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RESEARCH INTO CURRENT SCIENTIFIC DEVELOPMENTS ON ALTERNATIVE FOOD PRODUCTION

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Research into current scientific developments on alternative food production

Controlled environment agriculture (CEA) has seen substantial investment into the scientific developments spanning a broad range of applied techniques and technologies to enable a sustainable food production system with a minimal impact on the environment, utilises closed-loop environmental systems and increasing the crops nutritional values.

The three major systems are hydroponics, aeroponics and aquaponics. Hydroponics is the most utilised growing system under hydroculture, where roots are submerged in a nutrient enriched aqueous solution. The nutrient feeds can be derived from organic of chemical fertilisers. Aeroponics (a version of hydroponics) it the system of growing the product in the air on ranks where the roots hang down and a misting of water and nutrients is applied to the roots. Aquaponics is projected as the most sustainable system utilising a circular economy and therefore minimising waste and environmental impacts and therefore has seen a great surge in research and scientific developments due to (Kheir 2018).

See appendix, table 1; Evaluating the CEA growing method and their common technologies.

CEA has vast variants in the scale of production, which dictates the technology used, yet all commonly feature low water usage, recycled rain water from collection tanks, recycled water usage, automatic air-temperature and humidity control, renewable energy source for lighting and timed LED illumination. These systems within CEA have enabled crop growth in environments that previously would be deemed unsuitable for traditional agriculture (Martin 2016).

LED. LED technology is deemed as the most significant development within CEA. The LED developments allows the growth of plants in areas where previously could not. LEDs can be used in all CEA environments from glasshouses and TCEA (Total Controlled Environment Agriculture). Without the development of the LEDs indoor farming could not be developed on the scales currently projected (Chritis et al 2016).

See appendix, Table 2; Differing light frequency and the plant effects.

The LED developments are the determining factor in the growth rate of the crop. Differing spectrums emit throughout the growing period to optimise photosynthesis and are specific to each crop. The light spectrum can be changed depending on the crop and its desired outcome, influencing germination, branching and flowering. Light variants have also shown to develop increased flavouring periods and crops nutrient values. LED spectrums can control the nutritional values of crops, in particular microgreens where changes are evoked by specific lighting treatments that lead to higher phytochemical (phenols, ascorbic acid, flavanols, anthocyanins) and mineral element (Ca, K, Mg, Na, P, Fe, Zn) contents. Light spectrum controls enable higher DPPH and ABTS free radicals scavenging activities within all microgreens, therefore LED's have the potential to manipulate superior nutritional quality microgreens in greenhouses, plant factories and CEA and therefore increasing the nutrient intake of the population (Vastakatie et al 2015).

Costings to the LED components have been projected at 28%, with the desired efficiency rate established at 50-60% as a minimal requirement to serve as a cost-effective method (Eve 2016). *Phillips* lighting engineers have reported LED designs that produce lighting systems with an increased efficiency of 68% and 'induction' lighting that uses electro-magnet fields to excite argon gas to produce light. Furthermore, the specific colour spectrum induces faster growing fruits and vegetables; the use of such will dramatically reduce energy costs for future CEA (Matuskak 2017). Additionally, *PlantLab* have created a CEA specific LED that emits the specified sunlight wavelengths attributed to plant growth, aiding food growth with a low carbon footprint (Leverston 2017).

HVAC systems. HVAC systems (also known as grow rooms) have been developed to enable tight control of all parameters of the growing conditions, which has allowed the in-depth investigation of plant behaviour under a variation of climates. That has significantly enabled scientists and researchers to determine the variant factors within

CEA and the specific outcomes to the produce and the energy usage (Dodd 2016). The systems have been designed to control temperature, humidity, nutrient delivery, light, nutrient delivery, pH, disease identification and CO2 levels for optimal crop growth.

Computerised and monitoring systems. CEA farm operations are projected to be fully automated with the wide use of monitoring systems placed in each plant-bed to detect the levels of humidity, temperature, water and nutrient levels. Sensors have also been developed to detect the onset of decay, harmful bacteria and virus presence. Advances in gas chromatography can indicate the optimal period for harvesting via assessing the flavonoid and phytonutrient contents of the crop (Matusxak 2017). IT companies are developing specific apps and crop specific nutrient solutions that can be accessed online and consequently the entire process can be controlled remotely.

Unit developments. Development units such as *GrowCube* enables an increased yield and overall efficiency. These systems control plastic plates that rotate on a wheel, lit by LED's that provide the required light frequency for the specific crop type and growing stage. The system distributes mist with the required nutrients. This microclimate can be manipulated via computer, electronic devise apps and remote sensors (Cooper 2017).

Nutrient systems. These automated nutrient feeding systems include trays and racking systems that can be constructed to meet any scale of production. The nutrient delivery systems require differing racks and trays dependent on the method of CEA. Currently within hydroponics Ebb and Flow (flood and drain system) are the most popular, followed by drip systems and nutrient flow systems. With the integration of monitoring systems, the trays and racks have been designed utilise the applied technology. Racking has also become automated where individual ranks can be lifted via helix lifts into place saving labour cost and increasing output (Agri-Tech East 2019).

Fogging systems. Developments of controlled fogging systems and second-generation ultrasonic fogging systems have enabled water reduction whilst increasing a targeted water and nutrient delivery to the plants upper roots to penetrate the root tissues. Such systems maintain well-nourished and decay free plants. Though using such system root hair growth is stimulated and therefore increasing the root systems ability to absorb nutrients, water and gases exchange.

Hydroponic systems rely on chemical formulation liquids to be applied on to nutrient films and are largely non-circular water systems. In hydroponics reports that the produce is tasteless is connected the limited oxygen supply and the added chemical in the system, these short comings are addressed by aeroponics (Hedenblad et al 2017).

Growing mediums. Traditionally the trays in hydroponics have been lined with Rockwool, Oasis cube, expanded clay, coco chips, perlite or vermiculite that can incur high LCA costs. New developments in cellulous membranes have been developed to enable the bedding of root system and optimise growth but us fully compostable, biodegradable an can be fed into aquaculture. Furthermore, the cellulose membrane is strong enough to hold aeroponics and as a result remove the need of plastic trays (Forrest 2019).

Aquacultures and closed-loop ecosystems. The uses of solar aquaculture have developed controllable ponds stocked with fish that are exposed to sunlight. The conditions enable the fast-growing green micro-algae by utilising the nutrients in the water. The warmth from the sunlight enable the fast growth of both algae and fish stocked. This method is suitable for sites that require high rates of production in limited spaces. In addition, the ponds serve as units to store solar heat. It is expected that algae trap approx. 5% of the solar energy and the water the remaining 95%. The ponds emit cool air in the day and radiate warm air during the night, reducing energy use for heating systems. The maintenance of the pond and its waste enters into the closed-loop system recirculating aquaculture and plant matter creating a symbiotic environment (Kheir 2018).

The hydroponic bed also acts as filter that that can remove the gases, chemicals such as nitrates, ammonia and phosphates. Furthermore, the gravel bed layer acts as a nutrient habit to nitrify bacterium which augment nutrient cycling and filter water that can be recirculated to the fish tanks. This method of aquaponics minimises the problem of waste, chemical nutrient uses and water usage that is a current negative with hydroponics and aeroponics systems.

Aerobic digestibility Recovering biogas from the waste plant-matter can be used in the heating and powering of the systems used in CEA (Agstar 2017). This process further enhances the closed-loop system and the reduction of energy usage and environmental impacts.

Robotics. Robotics have been designed and piloted to augment the data outputs from the plant-bed sensors and monitoring systems, to rank plants in the specified zones from germination though to harvesting and cultivating. Within CEA, robotics can be utilised as both static machines, through to drone observation robots. The use of drones can optimise farming inputs and reveal critical information for the farmer from aerial views and static robots in the aid of accessing high rise ‘vertical farm’ areas. Whilst robot have been predicted to be an essential contributor to CEA’s automation, but it is deemed unrealistic to expect an entirely automated farming system in the very near future (Duckett et al, 2018).

Plant breeding. Plant breeding has started to enable the crops to be fully functional in a CEA environment. Whilst light changes can manipulate plant stems and height to a degree, the need for specific developmental crops and seed breeding for shorter crops, with a large leaf growth is optimal for CEA sustainability. Biofortification has enabled crops to contain superior nutritional values compared to traditional crops. Plant breeding is believed to be the most complicated element of the CEA production with the need for agriculturists, horticulturists, geneticists and agronomists collaborating to create the desired crop for the growing environment (Voss-Fels et al 2019).

Summary. CEA systems are gaining substantial interest and investment from a broad range of industries driving growth and scientific developments within electronics, robotics, software, technological, chemical, biological, horticulture and agriculture. The need for industry and science collaboration is essential foe CEA’s success.

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Appendix 1

Table 1; Evaluating the CEA growing method and their common technologies (Adapted from Kheir 2018 & Alkodmany 2015)

Farming method	Key characteristics	Major benefits	Common applied technologies
Hydroponics	Uses water trays as a growing medium	Rapid plant growth Eliminates impact on soil	

		Eliminates pest control methods and chemical uses Reduced water usage	Computer controlled monitoring and sensor systems Technological applications to identify the nutrients, growing conditions and energy usage Remote control software to enable long distance control Automated racking systems Light spectrum specific LED's to enhance growth stages and nutritional values Closed-loop systems Aerobic digesters Climate controls HVAC rooms Agri-robots Water collection and regulation systems
Aeroponics	Uses misting and spraying systems applied to the roots	Rapid plant growth Eliminates impact on soil Eliminates pest control methods and chemical uses Further reduces water usage compared to hydroponics	
Aquaponics	Circular economy using aquacultures	Circular environment utilising the needs and waste of both fish and plants	

Appendix 2

Table 2; Differing light frequency and the plant effects (Excite 2019)

LIGHT	Frequency (nm)	USES
Ultra violet light	10-400	Plant color, tastes, aromas, metabolism, THC level elevation (in cannabis)
Blue light	430-450	Vegetative growth, seedlings in young plants, production of secondary pigment, fragrance production
Green light	500-550	stomatal control, plant growth patterns
Red light	640-650	Seed germination, fruiting regulation, stem growth, leaf expansion, pigment synthesis, induce flowering of long-day plants, or to prevent flowering of short-day plants
Far-red light	730	Ideal for plants that require little light for short periods.