Impacts of LED lighting on bioefficiency and quality in oyster mushroom production

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Why Mushrooms?

Why Mushrooms?

Fungi are the 3rd critical component in energy and resource cycling

Producers (plants)

Consumers (animals)

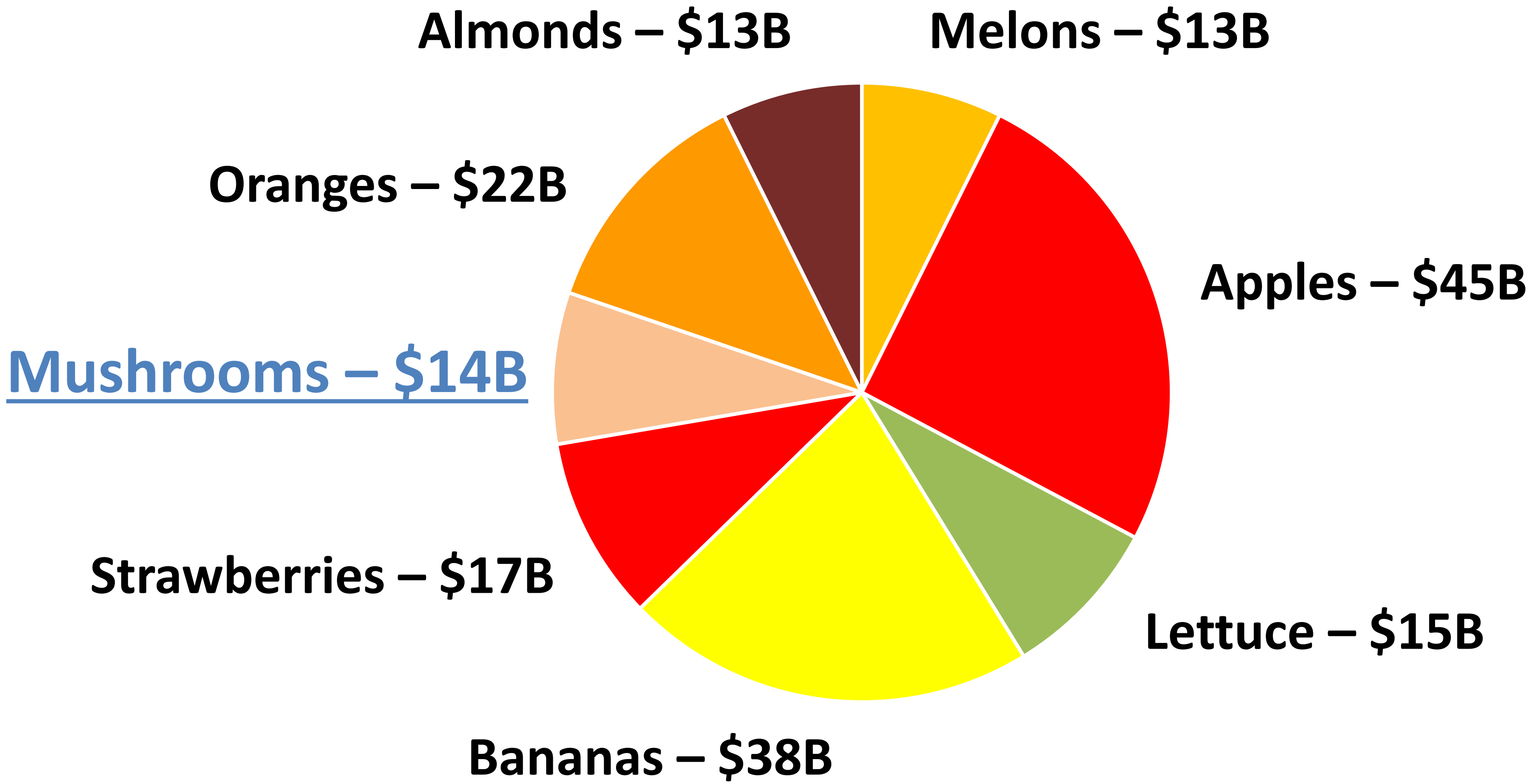
Decomposers (fungi)

Why Mushrooms?

Profit!

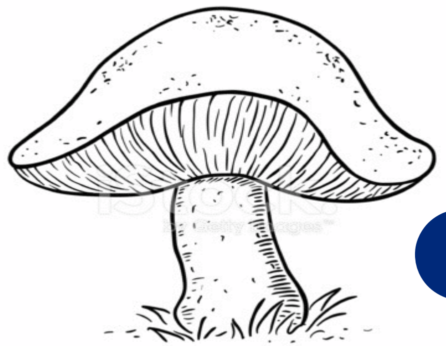
Globally, the mushroom market is expanding rapidly by 10-20% annually!

World mushroom production is BIG BUSINESS!!



World Market Values
FAOSTAT 2016

Establishing mushroom production in Arizona



Arizona Mushroom Growers Association

- ✓ Funded by the Arizona Department of Agriculture Specialty Crops Block Grant program, 2015, 2017, and 2019

- ✓ Providing cultures, resources, research, expertise, and training to assist small businesses integrate mushroom production into diversified farming systems

- ✓ Currently 215 members (~45 commercial growers) representing production in 12 of the 14 counties

- ✓ Visit our website: http://www.azmushroomgrowers.org/

What is driving this market?

Health

“The market is being driven by the rise in consumer awareness about health and wellness, cultivation being a promising and profitable business, and continuous R&D and innovations to expand applicability and accelerate growth.”

“Mushroom Market – Global Trends & Forecast to 2019”’ MarketsandMarkets

Are fungi nutritious…..Yes!!
A first class source of protein

Button mushrooms

Nutrition Facts

Serving Size 5 medium (84g/3.0 oz)

Amount Per Serving	
Calories 20	Calories from Fat 0
	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 15mg	**1%**
Potassium 300mg	**9%**
Total Carbohydrate 3g	**1%**
Dietary Fiber 1g	**4%**
Sugars 0g	
Protein 3g	

Vitamin A 0%	• Vitamin C 2%
Calcium 0%	• Iron 2%
Vitamin D 4%	• Thiamin 4%
Riboflavin 20%	• Niacin 15%
Vitamin B6 4%	• Folate 4%
Pantothenic Acid 15%	• Phosphorus 8%
Magnesium 2%	• Zinc 2%
Selenium 10%	• Copper 15%
Manganese 2%	

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Saturated Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500 mg	3,500 mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

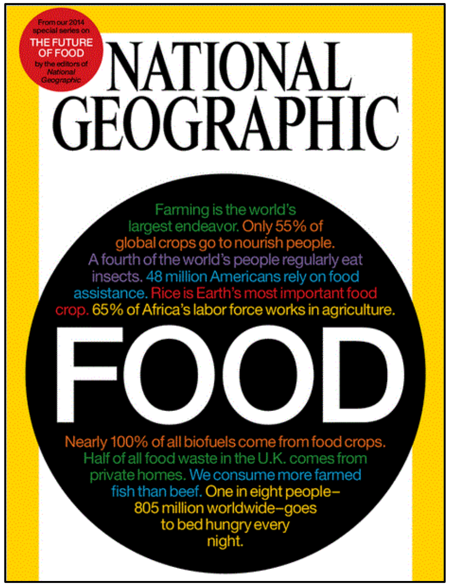
Mushroom are approx. 40% dry weight protein. **Mycoprotein** is a good balance of all nine essential amino acids in roughly the same proportions as egg.

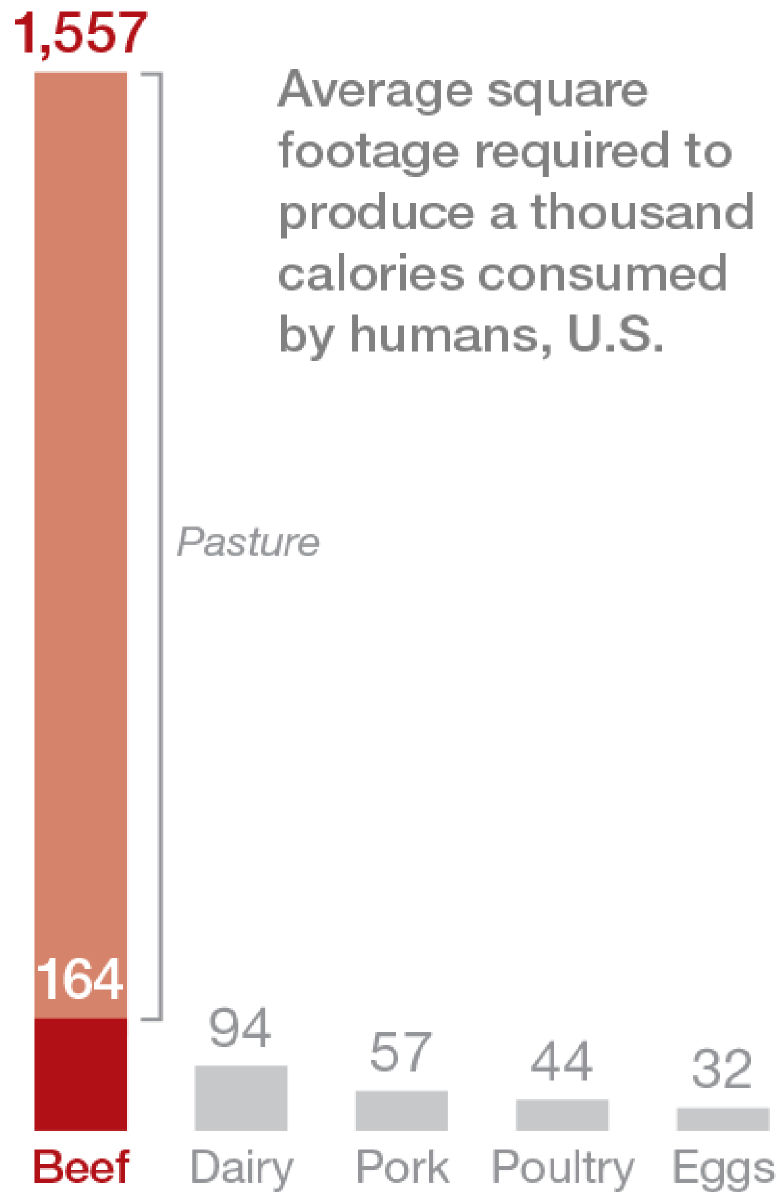
A first class protein product, comparable to meat and fish but with no cholesterol, high in fiber, low in fat, and no trans-fats.

Compare this to CORN, which is less than 10% protein and deficient in three essential amino acids: lysine, tryptophan, and methionine.

Myco-protein products!!
from ***Fusarium venenatum***.

Creating sustainable food productions systems

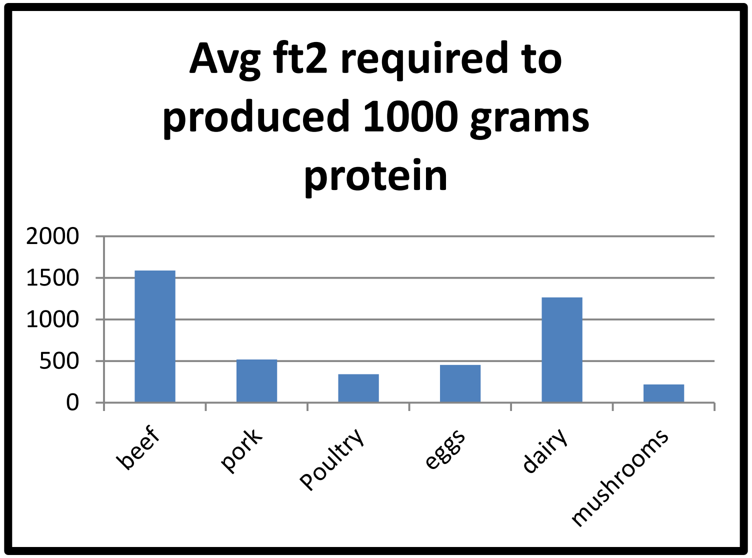


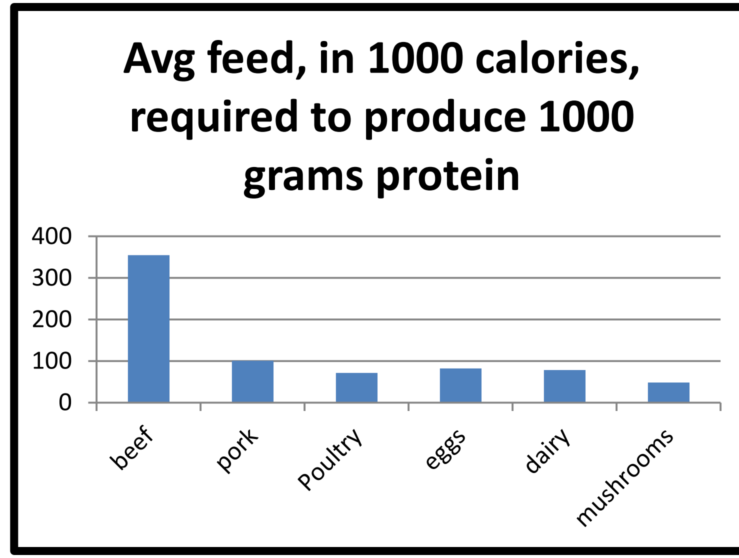


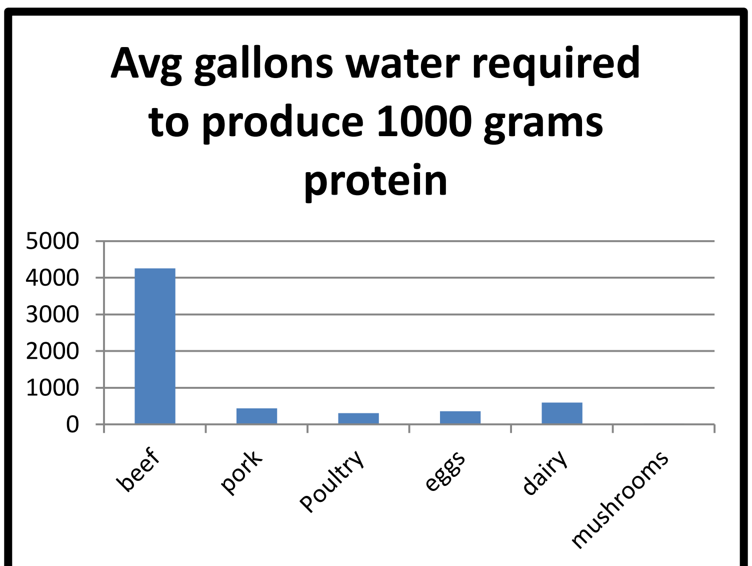
http://www.nationalgeographic.com/foodfeatures/meat/.

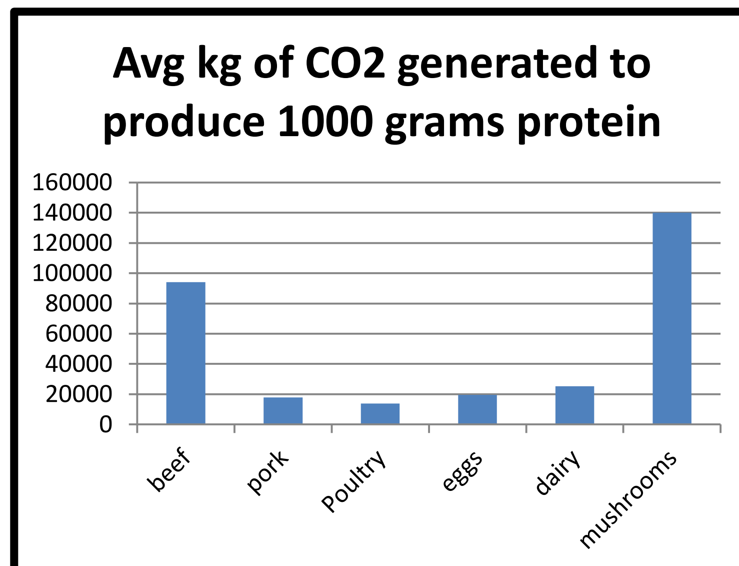
What are the impacts of <u>protein</u> production in sustainable food systems?

The sustainability of mycoprotein production









NGM Staff. Sources: Gidon Eshel, Bard College; Alon Shepon AND RON MILO, Weizmann Institute of Science; Tamar Makov, Yale School of Forestry and Environmental Studies, *PNAS,* July 21, 2014

Most modern mushroom production occurs in dedicated **controlled environment facilities**.

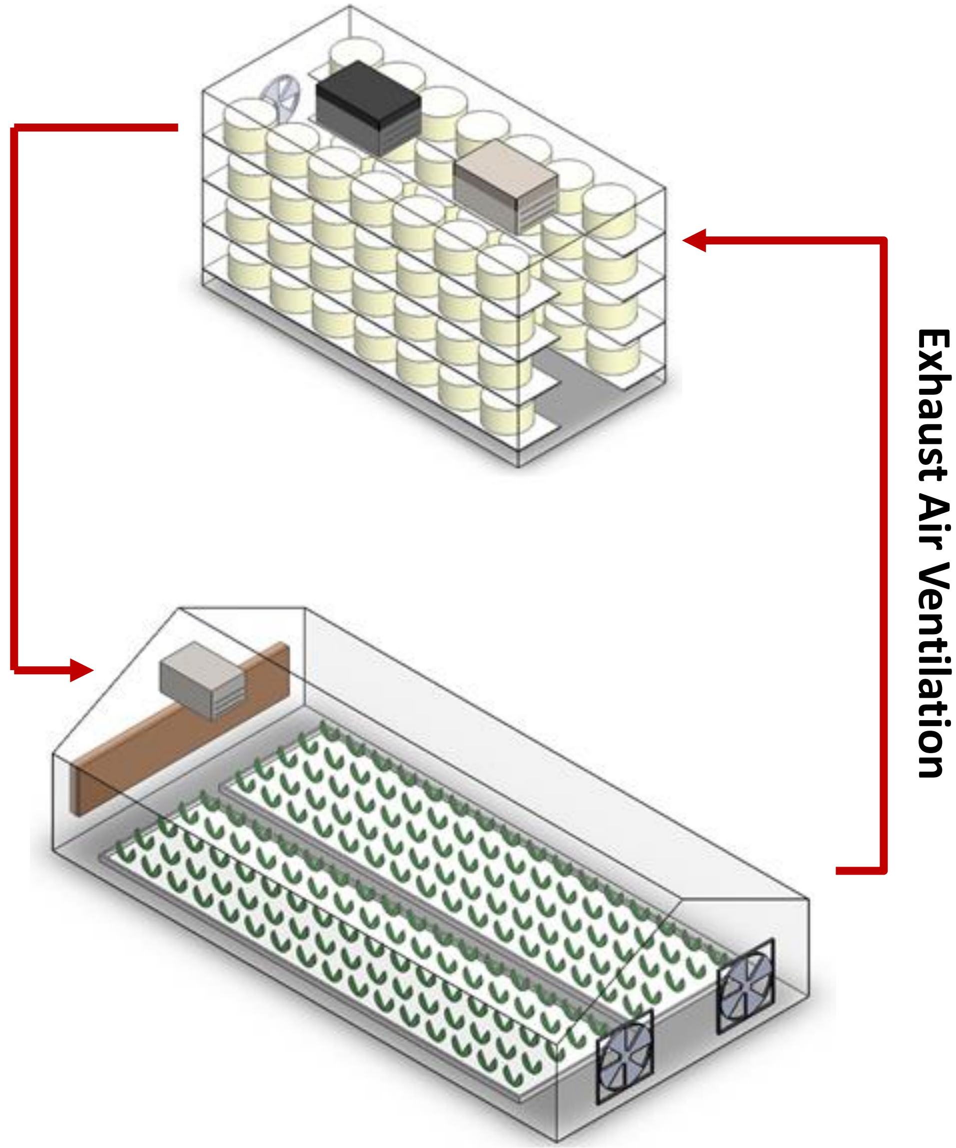
Controlling three parameters: temperature, humidity, and CO_2……..and lighting!

Engineering modeling and analysis of sustainable indoor mushroom production system strategies in semi-arid climate
Caitlyn Hall, ABE M.S. graduate, 2016

- Ventilation from greenhouse to mushroom satisfied the mushroom house ventilation requirement (359 $m^3 h^{-1}$) and assists in humidification
- Mushroom exhaust air to greenhouse house to utilize CO2

Results

- Mushroom House Energy Use Comparison
  - Day time average decreased energy use: ↓ **76.2%**
    - Spring, Winter
  - Day time average increased energy use: ↑ **56.6%**
    - Summer, Monsoon, Fall
  - Night time average decreased energy use: ↓ **33.6%**
    - Spring, Summer, Fall
  - Night time average increased energy use: ↑ **34.2%**
    - Monsoon
- Mushroom House Water Use Comparison
  - Day time average decreased water use: ↓ **65.7%**
    - All seasons
  - Night time average decreased water use: ↓ **38.6%**
    - Spring, Summer, Monsoon, Fall



How efficient are mushrooms in biomass conversion to protein?

Biological Efficiency

$$BE\% = \frac{Fresh\,Weight}{Dry\;Substrate\;Wt.} \times 100$$

Evaluation of yield per quantity of substrate

A comparison of bioefficiencies

(wet wt output/dry wt input)

Processed pelleted feed

Beef	**5-15%**
Chicken	**30-50%**
Fish	**60-80%**
Crickets	**70-90%**
Mushrooms	**80-150%**

-Per gram protein, lower water usage and lower footprint as well

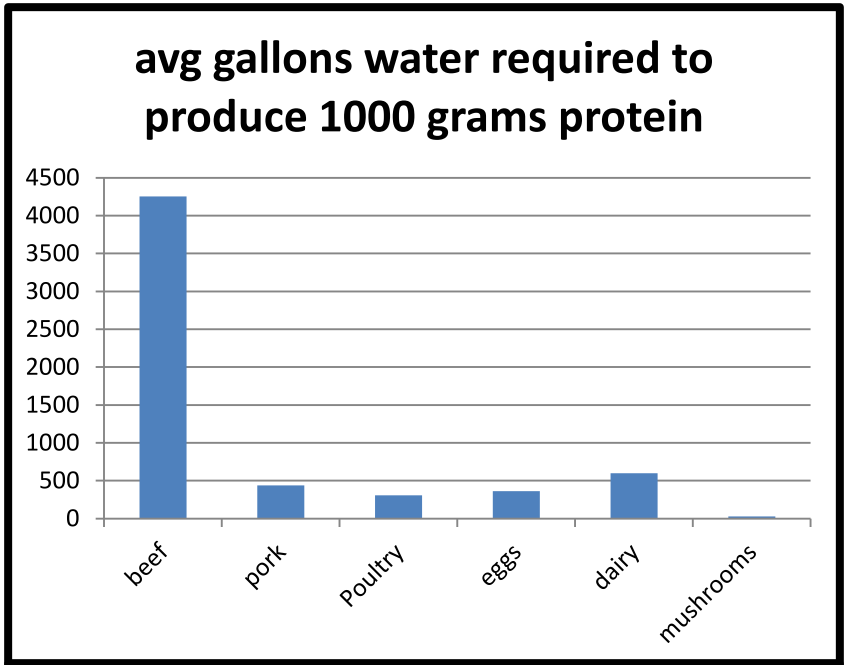
-And you can feed mushrooms things even chickens, fish, or crickets won't eat!

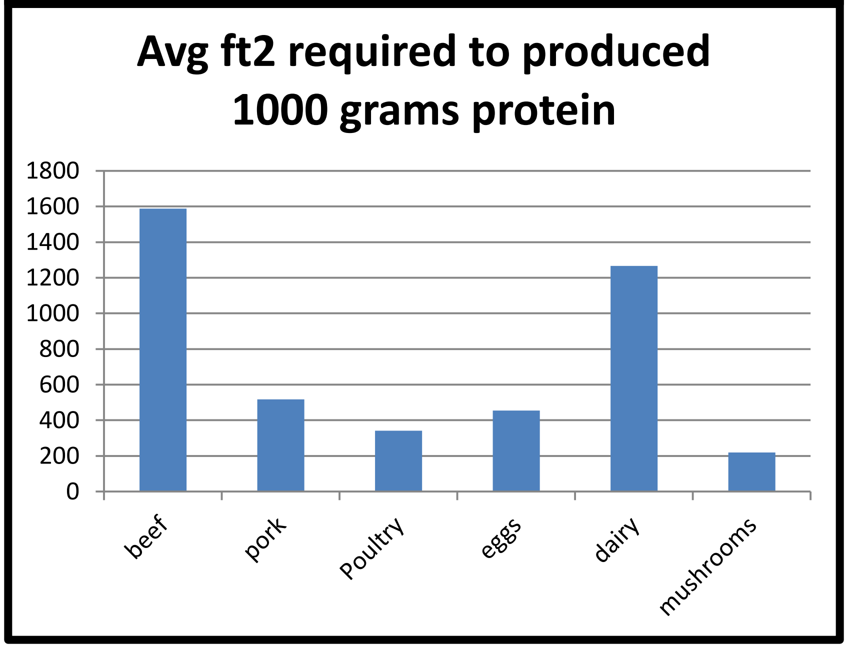
-Then you can feed the remains of mushroom production back to the chickens, fish, and crickets!!

Can mushrooms be produced in the desert in a sustainable manner?

Yes! <u>In highly efficient controlled environment facilities.</u>

The feedlots of the future!

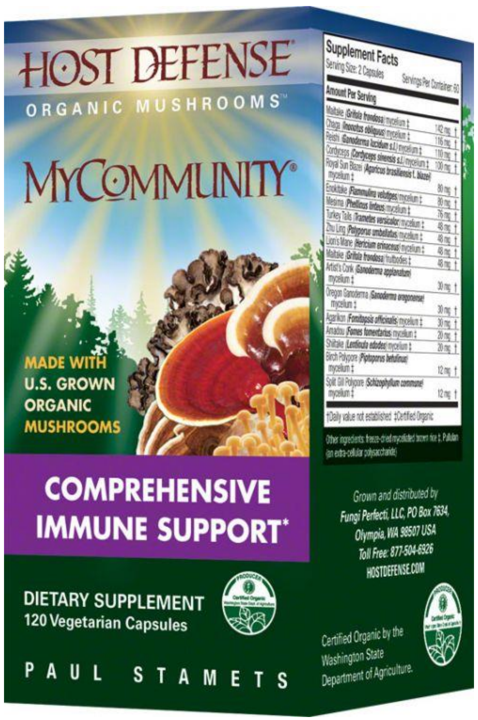




NGM Staff. Sources: Gidon Eshel, Bard College; Alon Shepon AND RON MILO, Weizmann Institute of Science; Tamar Makov, Yale School of Forestry and Environmental Studies, *PNAS,* July 21, 2014

Are fungi nutritious…..Yes!
All those amazing nutraceuticals!

- conjugated linoleic acids (CLA), isomers of linoleic acid found mainly in the meat and dairy products. Powerful anti-carcinogens; significant effects on body lean/fat ratios
- The statins, HMG-CoA reductase inhibitors, produced by many fungi reduce cholesterol production in the liver.
- Aromatase and 5-alpha reductase inhibitors, inhibit enzymes important in the biosynthesis of estrogen and dihydrotestosterone, respectively
- Beta glucans, e.g., lentinans, effective in reducing serum cholesterol (both total and LDL); effective immuno-modulators that enhance the innate immune response by stimulating natural killer (NK) cells, and enhancing adaptive immune response by stimulating dendritic cells (DC) maturation and their antigen-presenting functions
- Egothioneine, a natural antioxidant found in beans, oats, liver, with the highest concentration in mushrooms.



Agaricus bisporus: the champion of the industry

- ***Agaricus bisporus*** **is the dominant cultivated mushroom species worldwide – different varieties include the white button, crimini, and portobello mushroom. Approx 50% of mushrooms cultivated are white button *A. bisporus*.**

Specialty mushrooms are where the real growth is!

Shiitake

Pearl Oyster

Blue Oyster

Lion's mane

Pioppino

Maitake

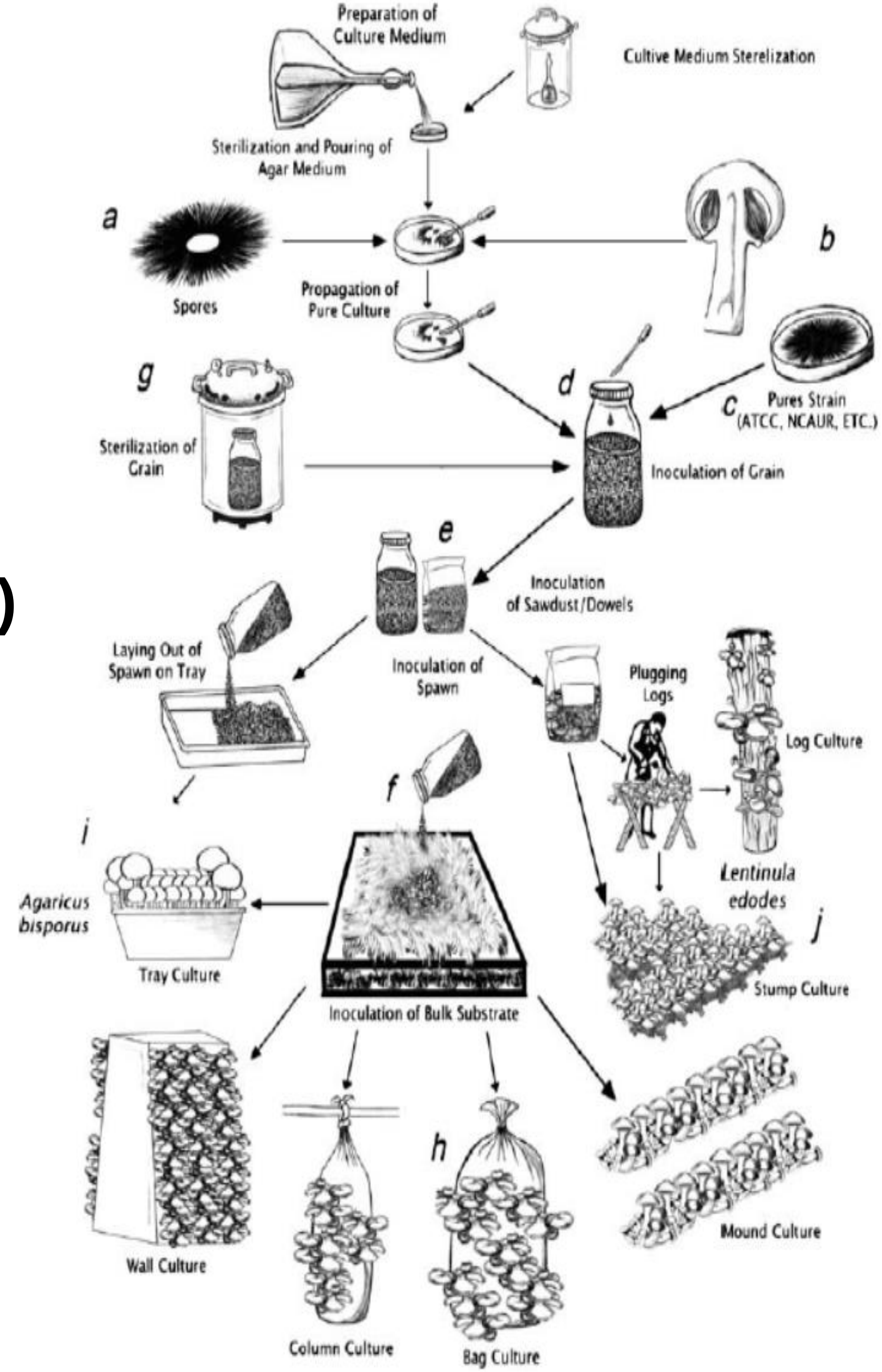
Why *Pleurotus* (oyster mushroom)?

- The second most cultivated mushroom after button mushroom
- Approximately 200 identified species
- Popular for its flavor, color, nutrition, and medicinal qualities
- Shorter growth time compared with other edible mushrooms
- A white-rot fungus, capable of degrading a wide variety of substrates and outcompeting many other microbial contaminants

Our 4th of July variety pack!

The production process

- Prepare <u>cultures (1 wk)</u>
- <u>Spawn</u> production (2 wk)
- <u>Substrate</u> preparation
- <u>Spawn run (2 wk)</u>
- <u>Production</u> flush (4 wk)
- <u>Harvesting</u>



Four principles of mushroom cultivation

1. Create a nutrient source, the substrate, that is selective for your mushroom.

2. Inoculate this substrate with your fungus spawn so it will dominate.

3. Manage the environment to favor initial growth and nutrient utilization (spawn run).

4. Manage the environment to favor periodic mushroom initiation and development.

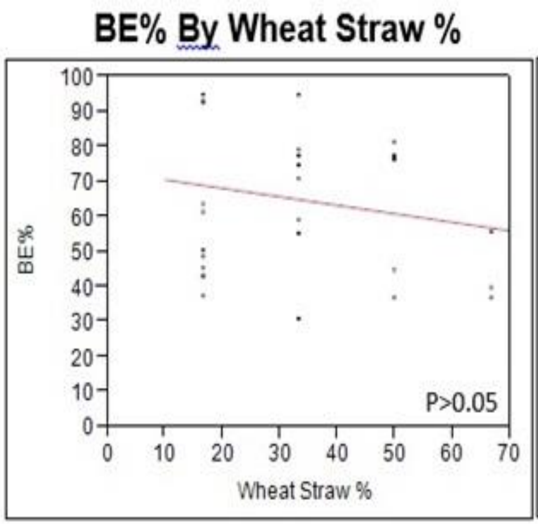
What impacts mushroom bioefficiency and quality?

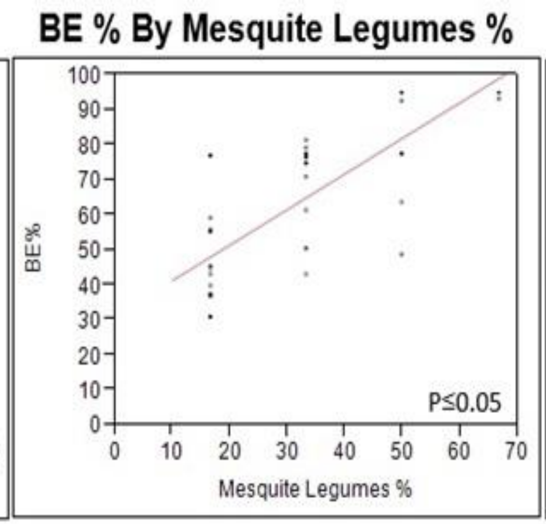
1. The growth materials: spawn, carbon source, nitrogen source, other amendments
2. The environment: temperature, rel. humidity, CO_2, lighting

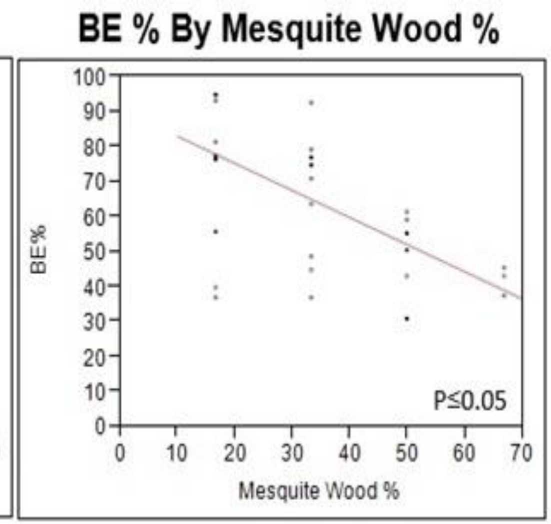
Optimization of yield and nutrition response of *P. ostreatus* cultivated on substrates containing of *Prosopis spp.* legumes.

Lauren W. Jackson. SPLS graduate student

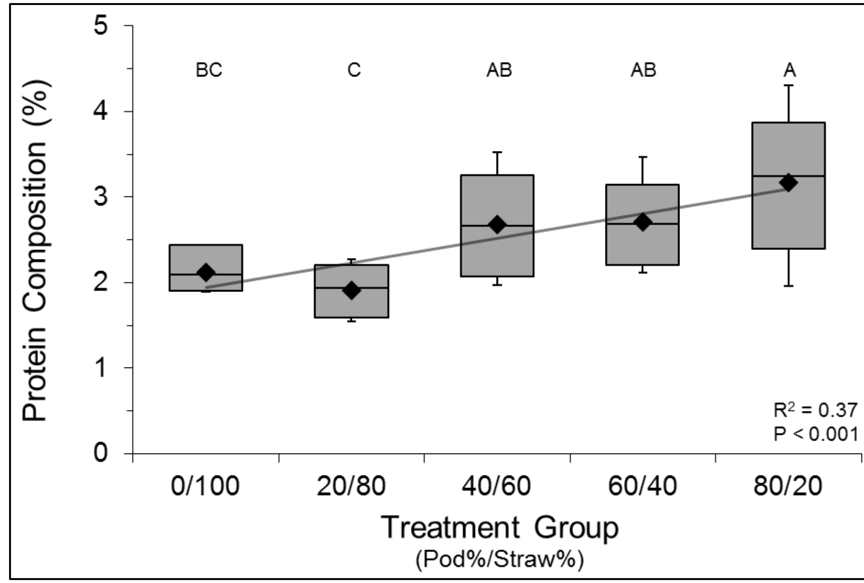
Initial research on the use of mesquite pods in mycocultivation

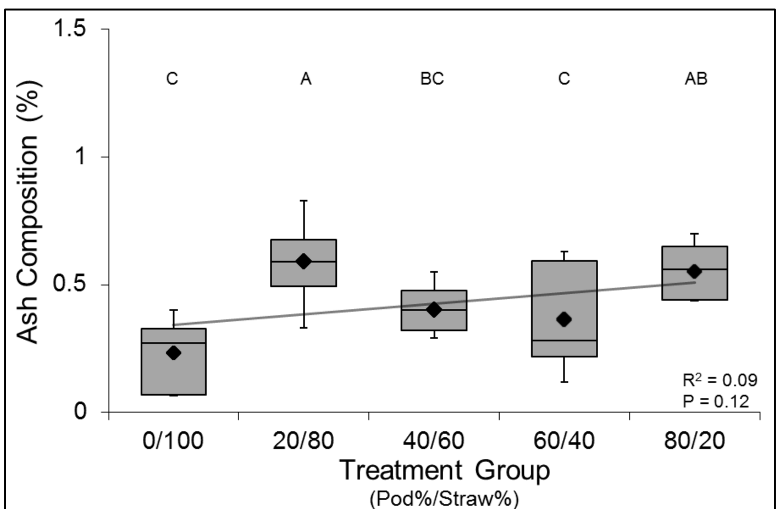


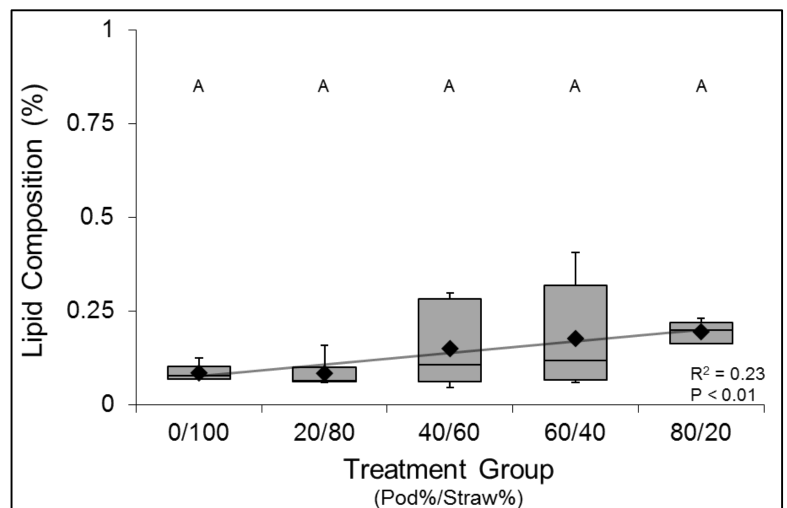




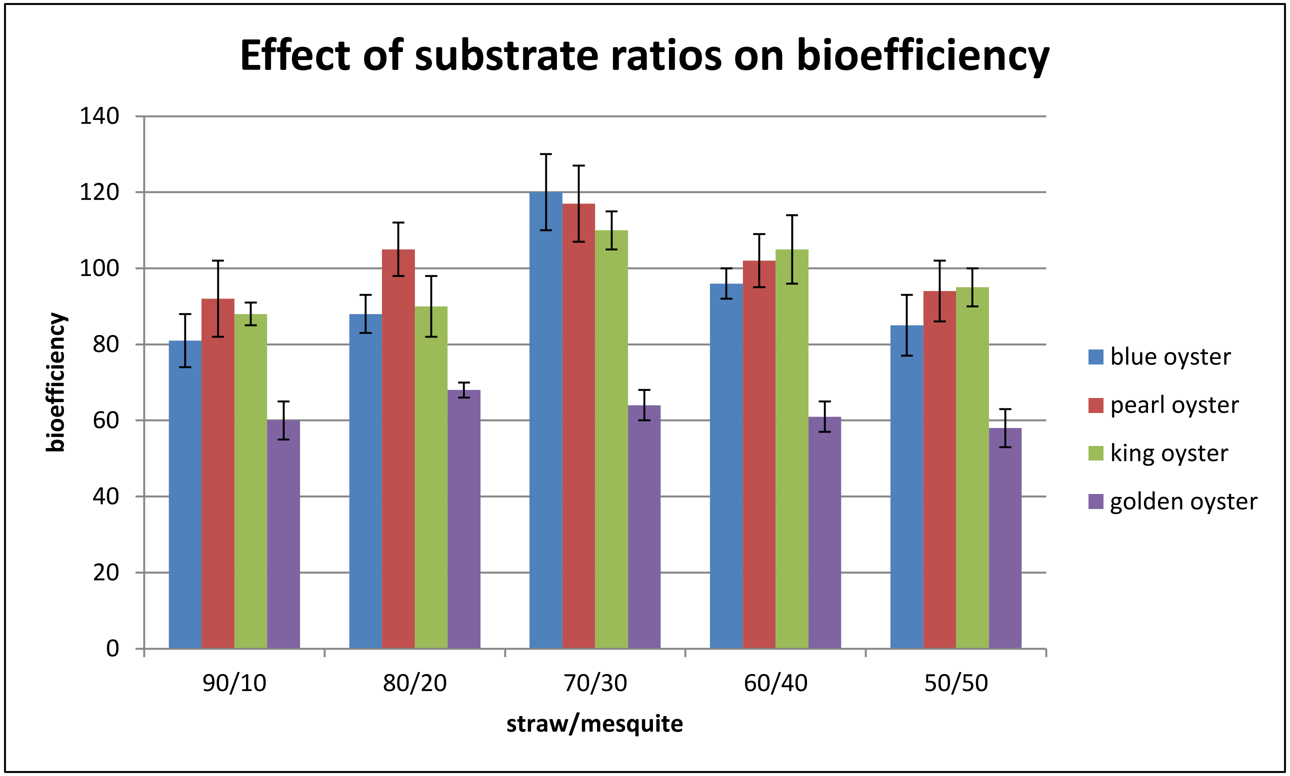
Nutritional analysis based upon pod content







Dialing in the right substrate ratios



P. ostreatus

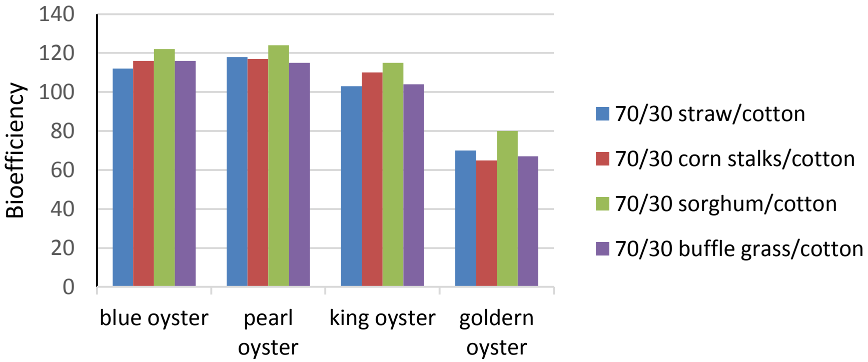
P. columbinus

P. eryngii

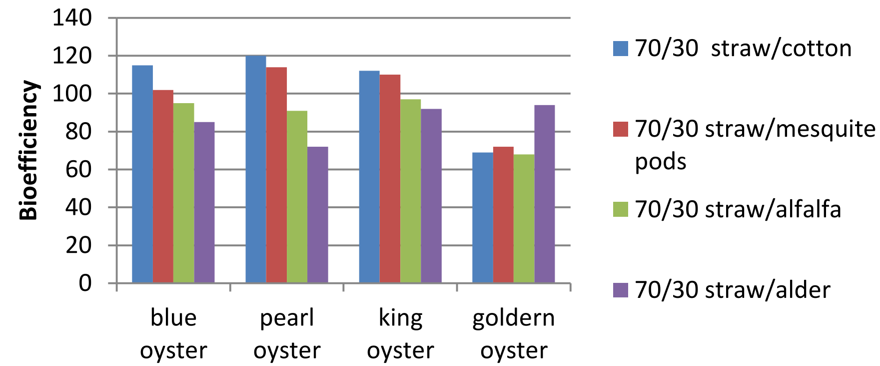
P. citrinopileatus

Expanding to other substrates: Impact of substrate composition on bioefficiencies

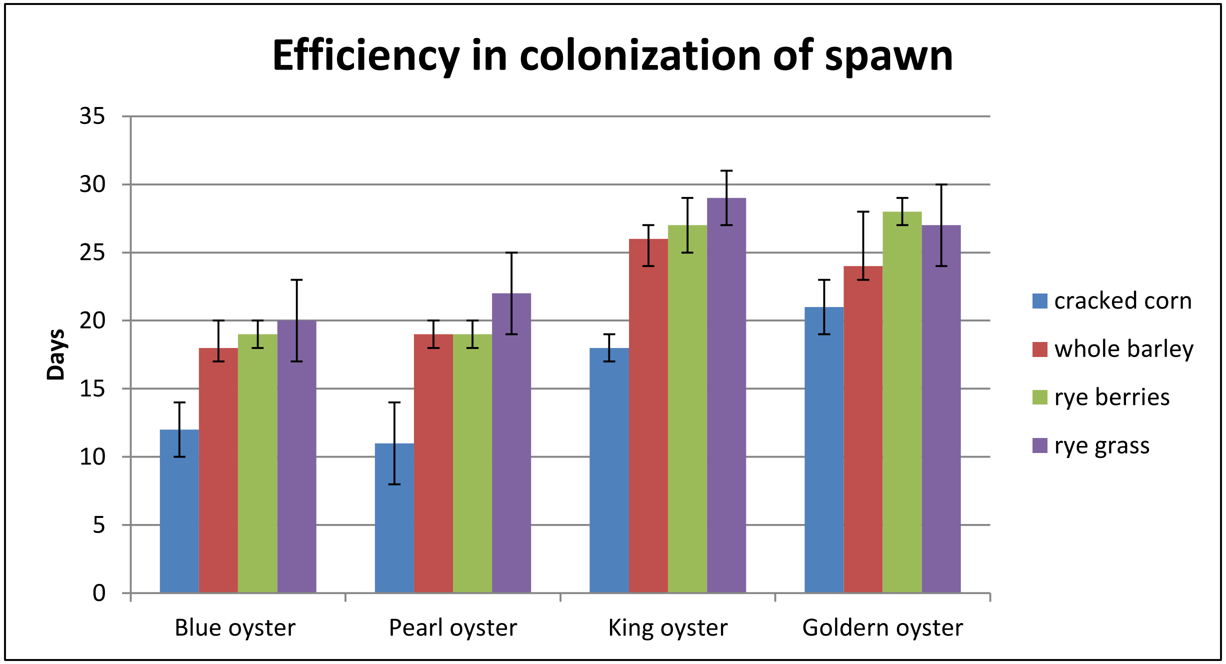
Effect of substrate carbon on bioefficiency

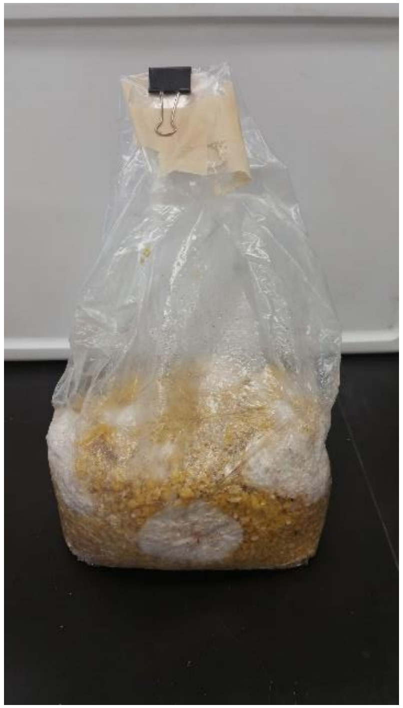


Effect of substrate nitrogen or additives on bioefficiency

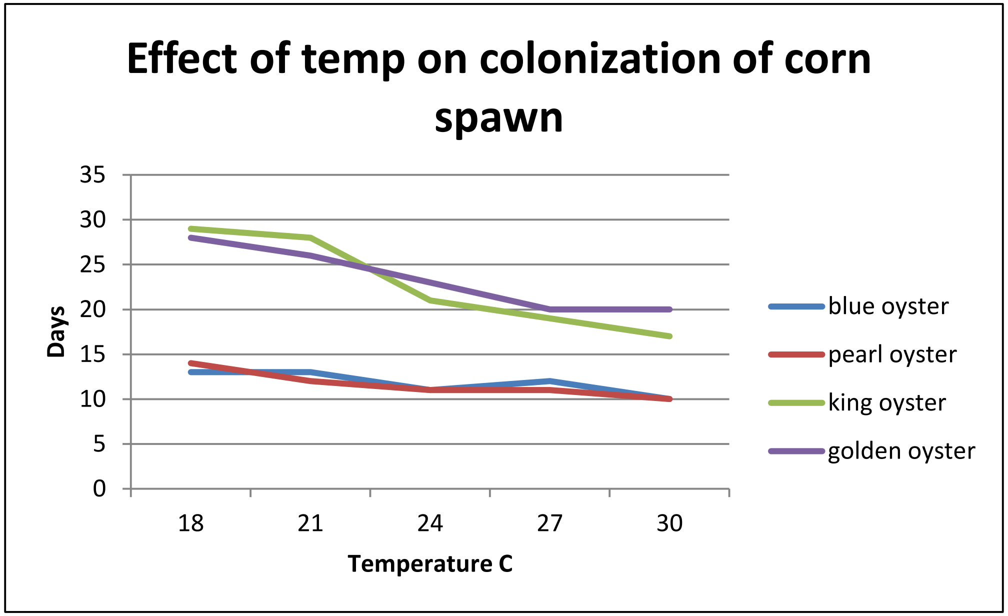


Impact of substrate on spawn production

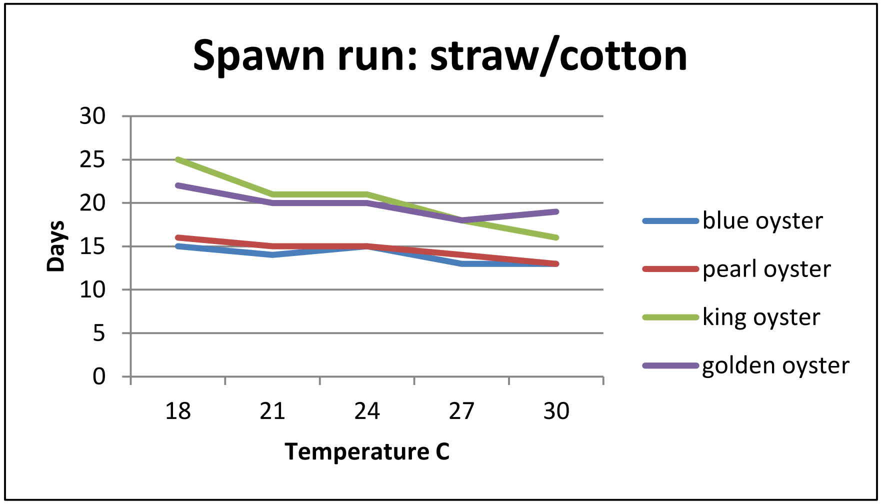


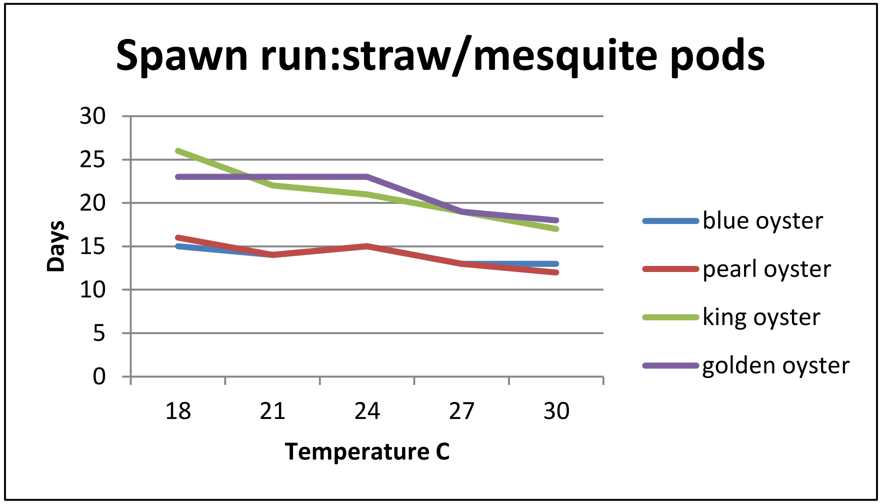


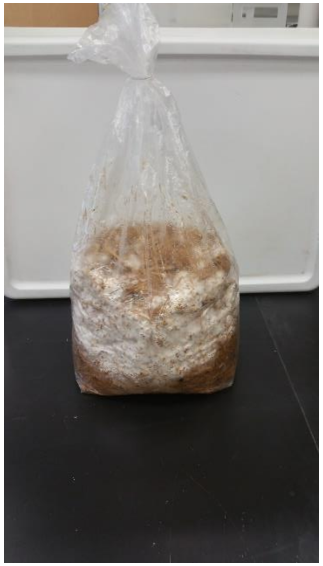
Impact of temperature on spawn production



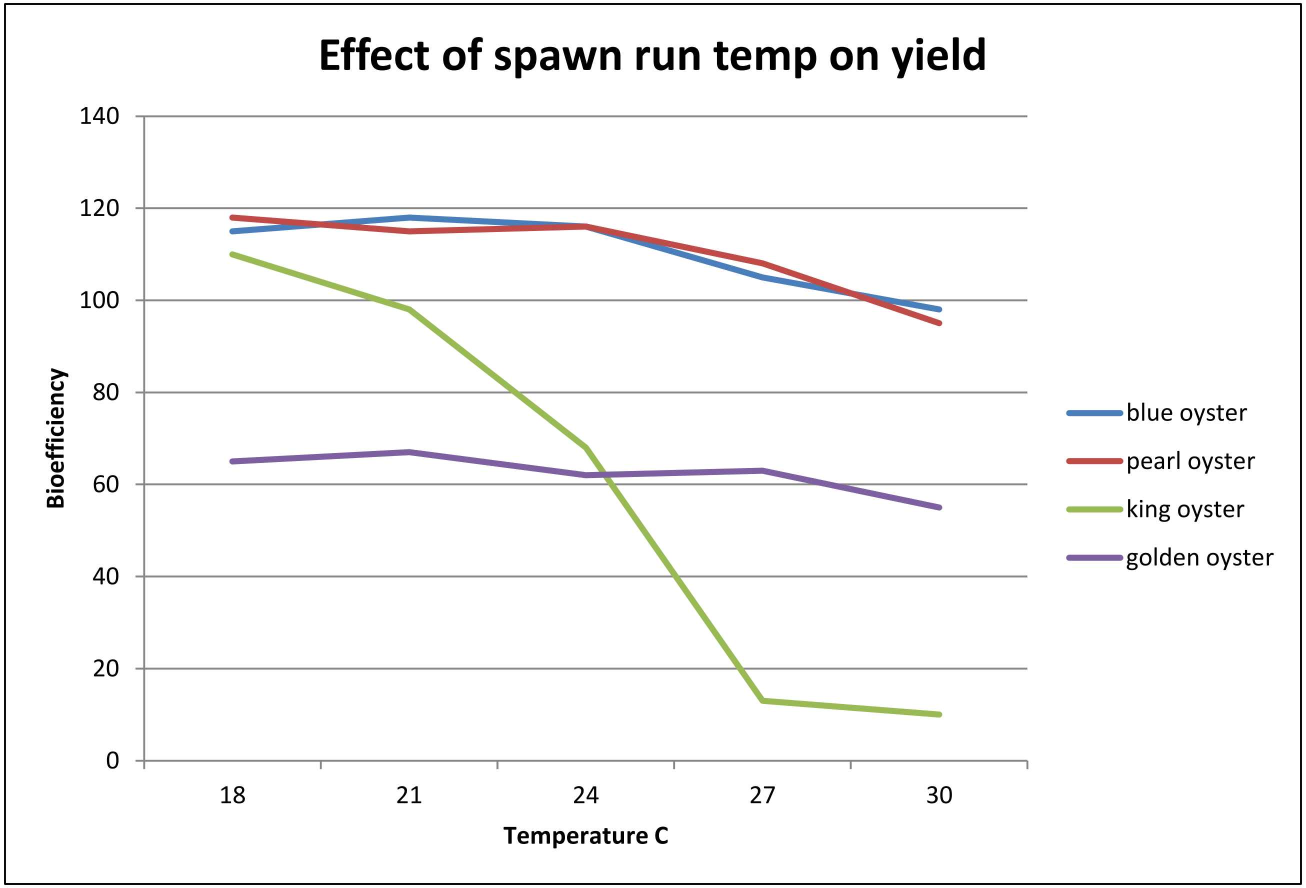
Impact of temperature on spawn run



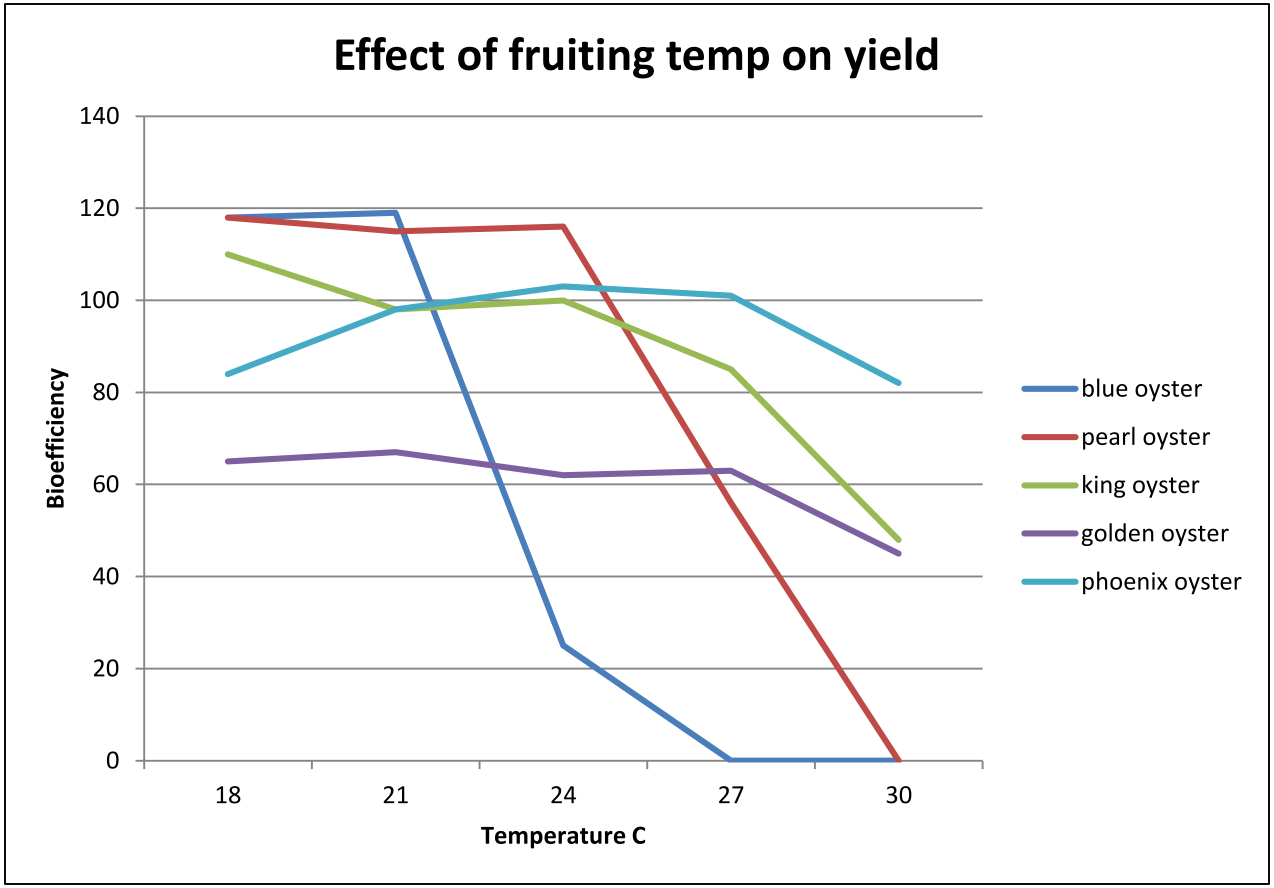




Impact of spawn run temperature on bioefficiency: The lesson of the kings



Impact of fruiting temperature on bioefficiency: The lesson of the blues



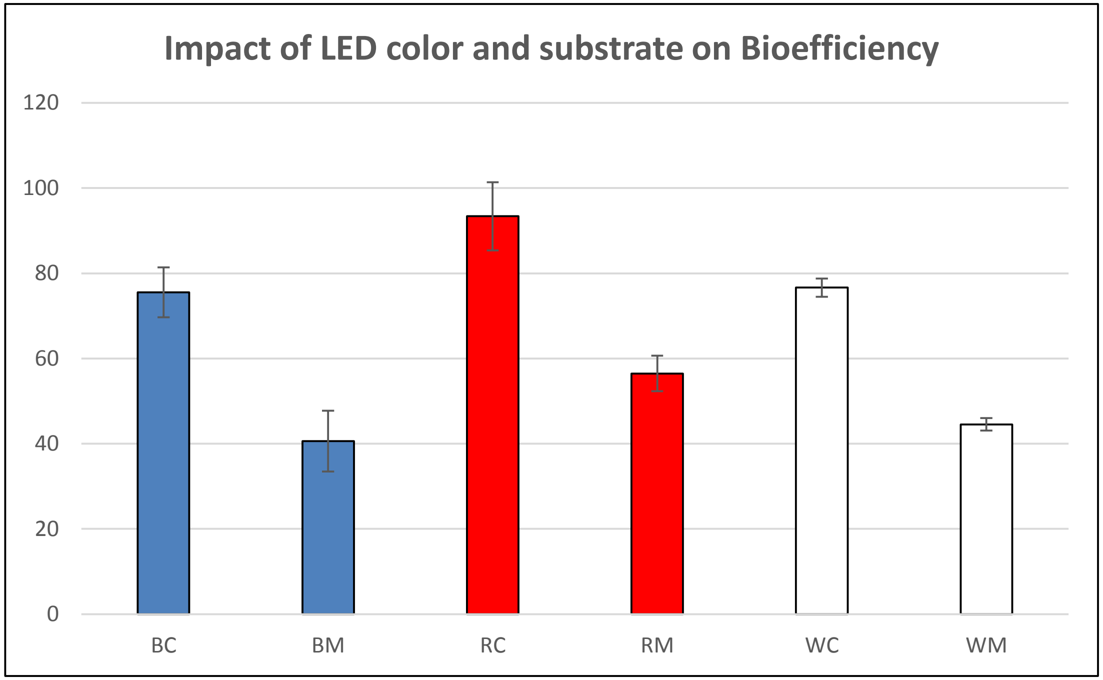
Other environmental effects on production

Humidity	95-100%	Pearl oyster mushrooms get soggy
	85-90%	Everything is fine
	<65%	Many small clusters abort
CO_2	450-600 ppm	Everything is fine
	800-900 ppm	mushrooms begin to get “stemmy”
	900-1100 ppm	Mushrooms begin to get deformed
	> 1200 ppm	Many species fail to produce
Lighting	dim incandescent	pearl oysters are pearly white
		blue oysters are light gray
	bright fluorescent	pearl oyster are tan colored
		blue oysters are deep blue, almost iridescent on the first flush

What about LED lighting???

Currently driving the greenhouse industry forward with efficiency, innovation, and value added products

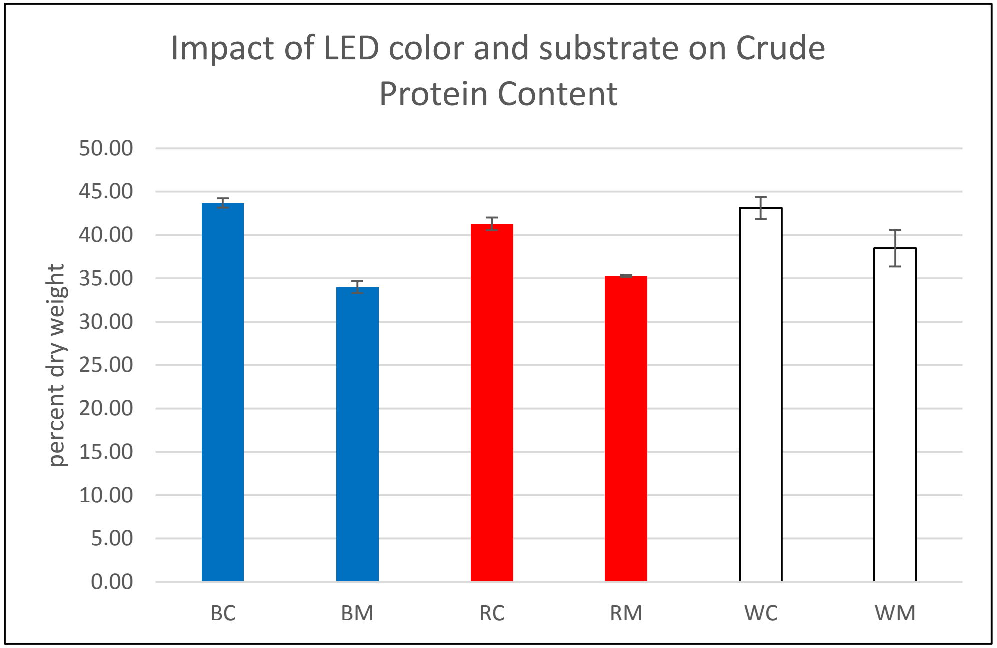
Impact of substrate on bioefficiency under varying LED illumination



Cotton seed (BC, RC, WC) vs mesquite pods (BM, RM, WM)

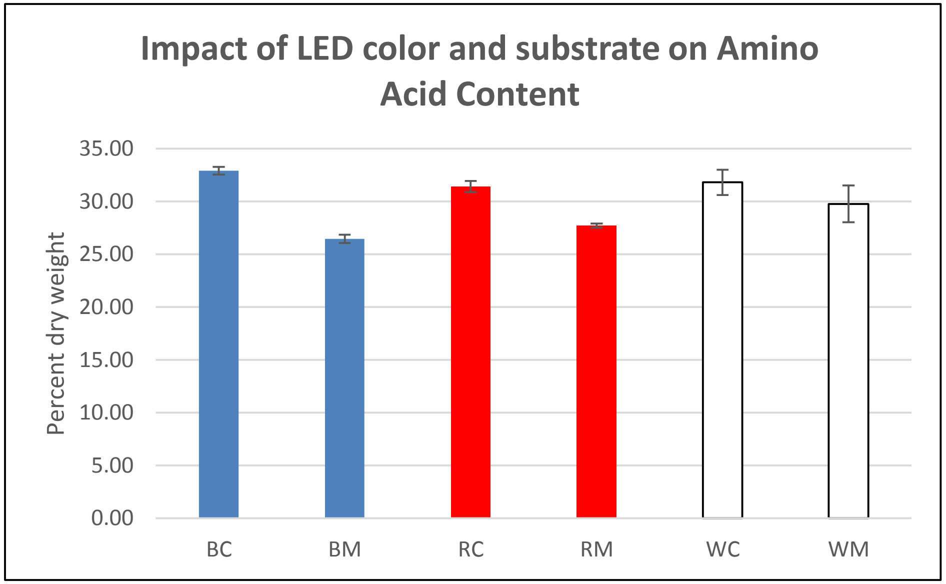
Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LED color	2	2	333547.1	4.6751	0.0369
Substrate	1	1	1870823	52.4442	<.0001
Block	2	2	196245.8	2.7506	0.1117
LED*Substrate	2	2	14003.1	0.1963	0.8249

Impacts on crude protein and total amino acids



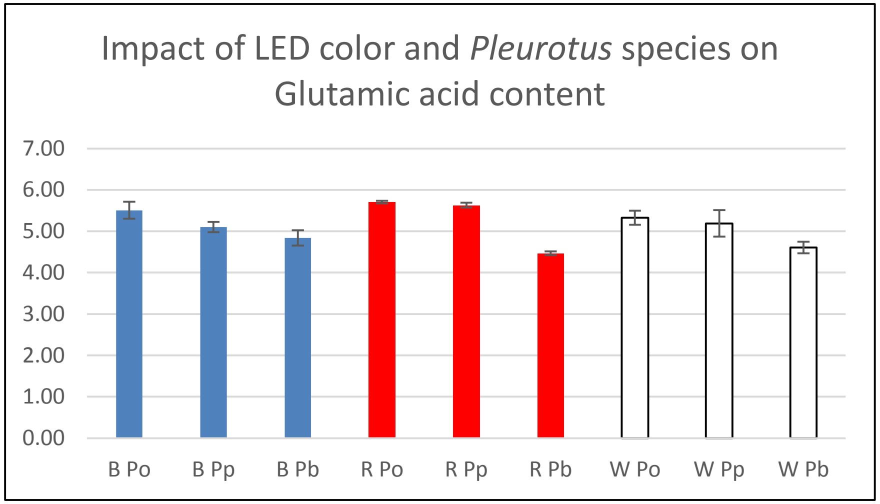
Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Substrate	1	1	206.5189	56.6807	<.0001
LED color	2	2	20.96693	2.8773	0.103
Block	2	2	26.4879	3.6349	0.0651
Substrate *LED color	2	2	20.70938	2.8419	0.1054

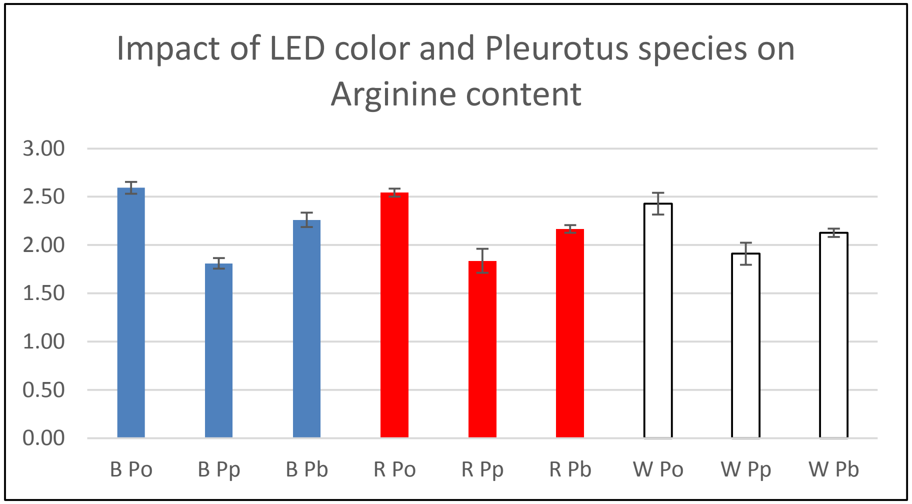
Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Substrate	1	1	108.2411	53.8253	<.0001
LED color	2	2	2.86058	0.7112	0.5143
Block	2	2	9.46014	2.3521	0.1455
Substrate* LED	2	2	6.43058	1.5989	0.2497

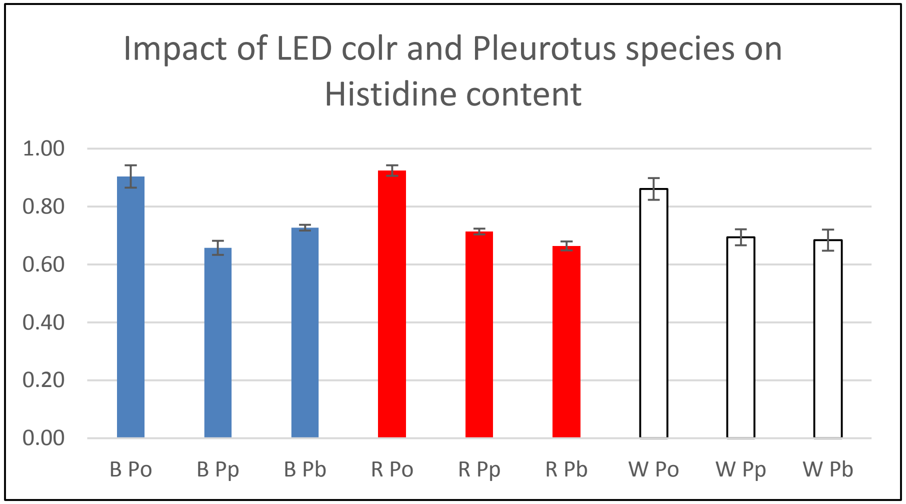


Impacts of LED on specific Amino Acids

All grown on straw/cotton mix



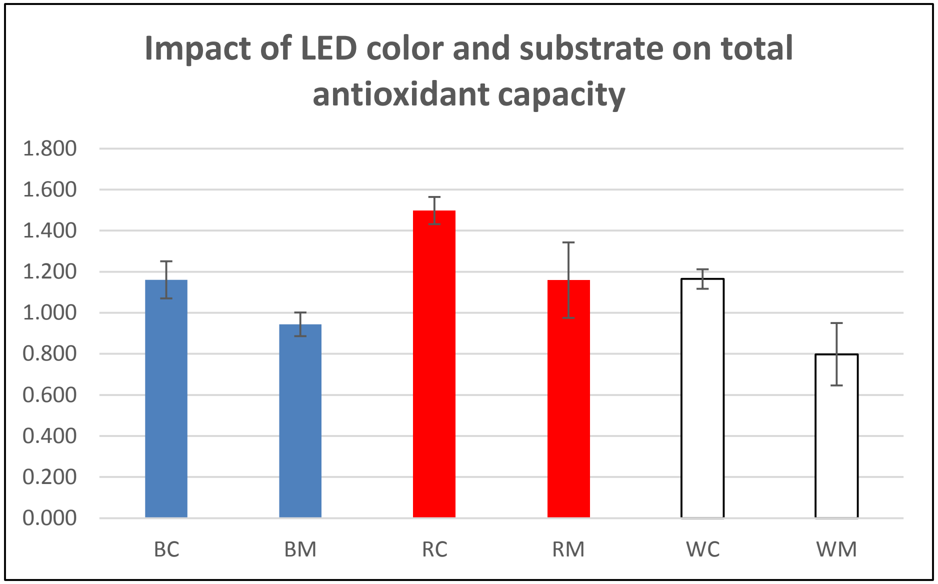




Po = ostreatus (pearl)
Pp = pulminarius (Italian)
Pb = columbinus(blue)

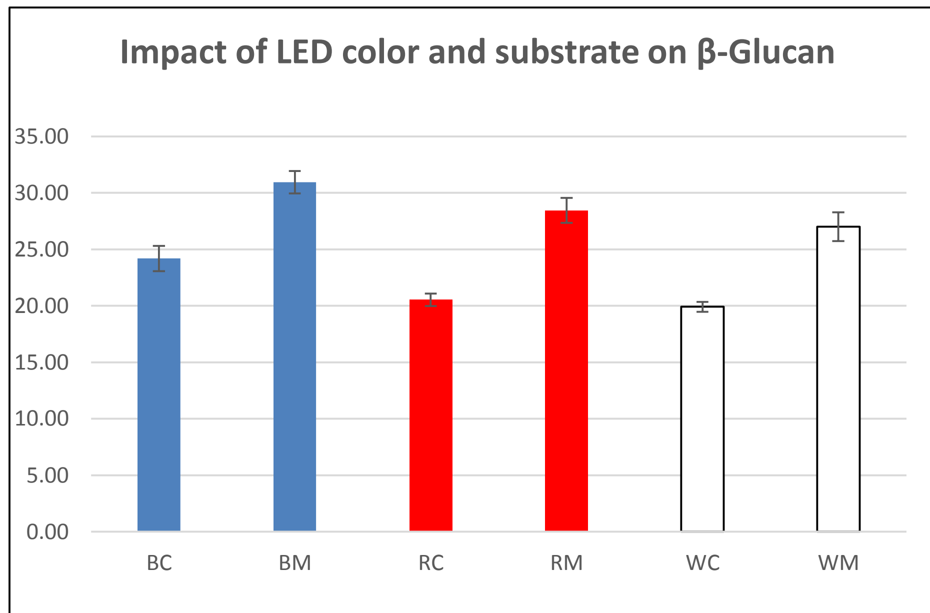
For all three AA:
effect of LED was not significant,
effect of species was significant,
with no interaction.

Impacts on antioxidants and β-glucan content

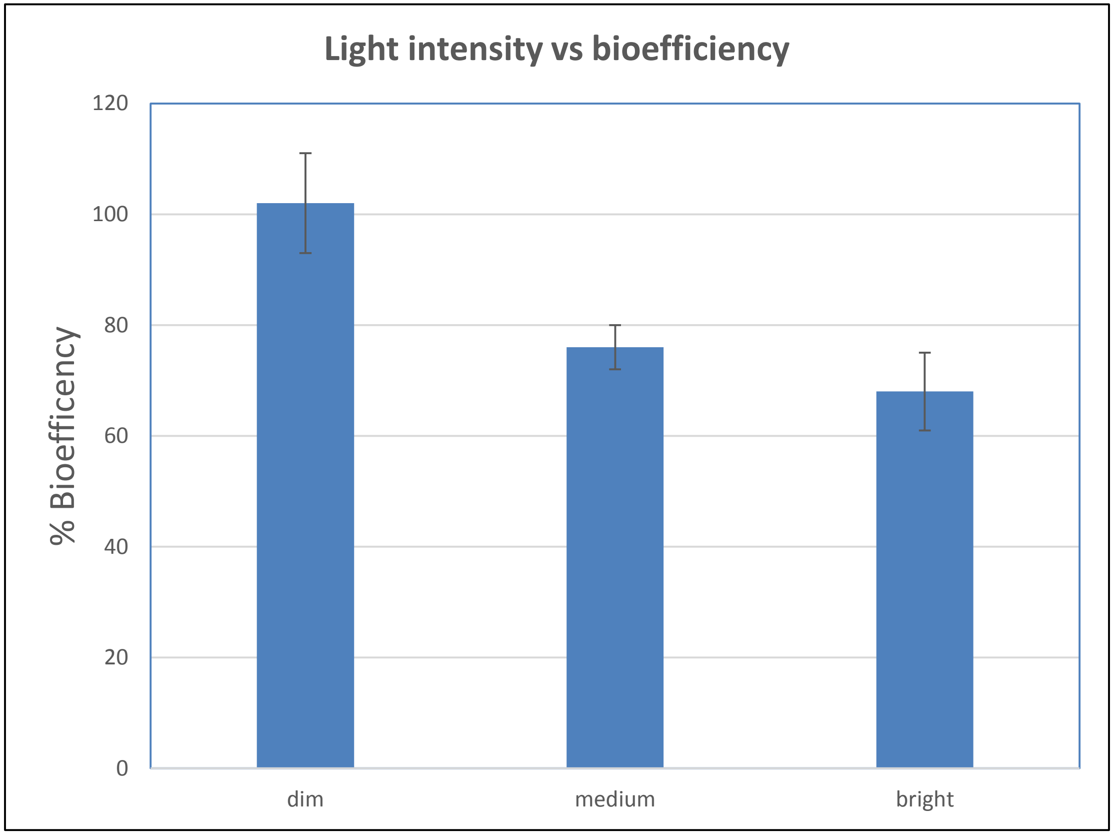


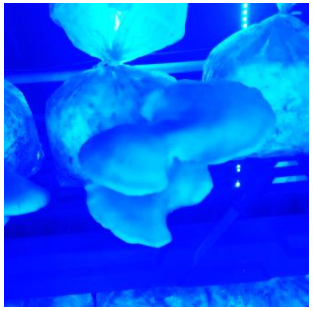
Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Substrate	1	1	0.42658	8.4127	0.0158
LED	2	2	0.403804	3.9818	0.0535
Block	2	2	0.145236	1.4321	0.2838
Substrate* Color	2	2	0.019025	0.1876	0.8318

Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Substrate	1	1	226.4901	48.035	<.0001
LED	2	2	50.14431	5.3174	0.0267
Block	2	2	3.62674	0.3846	0.6904
Substrate*LED	2	2	1.53444	0.1627	0.852



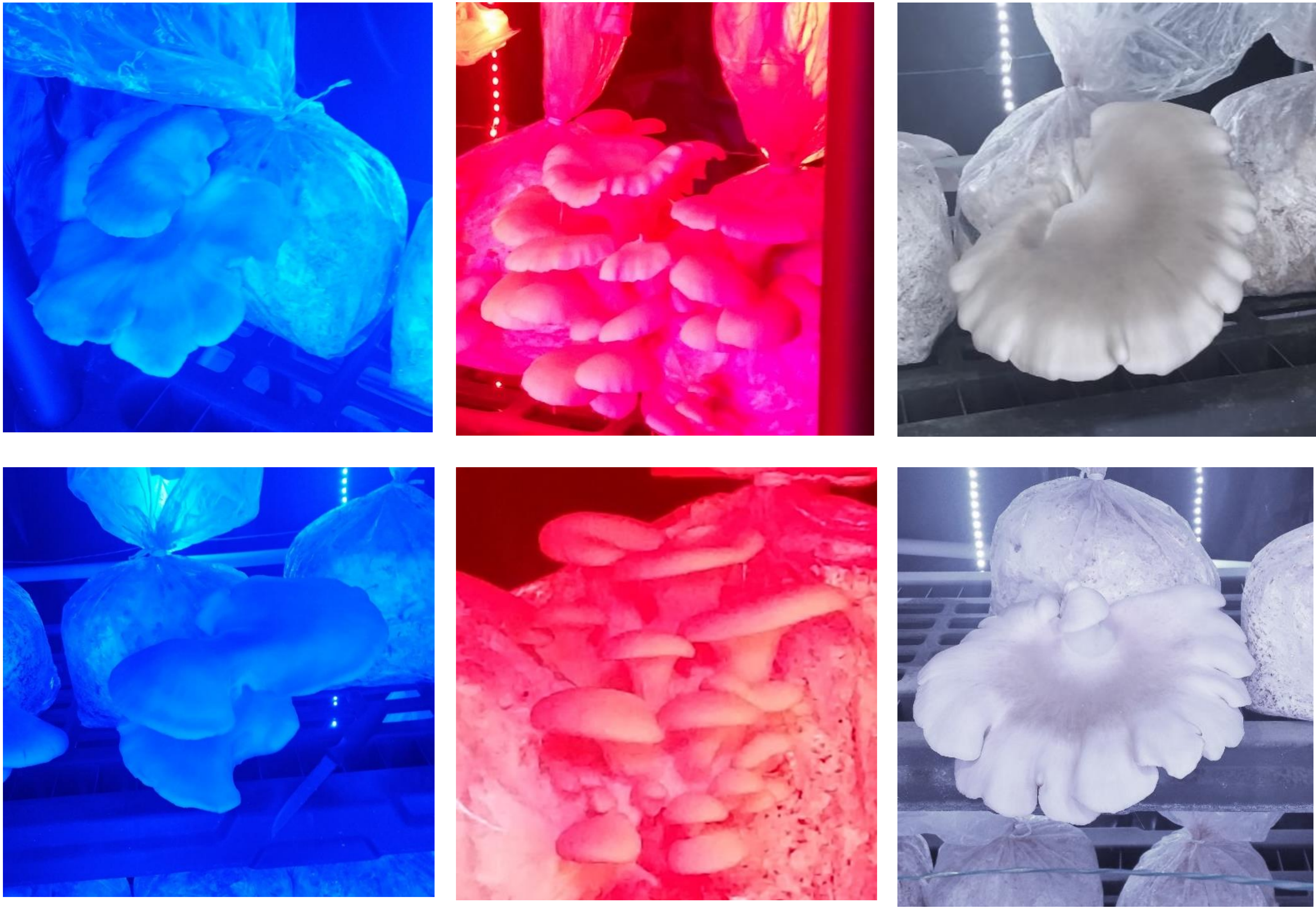
Impact on lighting intensity on BE



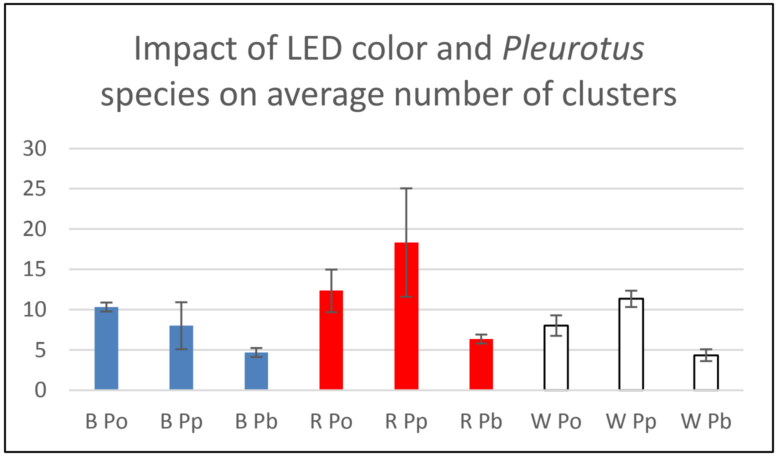


What will be the impacts on beta-glucan and other nutraceuticals?

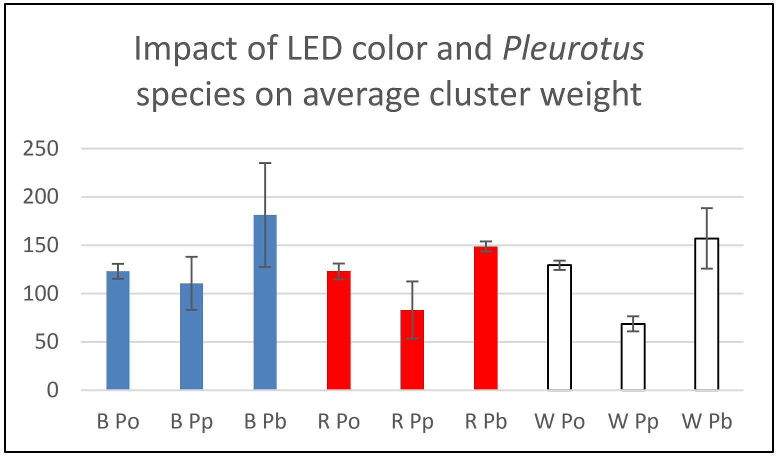
Effects of LED illumination on cluster architecture



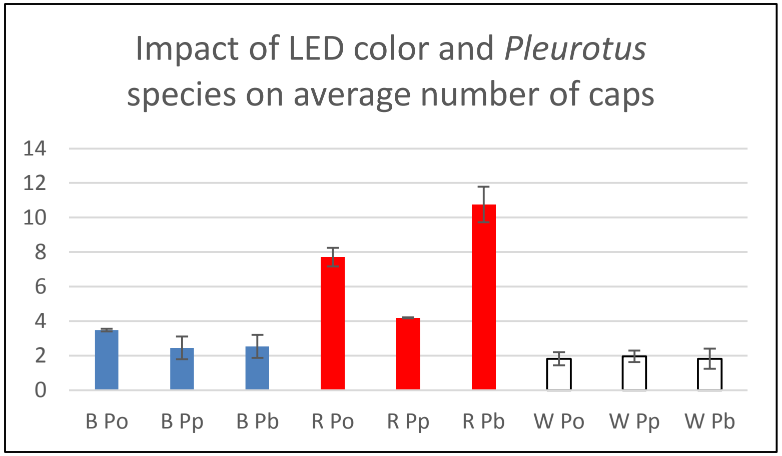
Impact of LED on cluster architecture for different species of *Pleurotus*



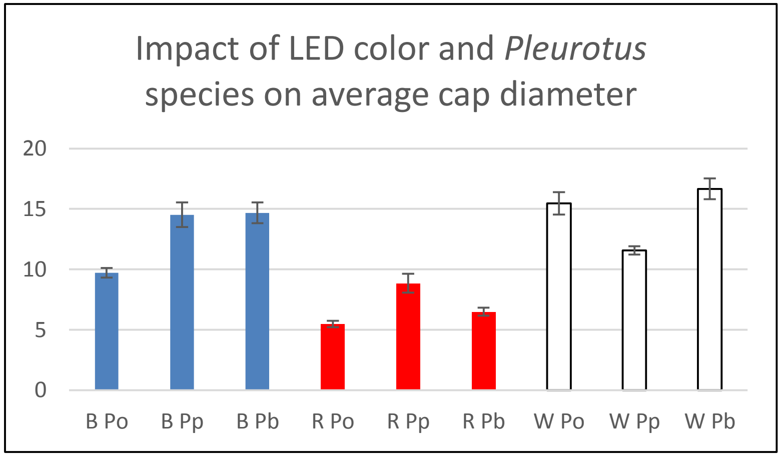
LED -, spp. +



LED -, spp. +



LED +, spp. +



LED +, spp. +,

Po = ostreatus (pearl)

Pp = pulminarius (Italian)

Pb = columbinus (blue)

The effect of CO_2 on cluster architecture

500 ppm

800 ppm

1200 ppm

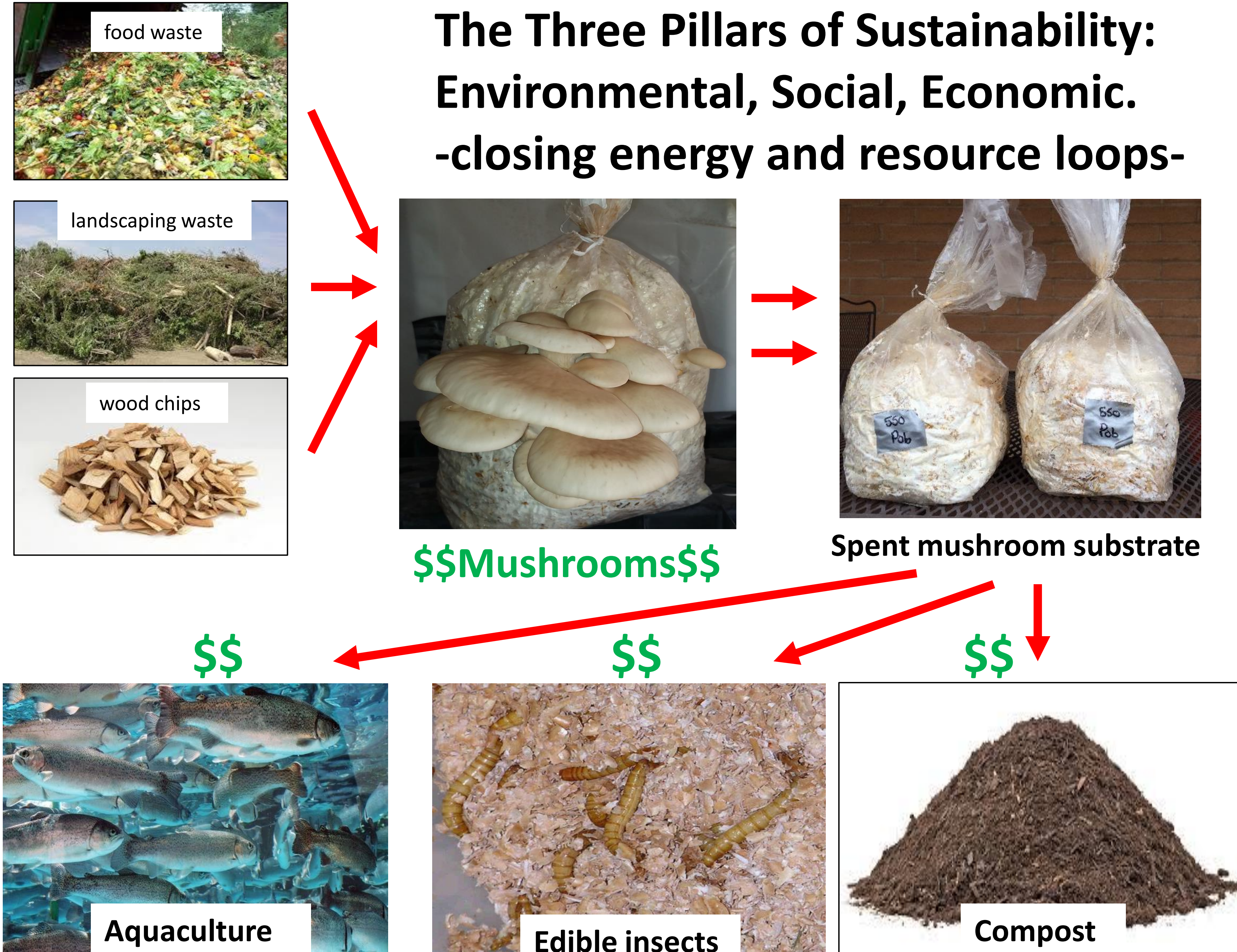
- **Similar effects seen with red LED illumination**
- **Disadvantage of CO2 effects is a reduction in bioefficiency**

Fungi also contribute to food production systems by recycling waste..

BACK TO THE ROOTS

- **Fungi are the great decomposers of the Earth**
  - Liberate nutrients from nearly everything
  - Accomplished via arsenals of extraceullar enzymes
- **A wide variety of agro-industrial plant-based byproducts can be used to cultivate mushrooms**
  - Straws, corn stover, tomato pomace, coffee pulp, cotton hulls, sugarcane bagasse, legume roughage, paper products, wood byproducts, brewery waste, etc.
- **Spent substrate can be re-purposed in regular composting systems because much of the decomposition has been accelerated.**

Even textiles!!


The Three Pillars of Sustainability:
Environmental, Social, Economic.
-closing energy and resource loops-
food waste
landscaping waste
wood chips
$$Mushrooms$$
Spent mushroom substrate
$$
$$
$$
Aquaculture
Edible insects
Compost

Why Mushrooms?

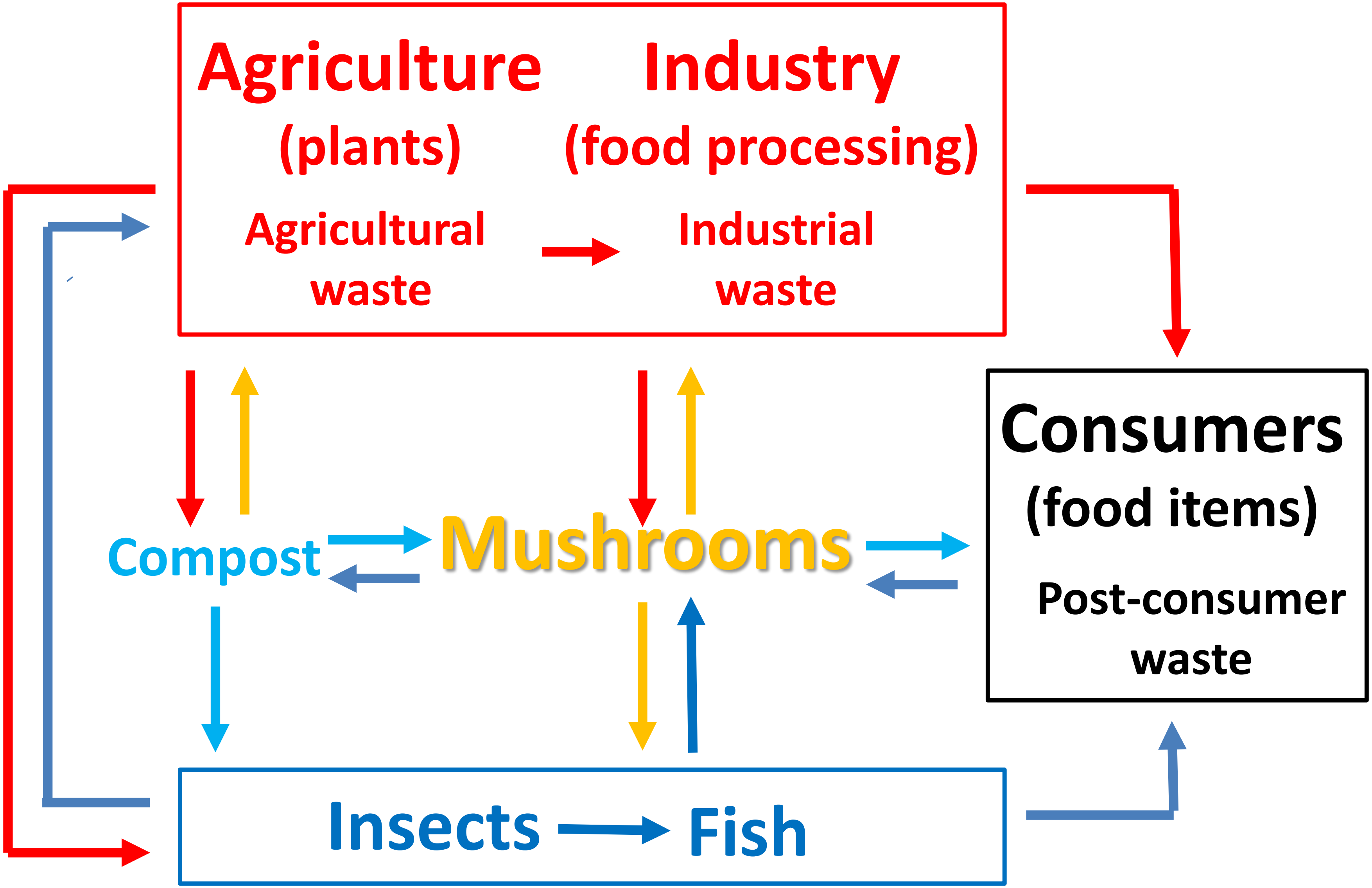
Fungi are the 3rd critical component in energy and resource cycling

Producers (plants)

Consumers (animals)

Decomposers (fungi)

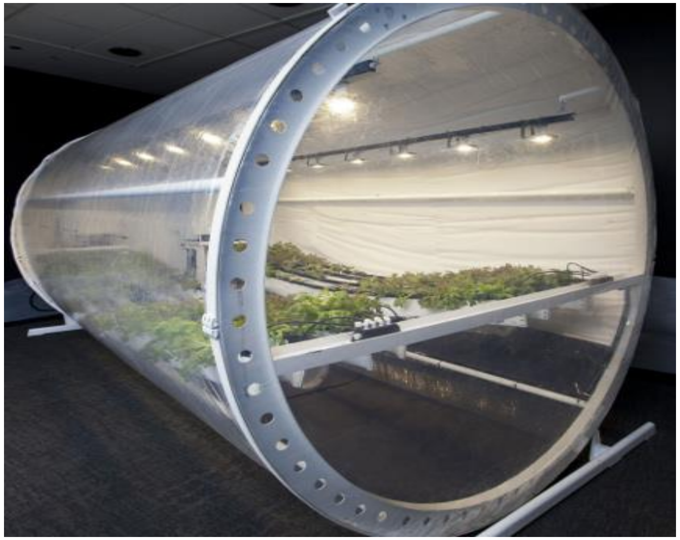
Bioregenerative Resource (Food) Cycling



In Summary…..

- Mycoprotein and mushroom production is a diverse, sustainable, and profitable industry that can be integrated into many cropping systems.
- Mycoculture can also provide many additional nutritional and value-added food resources.
- The question is where will we produce mushrooms <u>in the future</u>?

Underwater on the continental shelf?



UA Lunar Greenhouse?

Mushrooms to Mars!

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Recycling with Mushrooms

MycoCats

MS Students Lauren Jackson and Parker Evans

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CEAC Controlled Environment Agriculture Center

Compost Cats Students for Sustainability

Facilities Management

Arizona Mushroom Growers Association