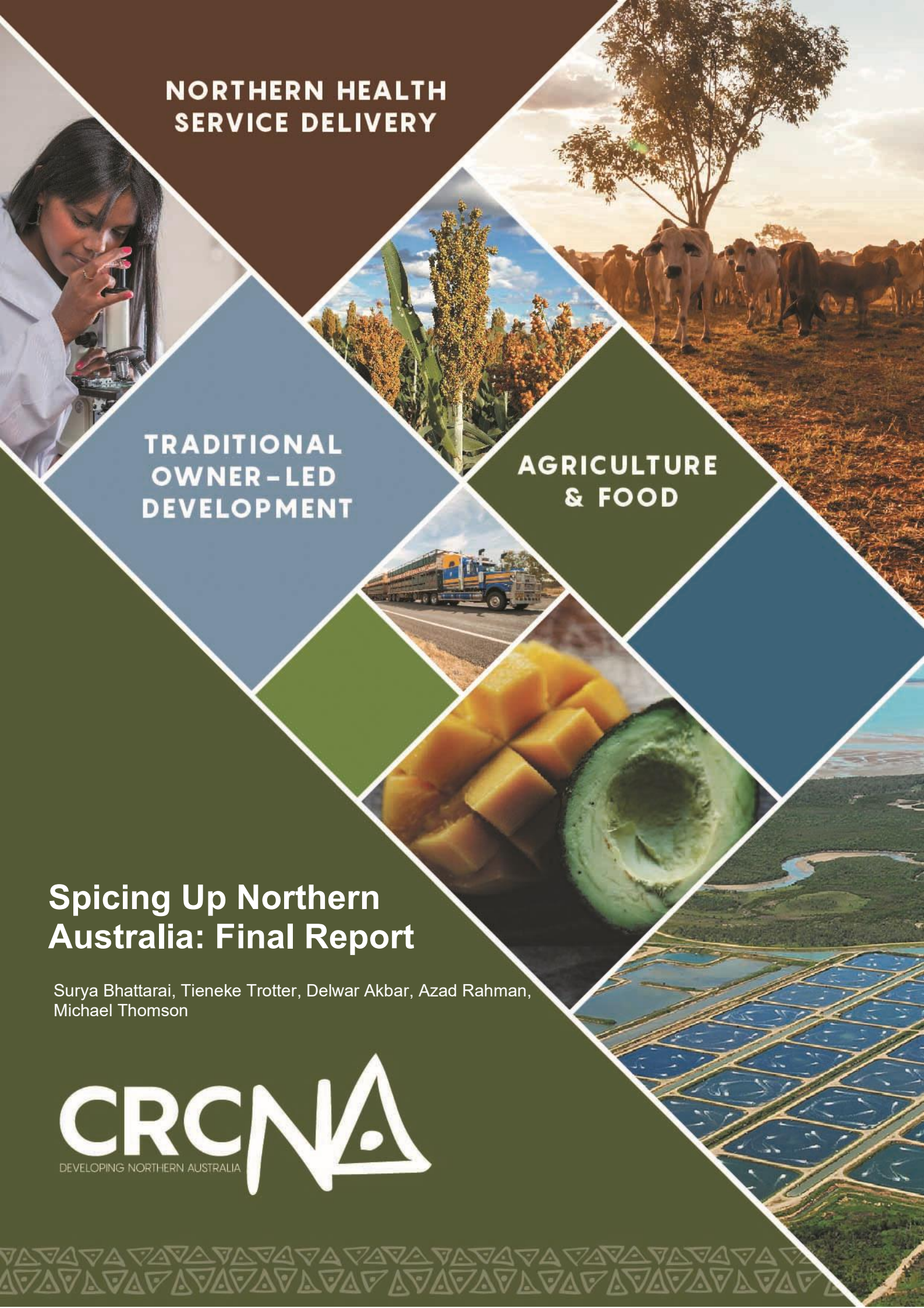


Spicing Up Northern Australia: Final Report

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CRCNA
DEVELOPING NORTHERN AUSTRALIA

Acknowledgments

This research is funded by the CRC for Developing Northern Australia (CRCNA), which is supported by the Cooperative Research Centres Program, an Australian Government initiative. The CRCNA also acknowledges the support of its investment partners: The Western Australian, Northern Territory and Queensland Governments. We also acknowledge the financial and in-kind support of the project participants.

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The CRCNA recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.

The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2018),

and provided constructive feedback which was considered and addressed by the author(s).

This report should be cited as: Bhattarai, S., Trotter, T., Akbar, D., Azad, R. and Thomson, M., 2023. Spicing Up Northern Australia: Final Report. Project Report for CRCNA. CQUniversity Australia, Rockhampton, 25 pages.

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ISBN 978-1-7639363-9-3

Table of Contents

Acknowledgments 1
Disclaimer 1
Peer Review Statement 1
List of Figures 3
Acronyms 4
Project participants 5
Executive summary 6
1. INTRODUCTION 7
2.3 ..... Background of the project 7
1.2 Objectives of the project 7
1.3 Organisation of the report 8
2. KEY FINDINGS AND RECOMMENDED ACTIONS 9
2.1 Objective 1 – To assess global and domestic markets of five selected spice crops (Market analysis) 9
2.1.1. Key findings 9
2.1.2. Recommended actions 10
2.2 Objective 2: Conduct scoping studies of selected spices crops (initial evaluation trials in year one) 10
2.3.1. Key findings 10
2.2.2. Recommended actions 11
2.3 Objective 3: Investigating crop quality assessment (seed quality standards) 12
2.3.1. Key findings 12
2.3.2. Recommended actions 14
2.4 Objective 4: Explore through verification trials the results from the initial evaluation trials in year two (verification trials) 14
2.4.1. Key findings 14
2.4.2. Recommended actions 15
2.5 Objective 5: Examining the crop performance in commercial trials in year 3 (commercial production trials) 15
2.5.1. Key findings 16
2.5.2. Recommended actions 16
2.6 Objective 6: Examine an economic analysis of the spice crops production (Gross margin analysis) 16
2.6.1. Key findings 17
2.6.2. Recommended actions 17
2.7 Objective 7: Dissemination of key findings to producers and industry 17
2.7.1. Communication and dissemination 17
2.7.2. Recommended actions 19
2.7.3 End-users engagement and capacity building 19
3. CONCLUSION AND FUTURE RESEARCH 21
References 23
Appendices 24
Appendix 1: Web links for full reports 24

List of Figures

Figure 1: The five spice crops evaluated for “Spicing up Northern Australia Project” over 2019-2022 seasons. The images show at flowering/fruiting stage (from left) black sesame, fennel, kalonji, cumin, and kalijiri. The first three crops from the left with red ticks were progressed through initial evaluation, to the verification and commercialisation stages, whereas the last two crops, did not progress to the verification and commercialisation trials. 7

Acronyms

ASIDA	Australian Sesame Industry Development Association
BBIFMAC	Burdekin Bowen Integrated Flood Management Advisory Committee
CAGR	Compound annual growth rate
CQU	Central Queensland University
CRCNA	Cooperative Research Centre for Developing Northern Australia
GMA	Gross Margin Analysis
LEISA	Low external input sustainable agriculture
NT DITT	Department of Industry, Tourism and Trade, Northern Territory Government
RRC	Rockhampton Regional Council
TQ	Thymoquinone
TRAP Services	Technical Reporting and Analytical Services
WA DPIRD	Department of Primary Industries and Regional Development (WA DPIRD)

Project participants

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- AgriVentis Technologies Pty Ltd - seed company and spice business, NSW 2060
- Rockhampton Regional Council (RRC) - Local government, QLD 4700
- TRAP service, Euramo, Tully North Australia, QLD 4854 - Research partner
- BBIFMAC, Ayr North Australia, QLD 4807 - Research partner
- L. A Foxwell, M. M. Foxwell, P.R. Foxwell & R. L. Foxwell (Foxwell farming, Rockhampton, QLD 4702- Grower partner
- G. Kennedy and I. J. Kennedy, Biloela, QLD 4715- Grower partner
- Kenrose Co Pty Ltd, (Kenrose), Ayr, QLD 4807 - Grower partner
- A.K. Bush & G.W. Bush trading as Kennedy Valley Farming, QLD 4816 - Grower partner
- The Northern Territory Government of Australia, the Department of Industries, Tourism and Trade (NT DITT), NT0801- Research collaborator
- Department of Primary Industries and Regional Development (WA DPIRD) - Research collaborator

Executive summary

The Spicing Up Northern Australia project, funded by the CRCNA with support from AgriVentis Technologies Ltd and CQUniversity Australia, aimed to assess spice varieties, agronomic practices, and market prospects for selected spice crops with a view to incorporating them into different farming systems in northern Australia. Through the participatory research design, which involved farmers, agronomists, commercial seed companies, and value chain operators, this project aimed to develop practical technologies and build the supply chain links needed to support the emerging spice industry in northern Australia.

On-farm research over three years was carried out over six locations in northern Australia (i.e., Biloela, Rockhampton, Ayr and Tully in Queensland, and Darwin and Katherine in the Northern Territory), whereas black sesame verification research in the second year was also extended to Kununurra WA to capture crop performance in different agroecological environments. The research activities addressed seven key deliverables of the project that included market and economic analysis of spice production, identification of suitable spices varieties, agronomic analysis, and dissemination of the key findings to producers and industry.

Production and agronomic analysis were conducted through three stages: initial varietal evaluation, verification, and commercial production trials. From the initial varietal evaluation trials, three commodities (black sesame, fennel, and kalonji) progressed through to the verification and commercial production trials in years two and three respectively. Cumin and kalijiri did not progress due to the poor yield performance of cumin, and harvest challenges associated with kalijiri.

The research established that black sesame can be grown as a summer season crop across all locations and also as a winter season crop in North Queensland and the Northern Territory, whereas fennel and kalonji showed strong adaptation as winter season spices.

There was a large yield gap between the hand-planted and hand-harvested evaluation trials in year one compared to the verification and commercial production trials planted and harvested by machine. These are largely associated with losses incurred through machine harvesting, poor precision planting with conventional planters, and larger post-harvest losses in cleaning/grading facilities.

Optimisation of agronomy for mechanisation of planting and harvesting, the development of effective post-harvest moisture control, and improved cleaning and grading technologies suitable for a range of spices crops will all be required to realise the yield and quality potential of these crops and ensure they can be viable at commercial scale in Northern Australia.

While growers and industry continue to pursue the opportunities on offer from spices, the key impediments for commercial-scale production are the lack of agronomic advice for mechanised farming; weed, insects pest and disease control; and post-harvest processing technologies. These are all within the scope of work for a follow-up project, “Great Northern Spices, 2022-2026” that will build upon the findings from “Spicing Up Northern Australia”.

This report provides a summary of each deliverable from Spicing Up Northern Australia, along with key findings and recommended actions. Detailed reports for each crop type are presented separately.

1. INTRODUCTION

1.1 Background of the project

The term ‘Spices and Condiments’ refers to natural plant products or mixtures used in whole or ground form as food adjuncts, mainly for imparting flavour, aroma and pungency to foods, as well as for the seasoning and flavouring of foods and beverages. Bioactive compounds extracted from spices and condiments are increasingly marketed as health-benefiting compounds in the health food industry. This brings new opportunities for producing high-quality spice crops in Australia that capitalise on our global reputation as a source of clean and green food ingredients.

A high-value broadacre spice and condiment industry in Northern Australia would both replace imports and generate exports to meet the rapidly increasing market demands for spices in Asia and the Middle East. The northern Australian climate is favourable for the production of a wide range of tropical and sub-tropical spices and condiment crops and these could bring new economic opportunities for Australian growers and spice businesses.

The spices research collaboration between CQUniversity and AgriVentis Technologies Pty Ltd commenced in 2015 with foundational research on a wide range of spice crops. Initial research involved controlled environmental conditions (glasshouse trials) and semi-controlled environments (pot trials under glasshouse and net house) as exploratory evaluations of spices production in northern Australia. Six seed species (black sesame, fennel, kalonji, cumin, caraway and kalijiri) were chosen by the industry for field evaluation at the regional level as they showed promise for tropical adaptation and a potential fit within broadacre farming rotations in northern Australia. After the initial evaluation, only five were progressed for detailed investigation (Figure 1).



Figure 1: The five spice crops evaluated for “Spicing up Northern Australia Project” over 2019-2022 seasons.

The images show at flowering/fruiting stage (from left) black sesame, fennel, kalonji, cumin, and kalijiri. The first three crops from the left with red ticks were progressed through initial evaluation, to the verification and commercialisation stages, whereas the last two crops, did not progress to the verification and commercialisation trials.

The foundational research paved the way for CRNCA to fund the Spicing Up Northern Australia project from 2019 to 2022. The project aimed to evaluate the adaptability of the selected spice crops at six different agro-ecological zones in Northern Australia as new crops to fit within existing farming systems. The project also assessed the market demand and gross margin analysis of production to evaluate the economic feasibility of growing these five selected spices. Based on the results, crop-specific production and industry development recommendations have been made.

1.2 Objectives of the project

The objectives of the project were:

1. to assess the global and domestic markets of five selected spices through a desktop review to identify global production trends, major exporting and importing countries, and market specifications for different spices and condiments;

2. to conduct scoping studies of selected spices crops, using small scale field trials to determine the performance of varieties and evaluate their suitability to six selected growing locations in northern Australia;
3. to perform seed quality assessments to evaluate the effects of variety and production environments on the quality of the five seeds;
4. to verify the results of the year one trial via larger scale field trials in years two and three. The verification trials were conducted on larger plot sizes, managed by farmers, with farmers growing the preferred crops and varieties identified during the scoping study in year one;
5. to conduct large scale field trials in year 3, with a view to developing recommended agronomic practices to support commercial production of the selected varieties. During year three, the spice crop type and variety best suited to each different environment was utilised for commercial trials managed by growers and contracted for seed sales to AgriVentis;
6. to undertake an economic analysis (i.e., gross margin analysis) of selected spice crops production; and
7. to engage with growers and disseminate research results.

1.3 Organisation of the report

Section one of the report presented the general introduction including background, objectives and organisation of the summary report. Section two of the report describes the key findings from different studies that addressed each of the objectives and recommended actions. This is followed by a conclusion and recommendations in Section three.

2. KEY FINDINGS AND RECOMMENDED ACTIONS

This section presents the key findings relating to the seven objectives of the study. In addition, result-based recommendations are also provided.

2.1 Objective 1 – To assess global and domestic markets of five selected spice crops (Market analysis)

The key findings and results-based recommendations below are drawn from five separate reports prepared as part of the project by Rahman et. Al. (2020). These Market Analysis Reports, covering black sesame, fennel, cumin, caraway and kalonji, are published on the CRCNA website. A study was not undertaken for kalijiri, which was added to the project to replace caraway following initial seed germination evaluations.

2.1.1. Key findings

- Sesame is produced in Australia on a small scale, therefore, market demand is currently met by imports. Australia imported 6,740 tonnes (t) of sesame in 2016 and demand is forecasted to reach 9,800t by 2025. Globally, sesame is cultivated on 11.7 million hectares (Mha), producing 6.02t with an average seed yield of 512kg/ha. The global sesame market is expected to reach US$ 17.77 billion by 2025. In international markets, the price of sesame seed was US$ 1229/t in 2018, with black sesame returning approximately 45% more than white sesame. The rapidly growing sesame market and the attractive prices on offer provide a strong basis for Australian growers to expand production.
- Kalonji is not currently produced commercially in Australia and therefore is imported to supply the market. India, Pakistan, Syria, Turkey, Saudi Arabia, Egypt, Bangladesh and Ethiopia are the major producers (Ahmad et al., 2013, Malhotra, 2004). Global trade data for kalonji is also not available in the literature. However, one market insight report estimated that by 2025, the kalonji oil market will be worth US$ 25M/year in the USA and is expected to expand at a compound annual growth rate (CAGR) of 7.2% from 2022 to 2028. Production data was only available for Turkey which showed that in 2018 it produced about 3,300t with an average yield of 980 kg/ha. The international trading price of Indian kalonji seeds ranged from US$ 2,258 to US$ 2,750/t, while the value of Egyptian kalonji seeds is up to US$ 2900/t. The largest Australian processor of kalonji, Hab Shifa, imports about 800t annually for processing to health food products.
- Australia currently produces vegetable fennel only, not seed fennel. In 2018, Australia imported about 568t of the spice group in question, including fennel, worth about US$ 1.37 million. The majority of imported spices in Australia are produced in India and China (UN Com Trade, 2019). There is evidence of continuous growth in the demand for fennel and similar spices in Australia. Calculations made by CQUniversity using the available data and trend analysis suggest that in 2025 the demand for fennel and similar spices in Australia will exceed 2,000 t/year. The unit trade price of fennel and other similar spices was volatile over the last decade, however, in 2018, the price in the international market was US$ 2,408/t. Given the unit value and the size of the market, it is likely that a local industry in Australia could initially target the domestic market before scaling up for export markets. India is the world's largest fennel producing country with Syria, Egypt, Turkey, Germany, Spain and Pakistan contributing to global production.
- Currently, about 91% of the world's cumin is produced in four countries: India, Syria, Turkey and the United Arab Emirates (UAE). India is estimated to produce about 70% of the world's cumin. India exported about 187,000t of cumin at a net value of US$ 438M in 2018. In the US, the domestic market price of cumin is approximately US$ 3000/t (UN Comtrade, 2019, DASD, 2019, TurkStat, 2019). The Australian domestic market for cumin is supplied by imports, with 1,080t imported in 2018, valued at about US$ 3.8M (UN Comtrade, 2019). The majority of the cumin was imported from India. The limited available data indicates there has been a continuous growth in the quantity of imported cumin, both in Australia and other international markets. The trade price of cumin in Australia has been volatile over the last decade, with rates varying depending on the product origin and transport costs. In 2018 the price was US$ 3,553/t (UN Comtrade, 2019).

- The caraway seed market was valued at US$ 1,633M at the end of 2021 and is projected to exhibit annual growth of 4.8% in 2022. Finland and Canada are the largest exporting countries with the leading market destinations being India, Germany and the USA. Significant price variations exist in international markets, depending on the crop's origin, with the average price of Canadian spices over US$ 1,750/t, whereas the price of Indian caraway was only US$ 1,266/t (ITC, 2019, UN Com Trade, 2019). Australia's domestic market for caraway and other similar spices is entirely supplied through imports. In 2018, Australia imported about 568t of the caraway spice group (juniper, anise, badian, caraway, and fennel), worth about US$ 1.37illion. About 70% of imported spices in Australia were sourced from India and China (UN Com Trade, 2019). In 2018 Australia's import price for the group of spices was US$ 2,408/t. Given the unit value and the size of the market, an Australian spice industry would need to target the domestic markets first, before scaling up for international trade. Market data for kalijiri are very scanty, hence, the market analysis for kalijiri could not be progressed with reliable information.

2.1.2. Recommended actions

- A detailed study on domestic and international consumer preferences for the selected spices seeds and their value-added products.
- Development of higher yielding varieties and better agronomic practices that minimise environmental risk and improve production feasibility
- Development of an Australian-grown spice brand, which articulates the environmental credentials of Australian spices to maximise consumer willingness to pay.
- Establishment of an Australian spice industry network to enhance industry capabilities for production and develop market opportunities.

2.2 Objective 2: Conduct scoping studies of selected spices crops (initial evaluation trials in year one)

Scoping studies were successfully conducted and completed for five selected spice crops; black sesame (4 varieties), kalonji (4 varieties), fennel (3 varieties), cumin (3 varieties) and kalijiri seeds (2 varieties) over six locations in QLD and Northern Territory. The scoping study for caraway was unsuccessful and it was removed from the project.

In the first year, black sesame and fennel were planted as summer season crops whereas kalonji, cumin and kalijiri were planted as winter crops. Only black sesame, fennel and kalonji progressed to years two and three. The results-based recommendations below are based on the three crop-specific final reports for black sesame, fennel and kalonji, by Bhattarai et al. (2023a, 2023b and 2023c).

2.3.1. Key findings

- Four black sesame varieties were planted over six locations as summer season crops in the initial evaluation trials and performed well at all sites. The crop duration ranged from 90-105 days, with a longer duration at southern locations compared to northern locations. The hand harvested seed yield had a range of 1.111-3.315t/ha, with the highest seed yield recorded for Biloela, followed by Rockhampton, Katherine, Ayr, Darwin and Tully. Regarding the varietal performance, genotype AVTBS#6 recorded the highest yield in Biloela and Rockhampton, whereas AVTBS#11 recorded the highest yield in Ayr. The seed yields recorded in these trials were significantly higher than the global average of 0.554t/ha. The combined analysis for the seed yield for genotype x environmental interaction suggests that the performances of the genotypes are not consistent across sites. The genotypes AVTBS #6 and AVTBS #11 were generally high yielding varieties in most of the sites. The performances of genotypes AVTBS #3 and AVTBS #16 were not consistent across Darwin and Tully, as in the former site AVTBS #3 was the lowest performer whereas, in the latter site, AVTBS #16 was a significantly lower performer. These

varietal evaluation trials were largely researcher managed and the yield data were recorded from the hand-harvested samples.

- Three fennel varieties were planted over four locations as a summer crop in the initial evaluation trials and showed inconsistent performance across the sites. The crop duration ranged from 194 to 255 days with a longer duration for Biloela and Katherine and a shorter duration for Rockhampton and Ayr. The hand-harvested seed yield ranged from 50 to 1574kg/ha, with the highest seed yield recorded for Ayr and Katherine, followed by Rockhampton and the lowest yield in Biloela. Regarding the varietal performance, AVTFS#1 was the highest yielding variety in Ayr and Katherine, whereas AVTFS#3 performed best in Rockhampton and Biloela. The seed yields recorded in these trials were not higher than the global average of 1500 kg/ha. The combined analysis for the seed yield for genotype x environmental interaction suggests that the performances of the genotypes are not consistent across sites. The crop also produced a significant biomass of 0.5-9.99 t/ha and shows potential for value-adding by extraction of essential oils or utilising the fennel fibre for high-value market uses, e.g. biosorption material for cadmium (Rao, et al., 2010). The crop demonstrated its tolerance to hailstorm damage but suffered severely from the impacts of high temperatures which suppression seed germination and plant establishment.
- Four kalonji varieties were planted across six locations as a winter crop in the initial evaluation trials and a strong environmental effect was observed, but no varietal effect was evident in the yield performance. The kalonji seed yield (hand harvested) ranged from 7kg/ha to 3107kg/ha with the highest seed yield in Biloela, followed by Ayr (914 kg/ha), Rockhampton (908kg/ha) and Katherine (247kg/ha). A yield of just 7kg/ha was recorded in Darwin due to poor establishment. Similarly, the wet tropical environment of Tully also suffered a poor establishment and the crop did not produce any harvestable yield. The crop duration ranged from 105-148 days, with later crop maturity recorded in Biloela and Rockhampton and early crop maturity recorded in North Qld (Ayr) and NT (Katherine and Darwin). The yield potentials recorded in the initial evaluation trials are higher than the national average yield in major kalonji producing countries, such as Bangladesh with 1.31-1.7t/ha (Karim et al., 2007) and Iran with 1.71-2.1t/ha. The high yield potential demonstrated in the on-farm trials, the non-shattering seed capsule, and the low level of insects/pest and disease occurrence on this crop across all trial sites, together provide promise for future commercial production of kalonji in Australia, particularly in the southern end of northern Australia.
- Three cumin varieties, planted as a winter crop in 2020, matured between 97 and 127 days after sowing. Cumin showed highest yield potential of 704 kg/ha for hand harvested yield for AVTCuS#3 at Rockhampton. The highest cumin seed yield (averaged for three varieties), was recorded for Rockhampton (688 kg/ha), followed by Ayr (460 kg/ha), Biloela (388 kg/ha) and lowest at Katherine (388 kg/ha). The yield difference between the varieties was not significant in any of the trial locations. The crops at Tully and Darwin did not establish due to very poor growth and incidence of rot root, largely associated with wetter soil. The incidence of root rot disease at the early establishment stage and powdery mildew at the reproductive stage were two major disease challenges. The crop showed low growth resulting into short plant stature with most of the seed development occurred near to the ground, that will make the crop unamenable for machine harvest.
- Two kalijiri (*Veronia anthelmintica* L) varieties were planted as a winter crop in 2020 and matured 104-155 days after sowing. The kalijiri trial crop was established at five out of six sites planted, with the crop at Rockhampton not established to produce a harvestable yield. The highest hand harvested seed yield was recorded at Ayr (1986kg/ha) for AVTKJ#1. The seed yield varied significantly between sites. The highest kalijiri seed yield (averaged for two varieties), was recorded for Ayr (1734 kg/ha), followed by Biloela (1292 kg/ha), Katherine (349kg/ha), Darwin (279kg/ha)) and lowest at Tully (86 kg/ha). The yield difference between the varieties was not significant in any of the trial locations, except for Ayr where the AVTKJ#1 produced 33% more seed yield than AVTKJ#2 (Figure 4) . The crops at Rockhampton did not establish due to very poor growth and incidence of rot root, largely associated with wetter soils in heavy clay soil. The yield data for kalijiri from other countries are not readily available for comparison. However, a trial conducted in Gujrat, India, to evaluate the effect of organic manure dose, recorded the highest seed yield of 1024 kg/ha (Hirpara et al., 2017). The world production and average yield statistics for kalijiri were not available to authors while developing this report.

2.2.2. Recommended actions

- Assess new non-shattering black sesame varieties for their suitability to mechanised production and harvesting, and evaluate these lines for adaptation to northern farming systems. As crop duration is

generally longer (>90 days), evaluation of varieties with early maturity and potential drought tolerance will likely confer a greater advantage for adaptation to northern Australian conditions.

- Fennel as a summer crop did not perform at a satisfactory level due to high temperature effects on seed emergence and seedling establishment. An informal observation trial planted during the winter months showed the opportunities for winter fennel in northern Australia. Excessively longer crop duration not only delayed the crop maturity but also created a challenge for fitting fennel in the crop rotations. Therefore, the opportunity to grow fennel as a winter season crop will rely on identifying early maturing short-season varieties, and evaluating fennel in broadacre mechanised production systems. Fennel produces high biomass and has a smaller harvest index, therefore further investigation is recommended of alternative uses of fennel biomass for value-added products such as essential oils. The fennel plants' ability to tolerate hailstone impacts, as noted in Biloela showed the plants' ability to withstand hailstorm damage, and plants' ability to ratoon/regrowth could provide further opportunities for harvesting biomass.
- Australian kalonji demand is currently met by imports as there is no local commercial production. Kalonji establishment in the field was noted as very slow (emergence 2-3 weeks), and therefore susceptible to competition from weeds. Improvements in the speed of emergence and canopy cover are crucial. Australian kalonji processing company, Hab Shifa, has developed global marketing of kalonji products. Developing the local production base of kalonji seeds in Australia, therefore, has a ready-made avenue for import substitution and for evaluating whether Australian seed meets quality requirements. The kalonji seed for the processing market has different criteria than the kalonji seed market. Higher oil contents, as well as superior oil quality in terms of higher Thymoquinone (TQ) contents, are the key criteria for the processing markets. Future R&D is suggested for evaluating the effects of genotypes and production environments on the oil contents and oil quality. According to Hab Shifa, organic seeds are utilized for the production of high value health products, therefore, an agronomic package of organic practices and low external input sustainable agriculture (LEISA) systems is likely to receive greater market attraction.
- The yield performance of cumin with hand-harvesting methods was not comparable to the global average and lower than some of the large cumin-producing countries such as Turkey. Hence the crop with its current yield is not competitive. The crop yield could be improved by high yielding, disease tolerant, and introduction of more tropically adapted varieties, optimising the agronomy with respect to nutrient management, diseases and weeds control, optimisation of density and time of planting, and mechanisation of planting, harvesting and seed processing. For the current varieties, the crop challenges for commercial production are far greater than the opportunities, hence, grower participation in the verification and commercial trials could not be attracted. More on-station research is required to overcome the barriers to cumin production.
- Kalijiri market is currently limited to the medicinal use of the seeds rather than wider use in spices and condiments. The seed yield was as high as 2t/ha at Ayr but there were significant challenges in harvesting, threshing and cleaning of seeds. The flower head bears 30-40 minute purple flowers which upon drying turn into light hairy materials that can cause skin allergies for operators during threshing. At this stage, post-harvest handling is more challenging than the market opportunities and therefore grower participation in the verification and commercial trials could not be attracted. Future research into the mechanisation of harvesting and post-harvest processing is required before large-scale verification and commercial trials can be planned.

2.3 Objective 3: Investigating crop quality assessment (seed quality standards)

Seed quality analysis was carried out for three selected spice crops: black sesame (4 varieties), kalonji (4 varieties), and fennel (3 varieties). These crops were grown over six locations in Qld and the NT. The project analysed seeds for three quality aspects: physical qualities using seed harvested in year one (test weight, density, shape, size, colour); seed chemical qualities using seed harvested in year one (i.e., oil content, the density of oil and cake content); and, post-harvest characteristics (i.e., cleaning and grading qualities) using seed from the verification and commercial trials of years two and three. The results and recommendations below are drawn from the three detailed crop-specific final reports (Bhattarai et al., 2023a, 2023b and 2023c).

2.3.1. Key findings

- Four varieties of black sesame seeds from the initial evaluation trials were analysed for quality. The results revealed that the seed test weight (weight of 1000 grains) and oil content were significantly different between varieties and locations without interaction effects. The genotypes AVTBS#6 and AVTBS#11 recorded significantly higher test weights compared to the other genotypes. The seeds produced in Ayr and Tully recorded a lower test weight compared to the other locations. The lowest test weight could be due to fertiliser leaching associated with high rainfall in these two locations during the grain-filling stage. The oil content ranged from 41% to 47%, and did not vary significantly between the genotypes at any site. The highest oil content was recorded from the Tully samples (47%), followed by Darwin (46%), a mid-range oil content was recorded in the samples from Katherine, Ayr and Rockhampton (44%), and the lowest oil content was recorded in Biloela (43%). In the verification summer trial of year two, machine-harvested seed loss had a range of 44-82%; the 1000-seed weight ranged from 3.51 to 4.22g; filtered oil content ranged from 38% to 51% (highest in Kununurra WA and lowest in the Biloela QLD samples); and cake output ranged from 43% to 49% of the seed weight. In the sesame winter crop verification trials in North Qld, the estimated header loss was 30-40%, suggesting that the current Agriventis black sesame variety under the trial was susceptible to the shattering loss for machine harvest irrespective of the season. The clean seed output from harvested seeds in the header was also very low as the seed recovery from a pilot run of a seed cleaner unit using harvested seed from a KEW header showed that the recovery of clean seeds was about 38.2% (119g from 500g uncleaned product). Very low recovery of the clean seed was due to excessive moisture and biomass debris associated with wet weather impacts on the crop at the late maturity and harvesting stages. The excessive shattering of the black sesame lines in years one and two led to the introduction of two non-shattering black sesame lines (S57B, S56) for the year three commercial trials. With respect to the physical quality of the seeds, the test weights for S57B and S56 were 3.81 ± 0.18 and 3.73 ± 0.20 g/1000 seeds respectively. Likewise, the seed density of 631 ± 12.6 and 642 ± 13.9 kg/m^3 were recorded for S57B and S56 respectively. The oil contents through the screw oil press mill at 80-100 °C were 42 ± 1.49 and 41 ± 1.43% for varieties S57B and S56 respectively.
- Fennel seed quality assessments were conducted for three varieties using seed harvested in the year one evaluation trials. They revealed that the test weight across four test sites ranged from 2.69g to 5.16g, with significant differences between the genotypes and locations. In general, there was a low test weight (3.33g) for AVTFS#1, medium (3.46g) for AVTFS#2, and larger (3.90g) for AVTFS#3. The significant effect of the growing environment was reflected by larger seed test weight (3.34g) for Katherine, medium (4.0g) for Ayr and smaller seed (2.81-2.83g) for Biloela and Rockhampton. Likewise, the seed bulk density (kg/m^3) ranged from 318 to 425kg/m^3 between sites. The highest seed bulk densities were recorded in Ayr (402kg/m^3), medium in Rockhampton (388kg/m^3) and Katherine (387kg/m^3), and the lowest in Biloela (337kg/m^3). The seed bulk density varied significantly between genotypes only in Ayr where the higher seed bulk densities were recorded for AVTFS#2 (406kg/m^3) and AVTFS#1 (402kg/m^3) compared to AVTFS#3 (379kg/m^3). Regarding the seed size, the seed length ranged from 7mm to 11mm and the seed width was 2-4 mm. The seed colour ranged from green to brown. The effects of variety and production environments on the seed quality parameters were not consistent. The trial crop at Ayr was machine harvested with Kingaroy Engineering Works (KEW) plot harvester, however, seed quality for the machine-harvested crop was compromised by the wet weather effects, by poor desiccation and biomass contamination in the header. The seed cleanout ratio was very small, with only 38.2% of seed recovered clean from the grab samples collected from the header.
- Kalonji seed quality assessments were undertaken for four varieties following the year one evaluation trials. They revealed that the test weight across five sites ranged from 1.86g to 2.80g, with significant differences between the locations but not the varieties. The significant effect of the growing environment was reflected by larger seed test weight for Biloela (2.80g) and Katherine (2.77g), medium test weight for Ayr (2.71g) and Rockhampton (2.43g), and smaller seed test weight for Darwin (1.86g). The test weight for varieties ranged from 2.61g to 2.71g/1000 seeds. The seed bulk density did not differ significantly between the varieties and had a range of 460-469kg/m^3. While the difference between the sites was significant and ranged from 428 to 487kg/m^3, the highest seed bulk densities were recorded for Darwin (533kg/m^3) and Katherine (487kg/m^3), medium in Biloela (472kg/m^3) and Ayr (465kg/m^3), and lowest for Rockhampton (428kg/m^3). In the verification trials of 2021, the clean-out ratio was 47.5% for the seed harvested by plot header. In the commercial scale trial during 2022, the test weight was low for Rockhampton (2.3g/1000 seeds) but higher for Biloela (2.8g/100 seeds), and a similar trend was observed for seed bulk density with low density for Rockhampton (519kg/m^3) and a higher density for Bilolea (537-

540kg/m^3). The seed oil contents ranged from 27% to 29% with no clear trend for the effects of the environment. The seed cleanout ratio was greater with up to 86% of seeds recovered from the machine harvested samples.

- Cumin and kalijiri presented a number of challenges for the production and post-harvest management of the seeds. On this basis, grower verification trials were not carried out for these crops. While data collection and analysis were carried out for crop phenology and yield determination in the initial evaluation trials, no post-harvest seed quality assessments were carried out for these two crops.

2.3.2. Recommended actions

- Harvestability with a combined harvester is essential for successful broadacre sesame farming. Among the two new lines of non-shattering black sesame (S57B, and S56), line S57B planted at Rockhampton showed commercial potential. The seed quality for these two new non-shattering lines and their association with growing environments and harvest performance needs to be undertaken. Addressing post-harvest seed cleaning, grading, and colour sorting is also essential to meet the market specifications for both domestic and export markets. The sesame production program needs strong supply chain linkages, particularly for post-harvest cleaning, grading, colour sorting and dehulling if it is to achieve market standards.
- The seed cleaning for winter planted fennel showed that seed recovery was only 38% from the bulk harvest, therefore, future research into effective desiccation is required for greater moisture control and post-harvest seed separation. Separation of plant debris from field harvested spices seeds is a challenge for current seed cleaning/grading facilities such as Allenden seeds. Therefore, primary seed cleaning using mobile on-farm seed cleaning equipment can reduce the burden for dedicated cleaning/grading facilities.
- Current challenges for kalonji growers in northern Australia are related to the control of moisture at harvest, lack of specialised harvesting equipment, lack of cleaning, grading and colour sorting of the seeds after harvest. The Australian processor, Hab Shifa, desires organic seed with high Thymoquinone contents (>0.8%). Therefore, future kalonji production in Australia needs to focus on the seed quality aspects to meet market specifications.

2.4 Objective 4: Explore through verification trials the results from the initial evaluation trials in year two (verification trials)

Unlike initial evaluation trials in year one (manual planting and hand harvesting), all verification trials of sesame, fennel and kalonji in year two were planted with a Jang planer and harvested by plot harvester. While sesame is generally a summer season crop in Australia, the verification trials tested whether sesame can be successfully grown as a winter crop in North Qld. The fennel verification trial was also planted as a winter crop in Ayr. The kalonji verification trials were planted as winter crops in Qld. The low yields for all crops in the verification trials were associated with a lack of a precision planter (resulting in erratic plant population), the slow establishment of spices crop, weed pressure and harvest coinciding with wet weather, and a plot harvester not optimised for dealing with these spices crops.

The results and recommendations below are drawn from the three separate crop-specific final reports (Bhattarai et al., 2023a, 2023b and 2023).

2.4.1. Key findings

- Black sesame verification trials as summer season crops were planted across multiple locations in northern Australia. The hand-harvested yield ranged from 306kg/ha to 2607kg/ha in year one. The machine-harvested seed yield ranged from 91kg/ha to 1088 kg/ha in year two. The highest yield was recorded at Biloela followed by Rockhampton, Darwin and then the lowest in Tully. Both varieties planted

in trials showed strong shattering properties, but at lesser intensity for winter planted crops. However, the machine harvested loss ranged from 44% to 82%. Incomplete desiccation, wet weather at harvest, excessive vegetative growth, and poor adjustments to the plot harvester were some of the issues related to poor yield performance associated with the machine harvest losses. The winter-planted sesame in Ayr was established well, producing shorter plant height and early maturity compared to summer-planted crops. The machine harvested yield of sesame was 512kg/ha, with an estimated header loss of 30-40%.

- The fennel crop showed promising results from the winter planting in year two, as the crop establishment greatly improved compared to year one's summer planting. The yield potential of the crop was demonstrated with a record of 1272kg/ha of hand-harvested yield. The machine harvested yield (337kg/ha) was compromised by weak desiccation of the crop and harvest coinciding with wet weather, with the harvest loss by machine estimated to be 73%. The crop at harvest consistently showed a high biomass yield of 9.325t/ha, highlighting the potential to develop value-added products from the fennel biomass. There were not many disease or insect pressure observed (although no measurements were taken), except for very strong aphid infestations commencing post flowering that required insecticides for control.
- The kalonji verification trial was planted as a winter crop at all Qld sites and showed slow emergence except at Tully where crop emergence failed due to the herbicide residue from the previous crop. The crop grew without any major insect pests and showed greater traits for harvestability by the research plot harvester. The highest machine harvested seed yield was 346kg/ha in Rockhampton and the lowest yield (47-123kg/ha) was recorded by a second producer at Rockhampton. The hand-harvested yields were 1.5-2 times greater than the machine-harvested yield, suggesting that a significant amount of harvest loss still existed, despite the capsules being less prone to shattering. Slow emergence, weed competition, harvest loss and post-harvest cleaning, grading and sorting, were all noted as major challenges for kalonji production.

2.4.2. Recommended actions

- For black sesame, the yield gap between the hand harvest and machine harvest is very high. Precision planting equipment, effective weed control, desiccation, optimisation of header and appropriate post-harvest seed technologies for cleaning, grading and seed soring are recommended for closing the yield discrepancy. The search for non-shattering black sesame genetics was strongly suggested, with new lines identified for the year three trials.
- Fennel winter planting demonstrated the potential for growing fennel in northern Australia. However, the winter crop also demonstrated associated challenges from insects (aphid), improved desiccation before harvest, and the need for the optimisation of header settings. The challenges associated with seed cleaning, grading and sorting were also identified as a major bottleneck for successful commercial production of fennel in northern Australia.
- Kalonji showed poor establishment resulting into early weed competition. It is recommended that future research focus on stable yield and quality attributes such as oil and TQ contents, seed cleaning, grading, and sorting to meet market specifications.

2.5 Objective 5: Examining the crop performance in commercial trials in year 3 (commercial production trials)

The commercial trials in year three were all planted with a precision Monosem planter and were harvested with a Zurn150 research plot harvester. Two non-shattering black sesame lines bred by Sesaco USA were introduced by AgriVentis to Australia for their resistance to shattering. They were evaluated for their yield potential under conventional and zero tillage rainfed systems. The winter crop of fennel was planted in Rockhampton, whereas the Kalonji crop was planted at Rockhampton and Biloela both with the Monosem precision planter and harvested with a research plot harvester (Zurn150) to assess the commercial yield potentials.

The results and recommendations below are drawn from the three separate crop-specific final reports (Bhattarai et al., 2023a, 2023b and 2023).

2.5.1. Key findings

- The black sesame machine-harvested seed yield in Rockhampton was 653kg/ha for variety S57B, whereas a very low seed yield (28.25kg/ha) was achieved under zero tillage rainfed system for S56 in Biloela. The yield of non-shattering sesame at Rockhampton was compromised by the impact of leaf roller and capsule borer insects, whereas in Biloela the yield was compromised by the lack of soil moisture during the seed filling stage causing terminal drought effects. Incomplete desiccation of the crop before harvest and sub-optimal header settings also resulted in yield loss at harvest.
- The machine-harvested seed yield reached 629kg/ha at Rockhampton compared to the hand-harvested seed yield range of 816-956kg/ha. The calculated machine harvest loss was about 29%. The commercial yield potential was compromised by aphid infestations, inadequate desiccation, and higher moisture contents of seeds at harvest causing quality deterioration.
- Kalonji, planted under the conventional tillage system in Rockhampton, recorded machine harvested clean seed yield of 1076kg/ha. The machine harvested clean seed yield for zero till crop at Biloela was 259kg/ha and a hand-harvested yield of 935kg/ha was recorded for Biloela. This indicated a large loss of seed due to machine harvesting(677 kg/ha). The machine-harvested clean seed yield for conventional tillage and irrigated crops at Biloela was much greater at 926kg/ha and the machine-harvested seed contained 14.5% debris. A hand-harvested yield of 2,267kg/ha was recorded for Biloela; therefore, a total loss of 1,340.8kg/ha was attributed to machine harvesting, despite the non-shattering capsules. Optimisation of harvesting is required to realise greater efficiencies so that the machine-harvested yield is nearer the hand-harvested potential.

2.5.2. Recommended actions

- The black sesame crop showed an increasing issue with the leaf webber insects impacting yield in the commercial trials. The crop in Biloela under zero till also faced severe drought stress, hence identifying drought-tolerant varieties is suggested. Crop regrowth after wet weather for rainfed crops caused staggered crop maturity, hence an early-maturing type is desired. Optimisation of header settings to pick up lodged crops or pick up plants from ground level will improve the performance at harvest.
- Fennel recorded a machine harvest loss of about 29% in commercial trials. The commercial yield potential was compromised by aphid infestations, inadequate desiccation, and higher moisture contents in seeds at harvest. Effective on-farm trials for integrated pest management for Aphid and effective/full desiccation of the crop before harvesting is suggested.
- Kalonji is relatively more resistant to shattering loss at harvest. However, the hand harvested yield of 1,616.8kg/ha recorded in Rockhampton was 540.8kg/ha greater than the machine-harvested crop. The gap between hand-harvested yield and machine-harvested is high and this needs to be minimised by developing an optimum header setting for the harvesting of kalonji. As the crop establishment is very slow, enhancing the emergence process and responding to crop water use by irrigation, and optimisation of harvesting equipment will be required to achieve its potential yield.

2.6 Objective 6: Examine an economic analysis of the spice crops production (Gross margin analysis)

Gross margin and sensitivity to price and yield fluctuations were assessed for black sesame, kalonji and fennel produced in trial crops at Rockhampton. The key findings and results-based recommendations are given below. Detailed analysis is included in the crop-specific final reports (Bhattarai et al., 2023a, 2023b and 2023c).

2.6.1. Key findings

- With a lower seed yield at 0.32t/ha, the calculated gross margin of A$135.5/t and an average rate of return of 12.83% were achieved in black sesame production. A seed yield of 0.2t/ha was not enough to break even at any of the price points between A$1600/t and A$2400/t. Sensitivity analysis revealed that seed yields of 0.31t/ha, 0.27t/ha and 0.25t/ha were required to break even at the price of A$1600/t, A$1800/t and A$2000/t of seed respectively.
- An economic analysis of fennel production in Rockhampton with an average seed yield of 0.629t/ha resulted in an average gross margin of A$716/ha and A$938/ha at the product price of $2,500/t in two different models. In both models, a seed yield over 0.35t/ha will be required to attract profits for the fennel producers. A fennel seed yield over 0.35t/ha would attract some profits for the producers at the price of A$2,500/t. The results presented in this study indicate that fennel production in Rockhampton would only be profitable with a higher yield, which was not achieved in the first year with the trials on smaller plots, however, was achieved at 0.629t/ha in commercial trials as a winter crop in year3.
- The kalonji gross margin under model 1 with highly volatile fertilizer prices for the years 2020, 2021 and 2022 were -A$348/ha, A$121/ha and A$308/ha respectively in the trial field at Rockhampton. Sensitivity analysis under the same model revealed that a seed yield of 0.35t/ha and over would generate profit for the producers at a minimum farmgate price of A$2,400/t. Under model 2 with baseline fertilizer price the producers would secure some profit even with a yield of 0.25t/ha.
- Gross margin analysis for cumin and kalijiri were not conducted as these crop did not progress through to the verification and commercial production stages.

2.6.2. Recommended actions

- Black sesame cultivation, with existing technology was not relatively profitable in terms of gross-margin analysis compared to other contemporary rainfed summer crops, with seed loss during machine harvest being the major bottleneck. The development of suitable machine harvest technologies and non-shattering varieties with higher yields is recommended for the optimisation of the economic output of black sesame cultivation in northern Australia.
- Fennel yields are currently lower compared to the average yield in major fennel producing countries. The improvement in fennel yield by optimisation of agronomics and machine harvesting efficiency to break the yield barriers is required for the fennel to be economically profitable. The value of biomass could provide additional economic value when the extraction of essential oil and value added products bring positive income to the fennel crop.
- Kalonji yield performance and the current market price are favourable for commercial production in Australia. The market provides a premium for high oil, high TQ and organic seeds. The gross margin of kalonji production can be improved by targeting those premium price markets.

2.7 Objective 7: Dissemination of key findings to producers and industry

The project team set two communications objectives in 2019:

- to raise awareness of the spice research trials and their potential benefits for the Northern Australian agricultural economy; and
- support producers and industry to participate in the research and the potential new industries with detailed information on crop performance and market opportunities.

2.7.1. Communication and dissemination

To achieve these objectives the project utilised a participatory research model to maximise producer involvement and develop industry champions, in combination with broad awareness raising communications activities.

A key reason for selecting multiple geographic sites and for farmer participation in the project was to build local spice crop champions who will advocate on behalf of the project and connect their neighbours, friends and business partners to its activities. This was enabled by the involvement of AgriVentis as a commercial partner who provided commercial supply contracts for participating producers. As forecast in the 2019 strategy, this has resulted in localised spice crop production groups and an expanding production footprint.

The local champions were essential to encouraging the adoption of research findings by facilitating personal connections to the project, such that other producers and industries wish for it to succeed and emotionally invest in the process. The method for this to be achieved was via strong face-to-face and personal connections between the researchers, participants and their business/personal networks. There are now more than 20 producers connected to the project either as participants or as commercial growers. The exception to this approach was the fennel trials, where the mixed results dictated that the approach be used sparingly and cautiously until a clearer value proposition has been identified.

For these 'followers' to volunteer to join the industry and adopt recommended practices, production of spice crops they needed to see tangible evidence of viability as well as a strong support network. The former was informed by the research activities and promoted via media, social media, field days, fact sheets, and webinars. The latter was created throughout the project by bringing all participants together via video conferences and face-to-face meetings for information sharing and social networking. A project newsletter was also regularly distributed to this emerging industry network to build connections and share research insights. The events were complemented by additional face-to-face meetings with CQU and AgriVentis representatives who visited each site at key times of crop production (sowing, harvesting etc) each year.

Media

Media releases were distributed throughout the project to recruit participants, advertise results and promote industry events. Coverage was obtained in publications including *Grain Central, Qld Country Life, North Queensland Register*, ABC *Country Hour*, ABC *Landline*, Channel 7, WIN television news and online news (e.g. The IndianLink News).

- https://www.indianlink.com.au/india-in-australia/indian-spices-crops-australian-farmers/

Examples of the media releases can be found on the CRCNA website at:
https://www.crcna.com.au/search?keys=sesame

Examples of coverage in rural media can be found at:

- www.graincentral.com/news/spice-crops-potential-farming-option-for-australias-north/
- www.queenslandcountrylife.com.au/story/7386981/northern-spice-industry-gains-momentum/
- www.northqueenslandregister.com.au/story/6324867/spicing-up-the-north/

Social media

The awareness raising activities were supported by regular social media posts delivered via the CQUniversity and CQUniAg social channels on Facebook, LinkedIn, Twitter, Instagram, and YouTube. Wherever possible, posts tagged and recognised the support of industry partners to maximise the audience reached.

Field Days and Participant Meetings

Field days were undertaken at the Rockhampton site in 2020, Ayr in 2021 and Katherine in 2022. Several of these were timed to coincide with face-to-face meetings of the participant group for project review and building the grower support network. Researchers also presented at events hosted by the participants, including the 2021 BBIFMAC annual general meeting.

Webinars

The research team presented research findings at webinars hosted by CQU as project lead, by NT DITT as part of its broader grower engagement activities, and by the CRCNA.

Conferences

Posters and presentations promoting the research outcomes to industry and the agriculture research community were delivered at TropAg 2022 and the Developing Northern Australia conferences in 2020 and 2022.

The project team and the industry partners also presented at international spice forums, including an online international sesame conference in 2021 organised by Texas A&M AgriLife Extension Service (https://agrilifetoday.tamu.edu/2021/02/19/online-international-sesame-conference-feb-23-24/).

AgriVentis also represented the project at the Gulfood Trade Fair in Dubai in 2022 resulting in the commercial contract for the supply of Australian-grown spice to the domestic processing sector (https://www.queenslandcountrylife.com.au/story/7629001/how-a-100-tonne-order-has-spiced-up-a-whole-new-australian-farming-industry/).

A presentation at World Sesame Conference in 2022 by Agriventis and ASIDA also led to new networks with international sesame R&D operators, importers/exporters and marketing agencies.

2.7.2. Recommended actions

- Development of targeted and specific extension tools such as grower guides or a spice production manual will support growers' in adoption of new crops suitable for northern Australia
- On-farm demonstration of farm machinery and agronomic practices will be crucial for the integration of spices crops into the existing farming systems in northern Australia.

2.7.3 End-users engagement and capacity building

This was an industry-led applied research project. The project team and industry participants engaged actively with the end users (growers and marketers) throughout the project period. Grower engagement was fostered by co-design of on-farm trial activities, participation in trial planting, monitoring and evaluation as well as attending the field days to learn and share growers' experiences.

The market engagement was strengthened by the development of market analysis reports for each of the spice crops included in the project. Market preference and requirements were captured through sharing of the specifications sheet for different crops in terms of seed physical and chemical qualities (see specifications for individual crops in the final reports). The engagement of processors, such as kalonji processor Hab Shifa Australia, provided more insights into the specific requirements of the individual processing company. Mitsui was also engaged for sesame seed market specifications and Tsara Flavors for fennel seeds. CQUniversity also connected its agricultural supply chain expertise to work with Rockhampton Regional Council to assess the viability of the crop as a commodity for export to Asian and Middle Eastern markets, where expressions of interest have already been received from the global spice business, e.g. CJ Group South Korea (https://www.cj.co.kr/en/index), Mitsui & Co Ltd Japan (https://www.mitsui.com/jp/en/index.html).

The project brought together an interdisciplinary research team, including postgraduate student researchers, and connected them with growers and farm advisers to capture realistic feedback as to the performance and viability of the crops within northern farming systems.

Their research activities were strongly supported by industry investments in precision planting and harvesting equipment, as well as small scale threshing, cleaning and grading equipment to handle the research scale samples. These resources not only served the project activities but also provided infrastructure for future research. As a result of the project, a number of participating growers have started adapting their grain planting and harvesting equipment for use on spices – this grower knowledge and experience will be invaluable in future extension activities.

The postgraduate students projects (Masters by research) included projects on sesame drought tolerance, an assessment of kalonji for Thymoquinone contents, and bioactive compounds in sesame.

Project members have also contributed significantly to the national initiatives for spice industry development, e.g. Contributions to Australian Sesame Industry Development Association (ASIDA), AgriFuture sesame central, and Sesame national extension project have a strong bearing on spicing up Northern Australia project for national level capacity building on various aspects of spices research and development activities.

The engagement with partners and collaborators has also laid the foundation for longer-term collaboration through future research and industry development activities. Project members have contributed time and energy to new national industry development activities, including the formation of the ASIDA, and the establishment of a national program of sesame research to be funded by AgriFutures in collaboration with the CRCNA's Great Northern Spices project.

3. CONCLUSION AND FUTURE RESEARCH

The market analysis of five spices crops indicated that all spices assessed are currently imported due to no Australian production (other than production for research). The growing popularity of spice and condiment products brings new opportunities for northern Australian producers to grow spice crops for both domestic import substitution as well as for developing export pathways into the lucrative global markets.

The initial evaluation trials of black sesame, fennel, kalonji, cumin, kalijiri at six different locations revealed the yield potential for these crops under the diverse agroclimatic conditions of Northern Australia. Black sesame and fennel were planted as summer season spices whereas the kalonji, cumin and kalijiri were planted as winter season spices crops under different farming systems. From the four varieties of black sesame planted, two lines (AVTBS#6, and AVTBS#11) were selected based on the yield and quality performance data and growers' feedback for verification trials. Similarly, from the three varieties of fennel planted, AVFS#1, was selected for verification trials, while of the four varieties of kalonji planted, only AVTKS#2 was selected. The initial evaluation trials were also undertaken with four varieties of cumin and two varieties of kalijiri. However, these two crops showed challenges in managing disease, low yield (particularly for cumin), and harvesting challenges in the case of kalijiri. Therefore, growers and industries were reluctant to put the verification trials in the field for these two crops and suggested applied research on these crops under a controlled environment to address these challenges.

The verification trials in year two established the opportunities of growing black sesame as a winter crop in North Qld. Similarly, the option of growing fennel as a winter crop in northern Australia was tested and confirmed. With these findings, it was established that black sesame in northern Australia can be planted over the wider windows in summer and far northern for winter planting windows. All verification trials were planted with a Jang planter (a small vegetable seed planter) and harvested with the research plot combine harvesters. Black sesame lines with strong shattering properties recorded very high harvest loss under a combined harvester. The fennel and kalonji crops withstood the shattering loss in the combined harvesting, but the issue of poor desiccation and wet weather impact on harvestability and seed quality was apparent.

The innovation commercialisation trials in the third year with sesame were planned across trial sites with precision Monosem planter and harvester, plus research plot combine harvesters. The excessive shattering loss in Agriventis black sesame lines triggered the need for the search for non-shattering black sesame genetics. Therefore, the commercial crop trial of black sesame includes Sesaco S57B, and S56 for the trials. These varieties showed greater harvestability with a research plot harvester. However, effective desiccation and optimisation of the harvester for greater harvesting outcomes are still required to achieve a smaller gap between the hand-harvested yield and machine-harvested yield. The commercial scale kalonji trials planted with a precision planter and harvested with a combine harvester have shown improvements for the machine-harvested yields. The research also investigated the constraints for production for these commodities in terms of their insects pest and diseases, and post-harvest challenges in terms of seed drying, cleaning, grading and sorting.

Spice crops are generally smaller seeded, high-valued and have strict market specifications for purity (>99.5%), consistency in shape, size, and colour. Hence the post-harvest operation for seed processing is crucial to meet the market criteria for seed quality. The post-harvest and supply chain challenges have been highlighted as major constraints as there are no dedicated spice seed cleaning, grading, and colour sorting facilities currently available in Australia. The research assessed the option of using the on-farm mobile seed cleaning option with the VAL-1500 6 equipment and proved that on-farm seed cleaning could be useful for the primary cleaning of bulk harvested seeds so that the seed with low impurities levels can be forwarded for dedicated seed facilities for final cleaning. Control of moisture at harvest and storage is crucial for spice seeds as they mostly need to be kept within the moisture range of 6-8%. The current impediments to the adoption of spices technologies have been summarised as a priority for future research.

The follow up project, Great Northern Spices (GNS), funded by the CRCNA, builds on the outcomes and learnings from the current project, Spicing Up Northern Australia. It will address the key impediments to the production of sesame, fennel and kalonji as commercial spice crops in Northern Australia, as well as interrogate market segments and consumer willingness to pay for Australian-grown spices. The key research questions to be addressed are categorised under the following four themes:

Theme One – Enabling Agronomy

- What are the best practice operations to grow great quality and yielding fennel in different climates across Northern Australia?
- What are the best times for planting and planting densities?
- What weeds, pests and diseases are significant and initiate minor use permits for their control?
- What are the best control options, chemical or organic for the weeds, pests and diseases occurring in fennel crops?
- How do these spice crops fit into the broader cropping system in northern Australia?

Theme Two – Mechanisation, Harvest Quality Assurance and Post-Harvest Processing

- What are the best practice planting, harvest and post-harvest settings and options for the fennel crops?
- How can the seed be dried in the field and once harvested to maintain quality assurance?
- What are post-harvest processing options for fennel crops?

Theme Three – Economics, Value Chain and Export Protocols

- What are the gross margin analyses for fennel across the various northern Australian farming systems?
- What value chain options exist?
- What quality data is required to enable crop specific export protocols to be developed?

Theme Four – Extension and Communication

- How can more producers be informed about new crop options and engage in the fennel industry with confidence?

This Final Report is to be read in conjunction with the detailed crop-specific research reports for fennel, black sesame and kalonji, which are provided as appendices.

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Appendices

Appendix 1: Web links for full reports

Report No.	Report title	Web links
MILESTONES REPORT	Market analysis of sesame seed	https://crcna.com.au/sites/default/files/2020-02/200111%20Sesame%20Market%20Analysis.pdf
MILESTONES REPORT	Market analysis of fennel seed	https://crcna.com.au/resources/publications/market-analysis-fennel-seed
MILESTONES REPORT	Market analysis of kalonji seed	https://crcna.com.au/resources/publications/market-analysis-kalonji
MILESTONES REPORT	Market analysis of cumin seed	https://crcna.com.au/resources/publications/market-analysis-cumin-seed
MILESTONES REPORT	Market analysis of caraway seed	https://crcna.com.au/resources/publications/market-analysis-caraway-seed
MILESTONES REPORT	Technical report, sesame	https://crcna.com.au/resources/publications/summer-spice-technical-report-black-sesame
MILESTONES REPORT	Technical report, fennel	https://crcna.com.au/resources/publications/fennel-summer-spice-technical-report
MILESTONES REPORT	Spice crop newsletter	https://crcna.com.au/resources/publications/broadacre-cropping-northern-australia-newsletter-vol-2
BLACK SESAME REPORT (A)	Final report – Black sesame	TBA
FENNEL REPORT (B)	Final report – Fennel	TBA
KALONJI REPORT (C)	Final report – Kalonji	TBA
CUMIN REPORT (D)	Variety initial evaluation report – Spicing up Northern Australia project	TBA
KALIJIRI REPORT (E)	Variety initial evaluation report – Spicing up Northern Australia project	TBA