHNICALLY SOPHISTICATED

In August 2013, the country's first **solar PV greenhouse** was connected to the electricity grid in Liuge County, Hanchuan.



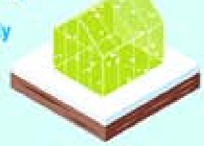
CHINA'S GOVERNMENT ENCOURAGES THE INDUSTRY THROUGH MYRIAD SUBSIDIES FOR NEW PRODUCTION CAPACITY

Heilongjiang Province offers an almost **US$8,750 per acre** subsidy for new hothouse capacity.

2 Handy Factoids on Heilongjiang Province: (i) it's the northeastern 'breadbasket' of China, home to some of the largest farming operations in the country (ii) it gets really cold in winter; it shares a border with Siberia!

Heilongjiang Province is the 'breadbasket' of China

Heilongjiang Province gets really cold in winter



Sources: bf150.com, farmer.com.cn, agri.gov.cn, "Hubei's first photovoltaic greenhouse power plant commences operation" news report, Calculated based on average of Rmb8-10k per mu from "Report on Heilongjiang's vegetable basket project.

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TAKING A LEAN APPROACH TO VERTICAL FARMING

Dan Albert, owner of Farmbox Greens, made the decision to start slow and expand his vertical farm system on his own terms rather than seeking outside investor capital.

By David Kuack

Dan Albert's first exposure to vertical farming came in 2008 during a design competition for the U.S. Green Building Council's annual conference.

"The architecture firm I was working for at the time in Seattle, Wash., sponsored a team of young designers to develop a conceptual architectural design that met the newly developed Living Building Challenge," Albert said. "The concept of the competition was to design a carbon neutral building that was self-sufficient. The building wouldn't consume any more energy or water that was found on the site and would achieve a high level of sustainability. During the development of this design the vertical farm idea really captivated my interest and became one of the main drivers for this conceptual building."

The design project won both regional and national awards. Albert said the design was not created specifically for a public entity or private developer.

"We ended up coming up with this concept for a vertical farm, which at the time we didn't know was a vertical farm," he said. "The idea of bringing food production indoors in a greenhouse façade on a building wasn't really being done per se in 2008. I became friends with Dr. Dickson Despommier at Columbia University and got to work with him on a number of other early stage design concepts."

Albert said there was a lot of theory behind growing food in the city, but not a lot of projects being done. He increasingly received questions from developers about how a vertical farm works, what kind of revenue it could generate, and what is the business model for a vertical farm.

"After two years of talking with people who were excited about these projects, I concluded no one was answering the hard questions about how vertical farm systems work and where are the real efficiencies," Albert said. "Through the process of working on vertical farm projects, I decided I should try growing with a vertical farm."

A lot of trial and error

Although Albert worked on a farm in upstate New York as a youth growing alfalfa, hay and corn, he didn't have any experience growing edible crops.

"I made the decision to really educate myself on highly productive urban farming systems," he said. "I attended the *Greenhouse Crop Production & Engineering Design Short Course* at the University of Arizona Controlled Environment Agriculture Center. I also did research into different companies and different production systems."

Albert purchased an aeroponic system in 2011 and started a prototype research farm. He trialed this production system for about eight months.

"It was a total learning curve for me," he said. "In Seattle, warehouse space is expensive and hard to come by. I set up the aeroponic system in converted office space. The floor had carpeting so I had to put down a subfloor and waterproof everything. It was a lot of trial and error. Initially I was going to grow salad greens because they are a high value product. It is also a crop that is highly perishable.

"I quickly realized that the yield was so little out of this unit that provided 100 square feet of production. But that kind of jump started me to thinking about how to turn this into a business."

Focused on year-round production

As Albert became more comfortable and confident producing edible crops he started to rethink how he was growing.

"I had people telling me to scale up the production," he said. “There was a lot of interest from investors. People were saying let’s scale this up. I started to rethink how and what I was producing.

“I kind of stumbled upon growing microgreens and culinary herbs as a highly perishable, high value product that chefs wanted. Essentially I was already growing microgreens, but I was letting them continue to the baby green stage at 17-20 days. I started to harvest them after 10-14 days instead. I pitched the product to a couple of restaurants and all of a sudden people were buying our microgreens. I started selling the crops as Farmbox Greens in 2012.”

Albert said one of the challenges of having a small production space was to determine how to use it to generate the most revenue.

“Even though I had limited space, the intensity of production that I could generate with microgreens enabled me to produce 52 harvests or more a year. It comes down to producing the same thing every week and having the right process in place. I have taken a Lean approach to growing great food. It’s a different model from some large greenhouse and vertical farm operations. I don’t have venture capitalists backing my company. It’s small for local food production.”

> **“I have taken a Lean approach to growing great food. It’s a different model from some large greenhouse and vertical farm operations. I don’t have venture capitalists backing my company. It’s small for local food production.”** ***Dan Albert, owner Farmbox Greens***

Focus on clean, efficient production

Albert purchased a new home in Seattle in 2012. The property included a 500-square-foot detached garage, which he is now using as his production facility. He restarted Farmbox Greens in February 2013 exclusively producing microgreens and culinary herbs.

Although Albert is still using his original aeroponic system, he redesigned the components and developed a vertical farm system. Microgreens are grown in trays on a moisture pad. The plants are fertilized with a recirculating nutrient film technique system. The NFT system consists of a pump, a water reservoir and a series of manifolds that deliver the water.

"The system has been modified so that I can grow microgreens efficiently," Albert said. "I still use the original aeroponic system, but it is not the main focus of my production anymore. I have installed one vertical system that is three levels of production and another that has five levels. I don't need a lot of vertical height in order to grow multi-levels of microgreens. In the same building there is a harvesting area along with refrigeration and storage space. It is a functioning revenue-generating farm.

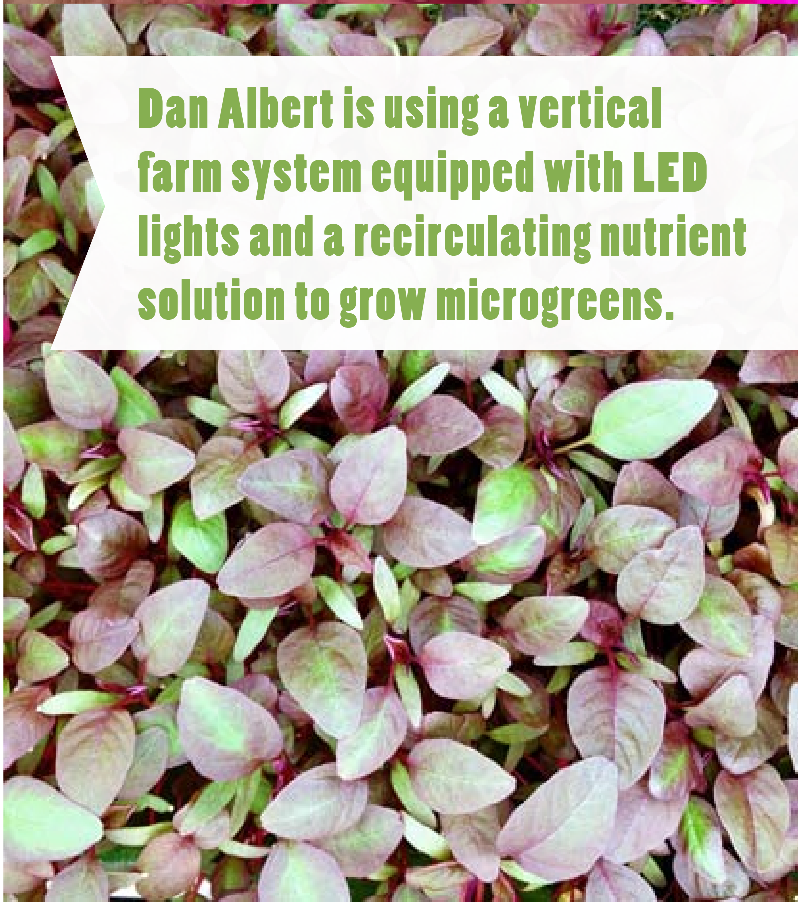
"I have been fortunate that I haven't needed to take on partners and I've been able to bootstrap it and expand. I have been able to pay with everything from cash flow. But the bad part is that it takes more time."

Albert said when he was designing the vertical production system he chose the best equipment he could afford.

"I put in Philips LED Production Modules as the primary lighting source in a stacked arrangement," he said. "I am using a high efficiency Energy Star Friedrich heat pump to cool and heat the facility. All of the environmental controls are within the building. I've also purchased a Hanna nutrient dosing system to measure the nutrients and pH as well. I have a very specific formula for growing microgreens on a small scale. There is no need to be operating a huge farm."

Albert said one of the most important aspects of trying to run a sustainable operation is not using any chemical controls for insects and diseases.

"I manage pests and diseases by being vigilant and keeping the facility and equipment clean," he said. "There is very little substrate for insects and diseases to come in and become established. Also, the crops don't stay in the facility very long. I grow only what I am going to harvest so that there is no waste."



Dan Albert is using a vertical farm system equipped with LED lights and a recirculating nutrient solution to grow microgreens.

Dan Albert has taken a Lean approach to production based on efficiency. The microgreens he harvests in the morning are sold out in the afternoon or the next morning.

Albert applies Lean principles to his "just-in-time" approach to crop production.

"The Lean approach is kind of here's what you need just in time," he said. "It is based on efficiency. I tried to develop a system where, for example, today I am planting for next week's harvest. I'm basing the planting on what was harvested last week, what I sold and what I'm projecting to sell. What I harvest in the morning is sold out in the afternoon or the next morning.

"I don't keep anything in the refrigerator for more than three days. I don't want to be holding product. Once you do that it hurts the quality, hurts the flavor and the overall look of the microgreens. I also want to be sure that my customers use all the product they purchase. I don't want them to have any waste. It's all about harvest, package, cool and deliver and then do it again."

Diversifying customer base

Farmbox Greens' customer base includes about 30 restaurants that purchase product on a weekly or biweekly basis depending on time of year.

"The restaurants vary from very high end to everything in between," Albert said. "The food is very high quality, but it is not all at a premium price point. Some people hear microgreens and they just assume it's going to be expensive. These are restaurants that care about local, high quality food."

Albert produces 15-20 different varieties of microgreens and herbs on a weekly basis.

"When it comes to microgreens, there are certain flavor profiles that chefs are interested in," he said. "I try to have a wide variety available, including peppery, crunchy and something lemony like sorrel or baby kale. I could grow a wider variety of crops, but on the herb side it comes down to just a few basics, including basil, cilantro and sorrel."

Farmbox Greens also participates in four year-round and five seasonal farmers markets.

"I have been really focused on building our customer base at the farmers markets," Albert said. "These markets are really well attended in Seattle. I am looking to build up our retail at these markets for the first half of this year."

Another company that Albert is working with is *Marx Foods*.

"This company is a local food distributor, but it also has retail space, so I sell some of my product through its store," he said. "Marx Foods also distributes to AmazonFresh, which is grocery delivery service. Marx wants to promote local, high quality products in its store and online. It is very committed to supporting local businesses and selling a variety of products including artisanal foods."

Dan Albert and his wife Lindsay Sidlauskas are looking to increase retail sales of microgreens and herbs at Seattle's well attended farmers markets.

Albert said his company has done well in terms of being able to meet demand.

"I have been able to balance what I'm growing with what I'm selling," he said. "The next step is to identify the scale of production that I need and the customer and crop mix. My company can get bigger, but microgreens aren't this unlimited market. It's about cash on hand to build out the production facility. It's about costs. It's about efficiency. It's about customers."

For more: Farmbox Greens, info@farmboxgreens.com; http://www.farmboxgreens.com.
To learn more about Farmbox Greens:
https://www.facebook.com/farmbox;
http://www.marxfoods.com/products/Farmbox-Greens.

David Kuack is a freelance technical writer in Fort Worth, Texas; dkuack@gmail.com.

EMPATHY GARDEN

The project Empathy Garden was born as an installation in the Central Pavilion of the Exhibition Centre of Villa Erba on the Lake of Como in occasion of Orticolario (3-5 October 2014) – one of Italy's leading events on advanced gardening.

An Evolution of the project St Horto, Empathy Garden is a hybrid space: a meeting point, a stage for events and promotion of a culture of sustainability as ecosystemic consciousness, a showcase for local farms products and an immersive experience where atmospheric perceptions, the activity of plants and people are converted into a soundscape. >> Click for more >>

{NEWS FROM THE INDUSTRY}

TWYCROSS ELEPHANTS WILL NOT FORGET THEIR FIRST HYDROPONIC MEAL

Twycross Zoo's elephants were treated to a futuristic free lunch this week courtesy of an innovative new vertical farming project which plans to help revolutionize food production in the UK, and any part of the world that struggles to grow enough food locally because of a lack of space or hostile environment.

Project 'Urban Grow' resulted in a crop of 2,000 lettuces being grown from seed to full size in just over half the time it usually takes to grow lettuce using traditional methods. The company and hydroponic experts behind the project, HydroGarden, based in Coventry, have created a fully-controllable modular environmental system. The system uses mobile racks fitted with inclined gully trays through which a water and nutrient solution is circulated.

>> Click for more >>

HARVEST FUNDERS

HarvestFunders.com is a crowdfunding website specifically designed to help provide the agricultural community with nonconventional funding for conventional needs using the power of crowdfunding.

>> Click for more >>

RAISING THE ROOF TO LIGHT UP THE FUTURE

North Yorkshire Applied Research provider Stockbridge Technology Centre (STC) has today confirmed it is to raise the roof on one of its glasshouses to create a new, state of the art research facility to examine the effects of different LED lights on long season crops such as tomato.

As innovative growers start to adopt LED lighting technology, the new facility at STC will provide valuable information comparing the effects of four different light regimes in the crop. Treatments will include traditional sodium lighting, LED lights both within and above the crop and diffuse glass in one compartment of the glasshouse. This specially treated glass scatters light to potentially provide better growing conditions.

>> Click for more >>

Hort Americas will be sponsoring and participating in the 2015 event!
More info coming soon!

www.tourdefresh.com | /tourdefresh | @tourdefresh2014 | #tourdefresh

3D PRINTING WITH LIVING ORGANISMS COULD TRANSFORM THE FOOD INDUSTRY

DEZEEN AND MINI FRONTIERS: *FOOD DESIGNER CHLOÉ RUTZERVELD HAS DEVELOPED A CONCEPT FOR "HEALTHY AND SUSTAINABLE" 3D-PRINTED SNACKS THAT SPROUT PLANTS AND MUSHROOMS FOR FLAVOUR.*

PREVENT TIPBURN on GREENHOUSE LETTUCE

by David Kuack

Photo courtesy of A.J. Both, Rutgers University

Photo courtesy of Cornell University

CORNELL UNIVERSITY RESEARCHERS DEVELOPED A "FAST CROP" PRODUCTION SCHEDULE FOR GREENHOUSE LETTUCE. BUT GROWERS MAY HAVE TO ALTER CULTURAL PRACTICES TO AVOID TIPBURN CAUSED BY CALCIUM DEFICIENCY.

Tipburn is a physiological disorder of greenhouse-grown lettuce that can be a problem for growers who are trying to produce their crops in a short period of time. Tipburn can have a significant impact on the salability of a lettuce crop. The same disorder can manifest itself in tomato crops as blossom end rot.

"A challenge for greenhouse growers trying to produce their lettuce crops as fast as possible is ensuring that all of the nutrients are distributed to all the different parts of the plant in the right quantities," said A.J. Both, associate extension specialist at Rutgers University. "In the case of lettuce, what sometimes happens is calcium cannot be transported fast enough in sufficient quantities to the quickly developing young leaf tissue. The plants' cell walls cannot form properly and the cells collapse. This happens in the inner hearts of the lettuce heads.

"When the young leaves start to push out and grow larger these brown leaf edges appear. This is referred to as tipburn. Research showed that it is a calcium deficiency that causes tipburn."

Both said Cornell University researchers encountered this disorder when they were developing a fast crop greenhouse production system for finishing lettuce in 35 days.

"This is a very fast crop—five weeks from seed for a 5-ounce head of lettuce," he said. "The time between seeding and transplanting takes 11 days. The remaining 24 days the plants are in the greenhouse.

"The five-week production cycle is not the way most commercial operations grow their lettuce. Growers usually allow the growth rate to fluctuate depending on the amount of natural light the plants receive. In the summer when light levels are higher, growers can finish a crop in five to six weeks. But in the winter when natural light levels are lower, the crops take longer, as much as double the production time that occurs during the summer. If a lettuce crop can be grown at a slower rate, tipburn may not be an issue. At a slower growth rate, the nutrient uptake rate can better keep up with the plants' demand.

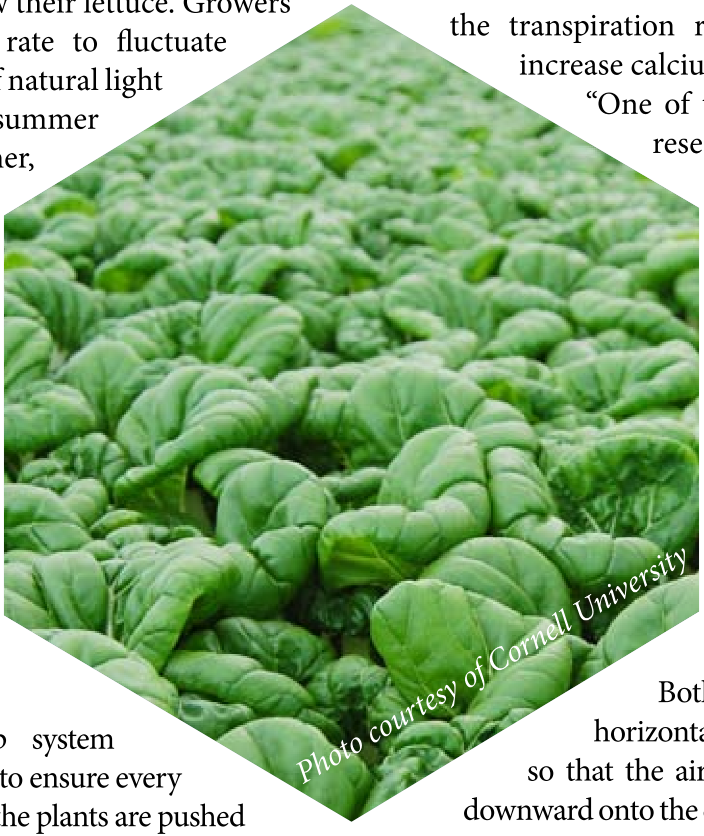


Photo courtesy of Cornell University

"In the Cornell fast crop system supplemental lighting is used to ensure every crop finishes in five weeks. If the plants are pushed with supplemental light allowing this fast growth rate to occur, then tipburn can show up very quickly. A growing strategy was needed that allowed for a fast growth rate, but prevented tipburn from occurring."

Both said the damage to the young leaves caused by calcium deficiency can happen within days. It may take a few more days after the damage occurs for growers to observe the symptoms.

"When the conditions for this disorder are right and there is not enough transport of calcium, the damage can start within a day," he said. "Depending on how long the deficiency lasts will determine how severe the tipburn symptoms will be."

INCREASING PLANT TRANSPIRATION RATES

Both said researchers and growers have found that the rate of nutrient uptake, including calcium, can be increased by stimulating plant transpiration.

"Increasing the rate of air turbulence around the leaves leads to a higher level of transpiration from the leaves," he said. "As a result, there is a higher rate of water uptake from the roots and translocation of the nutrients, including calcium, from the roots to the developing leaves."

Both said different methods have been tried to raise the transpiration rate in plants in order to increase calcium uptake into the leaves.

"One of the solutions mentioned in research literature is to hang a small plastic tube above each head of lettuce and blow air through it so that air is delivered onto each individual head," he said. "This might be feasible for a small growing operation, but for a large greenhouse with thousands of heads of lettuce that would be very difficult to do."

Working with Cornell University researchers, Both turned typical greenhouse horizontal airflow fans 90 degrees so that the air from the fans was directed downward onto the crop, resulting in an increased transpiration rate of the plants.

"We used regular horizontal airflow fans and mounted them on a different bracket so that instead of moving air horizontally, they were moving air straight down," he said. "If the fans were placed in a uniform pattern above the crop so that most of the plants received the air flow, we saw good results in preventing tipburn."

Both said determining how many horizontal air flow fans need to be installed to raise the plants' transpiration rate will require some trial and error. Traditional ceiling-type fans can also be used to create sufficient vertical air flow.

"The set up works, but on occasion conditions exist that despite our best efforts to increase air flow around the plant canopy, we still saw tipburn symptoms," he said. "We were able to prevent tipburn under most conditions, but not all the time. There really wasn't a satisfactory explanation for why sometimes we were able to prevent tipburn and other times it occurred.

"Although we have limited scientific data to back this up, the further away from the center of the fans there would be less air flow and the air movement may not be enough to sufficiently raise the transpiration rate to overcome tipburn. But where that location is in a particular greenhouse will require some experimentation with where the fans are placed, the distance between the fans and the plant canopy and how many fans are installed."

Both said the fan set up was trialed with lettuce crops grown in troughs and in a floating production system.

"We have used the fans with both types of production systems and they worked equally well in preventing tipburn," he said. "In a floating system, plants often experience a variety of conditions because the plants are usually pushed through the entire system from the seedling stage to the harvesting stage. In the case of troughs, the plants are usually stationary, but there could be more air movement between the plant rows because troughs are typically elevated. In either system, there is usually more air movement around the plants when they are smaller in size. Tipburn often becomes an issue when the plants have reached a larger size."

> THE RATE OF NUTRIENT UPTAKE, INCLUDING CALCIUM, CAN BE INCREASED IN LETTUCE BY STIMULATING PLANT TRANSPIRATION. BY INCREASING THE RATE OF AIR TURBULENCE AROUND THE LEAVES LEADS TO A HIGHER LEVEL OF TRANSPIRATION. THIS LEADS TO A HIGHER RATE OF WATER UPTAKE FROM THE ROOTS AND TRANSLOCATION OF NUTRIENTS, INCLUDING CALCIUM, TO THE DEVELOPING LEAVES.

MAXIMIZING GROWTH WITH SUPPLEMENTAL LIGHT

In developing the fast crop production system for lettuce, Cornell researchers used both natural and supplemental light to maximize growth. High pressure sodium lamps were used to provide supplemental light.

"We tried to achieve a daily light integral of 16-17 moles per square meter per day during the entire production cycle," Both said. "If the 16-17 moles were reached using natural light, then the lamps wouldn't come on. If it was cloudy and we couldn't achieve that light level with just natural light, then the HPS lamps came on to provide supplemental light.

"If we stayed at or just below this daily light integral number and provided vertical air flow, we were able, in most cases, to prevent tipburn. If we went above this daily light integral in order to try and push the growth of the plants even further, we were able to grow the plants, but tipburn occurred in many cases even though vertical air flow was used.

"We could have grown the lettuce at a lower light level and prevented tipburn, but it would have taken longer to finish the crop. This is also an economical consideration, because at a lower light level a grower wouldn't be able to turn as many crops and thus would make less money."

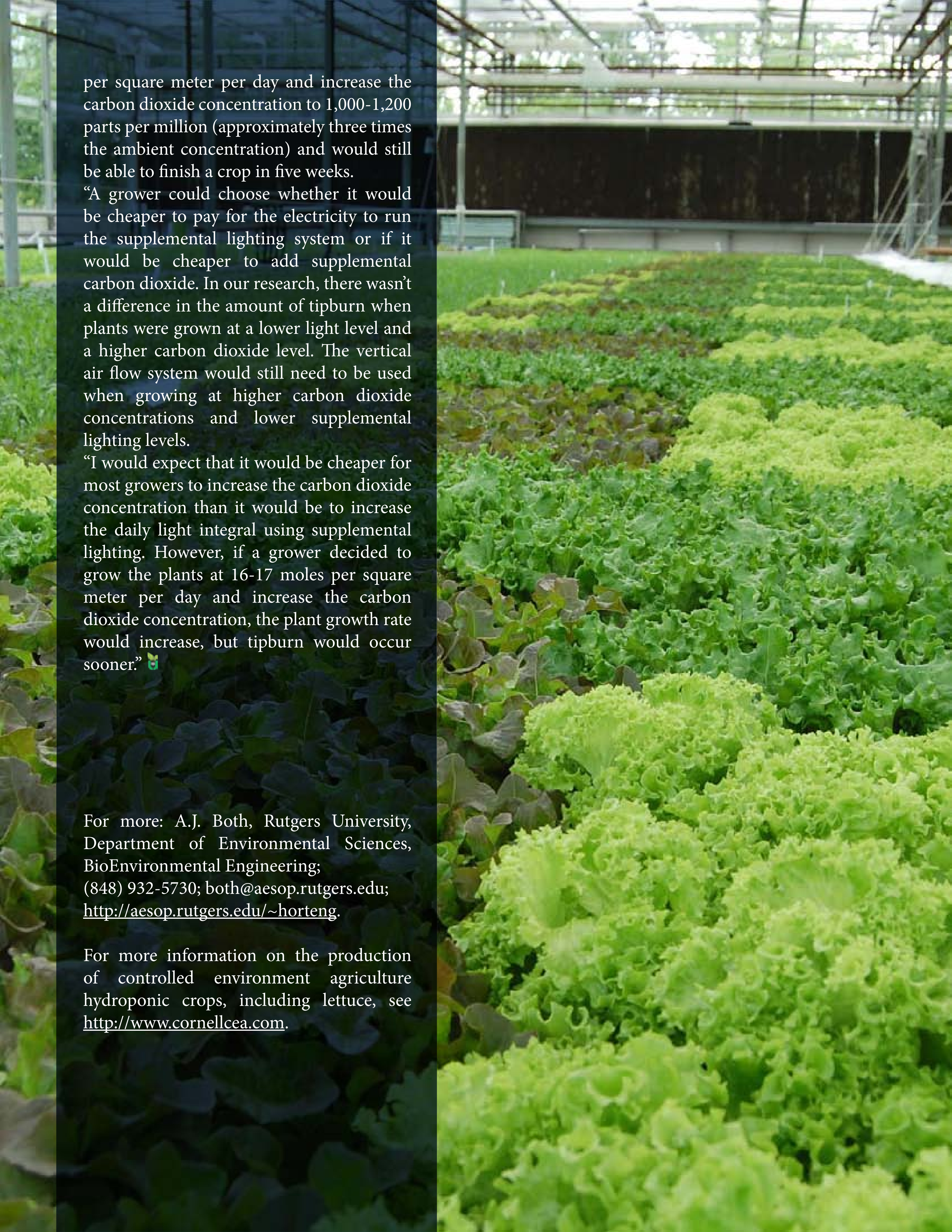
SUBSTITUTING SUPPLEMENTAL CARBON DIOXIDE FOR LIGHT

Another option that was studied to keep plants growing quickly was to use less supplemental light and to increase the amount of carbon dioxide in the greenhouses by a process called carbon dioxide enrichment.

"The grower would reduce the amount of supplemental light and increase the amount of supplemental carbon dioxide," Both said. "A grower can easily manipulate the carbon dioxide level by releasing pure carbon dioxide gas. Using this technique, a grower might provide a daily light integral of 12-13 moles

Photos courtesy of A.J. Both, Rutgers University

GROWERS USUALLY ALLOW THE GROWTH RATE OF LETTUCE TO FLUCTUATE DEPENDING ON THE AMOUNT OF NATURAL LIGHT THE PLANTS RECEIVE. TIPBURN MAY NOT BE AN ISSUE IF A LETTUCE CROP IS GROWN AT A SLOWER RATE, WHICH ALLOWS THE NUTRIENT UPTAKE RATE TO BETTER KEEP UP WITH THE PLANTS' DEMAND.



per square meter per day and increase the carbon dioxide concentration to 1,000-1,200 parts per million (approximately three times the ambient concentration) and would still be able to finish a crop in five weeks.

"A grower could choose whether it would be cheaper to pay for the electricity to run the supplemental lighting system or if it would be cheaper to add supplemental carbon dioxide. In our research, there wasn't a difference in the amount of tipburn when plants were grown at a lower light level and a higher carbon dioxide level. The vertical air flow system would still need to be used when growing at higher carbon dioxide concentrations and lower supplemental lighting levels.

"I would expect that it would be cheaper for most growers to increase the carbon dioxide concentration than it would be to increase the daily light integral using supplemental lighting. However, if a grower decided to grow the plants at 16-17 moles per square meter per day and increase the carbon dioxide concentration, the plant growth rate would increase, but tipburn would occur sooner."

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For more information on the production of controlled environment agriculture hydroponic crops, including lettuce, see http://www.cornellcea.com.

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SKYSCRAPER FARMS AND ABANDONED WAREHOUSES


Urban Plant Factories:

High in the Sky

or...

Pie in the Sky?

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HYDROPONICS - SOILLESS SYSTEMS AND CONTAINERS

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AQUAPONICS | GETTING MORE OUT OF LESS

Charlie Price from the social enterprise Aquaponics UK, explores the role aquaponics can play in the future of our collective food supply.
He provides an insight into both the applications for aquaponics but more specifically a new approach to urban agriculture, turning wastes into resources and transforming disused urban spaces to provide not only food, but resilient communities.

About **TEDx,** x = independently organized event
In the spirit of ideas worth spreading, TEDx is a program of local, self-organized events that bring people together to share a TED-like experience. At a TEDx event, TEDTalks video and live speakers combine to spark dep discussion and connection in a small group. These local, self-organized events are branded TEDx, where x = independently organized TED event. The TED Conference provides general guidance for the TEDx program, but individual TEDx events are self-organized.* (*Subject to certain rules and regulations)

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LETHAL EFFECTS of SHORT-WAVELENGTH VISIBLE LIGHT ON INSECTS

Masatoshi Hori*, Kazuki Shibuya*, Mitsunari Sato & Yoshino Saito

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We investigated the lethal effects of visible light on insects by using light-emitting diodes (LEDs). The toxic effects of ultraviolet (UV) light, particularly shortwave (i.e., UVB and UVC) light, on organisms are well known. However, the effects of irradiation with visible light remain unclear, although shorter wavelengths are known to be more lethal. Irradiation with visible light is not thought to cause mortality in complex animals including insects. Here, however, we found that irradiation with short-wavelength visible (blue) light killed eggs, larvae, pupae, and adults of *Drosophila melanogaster*. Blue light was also lethal to mosquitoes and flour beetles, but the effective wavelength at which mortality occurred differed among the insect species. Our findings suggest that highly toxic wavelengths of visible light are species-specific in insects, and that shorter wavelengths are not always more toxic. For some animals, such as insects, blue light is more harmful than UV light.

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Understanding the influence of visible light (400–780 nm) on organisms is important for identifying novel uses and examining hazards of exposure to visible light. However, little is known about the biological toxicity of visible light. Although recent studies have described damage by short-wavelength visible light (blue light, 400–500 nm) to the mammalian retina, called the 'blue light hazard'[1–5], there have been no reports on the lethal effects of irradiation with visible light on complex animals, including insects. On the other hand, the toxicity of shortwave UV light to organisms is well known. UVC (100–280 nm) and UVB (280–315 nm) induce mutagenic and cytotoxic DNA lesions[6,7], and UVC irradiation has lethal effects on insects[8] and microorganisms[9].

The use of UVC irradiation for control of pests such as *Tribolium castaneum, T. confusum, Cadra cautella,* and *Trogoderma granarium*, which infest stored grains, has been studied[10,11]. Lethal effects of UVC against larvae of the silkworm Bombyx mori are also well known[12,13]. Lethal effects of UVB have been reported for spider mites[14], in which UVB irradiation strongly decreases survivorship and egg production. However, there are no reports that describe lethal effects of UVB or UVA (315–400 nm) on insects, although UVA irradiation slightly decreases adult longevity in the lepidopteran *Helicoverpa armigera*[15]. It is well known that shorter wavelengths of light are more lethal[9,16,17]. In addition, positive effects of wavelengths ranging fromUVAto green (500–560 nm) have been reported for spider mites; irradiation with UVA, blue, and green light caused photoreactivation of mites damaged by UVB irradiation[18]. Therefore, irradiation with visible light is not considered lethal to complex animals, including insects. Here, in contrast, we show a strong lethal effect of blue light on insects. In this study, we found that blue-light irradiation by a common LED can kill insect pests of various orders and that highly lethal blue-light wavelengths are species-specific in insects.

RESULTS

Lethal effects of irradiation with various wavelengths of light on *D. melanogaster* pupae. First, we investigated the lethal effect of light (wavelengths from 378 to 732 nm) on *D. melanogaster* pupae using LEDs. Irradiation with wavelengths of 378, 417, 440, 456, and 467 nm at 3.0 X 10^{18} photons•m^{-2}•s^{-1} throughout the pupal stage significantly increased the mortality of *D. melanogaster* pupae compared with their mortality under DD (24-h dark) conditions (Fig. 1a, Supplementary Table 1). In particular, we identified two peak wavelengths (440 and 467 nm; Fig. 1a) that had strong lethal effects. More than 90% and 70% of pupae died before adult emergence after irradiation with wavelengths of 467 and 440 nm, respectively; the lethal effects of these wavelengths were stronger than those of UVA (378 nm). Wavelengths of 404 nm and ≥496 nm did not have a lethal effect on *D. melanogaster* pupae (Fig. 1a, Supplementary Table 1). In wavelengths ranging from 378 to 508 nm, mortality increased with increasing numbers of photons (Fig. 1b). Wavelengths of 440, 456, and 467 nm led to 100% mortality at 4.0 X 10^{18} photons•m^{-2}•s^{-1}; this number of photons did not have a lethal effect at wavelengths of 508, 657, and 732 nm. These results reveal, for the first time, that complex animals such as insects can be killed by irradiation with certain wavelengths of visible light, and that visible light is more harmful than UV light to some animals.

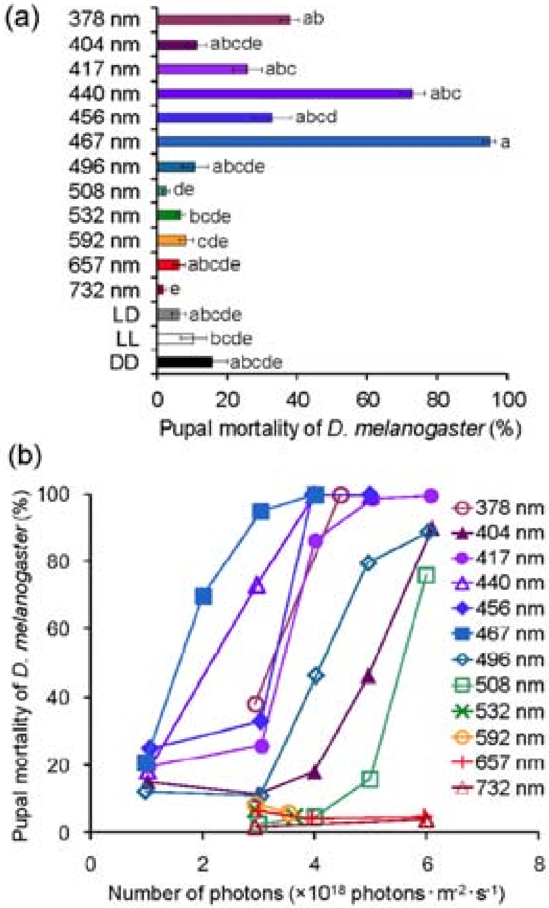

Figure 1 | Comparison of the lethal effects of light irradiation on *Drosophila melanogaster* pupae using various wavelengths of LED light. (a) Mortality of pupae irradiated with 3.0 X 10^{18} photons•m^{-2}•s^{-1}. Data are means ± standard error (SE). Different lowercase letters next to bars indicate significant differences (Steel–Dwass test, $P < 0.05$). LL, DD, and LD indicate 24-h light, 24-h dark, and 16L : 8D photoperiod conditions, respectively. (b) Dose–response relationships for lethal effects of irradiation on pupae for each wavelength. Data are mean values.

Lethal effects of irradiation with blue light on eggs, larvae, and adults of *D. melanogaster*. Irradiation with a wavelength of 467 nm had the strongest lethal effect on Drosophila pupae, although this wavelength was also lethal to other developmental stages. The mortality rate of eggs increased with increasing numbers of photons (Fig. 2a); the majority of eggs died after 48-h irradiation at $\geq 5.0 \times 10^{18}$ photons•m^{-2}•s^{-1}, whereas most eggs hatched under dark conditions. Irradiation with a wavelength of 467 nm for 24 h was lethal to final-instar larvae (L1–L2)[19] and showed a dose–response relationship (Fig. 2b). Most flies died before adult emergence after irradiation at 7.0×10^{18} photons•m^{-2}•s^{-1}. Flies died during earlier developmental stages as the number of photons increased. Forty percent and 27% of flies died during the larval stage following irradiation at 12.0×10^{18} and 10.0×10^{18} photons•m^{-2}•s^{-1}, respectively. Using these same irradiation levels, more than 90% of flies died during the larval or prepupal stages (L1–P4). With irradiation at 7.0×10^{18} photons•m^{-2}•s^{-1}, the flies that died before adult emergence were almost evenly divided among the flies that died during the larval or prepupal stages (L1–P4) and those that died during the pupal stage (P5–P15). Interestingly, none of the irradiated flies died during the developmental stages of P5–P9. Adult longevity decreased significantly as the number of photons increased (Fig. 2c, Supplementary Table 2). In contrast, the longevity of adult flies maintained under dark conditions was approximately 60 d.

Irradiation with a wavelength of 467 nm affected fly fecundity (Fig. 2d); the mean number of eggs deposited by surviving females decreased with increasing numbers of photons. These results show that irradiation with blue light has a lethal effect on the pupal stage of Drosophila, and also on other developmental stages of this insect—including the adult stage, which is typically considered tolerant of light irradiation.

Lethal effects of blue-light irradiation on *C. pipiens* molestus and *T. confusum*. We also investigated the lethal effects of various bluelight wavelengths (404–508 nm) on pupae of the mosquito Culex pipiens molestus. Blue light irradiation was lethal to mosquito pupae, although their tolerance was higher than that of *D. melanogaster* pupae (Fig. 3a, b). Compared with DD conditions, irradiation with wavelengths of 404, 417, and 456 nmat 10.0×10^{18} photons•m^{-2}•s^{-1} throughout the pupal stage significantly increased the mortality of *C. pipiens molestus* (Supplementary Table 3); the peak wavelength of 417 nm was highly lethal (Fig. 3a). Wavelengths of 404 and 417 nm killed substantial proportions of pupae before adult emergence, whereas wavelengths ≥ 440 nm were non- or negligibly lethal (Fig. 3a). The lethal effect of 417 nm increased with increasing numbers of photons; in contrast, the lethal effect of 404 nm was nominal, and the lethal effects of 440-, 456-, and 467-nm wavelengths increased only slightly with increasing numbers of photons (Fig. 3b).

Irradiation with a wavelength of 417 nm was lethal to mosquito eggs, and the mortality increased over time (Fig. 3c, Supplementary Table 4). Whereas only 34% of mosquitos died before hatching following 48 h of irradiation at 10.0×10^{18} photons•m^{-2}•s^{-1}, approximately 90% of hatchlings from the irradiated eggs died within 72 h after irradiation; this is compared with a 2% mortality rate of hatchlings from the eggs maintained under dark conditions. Accordingly, even if irradiated eggs hatched, most hatchlings died soon thereafter.

These results show that the lethal effect of blue light is not confined to flies; however, the effective wavelength at which mortality occurs is species-specific, and tolerance to blue-light irradiation differs among insect species.

Blue-light irradiation was lethal to pupae of the confused flour beetle *T. confusum* (Fig. 3d). All beetles irradiated with wavelengths ranging from 404 to 467 nm throughout the pupal stage at 2.0×10^{18} photons•m^{-2}•s^{-1} died before adult emergence. However, irradiation with the 532-nm wavelength did not have a lethal effect. These findings show that blue-light irradiation can kill insects of various orders.

DISCUSSION

In this study, we revealed for the first time that blue-light irradiation can kill insect pests and that effective wavelengths of visible light are species-specific. Our findings show that visible light is more harmful than UV light to some animals. The insides of the containers and media in which insects were housed did not register temperatures that would have affected the survival of any of the developmental stages in any of the irradiation treatments (Supplementary Tables 5 and 6). In addition, increases in lethal effects did not always correspond to increases in temperature. In the irradiation treatments in which increasing temperature corresponded to lethal effects, the temperatures were not high enough to affect insect survival[20].

Therefore, we concluded that temperature increases caused by LED light did not cause the mortality.

UVB and UVC directly damage DNA by inducing the formation of DNA lesions, notably *cissyn* cyclobutane pyrimidine dimers and pyrimidine (6-4) pyrimidone photoproducts[21]. The maximum absorption spectrum of DNA ranges from 260 to 265 nm, and absorption rapidly declines at longer wavelengths[22]. DNA damage induced by UVA is minimal because UVA is not absorbed by native DNA[6,7]. However, UVA indirectly damages lipids, proteins, and DNA by enhancing the production of reactive oxygen species (ROS)[23–25]. Increases in oxidative stress caused by UVA irradiation have also been shown in insects such as the cotton bollworm *Helicoverpa armigera*[26]. In addition, molecular-level responses to stress and damage by UVA irradiation have been confirmed in insects[27,28]. However, lethal effects of UVA irradiation on insects have not been shown[15,27]. Blue-light irradiation injures organisms by stimulating the production of ROS. Many microbial cells are highly sensitive to blue light as a result of the accumulation of photosensitizers such as porphyrins and flavins[29].

Mammalian retinas can also be severely damaged by ROS produced by blue-light irradiation[4,5]. It is probable that the lethal effect of blue light on insects is caused by the production of ROS, because the effective wavelength is species-specific and not always associated with the amount of photon energy delivered. In addition, light transmission of *D. melanogaster* puparia was not wavelength-specific (Supplementary Figure 1). These findings suggest that light absorption by certain inner tissues of the fly is wavelength-specific. That is, species-specific chromophores or photosensitizers in insect tissues absorb specific wavelengths of light, thereby generating free radicals.

Insects subsequently die from tissue damage caused by free-radical formation.

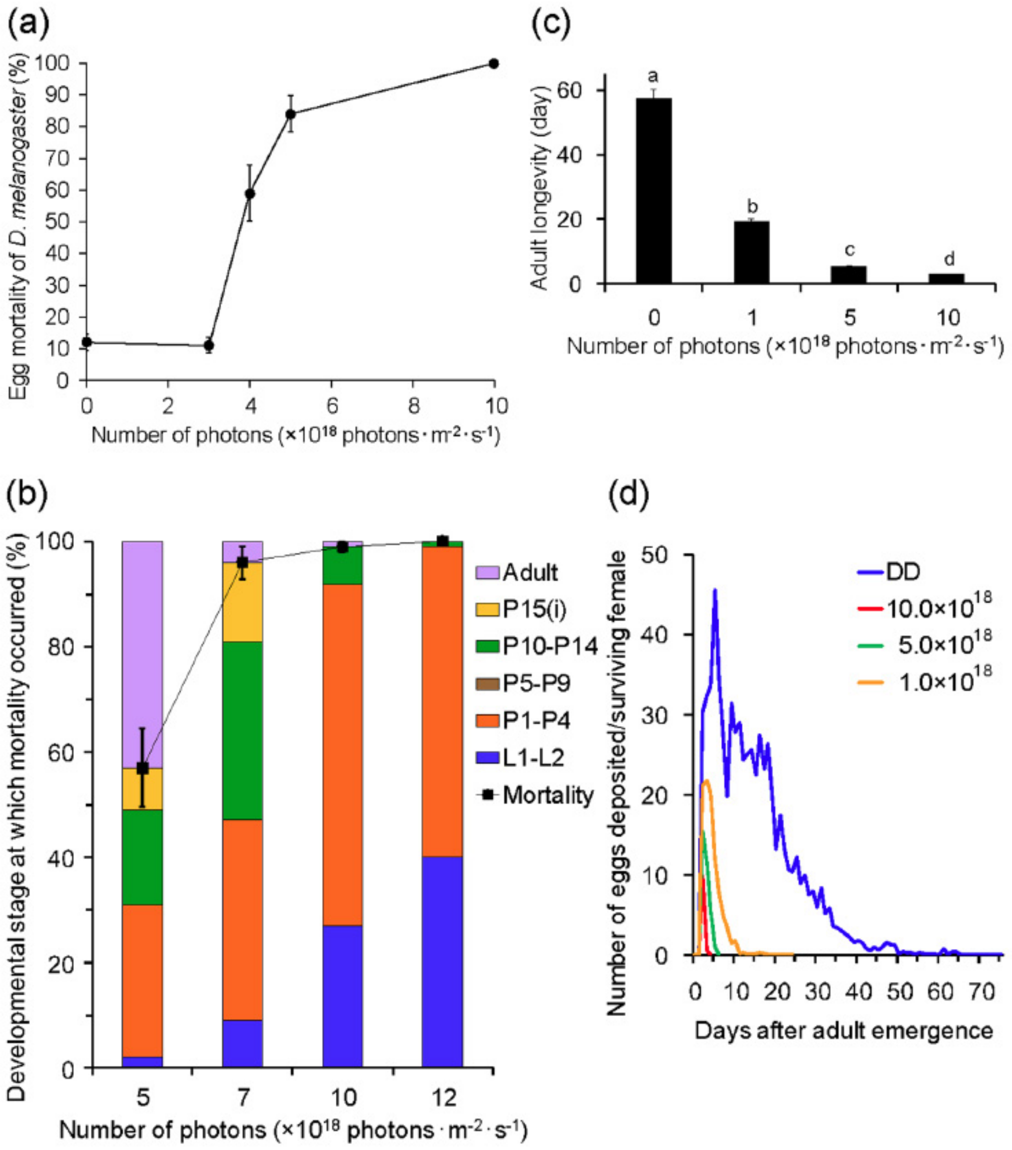

Figure 2 | Effects of irradiation with 467-nm blue light on eggs, larvae, and adults of *Drosophila melanogaster*.
(a) Dose–response relationships for lethal effects of irradiation with LED light on eggs. "0" photons represents the 24-h dark condition. Data are means ± standard error (SE).
(b) Relationship between light dose and developmental stage at which mortality occurred. Developmental stages of larvae and pupae were classified according to Bainbridge and Bownes (1981)[19]. L1 and L2 are third-instar larvae, P1–P4 are prepupae, and P5–P15 are phanerocephalic pupae. No irradiated flies died during the P5–P9 developmental stages. Data are mean values. Mortality (mean6SE) of flies that could not emerge is indicated by the black line. (c) Dose–response relationships for effects of irradiation with LED light on adult longevity. "0" photons represents the 24-h dark condition. Data are means ± SE. Different lowercase letters above bars indicate significant differences (Steel–Dwass test, $P < 0.05$). (d) Dose–response relationships for the effects of irradiation with LED light on fecundity. DD indicates the 24-h dark condition. Inset numbers (1.0, 5.0, and 10.0 X 10^{18}) indicate light dose in photons$\cdot$m$^{-2}\cdot$s^{-1}. Data are mean values.

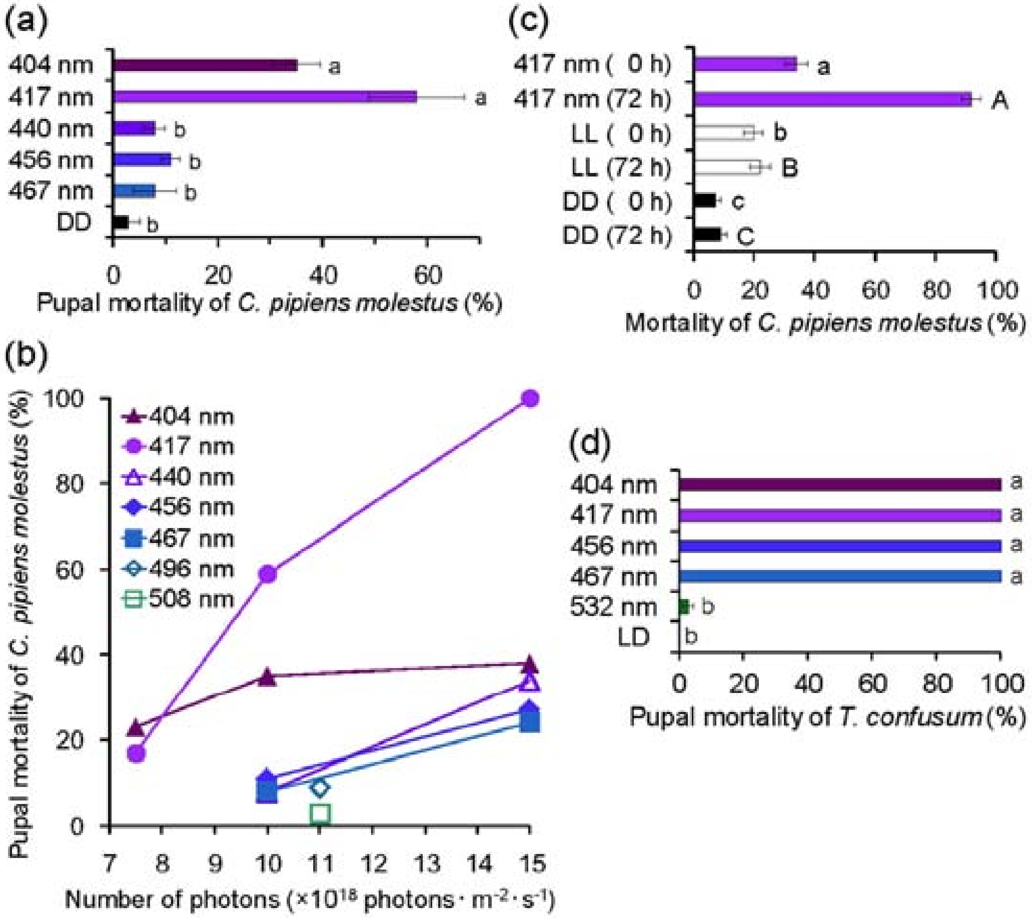

Figure 3 | Lethal effects of blue-light irradiation on the mosquito *Culex pipiens* molestus and the confused flour beetle *Tribolium confusum*.
(a) Mortality of *C. pipiens molestus* pupae irradiated with various wavelengths of blue light at 10.0 X 10^{18} photons•m^{-2}•s^{-1} during the pupal stage. Data are means ± standard error (SE). Different lowercase letters next to bars indicate significant differences (Steel–Dwass test, $P < 0.05$). DD indicates the 24-h dark condition.
(b) Dose–response relationships for lethal effects of irradiation with each wavelength of light on pupae. Data are mean values.
(c) Mortality of C. pipiens molestus that were irradiated with 417-nm light for 48 h at 10.0 X 10^{18} photons•m^{-2}•s^{-1} during the egg stage. Data are means ± SE. Hours in parentheses show the elapsed time after discontinuation of irradiation. Different lowercase or capital letters next to bars indicate significant differences among the three treatments for each time period (Steel–Dwass test, $P < 0.05$). LL and DD indicate 24-h light and 24-h dark conditions, respectively.
(d) Mortality of *T. confusum* pupae irradiated with various wavelengths of light at 2.0 31018 photons•m^{-2}•s^{-1} during the pupal stage. Data are means ± SE. Different lowercase letters next to bars indicate significant differences (Steel–Dwass test, $P < 0.05$). LD indicates 16L : 8D photoperiod condition.

We selected three insect species for the experiments presented here. *D. melanogaster* is a major model animal species with a short life cycle. Investigation of the lethal effects of blue-light irradiation on *D. melanogaster* can be conducted with ease and can be useful for studying damage caused by blue light or free radicals in animals. *C. pipiens molestus* is a major mosquito species that is easily reared, and thus is an appropriate model species for mosquito experiments. Mosquitoes are one of the most medically important insect pests and they transmit serious diseases, including malaria, dengue fever, yellow fever, West Nile fever, and Japanese encephalitis. This study showed lethal effects of blue light on mosquito pupae and eggs.

Reproduction of mosquitoes might be prevented by blue-light irradiation of water containing eggs, larvae, and pupae, and might consequently prevent outbreaks of mosquito-borne diseases. *T. confusum* is a globally important insect pest of stored grain. Our findings showed the potential of blue-light irradiation for pest control in stored products. That is, blue-light irradiation may be useful for pest control in various situations including agriculture, sanitation, and food storage. *D. melanogaster* and *C. pipiens molestus* belong to the order Diptera, whereas *T. confusum* belongs to Coleoptera. This implies that blue-light irradiation has lethal effects against multiple insect orders. Current techniques in pest management utilize light to influence insect behaviours, including attraction, repulsion, and light adaptation in nocturnal species[30]. The present study suggests the potential for a novel, clean, and safe pest-control technique that can easily kill insect pests simply by radiating blue light (e.g., LED).

However, tolerance to blue light varied widely among the insect species studied here. The order of tolerance was *C. pipiens molestus* ≫ *D. melanogaster* ≥ *T. confusum*. The tolerance of *C. pipiens molestus* to blue light was much higher than that of *D. melanogaster*, although both species belong to the order Diptera. The habitats of these three species differ. *T. confusum* inhabits stored foods in indoor environments. *D. melanogaster* lives in both outdoor and indoor habitats, but it occupies dark environments until adult emergence.

C. pipiens molestus usually lives in water in areas with low light until adult emergence. Therefore, the quantity of light to which these species are exposed is highest for *C. pipiens molestus*, followed (in decreasing order) by D. melanogaster and *T. confusum*. Tolerance of insects to blue-light irradiation is thought to be closely related to the light exposure experienced in their natural habitats. The numbers of photons of 470 nm and blue-light wavelengths (400–500 nm) in direct sunlight in the field associated with our laboratory (Sendai, Japan; 38ºN, 140ºE) were approximately 1.0–2.5 X 10^{18} and 7.5–9.0 X 10^{18} photons•m^{-2}•s^{-1}, respectively (1:00–2:00 PM in early summer). Therefore, we assume that *D. melanogaster* and *T. confusum* cannot survive under direct sunlight because of the lethal effect of blue light. Accordingly, eggs, larva, and pupae of *D. melanogaster* and *T. confusum* require dark habitats. The relationships between insect species (or habitats) and tolerance to blue light require further investigation in order to utilize blue-light irradiation for pest control.

Blue-light irradiation may be useful for controlling various insect pests. However, because the effective wavelengths of blue light are species-specific, several wavelengths (or broad-spectrum blue light) are needed for the simultaneous control of multiple species. In addition, genetic variation in resistance to UVC or ionizing irradiation has been confirmed in D. melanogaster[31,32]. It is probable that there is genetic variation in insect resistance to blue-light irradiation; this variation should be investigated so that the use of blue-light irradiation for pest control can be realized in the near future.

The purpose of this study was to reveal the lethal effects of light; the effects of low doses of blue-light irradiation on insects have not yet been clarified. In mammals, low doses of UV exposure provide health benefits including energy improvement, mood elevation, and vitamin D production, although high rates of exposure can present health risks such as increased susceptibility to cancer[33]. It is possible that low doses of blue light can also have beneficial effects on insects.

Our findings facilitate the development of clean and safe pestcontrol techniques, and provide important information on the hazards of exposure to visible light.

METHODS

Insects. Eggs, final instar larvae, pupae, and adults of Drosophila melanogaster; eggs and pupae of Culex pipiens molestus; and pupae of *Tribolium confusum* were maintained in our laboratory and used for the experiments. D. melanogaster was purchased from Sumika Technoservice Co. (Takarazuka, Japan). The flies were reared on culture medium consisting of glucose (2.5 g), dry brewer's yeast (2.5 g), agar (0.5 g), propionic acid (0.25 mL), 20% butyl p-hydroxybenzoate in 70% ethyl alcohol (0.25 mL), and water (total medium volume 550 mL) in a plastic box (723 72 3 100 mm). C. pipiens molestus were supplied by Earth Chemical Co., Ltd. (Tokyo, Japan). The eggs, larvae, and pupae were maintained in a plastic container (150 mm dia 3 91 mm tall) containing 250 mL of water, with a constant supply of fishery feed (trout juveniles). Adults were maintained in a plastic cage (340 3 250 3 340 mm) containing two plastic cups (30 mm dia 3 35 mm tall). Absorbent cotton impregnated with 3% honey solution was placed in one of the cups as a food source, and absorbent cotton soaked with water was placed in the other cup as an oviposition substrate. *T. confusum* were provided by Fuji Flavor Co., Ltd. (Tokyo, Japan) and were reared in a plastic container (130 mm dia 3 77 mm tall) on wheat flour containing 5% dry brewer's yeast. All insects were wild type and were maintained at 25 6 1uC under a photoperiod of 16L58D.

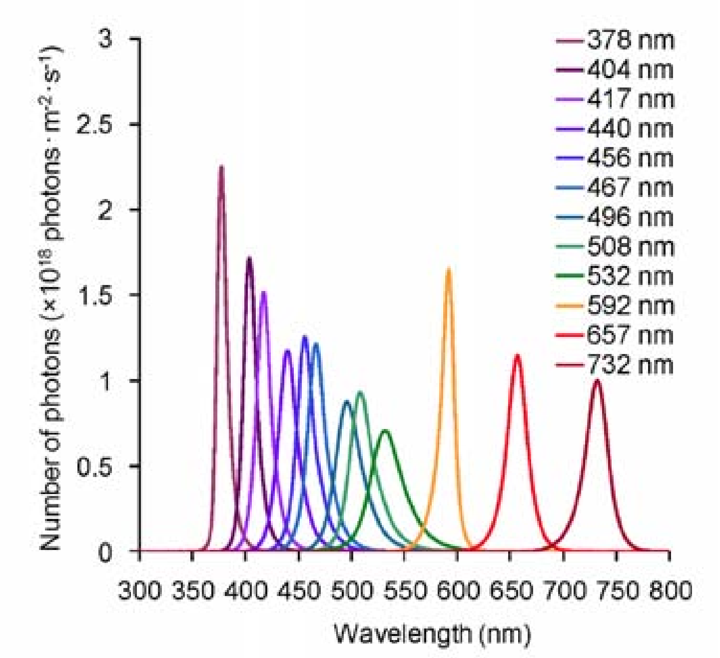

Figure 4 | Emission spectra of LED lighting units used for the experiments.

LED light radiation. LED lighting units (IS-miniH, ISL-150 3 150 Series; CCS Inc., Kyoto, Japan; light emission surface: 1503150 mm; 360 LEDs were equally arranged on a panel; LED type: Q 3-mm plastic mould) with power supply units (ISC-201-2; CCS Inc.) were used for UV and visible light radiation. Insects were irradiated with LED light in a multi-room incubator (LH-30CCFL-8CT; Nippon Medical & Chemical Instruments Co., Ltd., Osaka, Japan). The emission spectrum wasmeasured using a high-resolution spectrometer (HSU-100S; Asahi Spectra Co., Ltd., Tokyo, Japan; numerical aperture of the fibre: 0.2) Comparison of the emission spectra used in the experiments is shown in Fig. 4. The number of photons (photons?m22?s21) was measured using the spectrometer in a dark room and was adjusted using the powersupply unit. The distance between the light source and the spectrometer sensor during measurements was approximately the same as that between the insects and light source in the incubator. Because the insects were irradiated through a glass lid, polystyrene lid, or glass plate, the same lid or plate was placed between the light source and sensor during measurement. The distances between the lid or plate and the light source during measurements were approximately the same as those in the incubator.

Insect containers were placed directly under the light source during irradiation. We confirmed that the upper surfaces of the containers were irradiated homogeneously by measuring the numbers of photons. In addition, we assumed that temperature changes caused by the light source would not affect survival of the insects because LED light emits little heat. To check this assumption, we measured the temperature inside the containers using a button-type temperature logger (3650, Hioki E. E. Co., Ueda, Japan), of the insects and in the media except for water (filter paper, culture medium, bottom of dish) using a radiation thermometer (IR-302, Custom Co., Tokyo, Japan). We measured water temperature using a digital thermometer (TP-100MR, Thermo-port Co., Iruma, Japan). Temperatures that showed lethal effects in several light treatments were measured in each experiment and under DD and LD (16L58D photoperiod) conditions. The temperature data are summarized in Supplementary Tables 5 and 6.

Lethal effects of irradiation with various wavelengths of light on D. melanogaster pupae. Thirty pupae were collected from the rearing boxes within 24 h of pupation and placed on a sheet of filter paper (Advantec, No. 1, 70 mm dia) impregnated with 700 mL of water in a glass petri dish (60 mm dia 3 20 mm tall). The petri dish was sealed with parafilm, placed in the incubator, and irradiated with LED light for 7 d at 25 6 1uC. The numbers of emerging adults were counted 7 d after the start of irradiation. Eight replications (petri dishes) were performed for each light dose and wavelength. Initially, lethal effects at 3.0 3 1018 photons?m22?s21 were compared among 12 wavelengths (378, 404, 417, 440, 456, 467, 496, 508, 532, 592, 657, and 732 nm). We investigated mortality of pupae under 24 h light (LL), 24 h dark (DD), and 16L58D photoperiod (LD) conditions using white cold cathode fluorescent lamps (CCFLs) in the light periods. The relationships between lethal effects and numbers of photons were compared among the 12 wavelengths.

Lethal effects of irradiation with blue light on eggs, larvae, and adults of D. melanogaster.

1) Eggs. Five pairs of mated adults were released onto 10 mL of culture medium (same as rearing stock culture) in a glass petri dish (60 mm dia 3 90 mm tall) and allowed to lay 10 eggs on themedium within 6 h. The petri dish with eggs was immediately sealed with parafilm and placed in the incubator. The eggs were then irradiated with 467-nm LED light for 48 h at 25 6 1uC, and the numbers of newly hatched larvae were counted under a stereomicroscope. The lethal effects of irradiation at 3.031018, 4.031018, 5.031018, and 10.031018 photons?m22?s21 were investigated. We also investigated egg mortality under DD conditions. Ten replications (petri dishes) were performed for each light dose.

2) Larvae. Ten final-instar larvae (wandering third-instar stage, L119) were collected
from the rearing boxes within 24 h of wandering out of the culture medium and placed in a polystyrene petri dish (55 mm dia 3 15 mm tall). The petri dish was sealed with parafilm, placed in the incubator, and irradiated with 467-nm LED light for 24 h at 25 6 1uC. After irradiation, the petri dish was transferred to the thermostatic chamber (LP-1PH; Nippon Medical & Chemical Instruments Co., Ltd., Osaka, Japan) and maintained under 16L58D (white fluorescent lamps were used during the light period) at 2561uC. The number of adults that emerged was counted after 10 d. Pupae that died before emergence were dissected under a stereomicroscope, and their developmental stages were determined19. We investigated the lethal effects of irradiation at 5.0 3 1018, 7.0 3 1018, 10.0 3 1018, and 12.0 3 1018 photons?m22?s21. Ten replications (petri dishes) were performed for each light dose.

3) Adults. One pair of adults was collected from rearing boxes within 12 h of emergence and released onto 10 mL of culture medium (same composition as for rearing stock cultures) in a glass petri dish (60 mm dia 3 90 mm tall). The petri dish was irradiated with 467-nm LED light in the incubator at 25 6 1uC. Flies were irradiated for 24 h d21 until both the male and female died. Every 24 h, we counted the number of surviving adults and eggs deposited, and replaced the petri dish containing culture medium with a fresh one. Ten replications (petri dishes) were performed for each light dose.

Lethal effects of blue-light irradiation on C. pipiens molestus and *T. confusum*.

1) C. pipiens molestus pupae. Ten pupae were collected from the stock cultures within 1 h of pupation and released into water (100 mL) in a polyethylene terephthalate (PET) ice-cream cup (101 mm dia 3 49 mm tall), the opening of which was covered with a glass plate. The cup was placed in the incubator and irradiated with LED light for 5 d at 2561uC. The numbers of emerging adults were counted 5 d after the start of irradiation. Ten replications (cups) were performed for each light dose and wavelength. Initially, lethal effects at 10.0 3 1018 photons?m22?s21 were compared among five wavelengths (404, 417, 440, 456, and 467 nm). We also investigated pupal mortality rates underDDconditions. The relationships between lethality and number of photons were then compared among seven wavelengths (404, 417, 440, 456, 467, 496, and 508 nm).

2) C. pipiens molestus eggs. Thirty eggs were collected from the stock cultures within 1 h of deposition and placed in water (50 mL) in a PET ice-cream cup (60 mmdia3 38 mm tall), the opening of which was covered with a glass plate. The cup was placed in the incubator (25 6 1uC) and irradiated with 417-nm LED light at 10.0 3 1018 photons?m22?s21 for 48 h. The number of newly hatched larvae was counted 48 h after the start of irradiation. After checking hatchability, the cup with mosquitoes was maintained under DD conditions for 72 h (25 6 1uC), and the mortality of newly hatched larvae was then investigated. For comparison, hatchability and mortality rates were investigated under LL (white CCFLs provided light for 48 h, after which darkness was provided for 72 h) and DD (no irradiation, darkness for 120 h) conditions. Ten replications (ice-cream cups) were performed for each light dose.

3) *T. confusum* pupae. Ten pupae were collected from the stock cultures within 24 h of pupation and placed in a glass petri dish (30 mm dia 3 15 mm tall). The petri dish was placed in the incubator (25 6 1uC) and irradiated with LED light at 2.0 3 1018 photons?m22?s21 for 14 d, after which we counted the number of adults that emerged. The lethal effects of irradiation were compared among five wavelengths (404, 417, 456, 467, and 532 nm). Ten replications (petri dishes) were performed for each wavelength.We also investigated mortality of pupae under LD conditions (white CCFLs were used).

Statistical analyses. Mortality and adult longevity were analysed using a generalized linear model (GLM) followed by the Steel–Dwass test. Mortality of *T. confusum* pupae was analysed by Steel–Dwass test without GLM, because 100% mortality occurred under blue-light irradiation (404–467 nm) and 0% mortality occurred under LD conditions. The lethal effects on C. pipiens molestus eggs were analyzed by using GLM followed by the Steel–Dwass test among 417 nm irradiation, LL, and DD in each of 0 and 72 h after discontinuing irradiation.

1. Bynoe, L. A., Del Priore, L. V. & Hornbeck, R. Photosensitization of retinal pigment epithelium by protoporphyrin IX. Graefe's Arch. Clin. Exp. Ophthalmol. 236, 230–233 (1998).
2. Algvere, P. V.,Marshall, J.& Seregard, S. Age-related maculopathy and the impact of blue light hazard. Acta Ophthalmol. Scand. 84, 4–15 (2006).
3. Ro´z?anowska, M. & Sarna, T. Light-induced damage to the retina: Role of rhodopsin chromophore revisited. Photochem. Photobiol. 81, 1305–1330 (2005).
4. Wu, J., Seregard, S. & Algvere, P. V. Photochemical damage of the retina. Surv. Ophthalmol. 51, 461–481 (2006).
5. Kuse, Y., Ogawa, K., Tsuruma, K., Shimazawa, M. & Hara, H. Damage of photoreceptor-derived cells in culture induced by light emitting diode-derived blue light. Sci. Rep. 4, DOI: 10.1038/srep05223 (2014).
6. Sinha, R. P. & Ha¨der, D-P. UV-induced DNA damage and repair: a review. Photochem. Photobiol. Sci. 2002, 225–236 (2002).
7. Rastogi, R. P., Richa, Kumar, A., Tyagi, M. B. & Sinha, R. P. Molecular mechanisms of ultraviolet radiation-induced DNA damage and repair. J. Nucleic Acids 2010, DOI: 10.4061/2010/592980 (2010).
8. Beard, R. L. Lethal action of UV irradiation on insect. J. Econ. Entomol. 65, 650–654 (1971).
9. Reed, N. G. The history of ultraviolet germicidal irradiation for air disinfection. Public Health Rep. 125, 15–27 (2010).
10. Faruki, S. I., Das, D. R., Khan, A. R. & Khatun, M. Effects of ultraviolet (254nm) irradiation on egg hatching and adult emergence of the flour beetles, *Tribolium castaneum*, *T. confusum* and the almond moth, Cadra cautella. J. Insect Sci. 7, insectscience.org/7.36 (2007).
11. Ghanem, I. & Shamma, M. Effect of non-ionizing radiation (UVC) on the development of Trogoderma granarium Everts. J. Stored Prod. Res. 43, 362–366 (2007).
12. Nakajima, M. & Yoshida, H. Studies on ultraviolet sensitivity in silkworm, with special reference to the effect of UV-irradiation on melanin formation in the cuticle of the striped silkworm. Jpn. J. Appl. Entomol. Zool. 15, 51–55 (1971).
13. Nakajima, M.&Yoshida,H. Studies on ultraviolet sensitivity in the silkworm,with special reference to variations in its killing effect during the larval instar

stage. Jpn. J. Appl. Entomol. Zool. 15, 17–22 (1971).
14. Ohtsuka, K. & Osakabe, M. Deleterious effects of UV-B radiation on herbivorous spider mites: They can avoid it by remaining on lower leaf surfaces. Environ. Entomol. 38, 920–929 (2009).
15. Zhang, C. Y., Meng, J. Y., Wang, X. P., Zhu, F. & Lei, C. L. Effects of UV-A exposures on longevity and reproduction in Helicoverpa armigera, and on the development of its F1 generation. Insect Sci. 18, 697–702 (2011).
16. Clark, J. H. The physiological action of light. Physiol. Rev. 2, 277–309 (1922).
17. McMillan, T. J. et al. Cellular effects of long wavelength UV light (UVA) in mammalian cells. J. Pharm. Pharmacol. 60, 969–976 (2008).
18. Murata, Y. & Osakabe, M. Factors affecting photoreactivation in UVB-irradiated herbivorous spider mite (Tetranychus urticae). Exp. Appl. Acarol. 63, 253–265 (2014).
19. Bainbridge, S. P. & Bownes, M. Staging the metamorphosis of Drosophila melanogaster. J. Embyrol. Exp. Morph. 66, 57–80 (1981).
20. Hoffmann, A. A., Sørensen, J. G. & Loeschcke, V. Adaptation of Drosophila to temperature extremes: bringing together quantitative and molecular approaches. J. Therm. Biol. 28, 175–216 (2003).
21. Pfeifer, G. P. Formation and processing of UV photoproducts: Effects of DNA sequence and chromatin environment. Photochem. Photobiol. 65, 270–283 (1997).
22. Beggs, C. B. A quantitative method for evaluating the photoreactivation of ultraviolet damaged microorganisms. Photochem. Photobiol. Sci. 2002, 431–437 (2002).
23. Chamberlain, J. & Moss, S. H. Lipid peroxidation and other membrane damage produced in Escherichia coli K1060 by near-UV radiation and deuterium oxide. Photochem. Photobiol. 45, 625–630 (1987).
24. Moan, J. & Peak, M. J. Effects of UV radiation on cells. J. Photochem. Photobiol. B: Biology 4, 21–34 (1989).
25. Santos, A. L. et al. Wavelength dependence of biological damage induced by UV radiation on bacteria. Arch. Microbiol. 195, 63–74 (2013).
26. Meng, J. Y., Zhang, C. Y., Zhu, F., Wang, X. P.&Lei, C. L. Ultraviolet light-induced oxidative stress: Effects on antioxidant response of Helicoverpa armigera adults. J. Insect. Physiol. 55, 588–592 (2009).
27. Sang, W.,Ma, W. H.,Qiu, L., Zhu, Z. H.&Lei, C. L. The involvement of heat shock protein and cytochrome P450 genes in response to UV-A exposure in the beetle Tribolium castaneum. J. Insect. Physiol. 58, 830–836 (2012).
28. Zhou, L. J. et al. Identification and transcriptional profiling of differentially expressed genes associated with response to UVA radiation in Drosophila melanogaster (Diptera: Drosophilidae). Environ. Entomol. 42, 1110–1117 (2013).
29. Yin, R. et al. Light based anti-infectives: ultraviolet C irradiation, photodynamic therapy, blue light, and beyond. Curr. Opin. Pharmacol. 13, 731–762 (2013).
30. Shimoda, M. & Honda, K. Insect reactions to light and its applications to pest management. Appl. Entomol. Zool. 48, 413–421 (2013).
31. Gomez, F. H., Loeschcke, V. &Norry, F. M. QTL for survival to UV-C radiation in Drosophila melanogaster. Int. J. Radiat. Biol. 89, 583–589 (2013).
32. Vaisnav, M. et al. Genome-wide association analysis of radiation resistance in Drosophila melanogaster. PLoS One 9, e104858 (2014).
33. Sivamani, R. K., Crane, L. A.&Dellavalle, R. P. The benefits and risks of ultraviolet (UV) tanning and its alternatives: the role of prudent sun exposure. Dermatol. Clin. 27, 149–154 (2009).

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AUTHOR CONTRIBUTIONS

M.H. designed the experiments. K.S., M.S. and Y.S. performed the experiments. M.H. and K.S. analysed the data. M.H. wrote the manuscript. All authors reviewed the manuscript.

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GENETICALLY MODIFIED FOODS

Written by Nina Fedoroff, printed in the Spring 2007 issue of Science Journal;
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In chapter seven of his environmental masterpiece Walden, Henry David Thoreau writes about his bean field: "…making the yellow soil express its summer thought in bean leaves and blossoms rather than in wormwood and piper and millet grass, making the earth say beans instead of grass—this was my daily work."

You may wonder why I begin an essay on genetically modified foods with a quote from Thoreau. But to me, environmentalism and plant breeding are inextricably linked. Our civilization rests on our ability to make the earth say beans. Other creatures feed their young, but the adults of most species fend for themselves, spending much of their day doing it. By contrast, we humans have learned to farm. Over the last few centuries, advances in science have let fewer and fewer farmers feed more and more people, freeing the rest of us to make and sell each other hats and houses and computers, to be scientists and politicians, painters, teachers, doctors, spiritual leaders, and talk-show hosts. In some parts of the world, only one person in a hundred grows plants or raises animals for food. Most of us are surprisingly unaware of what it takes to create our bread and breakfast cereal, pasta and rice, those perfect fruits and vegetables, unblemished by insect bites or fungal spots. Free to live our lives with little thought for our food, we ignore the source of the gift.

Our civilization rests, in fact, on a history of tinkering with nature—on making the earth say beans instead of grass. Thoreau's beans were not wild. The pod of a wild bean bursts when its seed is ripe, flinging the bean far from the parent plant to find a new place to sprout. The pods of those beans we grow for food do not burst. Such beans can no longer seed themselves. Nor can the wild grasses we have changed, over the millennia, into our staple food sources: rice, wheat, and corn. To change a wild plant into a food plant requires changes in the plant's genes. To boost its yield, to make the earth say more beans, means changing the plant's genes, as well. For thousands of years, farmers have been picking and choosing plants, propagating those with the genetic changes—mutations—that made them better food plants. Our civilization is the beneficiary of this genetic tinkering.

> "TO CHANGE A WILD PLANT INTO A FOOD PLANT REQUIRES CHANGES IN THE PLANT'S GENES."

I have been studying plant genes—and tinkering with them—since the early 1980s, when I had the good fortune to work with Nobel Laureate Barbara McClintock, whose discovery of "transposons," popularly called "jumping genes," rewrote our concept of a gene. By identifying and cloning a jumping gene in 1984, I was able to identify the DNA sequences of McClintock's transposons and then to analyze and understand how they operate. Today we know that the genome is full of transposable elements and is constantly changing. Instead of being static "beads on a string," genes can move from one chromosome to another. Although the genes themselves are conserved over long evolutionary periods, there have been, and continue to be, numerous rearrangements, transpositions, duplications, and deletions, many of which are the work of the restless transposons.

McClintock and I worked on corn, and since then I and my students have used many of the techniques of genetic engineering invented in the last 20 years to uncover the secrets of how transposons and other kinds of plant genes work. I have never applied my knowledge to making a genetically modified crop, but my familiarity with both the techniques and the corn genome made me pay attention when corporations began doing so—and when the federal government began regulating the field-testing and marketing of these crops. I have given numerous public lectures on genetically modified foods and, with co-author Nancy Marie Brown , have written the book Mendel in the Kitchen: A Scientist's View of Genetically Modified Foods , published in 2004 by Joseph Henry Press, an imprint of the National Academies Press.

For instance, when did people begin tinkering with the genes of plants? Corn—maize—is one of humankind's greatest feats of genetic engineering. It looks nothing like a wild plant. Maize has no way of dispersing its seeds, stuck tight as they are on its enormous ears, which remain firmly attached to the plant. Scientists argued about what wild plant gave rise to maize for most of the 20th century. We now know its closest relative is a grass—teosinte. Discovered in 1896, teosinte looks so little like maize that it was assigned to a different genus: Teosinte was Euchleana mexicana; corn is Zea mays. Plants that belong to two different species (not to mention two different genera) are not supposed to cross-hybridize, but maize and teosinte do. Early genetic work by George Beadle (who would share the Nobel Prize in 1958 for the "one-gene one-enzyme" hypothesis) and his mentor Rollins Emerson of Cornell University suggested that a small number of genetic changes had transformed teosinte into maize, but it wasn't until 1992 that John Doebley of the University of Wisconsin-Madison and his colleagues, using modern molecular techniques, concluded that no more than five major genetic regions—in some cases single genes—were responsible. Changes in one of the critical genes softened the hard, silica-containing surface of the seed; another created an ear-like structure with tightly adhering seeds; and yet another telescoped a side branch into the dense husk covering the contemporary corn plant's ear.

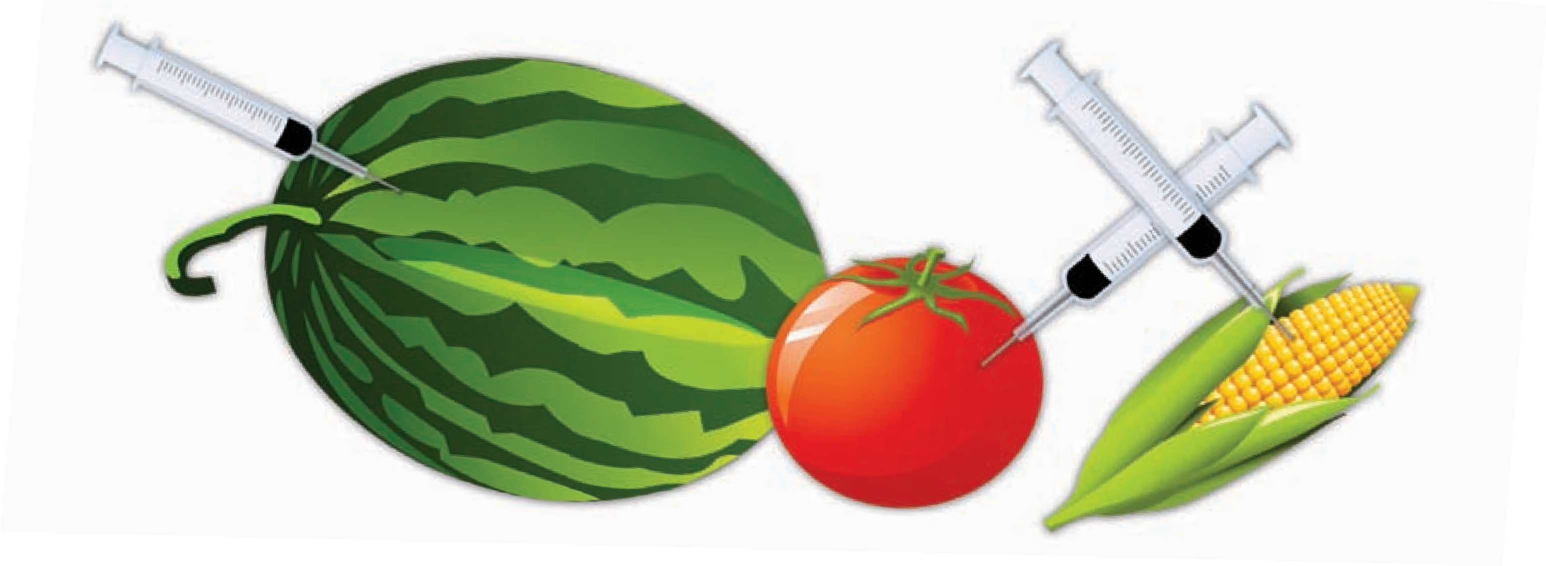
To make corn, teosinte was genetically engineered by generations of farmers in the Balsas River basin of southern Mexico between 5,000 and 13,000 years ago. When scientists accepted teosinte as corn's ancestor, late in the 20th century, they realized the two could not belong to different genera. So they renamed teosinte: It is now a subspecies, called parviglumis, of corn, Zea mays.

The teosinte plant, of course, had not changed at all—only our way of naming it. The classifications "genus" and "species" are not fixed and immutable. Nor does our current definition of species particularly apply to plants. Indica rice and Japonica rice, for example, are two popular types of cultivated rice, Oryza sativa. They are members of the same species, and it is often difficult to tell if a single grain comes from one type or the other. Yet they do not crossbreed.

Scientists in the 1950s, on the other hand, made a new, fertile grain called triticale by crossbreeding rye and durum wheat, which belong to two different genera. The secret to this early genetic engineering was colchicine, a chemical isolated from the autumn crocus. Colchicine doubles a plant's chromosomes, making the normally sterile hybrid set seeds. By the mid-1980s, triticale was grown on more than two million acres worldwide; triticale flour is commonly found in health-food stores. Colchicine is also used to make fruits seedless. A favorite fruit produced this way is the seedless watermelon.

Another way to make seedless fruits is by using radiation to cause mutations. The Rio Red, a popular red grapefruit, was created by exposing grapefruit buds to thermal neutron radiation at Brookhaven National Laboratory in 1968. Other notable successes of mutation breeding include Creso, the most popular variety of durum wheat used for making pasta in Italy; Calrose 76, a high-yielding California rice; Golden Promise barley, a fine-quality malt used in specialty beers; and some 200 varieties of bread wheat grown around the world.

Such work is still going on. In 1996, citrus breeders Mikeal L. Roose and Tim Williams of the University of California, Riverside, irradiated budwood to develop a seedless clementine called Tango. (Generally, seedless clementines are made by spraying the flowers with a chemical that mimics a growth hormone.) By 2006, nurseries had orders for millions of Tango trees, and the researchers had extended their radiation-breeding program to include 63 varieties of citrus including mandarins, oranges, tangelos, lemons, and grapefruits.



In 2001, researchers at the Colorado and Texas Agricultural Experiment Stations even used radiation breeding to create a hard red winter wheat, called Above, that tolerates an herbicide produced by the BASF corporation. Above wheat can be sprayed with herbicide and will not die, letting farmers use energy-saving no-till techniques. Yet, although the end result is the same as the Roundup Ready crops sold by Monsanto, Above is not considered a "genetically modified organism" or GMO.

In fact, none of the many crop varieties created over the last 50 years through chemical or radiation mutation is considered a GMO, and they are not covered by the regulations that restrict the field-testing and sale of GM foods. In fact, they are not covered by any regulations at all, although many of the public's concerns about GM crops—such as toxicity to humans or gene flow from modified crops to wild plants—apply to these crops as well.

GMO regulations only cover plant varieties created with molecular modification techniques, which plant breeders agree are more precise and controllable—and therefore safer—than the "conventional" techniques of chemical and radiation mutation.

The history of molecular-modification techniques begins in the late 1960s, when molecular biologists learned to isolate and study individual genes from among the tens of thousands of genes in every plant and animal. They began to decipher the information content of different organisms, from bacteria and yeast, plants and humans, discovering that genes change rather slowly. Maize plants and humans, for example, both have hemoglobin genes that code for rather similar oxygen-binding proteins, although they use them for very different purposes. Methods were developed as well to remove and replace genes and to add new ones. With a small amount of tweaking, any gene could work in almost any other organism. The functioning of genes and cells is so similar from one organism to another that if a bacterial gene is put into a plant, it will make the very same protein it did in the bacterium. Scientists also discovered that the movement of genes from one type of organism (such as a bacterium) to another (a plant) happens in nature. Building on that discovery, scientists developed ways to systematically introduce genes into plants in order to add just the right genes to help a plant withstand nature's biological and physical stresses.

> “TODAY THERE IS WIDESPREAD ACCEPTANCE IN NORTH AND SOUTH AMERICA FOR THE MOLECULAR MODIFICATION OF CROP PLANTS.”

One of their first successes was in making plants disease-resistant. For example, Hawaii's papaya plantations were saved from the scourge of the deadly papaya ringspot virus by expressing just a small genetic sequence of the virus in the plant. This sentinel gives the plants the ability to recognize and destroy an infecting virus before it can reproduce, much as we immunize children against the poliovirus, but by a different molecular mechanism. Other virus-resistant varieties include a plum that can withstand the plum pox virus that ravaged Pennsylvania recently, leading the state to invest $5.1 million towards its eradication. An heirloom variety of tomato, the San Marzano (said to be the inspiration for pizza), has been made resistant to the cucumber mosaic virus; by the year 2000, that virus had wiped out 90 percent of San Marzano production in its home fields near Naples, Italy. Unfortunately, neither the virus-resistant plum nor the tomato have been planted, due to anti-GMO activism. Widespread planting in Africa of a virus-resistant sweet potato, developed by Kenyan researcher Florence Wambugu through a collaboration with Monsanto, similarly has been delayed.

The most widely planted genetically modified crops are the corn and soybean varieties that tolerate herbicides, along with varieties of corn and cotton that produce an insecticidal protein from the bacterium Bacillus thuringiensis (Bt), long used by organic farmers to control insects. These crops, developed by a number of companies including Monsanto, Syngenta, and DuPont, have been found to substantially decrease farmers' use of pesticides and herbicides. Moreover, because they protect corn plants from invasion by certain kinds of boring insects, the fungi that follow the insects do not infect the plants, substantially decreasing the contamination of the harvested corn by harmful mycotoxins.

"Today there is widespread acceptance in North and South America for the molecular modification of crop plants, and growing acceptance in China and India. Yet the status of crops modified by molecular techniques remains contentious in both Europe and Africa." New crops under development are focusing on making foods healthier or easier to grow, especially in harsh environments. For instance, nitrogen fertilizer would no longer be necessary if corn, wheat, and rice could fix nitrogen from the air in the way that legumes, such as peas and beans, do. Nitrogen fixation is a complex symbiosis between the legume and rhizobial bacteria that live in nodules on the plant's roots. In 2001, the DNA sequence of the rhizobial bacteria that fix nitrogen in alfalfa was published; since then more than 100 scientific studies have cited this article. A breakthrough announced by British workers in 2006 was inducing formation of the nodules without the presence of the bacteria.

In March 2007, researchers from the United States and China reported on how plants respond to the depletion of calcium from the soil, one effect of acid rain. This knowledge is a first step toward developing plant varieties that need less calcium. Other researchers are trying to make crops that are salt-tolerant, drought-tolerant, heat-tolerant, and cold-tolerant. Monsanto has identified genes that enable some plants to withstand drought and has created corn and soybean lines that grow with less water. Drought-tolerant corn is now undergoing field trials.

Researchers also are working on ways to make common foods healthier. Golden Rice, a rice that contains vitamin A, was created by Swiss researchers in 1999. The trait is currently being bred into varieties of rice traditionally grown in regions where vitamin A deficiency leads to high rates of blindness in children. In 2006, researchers in Florida reported they had bred a tomato that contains 20 times the normal amount of folate. A B vitamin, folate is needed to prevent anemia in pregnant women and birth defects in their children; lack of folate also increases the risk of vascular disease and cancer. A goal for future work is to fortify staple crops such as rice, sorghum, maize, or sweet potatoes with folate. Other researchers have made a temperate plant that produces a more-saturated, tropical-like oil which has baking properties like margarine without the transfats; a rice high in cancer-fighting flavonoids; potatoes with zeaxanthin, which wards off eye disease; and soybeans and canola oil that contain heart-healthy omega-3 fatty acids.

Oddly, these innovations aren't called plant breeding, but "genetic engineering." The new crops are not simply crops—as are the ones created using chemicals and radiation to modify plant genes—but genetically modified organisms.

GMOs have met with strong resistance. Before GMOs, people might have protested the use of synthetic fertilizers or pesticides in modern farming, but they were unconcerned about whatever it was that plant breeders had done to create high-yielding hybrid corn or brilliant red grapefruits or seedless watermelons. Now, however, many people seem to agree with Britain's Prince Charles when he calls the new techniques of plant breeding "dangerous" and against God's plan.

> "THE MOST WIDELY PLANTED GENETICALLY MODIFIED CROPS ARE THE CORN AND SOYBEAN VARIETIES THAT TOLERATE HERBICIDES."

Part of the problem is in the words themselves. Much human effort goes into changing our environment, be it the building of highways, houses, air conditioners, shopping malls, dams, or airplanes. Although individual projects might meet with resistance, no one protests this kind of engineering. Yet the notion that plants were being engineered caught people by surprise. It was rather disquieting. Plants are, after all, natural, aren't they? Might we not be messing with Mother Nature if we began to engineer plants?

The fantastic recent growth of electronic communication has amplified the ability to spread misinformation. Numerous organizations devote themselves to the active opposition of molecular approaches to plant breeding (though none, strangely, focus on radiation mutation, for example). Unfortunately, our understanding of scientific concepts, such as what a species is or what genes do, is often a vague mixture of fact and belief, leaving us ill-prepared to separate fact from fiction. What genetic engineering actually is and how it differs from earlier techniques of plant breeding is little known outside the laboratory and breeding plot. Our lack of knowledge could have tragic consequences. By stifling the creativity of plant breeders and by banning the results of their work from the marketplace, a "no-GMO" attitude could keep hungry people from being able to grow enough food.

Here is my concern as an environmentalist: The human population is too large, and the Earth too small, to sustain us in the ways our ancestors lived. Most of the land that is good for farming is already being farmed. Yet 80 million more humans are being added to the population each year. The challenge of the coming decades is to limit the destructive effects of agriculture even as we continue to coax more food from the earth. Simply to provide all people living today with the same amount of food available to each American, we need to increase crop yields—unless more land is to be brought into production, which means plowing up more wilderness.

We cannot turn the clock back. At the end of the Stone Age, when most people lived in small tribes hunting wild game and gathering wild plants, the world's human population was stable at 8 to 10 million. When farming took hold as a way of life, the population began to grow. By the time of Christ, it had risen to between 100 and 300 million. When Columbus landed in the New World and the spread of food plants around the globe increased, the world's population was about 450 million. In the late 1700s, when the science of chemistry entered agriculture, it had doubled to 900 million. A century later, when Gregor Mendel's experiments were rediscovered, giving rise to the science of genetics, the population of the world was over one and a half billion.

> "THERE REMAIN PLACES IN THE WORLD WHERE MALNUTRITION PERSISTS AND HUNDREDS OF THOUSANDS OF PEOPLE, ESPECIALLY CHILDREN, DIE FOR LACK OF FOOD."

In just the last hundred years the population doubled and redoubled. The number of people on Earth reached three billion in 1950, then jumped to six billion in little more than a single human generation. Yet farmers kept pace. Two important inventions early in the 20th century supported an enormous increase in farm productivity. First was the Haber-Bosch process for converting the gaseous nitrogen in the air to a form that plants can use as nitrogen fertilizer. Second was the observation of George Harrison Shull that intercrossing inbred corn varieties produces robust and productive offspring. This is the scientific underpinning of the entire hybrid corn industry.

These inventions initially benefited the developed world. By mid-century, doomsayers were predicting famines in India and China. These famines were averted by plant geneticists, who derived mutant strains of wheat, corn, and rice that were markedly more productive than indigenous strains. From the 1960s to the 1990s, the new crop varieties and expanding fertilizer use—the Green Revolution—continued to meet the world's food needs. In 1950, 1.7 billion acres of farm land produced 692 million tons of grain. In 1992, with no real change in the number of acres under cultivation, the world's farmers produced 1.9 billion tons of grain—a 170 percent increase. If India alone had rejected the high-yielding varieties of the Green Revolution, another 100 million acres of farm land—an area the size of California—would need to be plowed to produce the same amount of grain. That unfarmed land now protects the last of the tigers. But the human population is still expanding. And there remain places in the world where malnutrition persists and hundreds of thousands of people, especially children, die for lack of food. Where will the next increments in food production come from? I believe they will come from genetic modification.

Today there is widespread acceptance in North and South America for the molecular modification of crop plants, and growing acceptance in China and India. In the first decade after these crops were introduced, their adoption progressed at a remarkable pace. By 2005, genetically modified crops, primarily cotton, corn and soybeans, were being grown by more than 8.5 million farmers in 21 different countries, with no substantiated reports of adverse health effects. Beneficial impacts, on the other hand, have been substantiated by peer-reviewed scientific studies, including the reduction in pesticide and herbicide use, the control of soil erosion through no-till farming, and the reduction in mycotoxin contamination of grain.

Yet the status of crops modified by molecular techniques remains contentious in both Europe and Africa. What remains to be seen is whether the wealth of the developed countries will be deployed to the benefit of the poorest countries, where people struggle to gain a foothold on the lowest rung of the economic ladder. Molecular modification of crop plants is expensive. And yet, as some of the examples I have given in this essay show, such modifications hold the promise of improving crop productivity under the most adverse climatic and biological conditions.

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