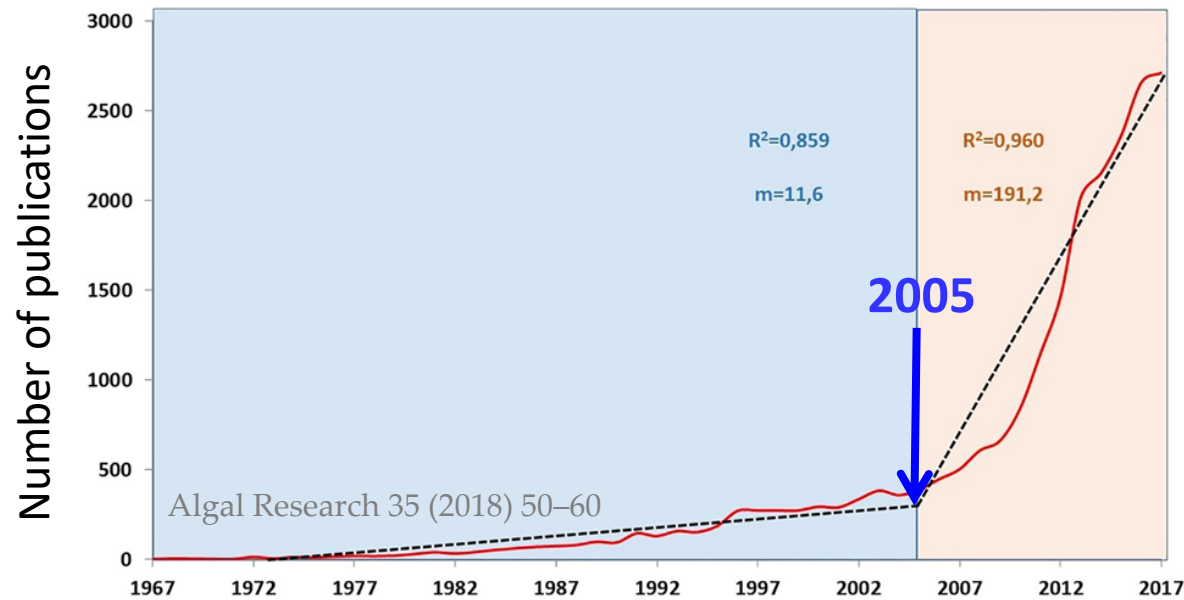


Algal Biorefineries: Recent Innovations and Pathways to Sustainable Biofuel Production

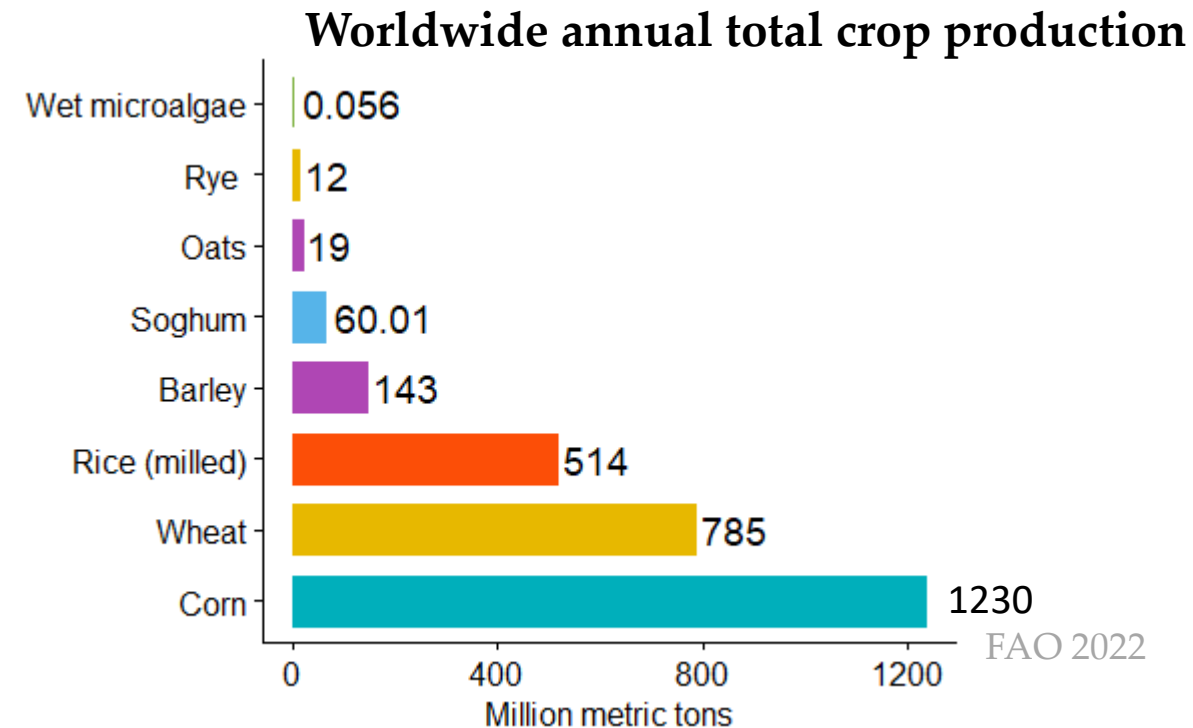
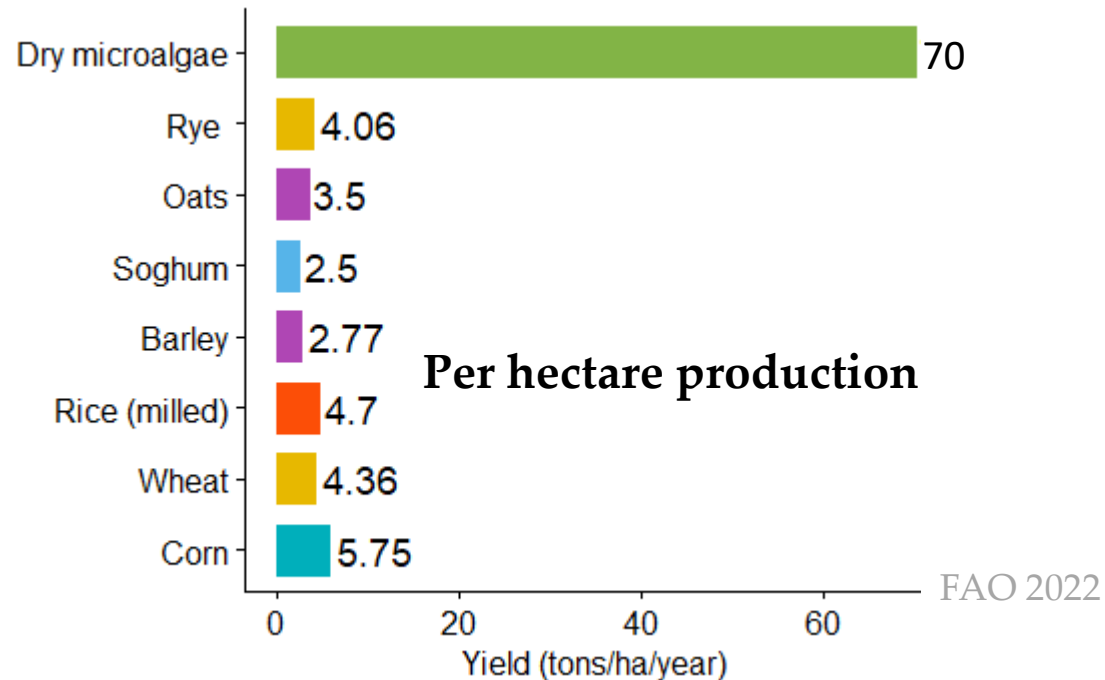
Shovon Mandal
The Energy and Resources Institute (TERI), New Delhi



Potential vs. Reality of microalgae

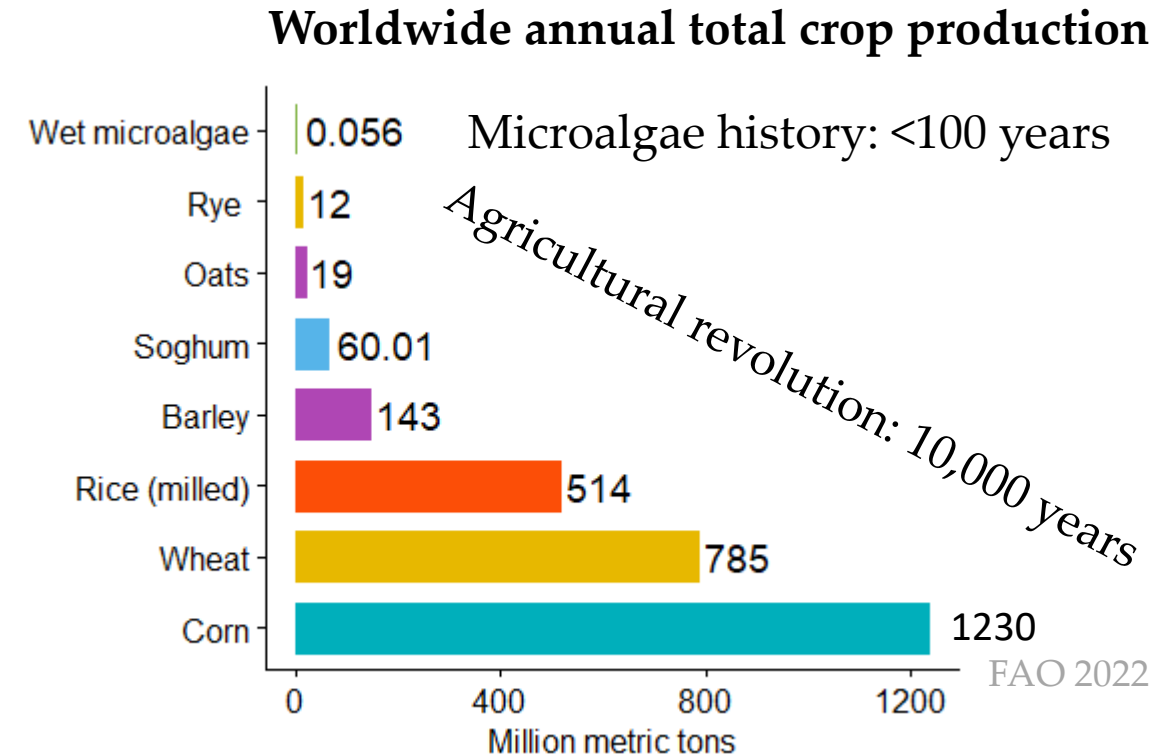
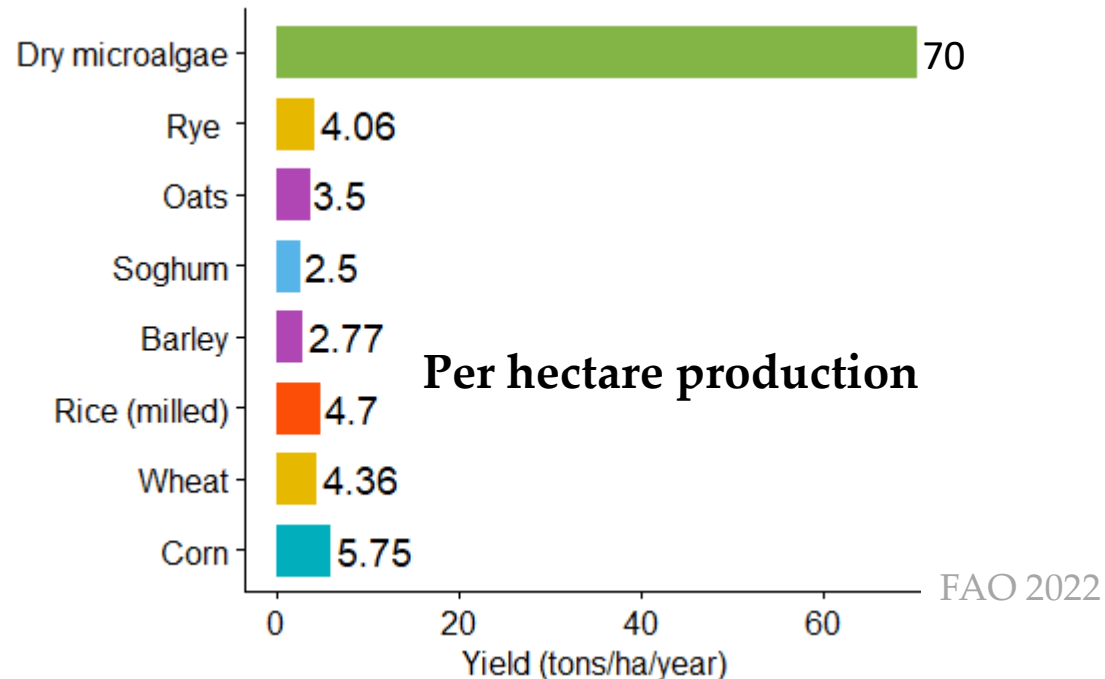


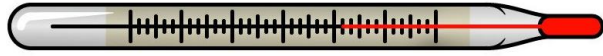
Publications on microalgae surged after 2005, driven by interest in biofuels.



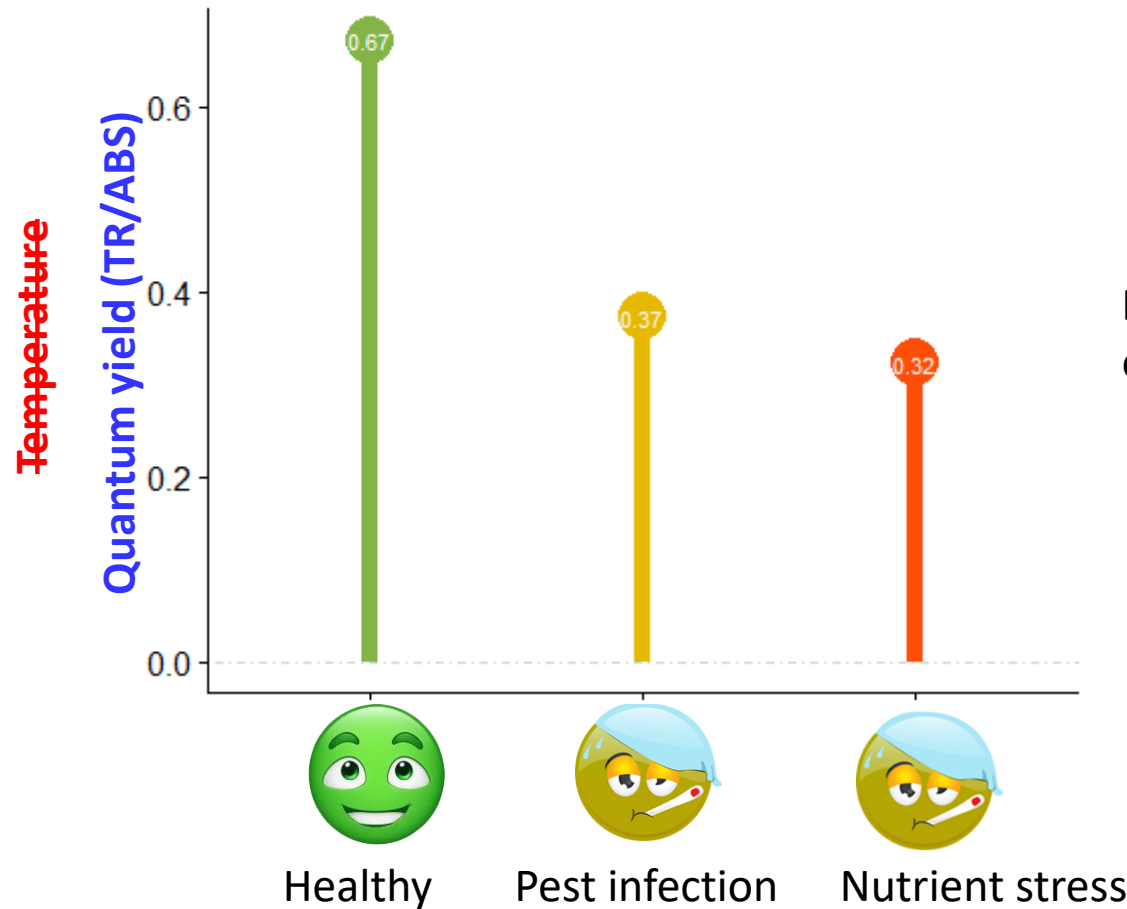
Potential vs. Reality of microalgae

- Challenges remains in the **domestication** of microalgae.
- Lack of experience of growing microbes in septic condition.
- Lack of available technology (patented).
- Lack of knowledge in biology and health of algae.

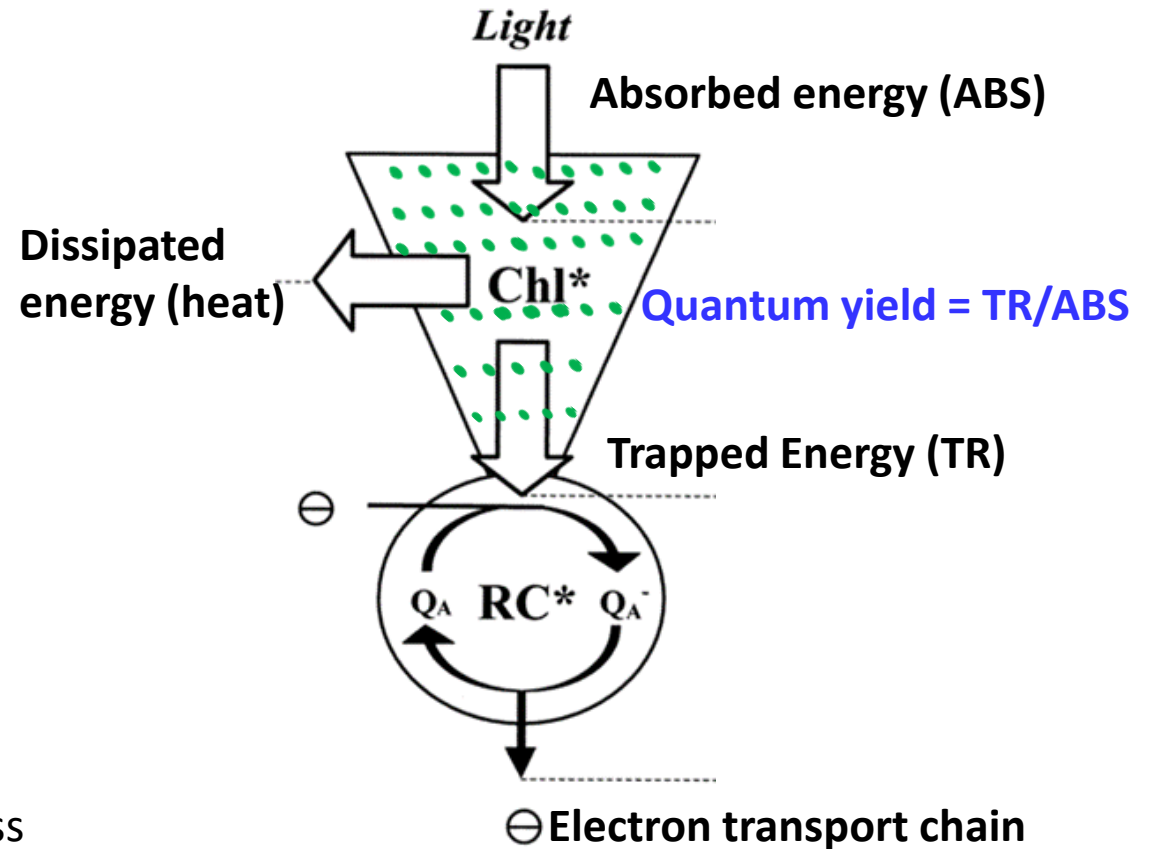




Is it possible to detect fever in algae within a minute?



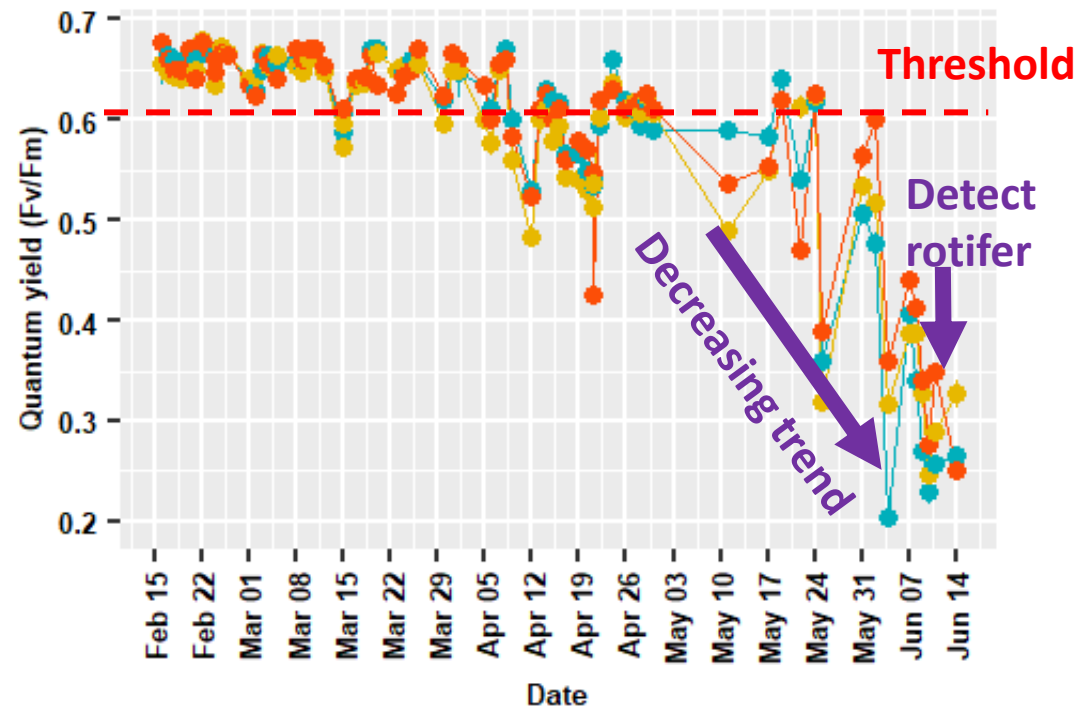
Quantum yield in *Nannochloropsis oceanica* reduced in stress





Can 20 μL sample represent a 200 L raceway pond?

Probability of finding a single pest = $1/10^7$



Quantify the response in algae rather than looking for pests.

Healthy culture at TERI



Infected culture



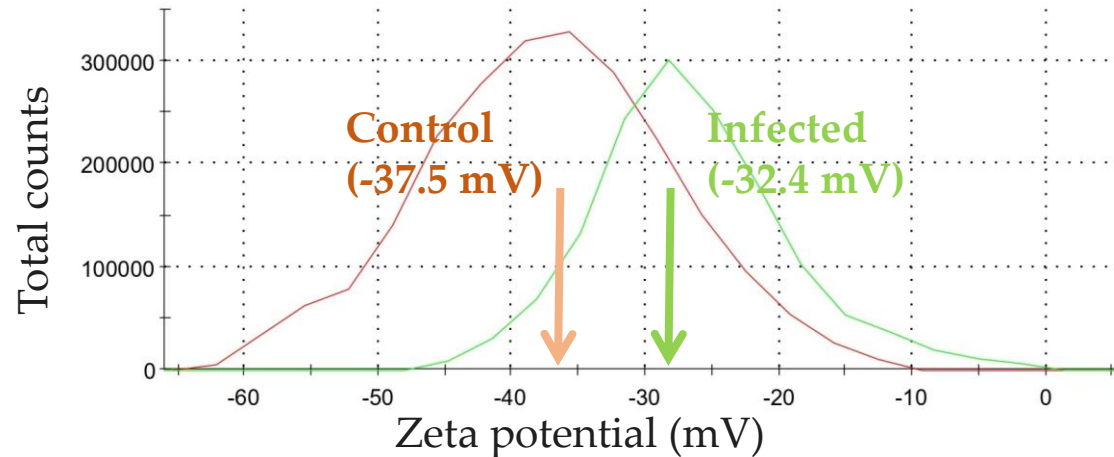
Isolated rotifer





Can 20 μL sample represent a 200 L raceway pond?

Probability of finding a single pest = $1/10^7$



Changes in surface potential of infected algae

Visual symptoms of culture crash

Cell attachment → Cell flocking → Chlorophyll loss → Culture crash

Healthy culture at TERI



Infected culture

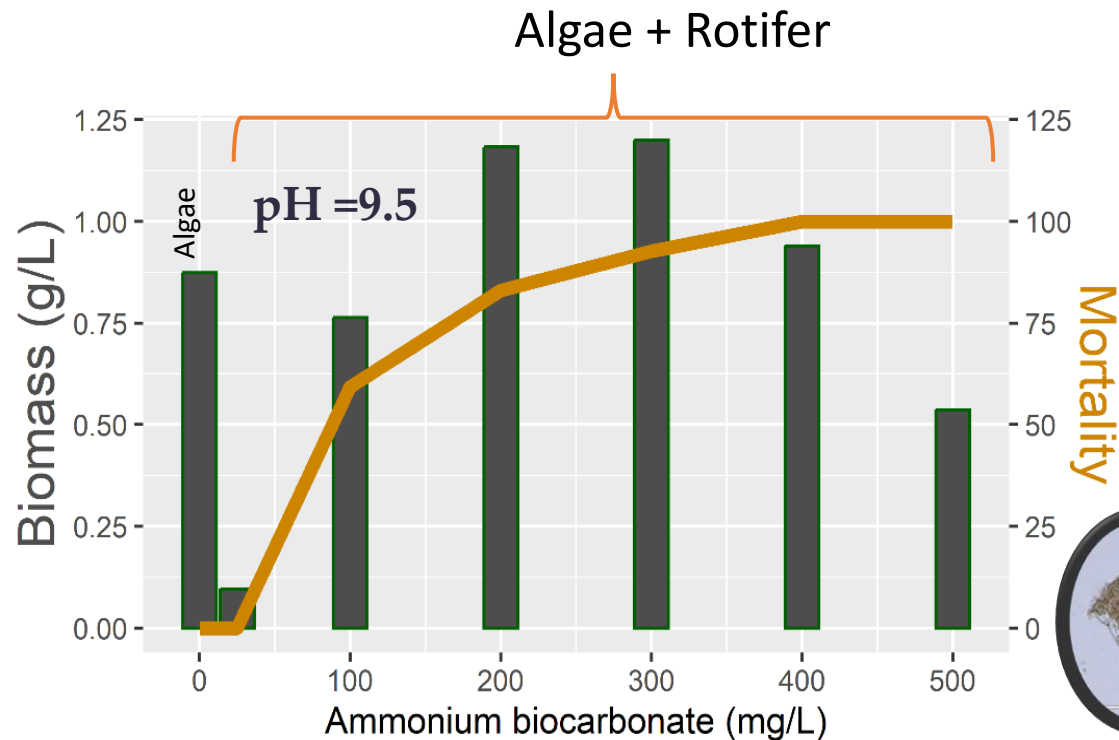
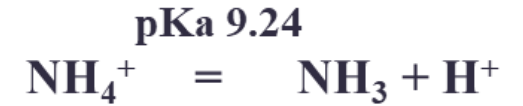


Isolated rotifer



A win-win situation: pesticides free (using ammonium bicarbonate) rotifer control & increased algal yield

- Gaseous ammonia is toxic to rotifer.
- At higher pH (pKa 9.24), ammonium is converted into gaseous ammonia.
- Bicarbonate helps to grow algae.



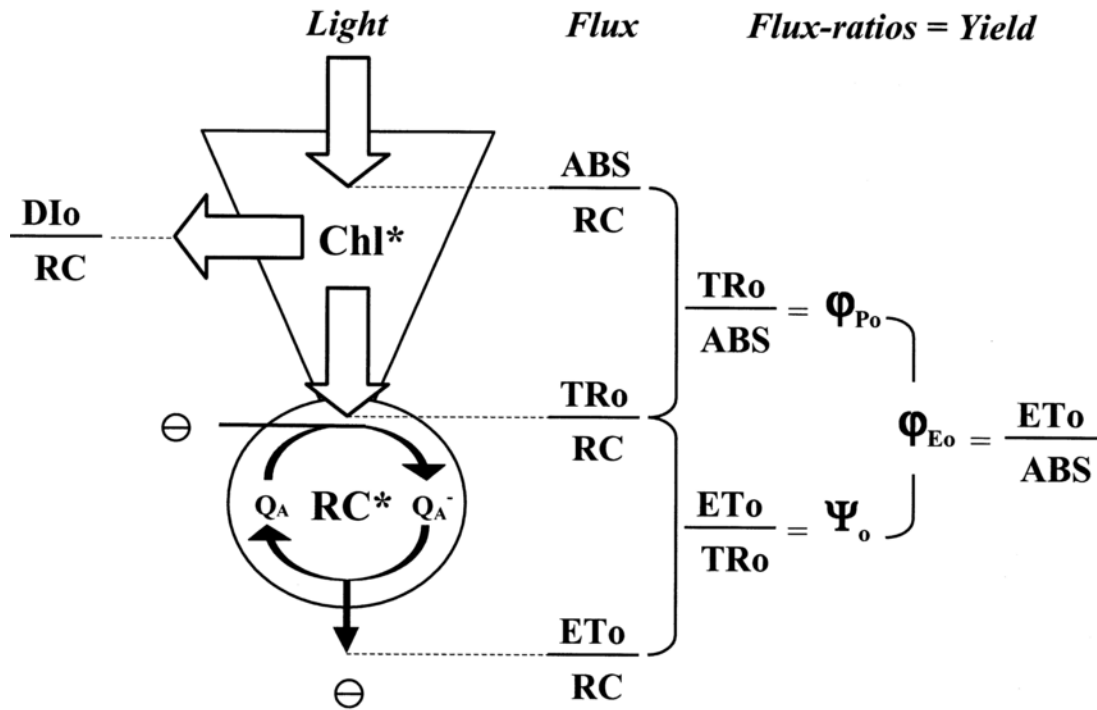
- **Ammonium bicarbonate** control rotifer at 200 to 300 mg/L.
- **Ammonium bicarbonate** increases biomass yield of 30%.



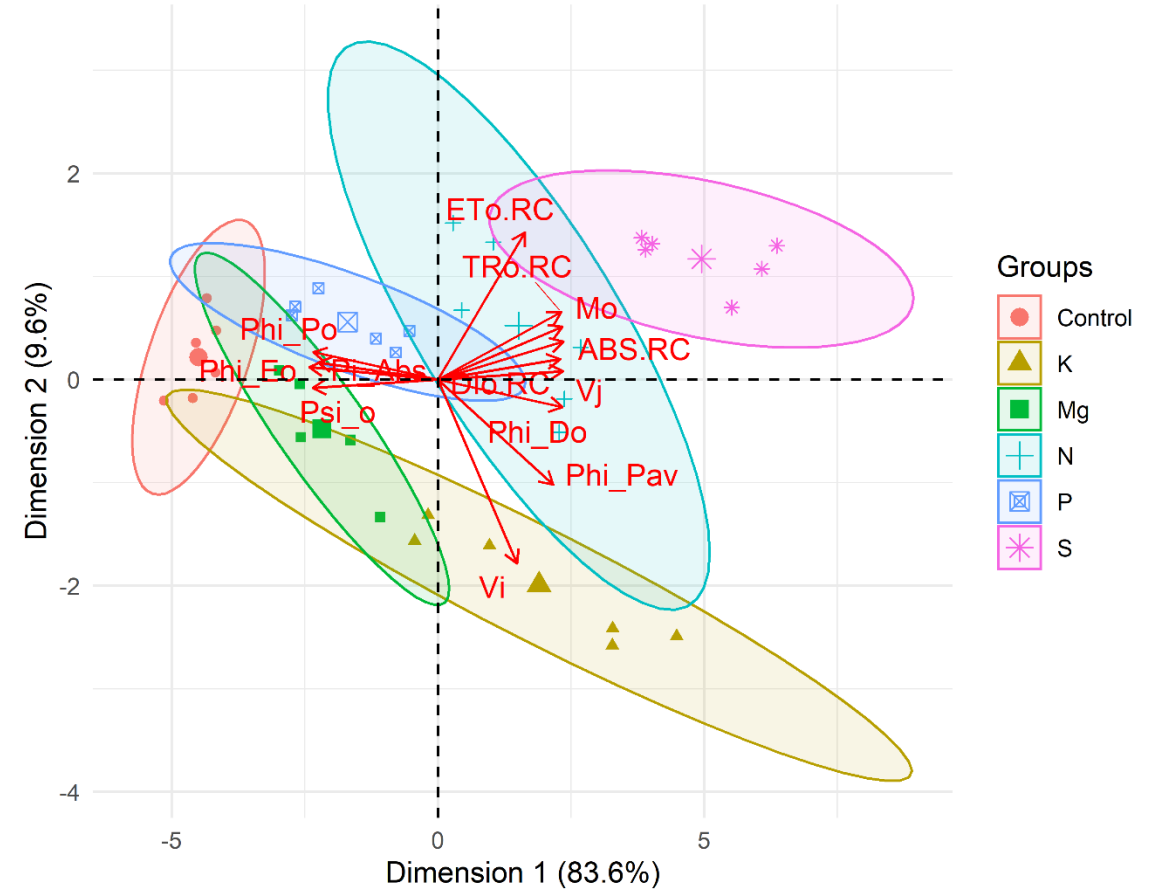
*Mortality measured after 24 hrs of treatment, biomass after 7 days

Can we classify the stress/infection?

Use of machine learning to classify nutrients stress by analyzing photosynthesis light reaction

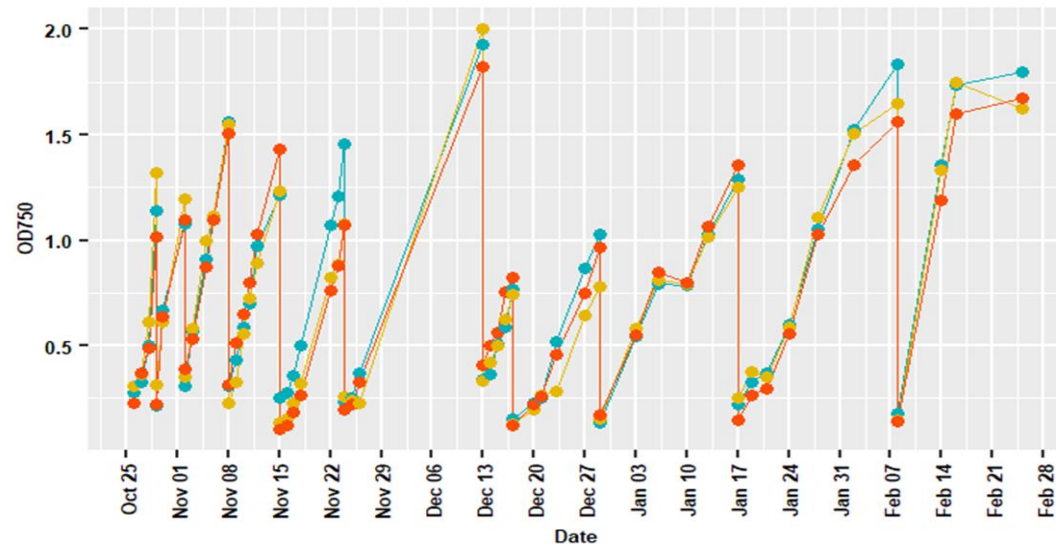
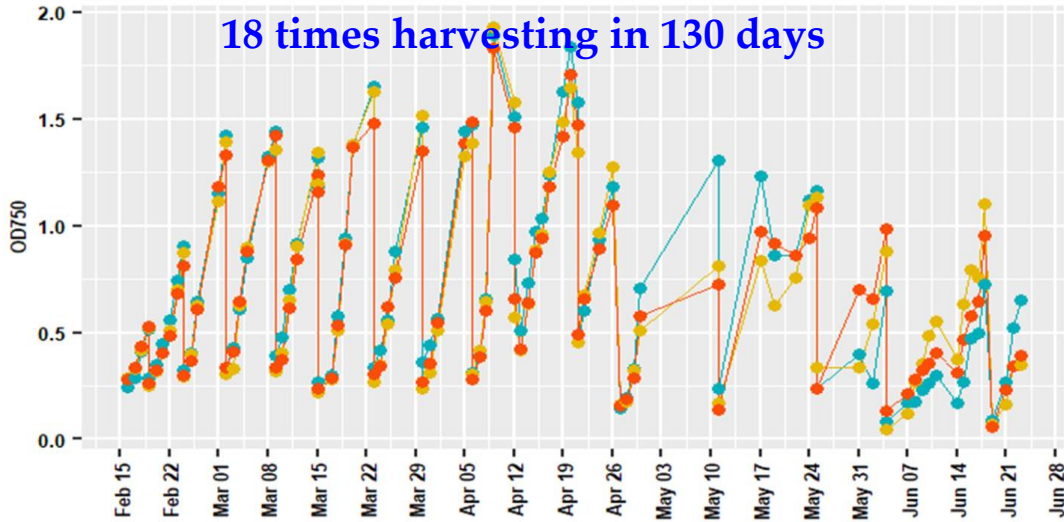


Photosynthetic traits

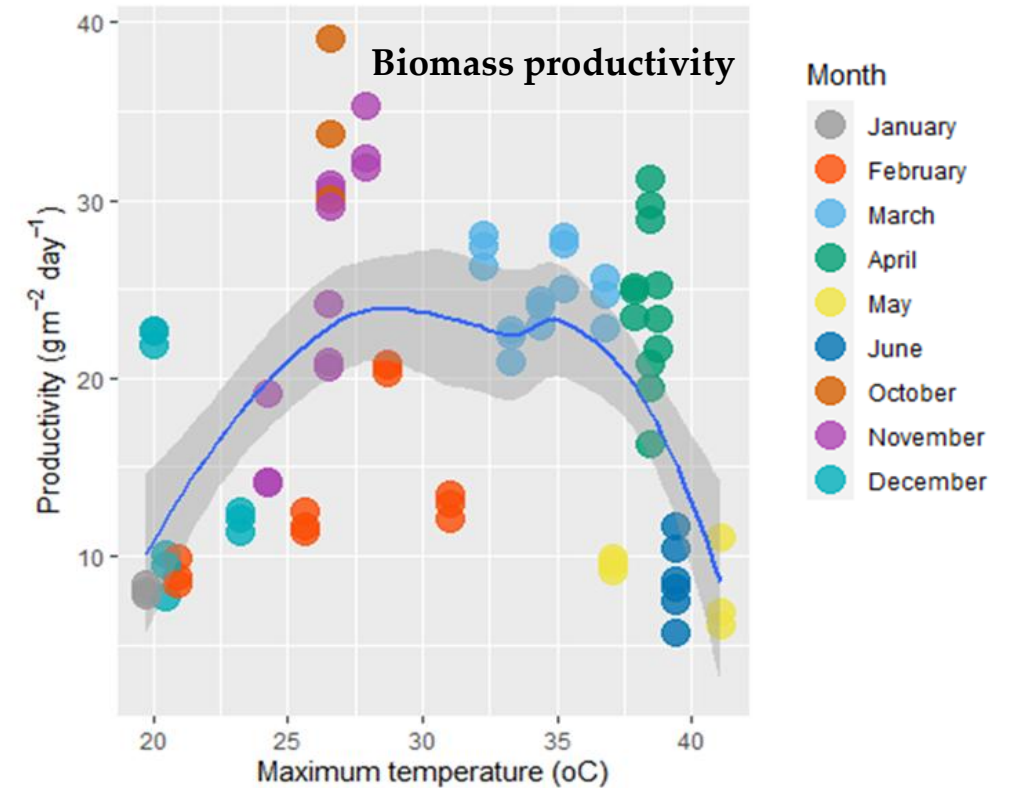


KNN model classified the nutrient status with an accuracy of 83%.

Harvesting frequency: key for high productivity and maintaining healthy culture



Maintain algae in a **young state**, as aged are more susceptible to infections.



The annual average biomass productivity of $19.1 \text{ g m}^{-2} \text{ day}^{-1}$ (**70 tons/ha/yr**)

Raceway pond cultivation of Nannochloropsis oceanica

Journal of Cleaner Production 428 (2023) 139450

Demonstration of Marine Algae Cultivation



Settling tank



Algal biomass

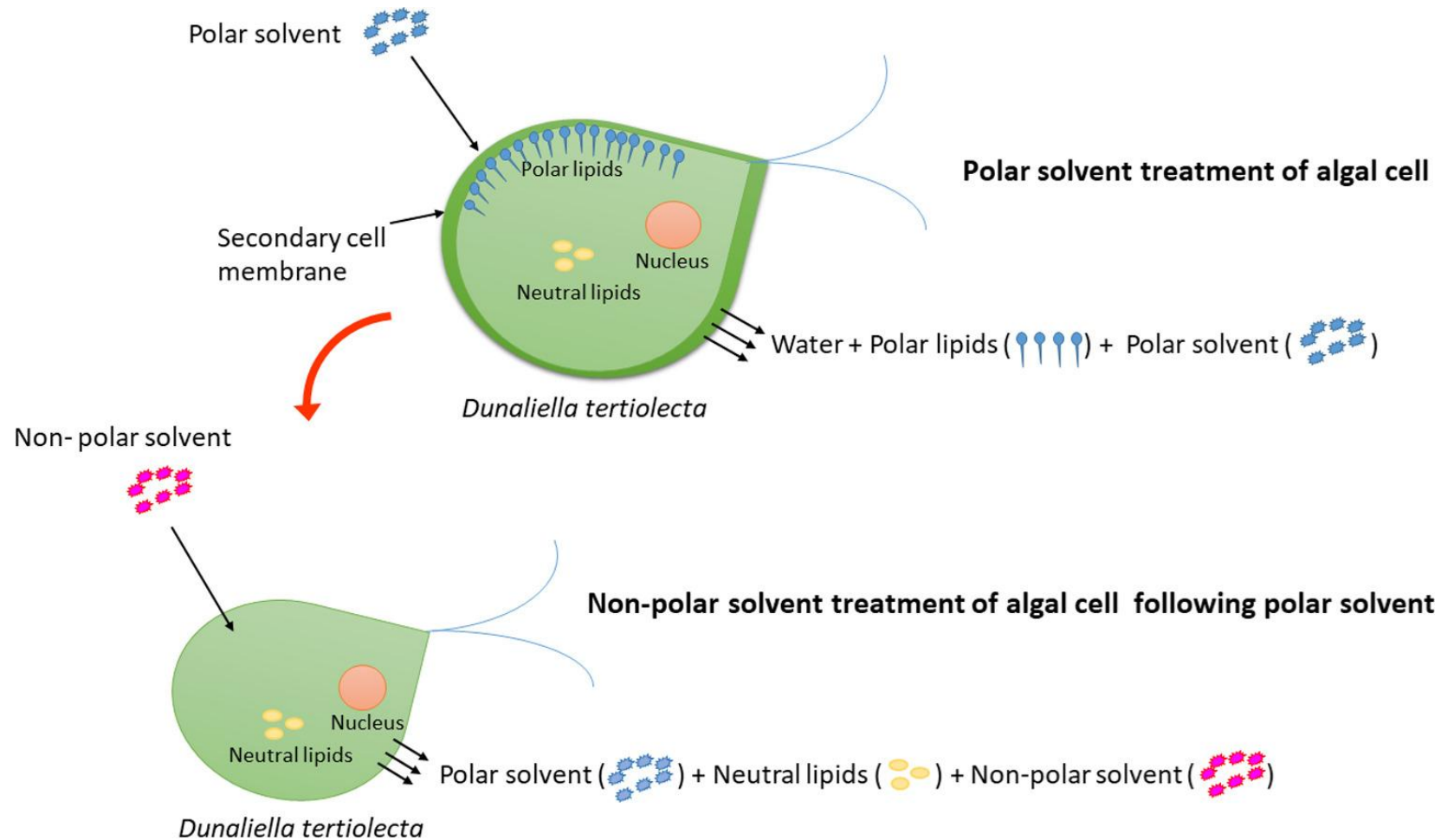


Industrial Centrifuge

- 100,000 L sunlight-distributed algal growth system established in Mumbai Coast (TRL: 5)
- Algal (*Dunaliella tertiolecta* & local strains, self aggregating) productivity;
 - 7-19.7 gm/ m²/day biomass
 - 15-20% lipid

1.5 Mha land area (coastal sites across India) available for algal cultivation.

Wet algal lipid recovery



- Efficient lipid recovery from wet algae without drying.
- Polar solvent pretreatment followed by non-polar solvent extraction.
- Polar solvent pretreatment replaces intracellular water in wet algal cells.

Pilot-scale Demonstration of Lipid Recovery from Wet Algae & Biodiesel Production



Pilot-scale wet algal lipid extraction system

A. Lipid extraction

- Demonstrated in 100 L scale (25 kg in 4 hours)
- >90% lipid extraction efficiency

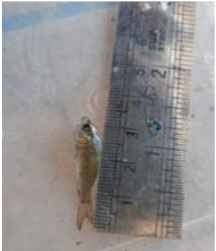
B. Biodiesel production

- Indigenous Ionic Liquid (IL) catalyzed process developed (IL 8 recycle and reuse> reported benchmark of 4)
- Conversion efficiency: 95-97%, Biodiesel purity; >90%

Aqua feed formulation (TERI-DA40) using Deoiled Algae Biomass



- Customized Aqua feed formulated named as; 'TERI-DA40' (TRL: 4)
- 180% growth enhancement in Catla
- 80% growth enhancement in Rohu
- 1 ton biomaa contains: 150-200 kg lipid, residual DAB (800-850 kg) can generate 2 tons of 'TERI DA-40'
- Based on these growth enhancements, price of 1 kg TERI-DA40 can be set at > Rs 140/ 1 kg. (Deoiled algae biomass cost in a hectare scale projected as Rs 70/ 1kg). TERI-DA40 will be commercially viable.



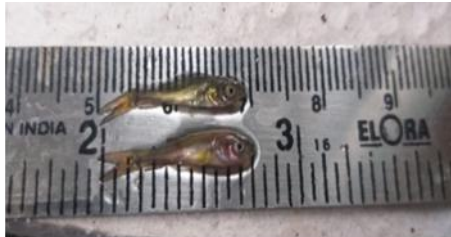
Day 0 Catla



Day 75 Catla



Day 0 Rohu



Day 90 Rohu

Producing omega-3 fatty acids enriched designer eggs through algae-based formulation



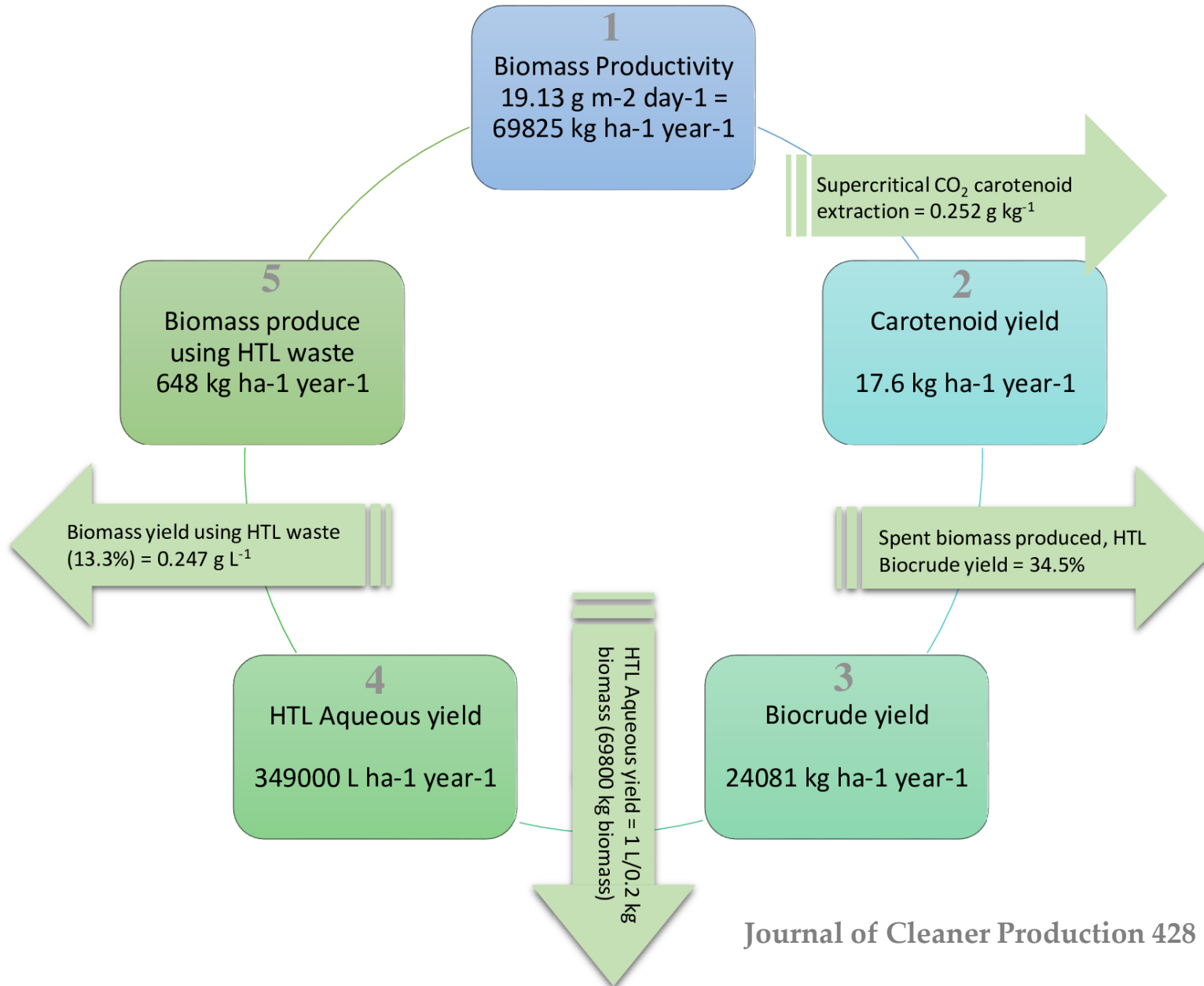
Egg properties after 30 days feeding

Egg parameters	Control	Algae feed
Production of 30 days	72.7%	77.9%
Egg weight (gm)	45.6	46.4
Yolk color index	5.6	5.8
Shell weight (%)	9.4	10.3
Docosahexaenoic acid (DHA) (mg/egg)	23.4	67.5

- DHA (C20:6) content 67.5 mg/egg
- Egg production increased by 5%.
- Increase in shell weight (shelf life)

Collaborator: ICAR Central Avian Research Institute, Bareilly

Simultaneous production carotenoids via supercritical extraction & bio-crude bio-oil via hydrothermal liquefaction (HTL)



Simultaneously produced carotenoids (17.6 kg/ha/yr) and bio-crude bio-oil (24 tons/kg/yr) and recycled aqueous phase of HTL.

Key takeaways

- Scale is the #1 barrier—better cultivation unlocks low-cost fuel
- The co-product model breaks at fuel scale—oversupply (**demand-to-supply ratio**) destroys prices.
- A Two-Pronged Strategy:
 - **Short-term:** Valorize high-value co-products to create immediate revenue.
 - **Long-term:** Invest in R&D to drive scalability, shape policy, and building a commercially and environmentally viable biofuel platform.





Thank You