Final Report

Examining key constraints to protected cropping systems for the production of high-value vegetable crops in tropical and subtropical climates

Project leader:

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Delivery partner:

Central Queensland University

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LP15007

Project:

Examining key constraints to protected cropping systems for the production of high-value vegetable crops in tropical and subtropical climates (LP15007)

Disclaimer:

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Content

Summary

The project supported PhD student Karli Groves to complete a doctoral research project embedded within a horticultural industry business. The project was part of the Hort Frontiers National PhD Leadership Program which aimed to foster the development of industry-focused research skills in future research leaders. This project focused on the protected cropping industry, and sought to identify and investigate key aspects affecting both crop yield and quality in a commercial cucumber production system. Increasing climate variability and consumer market expectations have influenced a marked change from conventional, open-field production to protected cropping within the Australian vegetable industry. While protected cropping represents great potential for increased yields of produce that is both higher in quality and grown more sustainably, there is a lack of knowledge surrounding the uptake of this transformative technology. This is particularly true for warmer tropical regions, with the majority of research centred in the cooler, temperate zones of Australia. While many aspects of production require further research to aid in the development of protected cropping in Australia, both crop yield and crop quality are recognised as among the most crucial. Maximising yields of higher quality produce may help to further incentivise the adoption of protected cropping, allowing growers to meet the demands of a discerning Australian market and contribute to the future security of Australian food production. While many crops are grown under protective structures in Australia, cucumber is one of the most economically important and widely grown crops in the country.

Public summary

PhD student Karli Groves commenced her studies at CQU in March 2018 and completed her thesis in July 2021. Karli formed a strong collaborative relationship with Eden Farms, who is an industry partner supporting this project, and with Dr Elio Jovicich (Qld Department of Agriculture and Fisheries) who was her PhD Associate Supervisor. She has gained comprehensive knowledge of the farming system from running experiments in the commercial farming operation. During the project Karli attended 3 major horticultural conferences and presented at the International Horticultural Congress in Turkey and the Protected Cropping Australia conference on the Gold Coast.

The research conducted by Karli in her PhD examined factors that may contribute to development of unmarketable bent fruit in cucumber crops. In the research completed in year 1, this issue was identified as a major financial cost in subtropical cucumber production. Variations in environment within greenhouses do not explain most of the bent fruit incidence, nor does presence of pests such as thrips and aphids or the fruit load on individual plants. Treatments examining light intensity effects revealed that fruit curvature severity worsened with increasing shade levels, suggesting that rate of photoassimilate supply may be a more important parameter for fruit shape development than competition for those resources between different fruit and shoots on the plant. Physiology studies revealed variations in water potential and cell turgor with a developing fruit that were consistent with turgor differentials driving bending of the fruit. Of commercial significance, Karli identified that bending of young fruit was reversible, and that the current practice of frequent fruit pruning to remove bent fruit resulted in decreased yield of marketable fruit compared to a less labour intensive weekly fruit pruning program. Karli documented the research for the project industry partner, and the recommended practices have now been implemented in the commercial operation saving the company in labour costs and increasing the yield of marketable fruit.

Keywords

Cucumber, protected cropping, greenhouse, research higher degree, capacity building

Introduction

The stated objective of the Hort Frontiers National PhD Leadership Program was to drive research innovation and develop future leaders of the Australian horticultural industry via a national PhD scholarship scheme. This project supported PhD student Karli Groves to complete a research thesis and gain research leadership skills through collaboration with a leading Australian vegetable crop producer as well as attendance at national and international horticultural conferences. Karli has gained employment as a Postdoctoral Research Fellow within the Institute for Future Farming Systems at CQU where she will deliver research services to horticultural producers in the Bundaberg region in Queensland.

The PhD project "Examining key constraints to protected cropping systems for the production of high-value vegetable crops in tropical and subtropical climate" focused on the subtropical/tropical protected cropping industry, and sought to identify and investigate key aspects affecting both crop yield and quality in a commercial cucumber production system. Protected cropping is a combination of technologies and crop management practices that involve the use of some kind of structure placed over plants, and which is used to improve productivity. In Australia, protected cropping is expanding rapidly both in terms of the variety of vegetables cultivated and area under cultivation. Currently, protected cropping in Australia is concentrated in southern temperate regions; however there is significant potential for the development of protected cropping systems in tropical north Australia.

To date, development of a protected cropping industry in north Australia has been constrained by the lack of appropriate knowledge in both biophysical and socio-economic areas. Knowledge deficits include the type of protective structure and production system most suited to tropical climates, the types and levels of risk that different scales of farming operations are able to manage, and the growers' perceptions of the risks and benefits of the production system. Significantly, the potential economic gains from the adoption of protected cropping under the production constraints of farmers in tropical north Australia remain to be investigated. This project has built research capability to support the protected cropping industry, with a PhD trained researcher possessing extensive industry knowledge of warm climate protected cropping production systems commencing her research career having strong industry connections.

The research project used a case study analysis approach with commercial horticulture enterprise Eden Farms as the industry partner. At the time of the study, Eden Farms was Australia's largest greenhouse cucumber producer, and had identified improving the percentage packout of first grade fruit as a priority area for the company. The PhD project completed by Karli examined this issue and identified strategies to reduce the losses incurred from production of misshapen fruit. During the project Karli was able to act in various production and research roles within the company to ensure she gained a deep insight into protected cropping systems.

Methodology

The project aimed to deliver training in research, and research leadership, via completion of a PhD project by student Karli Groves at CQU. As such, the methodology followed was the CQU research higher degree program which incorporates a body of research undertaken by the student as well as coursework training in research approaches and research communication. Attendance at national and international conferences was included in the training program to assist Karli to build a professional network and gain skills if presentation of research results to scientific and industry communities. When the project was initiated, an intention to incorporate additional leadership training components for the cohort of PhD students being supported by the funding scheme was envisaged, but this training did not eventuate. To ensure a high level of industry knowledge was captured during the project, and to build skills in industry engagement and delivery of industry-relevant research, the body of research completed by Karli was conducted while based in the commercial production facilities of Eden Farms.

The PhD research project consisted of a series of greenhouse and laboratory trials investigating the factors affecting development of misshapen fruit in commercial cucumber production. The initial trials identified that misshapen (bent) cucumbers was a major source of loss in the production system accounting for the majority of fruit that failed to meet grade 1 class. The effects of production environment on formation of bent fruit was then researched using temperature, humidity and light intensity sensors along with pest/disease scouting to monitor environmental variability within a commercial greenhouse and examining the relationship between the rate of bent fruit development and the measured environmental and biotic parameters. A detailed examination of the pattern of fruit development was also conducted. The next series of experiments investigated the impact of crop management practices (pruning and training) on bent fruit development, using commercial crops to ensure relevance of the results to the production system. The final series of experiments aimed at identifying the causal mechanism behind formation of misshapen fruit involved studying the anatomical and physiological changes that occur during normal (straight) and bent fruit development.

For all greenhouse experiments, one of two different Blueleaf® continental cucumber varieties (Litoral RZ F1 (24-199) and Inyanthi RZ F1 (24-192)) bred and developed by Rijk Zwaan were grown, depending on seasonality. Both varieties are used commercially in protected cropping systems Australia wide and are suited to unheated greenhouses such as those used in subtropical/tropical conditions.

Cucumber plants were grown and maintained by the grower according to current commercial crop production methods. All experiments were conducted in commercial crops in conjunction with pickers, sprayers, and crop workers, as well as current industry operations and procedures. The methods used to conduct experiments were therefore adapted to ensure they were applicable to current industry processes, both for the purpose of this PhD research and for later adoption of results and conclusions by growers.

Cucumber seeds were sown into a vermiculate substrate and grown for approximately three weeks in a nursery greenhouse. Plants were then transplanted into plastic bags filled with pre-moistened sawdust when they had 1-2 true leaves and placed in the greenhouses. A single bag (5l) contained two plants, with each assigned a single irrigation dripper for water and complete nutrient fertiliser delivery. Plants were trained using a modified umbrella method (figure 1), in which the main stem of the plant was trellised with a nylon twine to a horizontal highwire suspended approximately 2.5m above the bags. When the main stem of the plant reached the highwire, it was wound over twice and then allowed to fall to approximately chest height before the growing tip was removed to terminate stem growth. Two main laterals were grown from the section of main stem that was trellised over the highwire. All other laterals were removed from the central stem of the plant, and all fruit were removed below the 6^{th} node. Nodes thereafter were limited to a single fruit, with all regrowth fruit removed. Fruit loads were maintained on the stem with a 2 nodes on 1 node off pruning pattern, however lateral fruit were not thinned. Fruit was harvested 3 times a week when the crop was approximately six weeks of age. Harvested fruit measured between 35-45cm in diameter depending on the season and according to commercial quality guidelines and were removed from the plant with a sterilised knife, leaving a short stem attached to the fruit.

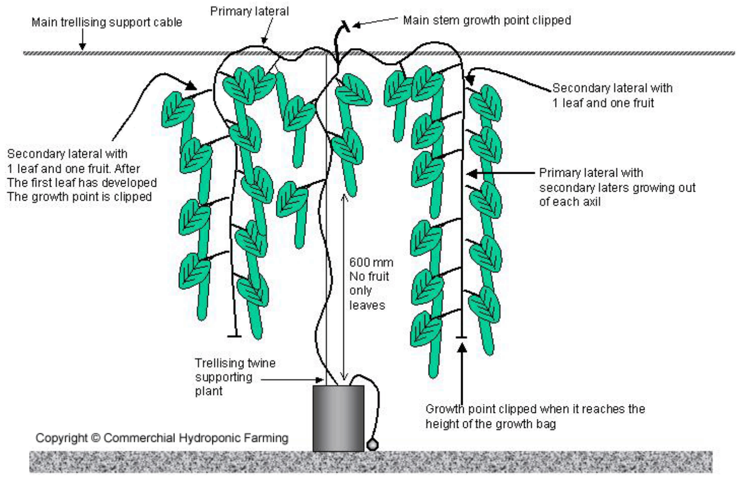

Figure 1; A modified umbrella trellising method was used to train the plants in all experiments

Environmental measurements

Temperature, relative humidity, and light intensity were measured using the following sensors;

HOBO Pro V2 temperature and relative humidity loggers (Onset, U23-001)

Each logger was secured within a Stephenson screen to protect them against both misting systems and heating outlets, while still allowing air circulation. Loggers were attached with plastic zip ties to the steel poles used to suspend the greenhouse roofing structures. Sensors were first installed to a level just above the crop canopy and were moved higher as the crop grew until the sensor was in line with the horizontal growing wire.

HOBO Pendant lux loggers (Onset, MX2202)

These sensors were attached to the top of the steel support poles with plastic zip ties. When the crop grew to the top wire and above the poles, plants and leaves shading or interfering with the sensors were moved in the case of experimental plants, or removed if encroached on by non-experimental plants. Loggers were frequently adjusted to ensure they were level with the greenhouse roof.

Fruit quality assessment

Fruit quality was assessed thought this research using a combination of both industry commercial quality guidelines, and quality parameters defined here.

Flower development stages

Fruit curvature was assessed on the first day after anthesis (stage 4), while fruit length and width measurements were recorded as soon as the fruit reached a measurable size, typically in the first and second stage of flower development (figure). Fruit width was measured with digital vernier callipers (Kingcrome 150mm) with the inside of the curvature facing towards the measurer, and length was measured with a retractable tape measurer along the outside of the curve of the fruit.

Figure 2; Fruit developmental stages: 1- small tight green flower bud; 2- flower bud remains green, with petals beginning to separate; 3- petals continue to separate and begin to turn yellow, 4- petals completely separate and turn a vibrant yellow.

Fruit quality assessments

While a cucumber fruit has a slight and natural curvature, a bend of greater than 2.5 cm from a straight edge renders the fruit unmarketable. Although not specified in commercial quality guidelines, fruit in this project with a curvature of less than 1cm were classified as first-class fruit, while those between 1.0 and 2.5cm were classified as a second-grade fruit.

Fruit curvature was measured by orienting fruit on the frame with the convex side of the curvature directed towards the laser (Fluke 411D Laser Distance Meter), which was able to reach the fruit through a small hole in the measuring frame. Because the laser had a minimum measuring distance between the top of the laser and an object, the laser was mounted on the frame at a known distance to the top of the frame. The curve was then determined by subtracting the known distance from the distance measured to the top of the fruit curvature.

Statistical analysis (SPSS IBM Statistics 27)

All data was subjected to skewness checks, with any skewness value greater than two times the standard error deemed to warrant data transformation by either square root or log10 where appropriate.

Pearsons correlation coefficient analysis was used to examine data to determine relationships between two variables.

Outputs

The primary output of the project is a trained scientist with skills in applied, industry focused research. The PhD graduate is expected to be a leader in horticultural research in the future. The project resulted in publication of a PhD thesis and research conference presentations.

Figure 3; PhD student Karli Groves on site at the Eden Farms production facility

Conference Presentations and attendance

- Attended and presented at International Horticulture Congress 2018 (Symposium on Tropical and Subtropical Vegetable Production). Poster presentation, and co-author of Acta Horticulturae paper.
- Invited presentation at the Australian Society of Horticultural Science ‘Future of Horticulture’ conference (24th June, Melbourne Convention and Exhibition Centre). Awarded First place in the Student Presentation section.
- Attended Hort Connections 2019 conference (Melbourne Convention and Exhibition Centre)
- Attended and presented at the COSTA Protected Cropping Australia 2019 Conference ‘Seduction by Technology: Knowledge Exchange for Greenhouse Growers’. Oral presentation in the Student section at the conference.
- Attended Hort Connections 2021 conference (Brisbane Convention Centre)

Figure 4; Project presentation to industry at PCA conference

Publications

Groves, K (in press) Examining key constraints to cucumber quality in subtropical protected cropping systems. PhD Thesis, Central Queensland University.

Brown, P., Groves, K. and Jovicich, E. (2019). Development of protected cropping systems for out-of-season vegetable production in the Pacific Islands. Acta Hortic. 1257, 195-200. DOI: 10.17660/ActaHortic.2019.1257.28

Outcomes

Protected cropping is expanding in tropical and subtropical regions in Australia. The structures used and management practices appropriate to the conditions vary from those of traditional cool climate protected cropping systems. Appropriate research expertise to support the continued expansion of protected cropping in Northern Australia is currently limited, and this project has contributed to addressing this issue by providing an industry focused PhD training opportunity for a young researcher who shows research leadership potential. Karli Groves has developed the skills and knowledge needed to make a significant contribution to Australian Horticulture in her future career.

The research undertaken in the PhD project resulted in one specific change in production practice that increased productivity and profitability for the industry partner in the project. The research identified that fruit displaying bending during early growth (that would normally be removed and discarded by pickers) would straighten if left on the plant. Therefore, less frequent pruning delivered higher yields of marketable fruit (on average an additional 1 fruit per plant over the cropping period) than the current pruning strategy as well as reducing labour costs.

Monitoring and evaluation

Project progress was monitored and reported through the CQU Research Higher Degree candidature review system. The PhD student submitted a detailed research plan for confirmation of candidature within 6 months of commencement, and successfully completed progress reports every 6 months over the duration of the project

Recommendations

The project successfully delivered training in research, and research leadership, to one PhD student. When the project was initiated, the national program approach in which it was embedded included a clear intention to incorporate additional leadership training components for a cohort of PhD students being supported by the funding scheme was envisaged. While this national coordination was not delivered, it is clear from the experience of the PhD student supported in this project that suc a program would be very beneficial. Karli's attendance at national and international conferences allowed her to build a professional network and gain skills if presentation of research results to scientific and industry communities, and to have done so with a group of peers would have established a cohort of future horticulture research leaders who would likely have benefitted greatly from a peer support network as their careers developed. The recommendation from this project is therefore that a great degree of national coordination and establishment of peer networks be incorporated if further funding for research leadership development via PhD training support is to be considered.

Refereed scientific publications

Journal article

Brown, P., Groves, K. and Jovicich, E. (2019). Development of protected cropping systems for out-of-season vegetable production in the Pacific Islands. Acta Hortic. 1257, 195-200. DOI: 10.17660/ActaHortic.2019.1257.28

Thesis

Groves, K (in press) Examining key constraints to cucumber quality in subtropical protected cropping systems. PhD Thesis, Central Queensland University.

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report

Acknowledgements

The support of Eden Farms in hosting the PhD research project is gratefully acknowledged. Financial support for the PhD scholarship and for conference attendance was received from CQUniversity.

Appendices

Appendix 1: IHC poster

Development of p Zoom in (Ctrl+Plus) ems for out-of-season vegetable production in the Pacific Islands

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INTRODUCTION

At present, high value vegetable production in the Pacific Islands does not match local demand, with a large proportion currently being met by imports. If this demand was met by local producers, income from vegetable production would improve the livelihoods of producers and their communities. However, current production systems are unable to supply the high value vegetables required to open new export market opportunities.

Protected cropping is a potentially transformational and enabling technology that could fill this import gap. Low cost protected cropping systems can effectively and economically overcome many production challenges and have the potential to deliver year round vegetable production. This would give growers access to high value markets for vegetable products that are otherwise very difficult to access with conventional production systems.

Effective uptake of the technology is currently constrained by a lack of information on key structure design considerations. Research was therefore initiated to identify design features of structures on which cost effective protected cropping systems for Pacific Island countries can be based.

MATERIALS AND METHODS

A survey of operating and abandoned protected cropping structures was conducted in Fiji in June 2018 to evaluate structure designs and identify key areas required for successful production. At each site visited, information was collected on structure type, current production status, major markets and growers comments on the protected cropping system.

Agronomic trials were conducted in protected cropping structures at three demonstration sites, 2 in Fiji and 1 in Samoa. These trials focussed on crop trellising strategies and varietal evaluations. Data on crop yields, product quality and production season duration were recorded. Gross returns were calculated using averaged market prices.

RESULTS

Design features for high value crop production were identified from the survey and from literature as follows;

- Irrigation system able to supply adequate water to the crops being produced
- Roof covered with a clear polyethylene film to exclude rain or a whitish polywave fabric
- Removable shading screen over the roof and clear polyethylene film material to reduce solar radiation
- Insect exclusion netting. Easy removal of netting in case it is necessary to increase ventilation or facilitate pollination by insects
- Roof vent, a vertical opening of 0.6-1 m on the roof to allow the escape of warm air through passive ventilation and to increase air exchange rate
- Tall structure (>3 m) -keep the warmer air far from the plant canopies - Allow for high vertical trellising - Increase the surface of lateral openings and increase air exchange rate
- High (>2.5 m) on all sides of the structure for improved ventilation
- Structure designed to withstand at least 80-100 km/h winds and with relatively simple methods for detaching and attaching covering materials and frame

Production of crops in 3 demonstration structures consistent with the design features mentioned above showed that high yields and good quality produce is achievable (Table 1). Mean marketable yields of 3.5, 2.4 and 8.4 kg/m² for tomato, capsicum and cucumber respectively in Fiji, and 6.4, 2.4 and 4.3 kg/m² in Samoa. These yields were possible as crops could be grown for extended durations in the structures. Gross returns based on the production figures suggest that investment in high, vented protected cropping structures would be profitable in the Pacific Island countries

	Tomato		Capsicum		Cucumber	
	Fiji	Samoa	Fiji	Samoa	Fiji	Samoa
No. of drip-irrigated crops	8	2	7	3	3	9
Marketable yield	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)	(kg/m^2)
Mean yield	3.5	6.0	2.4	2.4	8.4	4.3
Maximum yield	6.2	6.2	5.0	3.7	9.8	8.3
Minimum yield	0.9	5.8	1.1	1.6	6.0	0.9
SD for yield	1.5	2.0	1.3	1.0	1.7	2.5

Table 1: Crop production data for the 3 demonstration sites

CONCLUSION

High marketable yields for tomato, capsicum and cucumber crops grown in high, vented structures were demonstrated. However, the skills and knowledge required to manage these structures and production systems differ from conventional field production. Therefore, growers investing in these systems must acquire the skills and knowledge to balance the investment risks in establishing these systems. Which structure design is best suited for a grower will depend on several factors, most notably crop species to be grown, plant growing system, specific environmental and biological constraints of the location, desired level of environmental control, expected strength and durability of the structure, investment budget available and access to appropriate markets for produce.

Acknowledgements: Karli Groves is the recipient of a CQU PhD scholarship that is is funded by the Hort Frontiers National PhD Leadership Program, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from CQUniversity and contributions from the Australian Government.

Appendix 2; COSTA PCA conference presentation

Examining key constraints to protected cropping systems for the production of high-value vegetable crops in tropical and subtropical climates

- Protected cropping is a rapidly expanding horticultural sector in Australia
- Production (and research!) currently centred in temperate climate regions, but sector also expanding in subtropical/tropical areas
- Research is needed to adapt technology to the specific conditions and challenges faced by growers in tropical climates
- **Crop quality** and **crop yield** can be constrained by a range of factors in tropical climate protected cropping
- This PhD project will examine key factors impacting on cucumber crop yield and quality
    - **Crop quality** - Increasing first class, marketable fruit percentage
    - **Crop yield** - Increasing the longevity of the crop to extend harvest periods and improve yields
- Identification of key factors constraining yield and quality, and assessing strategies to overcome major constraints
- Detailed scientific investigation of agronomic and physiological aspects of crop yield and fruit quality

Appendix 3: Trial report prepared for Eden Farms

Trial Report

The trial was conducted to determine if fruit that was bent during early growth (and would normally be removed by pickers) would straighten if left on the plant, and if so would less frequent (or no) pruning deliver higher yields of marketable fruit than the current pruning strategy.

The continental variety 'Litoral' was planted on the 16/12/2020 in B block at Fallons Rocks Road. 5 treatments with 6 replicate rows of plants were established throughout the greenhouse.

The bent fruit was removed;

A; 3 times a week (current practice)

B; 2 times a week

C; once a week

D; once a fortnight

E; never

Each treatment had the damaged and misshapen fruit as a result of splitting and physical barriers removed twice a week.

At each harvest, the number of fruit from each row was counted. A subsample of 20 fruit from each row was also assessed for fruit curvature, to determine if the quality of the yield was affected by pruning frequency.

At the end of the trial, treatment D returned the highest cumulative fruit numbers, followed by E. Treatments A, B and C had the lowest, respectively. There was no significant difference in the fruit curvature between treatments.

A	B	C	D	E
6.69	6.71	7.00	7.78	7.60

Table one: Average cumulative fruit per plant

By removing the bent fruit less frequently, the fruit is given time to 'recover' and straighten into a marketable fruit. The treatments in which bent fruit was removed frequently had a lower yield, because the fruit that would have eventually straightened were removed before they had a chance to recover.

There was a difference of approximately 1 fruit per plant harvested between the D treatment and the A treatment. Over an entire block, like B block which has 8352 plants, that is a substantial amount of fruit that is potentially lost due to the removal of recoverable fruit.

The recommendation following from this trial is that bent fruit be removed less frequently. Not only will the time it takes for crop work to be completed be shortened, yield will be improved with no loss of fruit quality.

Future considerations if further trials were to be conducted may include the addition of a 'Selective pruning' treatment, in which only the most severe bent fruit are removed. In the D and E treatment, yields may have been further increased with selective pruning, to remove the unrecoverable bent fruit that acted as a sink and delayed marketable fruit development.

Further work may also focus on determining at what point fruit do not recover. Whether it is a matter of fruit size or fruit curve, establishing a 'point of no return' may further assist in improving crop management practices that allow only the unrecoverable fruit to be removed, while recoverable fruit are left to be later harvested.