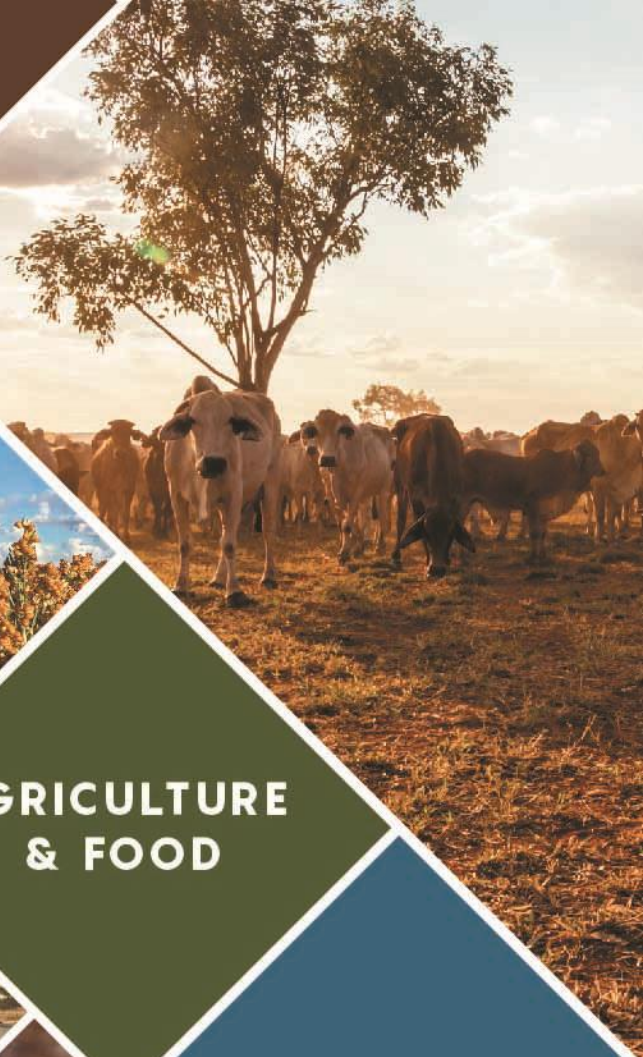
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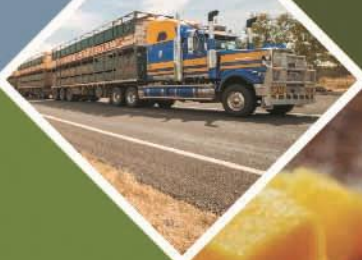






TRADITIONAL OWNER-LED DEVELOPMENT

AGRICULTURE & FOOD





PART A: BLACK SESAME 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 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),

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This report should be cited as: Bhattarai, S., Trotter, T., Akbar, D., Rahman, A., and Thomson, M. 2023, Black Sesame Trial Results: Final Report, Research project report for CRCNA, A.2.1819045.

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Table of contents

Acknowledgments 1
Disclaimer 1
Peer Review Statement 1
Table of contents 2
List of Tables 4
List of Figures 5
List of Acronyms 6
EXECUTIVE SUMMARY 7
1. INTRODUCTION 8
2. DELIVERABLE 1 - MARKET ASSESSMENT 9
3. GROSS MARGIN ANALYSIS 10
3.1 Introduction 10
3.2 Methods and Limitations 10
3.2.1 Limitations of the study 10
3.2.2 Case study area 11
3.2.3 Variables explained 12
3.3 Results 12
3.3.1 Economic analysis 12
3.4 Discussion 15
3.4.1 Strength- Weakness-Opportunities-Threats (SWOT) analysis 15
3.5 Conclusions 16
4. AGRONOMIC CROP ASSESSMENT 17
4.1 Introduction 17
4.2 Black Sesame Initial Evaluation Trials (Year 1) 17
4.2.1 Introduction 17
4.2.2 Materials and methods 17
4.2.3 Results 21
4.2.4 Discussion 31
4.3 Black Sesame Verification Trials - Summer Crop (Year 2) 32
4.3.1 Introduction 32
4.3.2 Materials and methods 32
4.3.3 Results 33
4.3.4 Discussion 36
4.4 Black Sesame Verification Trial - Winter Crop (Year 2) 36
4.4.1 Introduction 36
4.4.2 Materials and methods 36
4.4.3 Results 37
4.4.4 Discussion 38
4.5 Black Sesame Commercial Crop Trials - Year 3 39
4.5.1 Introduction 39
4.5.2 Materials and methods 39

4.5.3 Results 39
4.5.4 Discussion 40
5. WEEDS, PESTS, DISEASES & POST-HARVEST CHALLENGES 42
5.1 Post-Harvest Challenges 42
5.2 Results 43
5.3 Discussion 46
5.4 Insect Pests 47
5.4.1 Crop damage by insects 47
5.4.2 Beneficial Insects 47
5.5 Diseases 47
5.5.1 Crop damage by diseases 48
5.6 Other Challenges 48
5.6.1 Weather damage 48
5.6.2 Other pests (Birds, Rodents and Animals) 49
5.6.3 Weed control and herbicides residues 49
5.6.4 Physiological disorders 50
6. CONCLUSIONS AND RECOMMENDATIONS 51
REFERENCES 52

RESEARCH WITH IMPACT

CRICOS: 00219C

List of Tables

Table 16. Mean annual rainfall, maximum temperature, and minimum temperature for chief locations in Central Queensland 11

Table 17.. Fixed cost, variable cost and revenue for rainfed black sesame farming during 2018 and 2019 in central Queensland 13

Table 18. Sensitivity analysis of the average gross-margin from two years of black sesame production....14

Table 19. Gross margin of the dryland summer crops in Eastern coast region. Source: (Department of Primary Industries n.d), NSW government. 14

Table 20. SWOT Analysis– Australian Sesame Production....15

Table 1. Geographic location, in-crop rainfall, soil types and cropping systems of the small plot trial locations....18

Table 2. Trial planting and harvest dates 18

Table 3. Seed yield (t/ha) of four black sesame varieties planted at different locations in QLD and NT during 2019-20 cropping season 24

Table 4. Dry biomass yield (t/ha) of four black sesame varieties planted at different locations in QLD and NT during 2019-20 cropping season 24

Table 5. The harvest index (seed yield (t/ha)/above ground biomass (t/ha) + seed yield (t/ha) 25

Table 6. The plant density, the number of plants per m^2....25

Table 7. The number of pods per plant 26

Table 8. The weight (gms) of 1000 seeds....26

Table 9. The density of seeds (kg/m^3)....27

Table 10. The oil content (%) of the seed 30

Table 11. The relative density of black sesame oil taken at 20ºC....30

Table 12. The raw cake content (%) of the seed....30

Table 13. Crop planting, cropping system and maturity period of black sesame varieties planted at various locations in QLD, NT and WA during 2020-2021 cropping season....34

Table 14. Seed yield (kg/ha), seed quality and oil outputs of two sesame varieties planted at different locations in QLD, NT and WA during 2020-2021 cropping season 35

Table 15. Laboratory grain cleaning test results of the black sesame seeds after first and second stage cleaning in the laboratory grain cleaning equipment (seed received from winter planting verification trials at Ayr) 44

List of Figures

Figure 1. Location of case study area, Central Queensland highlighted in grey in the map of Australia. 11

Figure 2. Trial locations in northern Australia, including Biloela, Rockhampton, Ayr and Tully in Queensland and Katherine and Darwin in the Northern Territory.....18

Figure 3. The oil press used for extraction of oil from the cleaned dried black sesame seed 20

Figure 4. Weather data for the sesame crop period in different sites, a) Biloela, b) Rockhampton, c) Ayr, d) Tully, e). Katherine, f) Darwin.....21

Figure 5. The growing season of black sesame from planting to harvest at the six trial locations 22

Figure 6. The growth stages of the black sesame crop at the Rockhampton site a. seedling establishment, b. vegetative growth at one month, c. vegetative growth at six weeks, d. budding, e. flowering, f. mature pods and g. dried and shattered pods (Images. T. Trotter).....22

Figure 7. Plant height at harvest (column on the leaf) and height of first pod position (column on the right) for four black sesame genotypes tested at (a) Biloela, (b) Rockhampton, (c) Ayr, (d) Tully, (e) Katherine and (f) Darwin 23

Figure 8. The seed size and colour of the black sesame seed by site and variety (Image. T.Trotter) 28

Figure 9. Oil sample extracted from each of the four genotypes from the Darwin site (Image. R. Paudel).....29

Figure 10. The sesame cake by-product of oil extraction, which may bring potential opportunities for extracting high value protein and antioxidants (Image. R. Paudel).....29

Figure 11. The genotypes x location (environment) interaction for seed yield (t/ha) for four sesame genotypes tested over six different production environments across QLD and NT 31

Figure 12. Black sesame verification trial planting at Ayr, in sugarcane-based farming system, in the summer season of 2020/21, using the four-row Jang Seeder (http://bestmadeinkorea.com//product-14511/Seeders/Jang-Tractor-Walking-Tractor-Seeder-JDT-.html) (Image. S. Bhattarai) 33

Figure 13. CASE II header contractor harvesting black sesame trial crop in Biloela, QLD (Image. S. Bhattarai) .35

Figure 14. Winter sesame planted with Jang planter, double row configuration 50cm apart in a single sugarcane bed (Image. S. Bhattarai) 37

Figure 15. Early establishment of winter planted sesame showing the variable plant density, which was not due to temperature but rather the poor control of the planter (Image. S. Bhattarai) 37

Figure 16. Winter planted sesame defoliated for harvesting. The cooler weather effects on early vegetative growth is related to reducing the internode length, therefore, it displayed reduced plant height compared to summer-planted sesame (Image. S. Bhattarai).....38

Figure 17. Monosem seed planter in use for planting sesame seeds under different soil conditions (Image. P. Foxwell) 40

Figure 18. New Zurn 150 research plot harvester with sesame header used for harvesting of non-shattering sesame lines in the trials (Image. A. McDonald) 41

Figure 19. The on-farm seed cleaning machine, VAL-1500-6, with the capacity of cleaning 25 tonnes of seed per hour (Image. D. Frahn).....42

Figure 20. Theory and procedure for the operation of on-farm grain cleaning equipment, VAL 1500-6-2x3 Model 43

Figure 21. The seed samples from the harvest header (top) and when separated into different size to remove debris (>2.4 mm), and fine debris and sub-size seed (<1.8 mm). This separation requires the correct screens in the on-farm seed cleaning machine (Image. D. Frahn). 45

Figure 22: Cleaned seed following the correct use of screens and aspiration in the VAL-1500-6 (Image. D. Frahn). 46

Figure 23. Wind damage at the Coastal Plains Research Station in Darwin. (Image. C. Moore).....49

Figure 24. A flower distortion and leaf bunching found at Biloela and Rockhampton (Image. S. Bhattarai) 50

List of Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABC	Australian Broadcasting Corporation
ASIDA	Australian Sesame Industry Development Association
BBIFMAC	Burdekin Bowen Integrated Floodplain Management Advisory Committee Inc.
BMPs	Best management practices (BMPs)
BOM	Bureau of Meteorology
CQ	Central Queensland
CQU	Central Queensland University (also known as CQUniversity Australia)
CRCNA	The Cooperative Research Centre for Developing Northern Australia
DAF	Queensland Department of Agriculture and Fisheries
DAFF	Department of Agriculture, Fisheries and Forestry
FAO	Food and Agricultural Organisation
FNQ	Far North Queensland
FTA	Free Trade Agreement
GNS	Great Northern Spices
GRDC	Grains Research and Development Corporation
HI	Harvest Index
IPM	Integrated Pest Management (IPM)
KEW	Kingaroy Engineering Works (KEW)
LiDAR	light Detection and Ranging equipment systems
LSD	Least Significant Difference
MRO	Main research organization
N-P-K	Nitrogen (N), Phosphorus (P) and Potassium (K)
NSW	New South Wales
NT	Northern Territory
NT DITT	Department of Industry, Tourism and Trade - Northern Territory Government
NWMP	North-West Minerals Province
QDAF	Department of Agriculture and Fisheries, Queensland
QLD	Queensland
R & M	Repair and Maintenance
RCBD	Randomised Complete block Design
RD&E	Research Development & Extension
RS	Remote Sensing (RS)
SAR	Synthetic Aperture Radar
SWOT	Strengths, Weaknesses, Opportunities, and Threats (strategic management technique used to identify these four components of an organisation)
USA	United States of America
VIC	Victoria
VIS-SWIR	Visible and near (Short wave) infrared spectral systems
WA	Western Australia

EXECUTIVE SUMMARY

Australian sesame market is entirely dependent on import. Current trends indicate ongoing growth of the domestic market, forecasted to reach 9800 tonnes by 2025. Australian tropical climate can support production of sesame locally, but lack of suitable varieties, agronomic support, and supply chain are the current impediments for successful sesame production in Australia. This report presents the results of farmers and indsutry participatory research on black sesame varieties grown at six locations across Queensland, Northern Territory and Western Australia in 2019-2022. It also covers the results from crop agronomy trials (time/season of planting) in terms of yield and quality, followed by the postharvest seed cleaning, grading and an economic assessment for gross margin analysis.

The initial variety evaluation trials in year1 recorded hand harvested yield from 1.37 to 3.04 t/ha, with the highest seed yield recorded in Biloela followed by Rockhampton, Katherine, Ayr, Darwin, and Tully. Of the four varieties, AVTBS #6 and AVTBS #11 recorded higher yields compared to other varieties. Sesame oil content ranged from 43 to 47%, and was not significantly different between varieties, but the sites, with highest oil content recorded for Tully (47%) and Darwin (46%), medium oil content for Katherine (44%), Ayr (44%) and Rockhampton (44%) and lowest oil contents from Biloela (43%), showing a trend for decrease in oil contnents with increase in yield.

Verification trials in year2, for summer crop recorded machine harvested yield of 85-1088 kg/ha, with machine harvest loss very high (44-82%), while the winter crop at Ayr recorded machine havested yield of 512 kg/ha with harvest loss of 30-40%. The trials established that black sesame can be grown only as a summer crop in the central QLD, whereas as summer and winter crop in north Australia, north from Ayr. Excessive harvest losses warrants the needs of non-shattering sesame varieties for broadacre sesame farming in Northern Australia.

Commercialisation trials of black sesame (AVTBS#6) in year3, planted as winter crop (April-May) at Darwin matured after 111 days with a seed yield of 325 kg/ha. Despite the higher yields potentials the AgriVentis blakc sesame line showed very high susceptibility to the shattering, causing a significant mechanical harvest loss (30 – 87%). Therefore, two new non-shattering black sesame properties were introduced in 2022 and evaluated in the field trial at Rockhampton and Biloela. New non-shattering variety-S52 at Rockhampton recorded a machine harvested yield of 653 kg/ha. Optimsing the agronmy for the news line will allow achieving yield potentials from the non-shattering sesame under board acreapplciatons. Hence, the seeds of new non-shattering black sesame line harvested from year3 trials provide seeds for commercial crop trials in 2023. The machine harvest loss is a major bottleneck for commercialization of sesame in Australia, hence future evaluation of non-shattering white and black sesame genotypes is suggested for expansion of sesame production in Australia.

Two years of cost and revenue data from rainfed black sesame production from a single farm was used to evaluate its gross margin and sensitivity to price and yield fluctuations. The average seed yield from both years was 0.32 tons/ha with a gross margin of A$135.5/ton and an average rate of return of 12.8%. A seed yield of 0.2 tons/ha was not enough to break even at any of the price points between A$1600 and A$2400. Sensitivity analysis revealed that seed yields of 0.31 tons/ha, 0.27 tons/ha and 0.25 tons/ha were required to break even at the price of A$1600/ton, A$1800/ton and A$2000/ton of seed respectively. Development of suitable crop agronomic practices, machine harvest technologies and non-shattering varieties with higher yields are recommended for the optimisation of the economic output of black sesame cultivation in northern Australia.

The outcomes of the Spicing up Northern Australia project have informed the scope of work for a follow up project, Great Northern Spices (GNS), which has been funded by the CRCNA for 2022 to 2026, that supprot enabling agronomy research generating sesame production related practical outcomes relevant for commerical scale sesame production in Northern Australia.

1. INTRODUCTION

As a part of the CRCNA-funded project Spicing Up Northern Australia (2019-2022), the following progress and technical reports on black sesame were delivered:

- "Summer Spice Technical Report- Black sesame" (2020)- https://crcna.com.au/resources/publications/summer-spice-technical-report-black-sesame
- "Black Sesame Verification Trials Report" (2021), and
- "Market Analysis of Sesame Seed" (2020) - https://crcna.com.au/sites/default/files/2020-02/200111%20Sesame%20Market%20Analysis.pdf
- "Broadacre Cropping in Northern Australia-Newsletter" 2021 - https://crcna.com.au/resources/publications/broadacre-cropping-northern-queensland

These reports have been published and are available via the CRCNA website, summarised as below:

The "Summer Spice Technical Report- Black sesame" (2020) presents the results of black sesame initial varietal evaluation trials as a summer crop in small plot, multilocation trials over six regions in northern Australia. This report presented the varietal performance for hand harvested yield, seed quality and recorded abiotic and biotic challenges for black sesame production in northern Australia. The seed yields in small plot trial (potential yield) ranged from 1.37 - 3.04t/ha, with the highest yield recorded in Biloela followed by Rockhampton, Katherine, Ayr, and Darwin. The lowest yield was recorded in Tully. Agriventis variety AVTBS#6 and AVTBS#11 performed well across all sites.

The "Black Sesame Verification Trials Report (2021)" presents the results winter season machine planted (21 July) black sesame (AVTBS#11) in Ayr. The machine harvested yields of 512 kg/ha was reported with 30-40% of the seed lost in harvest. The verification trial demonstrated the options for sesame planting and harvesting by the machine instead of manual plating and hand harvesting. At also presented challenges associated with the harvest loss by the machine for shattering types of sesame varieties. The successful crop of sesame planted during winter in northern Australian locations demonstrated the opportunity of growing sesame as both winter or summer crop in far north QLD and NT but only as summer crop in the centra Queensland region.

The "Market Analysis of Sesame Seeds 2020" analyses the current and projected demand for sesame in Australia. It also review global markets, identify major global producers, exporters and importers of sesame seeds. The report also highlights are all Australian sesame demand is supplied through the import and it is growing steady. The sesame demands for Australia will reach to 9800 t by 2025. Australian grown sesame can make impact by import substitution.

The "Broadacre Cropping in Northern Australia - Newsletter 2021" presents the results of initial variety evaluation trials for five species crops, including sesame and fennel as summer season crop whereas kalonji, cumin and kailjiri as winter season spice crops. These trial results presented hand harvested yield to showcase the yield potentials of these selected spices crops in various locations in Northern Australia. Challenges (insects, pests, diseases, and crop and harvest management) for growing these crops has also been discussed.

The project outlines eight key deliverables for achieving the project objectives and purpose. The five key deliverables are related to sesame crop production, quality assessment and economic analysis, and these are linked to this report "PART A: BLACK SESAME FINAL REPORT". The common deliverables across the five crops, i.e. deliverable 6- Extension; deliverable 7- Complementary Activities and; deliverable 8, Research Insights and Future Directions are common for all the spices commodities are not included in this report. These common deliverables, 6-8 are presented in Final Report (An overarching report) to minimise the duplication of information and contents across the commodity reports.

2. DELIVERABLE 1 - MARKET ASSESSMENT

The market assessment undertaken in 2019-20, investigated the current and future trends of the international sesame markets and explored the market opportunities for Australian sesame producers. The following extract from the report summarises the key findings. The full report is available at www.crcna.com.au/resources/publications/market-analysis-sesame-seed. The report provides a baseline assessment of the global industry based on currently available information and identified areas for further research to address gaps in market information.

In 2017 the world production of sesame was approximately 5.5 million tonnes, and the major share of sesame was produced in Africa and Asia. In 2018 the global market value of sesame was estimated at US $6.5 billion. It is expected that by 2025 the global sesame seed market will reach US $17.77 billion. Global sesame production is forecast to reach 9.26 million tonnes by 2040, up from 5.53 million tonnes in 2017. The demand for sesame in China alone is expected to reach 2.56 million tonnes in 2040, up from 1.3 million tonnes in 2016.

Australia has been importing sesame since 1966, with demand gradually increasing over time. In 2016, Australia imported about 6,740 tonnes, and in the same period exported a very small amount of sesame, with main export destination New Zealand. Current trends indicate ongoing growth of the domestic market which is forecast to reach 9800 tonnes by 2025. This strong and ongoing growth in demand, both domestically and internationally, presents an opportunity for Australian growers to enter commercial production. The current production area for both black and white sesame in Australia is very small relative to the global production area of 9.9 million hectares.

In international markets, the average price of sesame seed was US $1,229/tonne in 2018, with black sesame returning about 45% higher than those for white sesame. The price difference is due to the higher production costs of black sesame, along with additional demand created by its perceived health benefits. White sesame is used solely as a food condiment; black sesame is in demand as a food oil, cosmetic and pharmaceutical ingredient.

The opportunity for the Australian industry to expand production will be determined by a combination of several factors such as growing market demand, climatic conditions, geographic proximity to Asian markets, and availability of suitable climate and land. Australia has free trade agreements in place with the major markets of China, Japan and Korea, giving Australia a potential competitive advantage over African exporters. However, high labour cost is a competitive disadvantage and a barrier to the growth of sesame cultivation in Australia.

Technological innovation, the adoption of high yielding and high-quality sesame varieties, and the economies of scale of Australian production systems will be key to overcoming labour cost competitiveness. Together, these four factors – growing global demand, proximity to international markets, high crop prices, and access to suitable land and sesame's inherent tolerance of Australian environmental stressors – place Australian grown sesame in a strong position to establish a viable long-term sesame industry generating revenue through import replacement and export sales.

3. GROSS MARGIN ANALYSIS

3.1 Introduction

This section has been adapted from the published thesis work by Timilsina, S (2022), a CQU Masters student attached to the project.

Black sesame is an emerging, potentially a high-value, drought tolerant crop suitable for rainfed farming in sub-tropical and tropical regions in Australia. Economic analysis on the profitability of black sesame farming under mechanised agriculture in Australia is necessary to help the farmers to make suitable farm decision regarding its cultivation. Being a very new crop in the Australian farming system, very few farmers are involved in black sesame production and economic feasibility studies of the crop are non-existent. This study was designed as a case study to assess the economic feasibility of black sesame in northern Australia and gross margin analysis was chosen as a method of economic assessment.

3.2 Methods and Limitations

The study was conducted as a case study on black sesame production from a single farm in central Queensland Australia. Black sesame production costs and revenues from two years (2018 and 2019) were collected to study the farm operation profit and conduct a sensitivity analysis. Data was collected using a quantitative questionnaire attached in the appendix supplemented with phone interviews. The collected data was converted to cost and revenue per hectare. The process and protocol of data collection were approved by CQU's Human Ethics Committee (project number 0000022421).

3.2.1 Limitations of the study

Following limitations are applicable to the study:

- The scenario assumes black sesame production within the existing farming system as a rotational crop instead of an entirely new farm business venture. As equipment and implements required in the production of existing mainstream broadacre crops are suitable for black sesame production as well, focus has been put on gross margin analysis instead of whole farm profit analysis. Depreciation cost of the existing farm asset has been included instead of the entire new investment in the farm machinery and equipment.
- The farm size during the two years of black sesame production was 12.5 and 22 hectares for 2018 and 2019 respectively. No other farms were involved in black sesame production in the region till the date of data collection. Given the availability of only two data points, it has been judged best not to extrapolate the findings for large broad acre black sesame farming. Thus, the findings are best suited for the farm size between 10 and 25 hectares. Since the variable cost for farming 22 hectares in 2019 was slightly less than the variable costs of farming 12.5 hectares in 2018, costs involved in farming in larger farm size may be less than projected in the study.
- Only the direct revenue of seed sales has been included in the benefits. Value added products including sesame oil and sesame oil press cake along with other indirect benefits from crop rotation on the farm are beyond the scope of the study.
- Black sesame production has been assumed as an incorporation into the existing farming system as a rotation crop as was the case in the case study farm. Black sesame production as a completely new business venture and new farmland use involving capital costs of new farm establishment are beyond the scope of the study.
- This black sesame feasibility study is targeted for rainfed production system in prime vertisol agricultural land. Semi-irrigated and fully irrigated production system is beyond the scope of the study.
- The chapter focuses on the gross margin of black sesame production and sensitivity analysis on the gross margin of black sesame production. While gross margin analysis is helpful in

comparing similar enterprises, however, caution is advised when comparing with farming enterprises which require different input resources in form of the capital costs.

3.2.2 Case study area

The case study was carried out in an area of prime agricultural land located in the Fitzroy agricultural basin, Central Queensland. Central Queensland is a non-formal region in Queensland primarily including regions surrounding Biloela, Emerald, Gladstone, Rockhampton, Yeppoon and Woorabinda covering a total area of 117,300 square kilometres (ABARES n.d.) as shown in Figure 1.

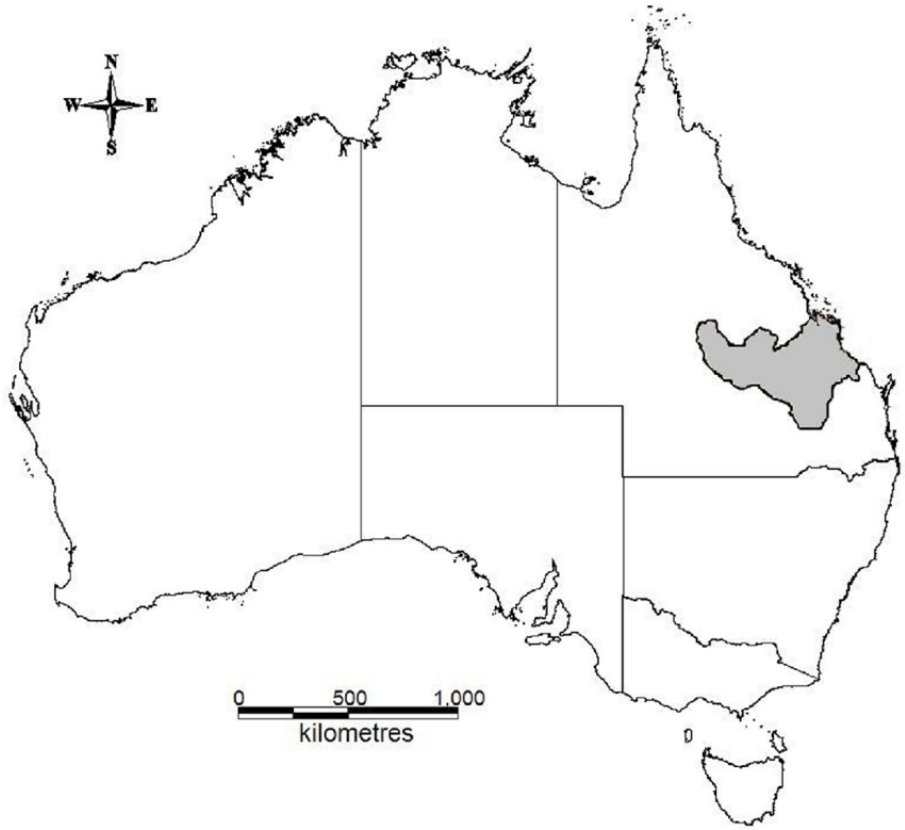


Figure 1. Location of case study area, Central Queensland highlighted in grey in the map of Australia. NB: Source (Dimity & Adrian 2017)

The region has sub-tropical climate with hot humid summers and dry mild winters (Bureau of Meterology 2001). The mean rainfall, average maximum temperature, and average annual minimum temperature for the chief locations in Central Queensland has been presented in the Table 1.

Table 1. Mean annual rainfall, maximum temperature, and minimum temperature for chief locations in Central Queensland

Location	Mean rainfall (mm)	Mean maximum Temp (°C)	Mean minimum Temp (°C)
Rockhampton	815	28.5	16.8
Biloela	686	28.4	12.9
Emerald	544	29.9	16.3
Gladstone	853	27.4	18.2
Yeppoon	979	25.9	18.7

The major soils found in the region are podosols and tenosols with vertisol prevalent in river basin areas (Queensland Government n.d.). Seventy-seven percent of the total land in the region is used

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for agriculture of which 47% is used for modified grazing pastures (ABARES n.d.). Other important agricultural industries were cotton valued at $70 million and pulses valued at $36 million (ABARES n.d.). Fitzroy river basin area contains vertisol soils with most farmland in the region classified as prime agricultural land (Read 1998). Rainfed production with cotton-fallow; corn-fallow; cotton-mungbean was practised in the case study farmland prior to sesame production.

3.2.3 Variables explained

The cost of production involved was segregated into fixed and variable costs. Variable costs involved the costs that would change with the change in the scale of the production. Fixed costs involved costs that did not change with the change in the scale of production. Since the land was owned by the farm, the land rent for the area was obtained from an adjacent farm which had 65 hectares of recently rented farmland.

Seed yield was obtained from the two years of black sesame production. The appropriate yield range for sensitivity analysis was determined by considering factors like world average sesame production, black sesame production from the field trials of the research, harvest loss percentage of black sesame during mechanical harvest and average productivity of mechanised sesame production in commercial US farms.

Labour cost of A$55 per hour for the farm machine operator was included within the cost of activities for land preparation, cultivation, and fertilisation. The cost for additional labour required for the fertilisation of the land was input at the rate of A$ 30 per hour within the fertiliser application activity.

The cost for fuel was input at A $1 per litre after the rebate and included within the farm activity cost, as was the cost of repair and maintenance of the farm equipment. To calculate the farm equipment repair and maintenance cost, total repair, and maintenance (R &M) cost of the farm vehicles and implements incurred was divided by the total expected life hours of the vehicles and implements respectively. It was then adjusted to cost for hectare, depending on the work efficiency of the vehicle/implement (hectare/hour) calculated by the farm owner. The cost of the R & M has been included in each farm activity, but the detailed individual R &M costs calculation has not been disclosed in the chapter as per the non-disclosure agreement with the farm owner.

Herbicides and insecticides cost has not been included in the variable cost calculation. The black sesame crop recorded no insect infestation above the threshold limit to trigger insecticide application. Furthermore, weeding was performed mechanically using a cultivator, hence cost of cultivator operation has been included instead of herbicides. The cost of fertiliser needed for the black sesame was calculated based on the fertilizer dose of 55: 30: 30 kg N: P: K per hectare.

All the capital costs incurred in the farm were halved, assuming two crops cultivated per year in rotation. Finally, all capital costs were adjusted on per hectare basis for both the years. Black sesame farmgate price was collected from a trading company involved in sesame and grains trading, not disclosed due to ethical reasons.

3.3 Results

3.3.1 Economic analysis

Gross margin analysis was calculated on large scale crops of black sesame on the same varieties planted for the initial evaluation and verification trials at Alton Downs and other trials in the Spicing up Northern Australia project. Black sesame at Rockhampton was farmed in 12.5 and 22 hectares in 2018 and 2019 seasons. The total cost of cultivation for the crop in these trial years incurred a total operational cost of A$7199 and A$10,769 respectively, resulting in the cost of per hectare of A$588.45 and A$565.40 for 2018 and 2019 seasons respectively. Variable cost accounted for the majority of the cost requiring 86.6% of the total cost (Table 2).

Table 2. Fixed cost, variable cost and revenue for rainfed black sesame farming during 2018 and 2019 in central Queensland

Item	Total cost 2018 (AU$)	Total cost 2019 (AU$)	Cost 2018 (AU$/ha)	Cost 2019 (AU$/ha)	Average cost (AU$/ha)
Fixed cost					
Land lease	$576.9	$1,015.3	$46.15	$46.15	$46.15
Office cost	$93.8	$93.5	$7.50	$4.25	$5.88
Depreciation	$156.3	$275.0	$12.50	$12.50	$12.50
Insurance	$156.3	$286.0	$12.50	$13.00	$12.75
Total fixed cost	$983.1	$1,669.8	**$78.65**	**$75.90**	**$77.28**
Variable cost					
Land preparation	$600.0	$1,056.0	$48.00	$48.00	$48.00
Planting	$387.5	$682.0	$31.00	$31.00	$31.00
Fertilizer	$2,125.0	$3,740.0	$170.00	$170.00	$170.00
Fertilizer application	$825.0	$1,452.0	$66.00	$66.00	$66.00
Weed management	$325.0	$572.0	$26.00	$26.00	$26.00
Harvesting	$1,450.0	$2,112.0	$116.00	$96.00	$106.00
Freight	$260.0	$455.0	$20.80	$20.70	$20.75
Seed cleaning	$400.0	$700.0	$32.00	$31.80	$31.90
Total variable cost	$6,372.5	$10,769.0	**$509.80**	**$489.50**	**$499.65**
Total expenses	$7,355.6	$12,438.8	**$588.45**	**$565.40**	**$576.93**
Revenue Segment					
	Total 2018 (AU$)	Total 2019 (AU$)	2018 (AU$/ha)	2019 (AU$/ha)	Average (AU$/ha)
Farmgate price	AU$ 2000/ton				
Production (Tons)	4.00	7.00			
Total revenue (AU$)	$8,000.0	$14,000.0	$640.00	$636.36	$638.18
Gross margin (AU$)	$1,627.5	$3,231.0	**$130 .3.20**	**$146.86**	**$138.53**
Net profit (AU$)	$800.6	$1,847.2	**$64.05**	**$83.96**	**$74.01**
Revenue: Cost ratio			1.09	1.13	1.11
Average rate of return			10.88%	14.85%	12.83%

NB: Fixed cost considered of half a year to represent crop rotation

Since the black sesame was grown in rotation with cotton in a single year, total annual fixed cost was halved to share the annual fixed cost between the two rotating crops. Fertilizer cost is one of the main sources of variable cost in cropping industries, as is the case in black sesame. Black sesame, however, required very less fertilizer compared to other grain crops. For a rainfed farming system in sesame, nitrogen fertilizer of 25-60 pounds N/acre has been recommended (Langham et al. 2008). Total amount of 55:30:30 kg N:P:K/ha was input in the field amounting to a total cost of $A 170/ha in both years.

Machine harvested yield during the two trial years was 320kg/ha and 318kg/ha respectively. Farmgate price of black sesame was put at A$2000 leading to a gross margin of A$130.2/ha and A$146.86/ha in 2018 and 2019 respectively. Revenue to cost ratio for the two years was 1.09:1 and 1.13:1 while the average rate of return was 10.88% and 14.55% respectively (Table 3).

Table 3 presents a sensitivity analysis of black sesame farming to observe the effect of price fluctuation and crop performance on gross margin. Average variable cost per hectare incurred during the two years was used for the sensitivity analysis. Seed yields of 0.31 tons/ha, 0.27 tons/ha and 0.25 tons/ha were required to break even at the price of A$1600/ton, A$1800/ton and A$2000/ton of seed respectively. None of the price points was profitable at the seed yield of 0.2 tons/ha.

Table 3. Sensitivity analysis of the average gross-margin from two years of black sesame production

	Yield (tons/ha)					
Price AU$/ton		0.2	0.3	0.4	0.5	0.6
	$1,600	-$179.7	-$19.7	$140.4	$300.4	$460.4
	$1,800	-$139.7	$40.4	$220.4	$400.4	$580.4
	$2,000	-$99.7	$100.4	$300.4	$500.4	$700.4
	$2,200	-$59.7	$160.4	$380.4	$600.4	$820.4
	$2,400	-$19.7	$220.4	$460.4	$700.4	$940.4

Harvest loss is one of the major constraints in black sesame production with the existing technology. Current black sesame genotypes exhibit a high degree of capsular dehiscence leading to major harvest loss when harvested with a combine harvester. The seed yield during the farmer managed operation of black sesame was estimated at 0.6 tons per hectare but due to high seed loss during mechanical harvesting the final seed yield collected was 0.32 tons/ha (Bhattarai 2019). Hence, seed yield up to 0.6 tons/ha is with the commercial yield potential if better harvest and post-harvest technologies are developed. Pre-harvest seed loss caused by lack of uniform maturity can be reduced using harvest aids like glyphosate, diquat-dibromide, glufosinate-ammonium, and carfentrazone-ethyl to induce uniform dry down of the sesame pods (Grichar, Dotray & Langham 2020).

Global trade price fluctuation of sesame seeds has a latency of about 2-3 months from the point of crop harvest season; the time required for the collectors and traders to receive stock, clean, and process the seeds before being ready for international trade. There is weak but consistent seasonality in the global sesame seeds stock but majorly the price fluctuation is related to the reduction in either production area or productivity due to natural disasters e.g., drought, flood and pests in top sesame producing countries, leading to the price fluctuation of up to 25-30% (Tridge 2020, n.d). To sum up, with appropriate technologies to reduce harvest loss during machine harvest, black sesame could have attained a gross margin of A$700 per hectare at the farmgate price of A$2000/ton (Table 4).

Table 4 presents the average gross margin of the rainfed summer crops in the Eastern coast region of Australia. The table is to be used as an indication of the performance of the crops in the region, rather than exact figures. The generated gross margin values are for the northeast regions of New South Wales (NSW) close to the Queensland border.

Table 4. Gross margin of the dryland summer crops in Eastern coast region. Source: (Department of Primary Industries n.d), NSW government.

Crop	Gross margin (A$/ha)
Cotton (Round Up ready)	$449.22
Cowpea (no till)	$248.89
Maize (no till)	$316.65
Mungbeans (no till)	$493.75
Sorghum (no till)	$476.85
Hybrid Sudan grass	$165.40
Soybeans (no till)	$319.88
Sunflowers (no till)	$370.89

Central Queensland and northeast NSW fall under the same agro-ecological domains of crop growing region as classified by the Grains Research and Development Corporation (GRDC). Thus, the given

figures are applicable for comparison with the gross margin from dryland cultivation of black sesame. No other profitability analysis of dryland farming of mainstream crops was found in the literature. Since the gross-margin figures presented in table 4 are for the rainfed cropping system, the figures are much less than present in the irrigated and semi-irrigation cropping systems. This table presents only the summer crops planted on the north-east coast of Australia. The winter crops like wheat, barley, oats, triticale, lupins, chickpea, faba beans, field peas etc are not in direct competition with black sesame, as black sesame is preferably a summer crop.

From table 4, black sesame provides a gross margin of A$300.4 at a yield of 0.32 ton/ha and a farmgate price of A$ 2000/ton. This gross margin is much less than the gross-margin value of most of the contemporary dryland cultivated crops presented in table 4. Given that cotton and sunflower require more water during their cropping season, black sesame could be specifically beneficial in low moisture regions where dryland cotton and sunflower may not perform optimally (Pabuayon et al. 2019). Having said that, mungbean is a highly drought tolerant, short duration crop that has very low water requirements (Pannu & Singh 1993; Samson et al. 2020). Similarly, sorghum is a highly drought tolerant crop with stable crop yield even this low soil moisture (Hadebe, Modi & Mabhaudhi 2017; Pabuayon et al. 2019). Both crops recorded a higher gross margin than black sesame. These crops are high volume, low value crops, in contrast to black sesame, which is a low volume, high value crop. Sesame would be more profitable in remote areas where the transportation cost of the produce to processing facilities would be higher (Ash et al. 2017).

The black sesame field trial yield under the verification experiments mentioned in crop sections above, recorded an average yield of 0.85 tons/ha with total water use of just 260 mm. Thus, with better harvest and post-harvest technologies to reduce seed loss during the harvest operations, the current sesame genotypes can produce yields up to 0.8 tons/ha making them highly profitable. But the long-term future of the black sesame industry in Australia lies in the development of non-shattering, high yielding varieties that are more suitable for mechanised cultivation practices.

3.4 Discussion

3.4.1 Strength- Weakness-Opportunities-Threats (SWOT) analysis

SWOT Analysis of Australian sesame Production is presented in Table 5.

Table 5 outlines the strengths, weaknesses, opportunities and threats of the Australian sesame industry, which may be of relevance to potential growers of sesame crops in the Northern Australian farming systems.

Table 5. SWOT Analysis– Australian Sesame Production

Strengths	Weakness
• Australian produced sesame seeds are considered clean, green, pathogen free, which international markets place a premium on • Australian sesames are generally considered to be of high quality • Sesame can perform particularly well as a rotational crop in major farming systems in northern Australia.	• Australia is a higher cost producer of sesame compared to other major producers, especially in Africa, Myanmar and south America • Australia possesses a very small domestic market for sesame and exports protocols not established • Post harvest processing, supply chain and value adding opportunities within Australia are very limited for the sesame growers and industry • Little incentive or price support is available to Australian farmers as low total production levels are insufficient to meet tariff-free quotas in certain importing countries • Australia's main competitor for export market, USA and South America, produces substantially more product in comparison to Australia.

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Opportunities	Threat
• Continued rollout of the New non-shattering sesame genotypes overseas sesame genetics companies (Equinom and Sesaco through Agriventis) varieties in Australia, generating increased yield opportunity and capturing a greater share of the high-value domestic and export markets. • Continuously increasing global demand and predominantly small-scale production system in major growing regions in Africa and Myanmar, allowing alternative producers to cater for any residual demand within the market • Australian supplies for northern hemisphere markets become the off season produce attracting market advantages • Recently established FTAs between Australia and countries within the Asia-Pacific to spur increases in trade • Ability to highlight and market the clean-green image status of Australian sesame to provide a clear competitive advantage over major suppliers • Many growing regions and high land availability within the northern Australia promoting strong feasibility for increased production • Roadmap, RD&E in place by AgriFuture Australia to plug the gap between current domestic production and demand of local sesame purchasers.	• Logistical challenges as a result of rudimentary sesame supply chain • Historical experience of Australian shipments of sesame being downgraded for inadequate cleaning, grading reducing export value • Low reliance of major sesame market on Australian product may impact future supply to the bigger global market. • Entering of trade agreements between key export markets of Australia and other suppliers with notable cost advantages.

3.5 Conclusions

Two years of cost and revenue data from rainfed black sesame production from a single farm was used to evaluate its gross margin and sensitivity to price and yield fluctuations. The average seed yield from both years was 0.32 tons/ha with a gross margin of A$135.5/ton and an average rate of return of 12.83%. Seed yield of 0.2 tons/ha was not enough to break even at any of the price points between A$1600 and A$2400. Sensitivity analysis revealed that seed yields of 0.31 tons/ha, 0.27 tons/ha and 0.25 tons/ha were required to break even at the price of A$1600/ton, A$1800/ton and A$2000/ton of seed respectively. 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.

4. AGRONOMIC CROP ASSESSMENT

4.1 Introduction

The sesame crop trials were carried out over the three-year project period. This section of the report presents results from the scoping studies of summer-planted black sesame yield and quality in the initial evaluation trials (small plot trials) from the first year, followed by the verification trials assessing the summer and winter planted sesame in farmer managed larger plot trials in the second year and commercial scale trials conducted during the summer season in the third year of the project.

4.2 Black Sesame Initial Evaluation Trials (Year 1)

4.2.1 Introduction

Genetic variability exist in black sesame germplasm. The geographical coverage of the spicing up north Australia project include wide range of agro-climate and farming systems. Field trials with multiple genotype provides opportunities for assessing the adaptabilities of these genotypes under these diverse conditions, allowing for analysis of genotype x environment interactions. Such analysis provide practical outcomes in terms of variety recommendations for different growing environments.

4.2.2 Materials and methods

Trial locations

Field trials were conducted to determine the suitability of four genotypes of AgriVentis black sesame to the climate, soils and environmental conditions in northern Australia. The trial locations included four sites in Queensland and two sites in the Northern Territory (Figure 2).



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Figure 2. Trial locations in northern Australia, including Biloela, Rockhampton, Ayr and Tully in Queensland and Katherine and Darwin in the Northern Territory

The range of in-crop rainfall was significant (from 136mm at Rockhampton to 996mm at Tully) and soil types unsurprisingly equally varied from alluvial and sandy loams, to vertisols and ferrosols. Farming systems were just as diverse (Table 6).

Table 6. Geographic location, in-crop rainfall, soil types and cropping systems of the small plot trial locations

Location	Latitude	Longitude	In-crop rainfall (mm)	Soils	Cropping system
Biloela, QLD	24°26'32S	150°31'53E	136	Alluvial loam	Hay crop-sesame-hay crop
Rockhampton, QLD	23°18'24S	150°21'35E	382	Vertisol	Cotton-sesame-cotton
Ayr, QLD	19°37'8S	147°31'52E	805	Sandy loam	Melon-sesame-melon
Tully, QLD	18°7'23S	145°31'14E	996	Sandy loam	Sugarcane-sesame-sugarcane
Katherine, NT	14°28'12S	132°18'28E	246	Ferrosol	Sorghum-sesame-sorghum
Darwin, NT	12°35'38S	131°18'16E	435	Ferrosol	Sorghum-sesame-sorghum

Planting season

The planting window varied (Table 7) from early to mid-summer depending on the availability of moisture in the soil and predictions for the onset of the wet season.

Table 7. Trial planting and harvest dates

Location	Black Sesame Planting	Black Sesame Harvest
Biloela	7 November 2019	11 February 2020
Rockhampton	16 November 2019	12 March 2020
Ayr	28 November 2019	10 March 2020
Tully	29 November 2019	12 March 2020
Darwin	9 January 2020	7 April 2020
Katherine	10 January 2020	14 April 2020

At each site, we followed local grower practice with regards to soil preparation. In Biloela, Rockhampton and Tully, the soil was prepared using minimum tillage to remove weeds and prepare a seed bed. At Biloela, Rockhampton and Tully, the black sesame was planted in plots 3m wide and 2m long. Each plot had six rows of black sesame planted 2m long. The two outside rows were guard rows and the four inside rows were used to collect data.

Raised beds 1.5m wide were prepared in Darwin and Katherine and the black sesame was planted in four rows 2m in length. The outside two rows were guard rows and the inside two rows were used to collect data.

In Ayr, 1.5m wide raised beds covered in plastic mulch were prepared and one row of black sesame 2m in length was planted in the centre of the plastic mulch and one guard row was planted on either side of the data row. At this site, the blocks of replicates were stacked along one long bed, rather than in a square block pattern.

Drip tape was installed at each of the sites to assist germination. One line of drip tape was installed along each of the guard and data planting rows. Irrigation was applied throughout the season to supplement rainfall to refill point.

RICHGRO all-purpose complete garden fertiliser (NPKS 9-2-7-12) and RICHGROW High Phosphate–Super Phosphate fertiliser (NPK 0-9-0) were applied to the soil, for the NPK rate of 81:40:63kg Ha^{-1} at planting as a basal application. No additional fertiliser was applied during the growing season.

For the weed control, at Katherine, a pre-emergent herbicide Stomp (Pendimethalin A.I 440g/L) was applied at the rate of 1.5L/ha two days post-sowing for weed control (http://www.herbiguide.com.au/labels/pen33_61322-1209.pdf).

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In all other sites, hand weeding was carried out throughout the first month of growth to keep the competition with the seedlings low. Once the sesame had developed a canopy, minimal weeding was required as the plant was prolific enough to outcompete any weeds.

Once the black sesame seeds had emerged and established, each of the rows was thinned to 30 plants per 2m row (target population of 30 plants/m^2). This occurred at approximately week 2-3 when the plants were 15-20cm in height. This provided uniform spacing of approximately 6cm between the plants.

Trial design (varieties, planting dates, and densities)

Four outstanding varieties of black sesame (screened from germplasm assessment carried out in earlier years at Rockhampton) were grown in small plots independently randomised at each site, following the randomised complete block design (RCBD), with multiple replications within the same farm in each selected location. The between-row spacing was 50cm and the plant spacing within row was approximately 6cm with an aim to achieve the target population of ~30 plants/m^2. The planting date varied between sites (Table 7**Error! Reference source not found.**).

Data collection

Crop phenological and reproductive data were collected at each site at key times throughout the growing season. The date of planting, emergence, emergence count, flowering, maturity and harvest, and plant stand at harvest rate, were recorded for each replicate. At maturity, the plant height, number of capsules per plant and height at the position of the first capsule were recorded for six plants selected as representatives of the plot. The data rows were harvested, and the seeds were separated and cleaned for the determination of seed yield (t/ha). The remaining biomass was oven-dried until a constant weight was reached and the dry biomass yield (t/ha) was recorded.

Calculations of various yield parameters and yield attributing characteristics (the plant physiological features which drive the yield the plant produces such as amount of biomass available to produce yield) were made for an explanation of the seed yield results. Harvest Index (HI) was calculated as a ratio of seed yield (t/ha) and Dry Weight Biomass (t/ha).

The quality assessment of the harvested seeds was undertaken in CQUni's crop science laboratory. For the quality assessment, a 100gm sample of seed was cleaned from plant trash and dust, dried in an oven at 40^{o}C and weighed for determination of seed moisture content. The weight (g) for 1000 seeds was taken for each sample using a seed counting machine (Wavwer, Model IC-VA Japan). A subsample of 50g of seed was then dried to 70^{o}C for 12 hours and the oil was extracted using a 460W automatic oil pressing machine stainless steel 304# nut oil press, and a benchtop mill that employs a screw auger oil press system for oil extraction (Figure 3). The cake and centrifuged filtered oil were weighed to determine % oil and % cake for each replicate for each variety.



Figure 3. The oil press used for extraction of oil from the cleaned dried black sesame seed

The seed density was calculated using the principle of a chondrometer modified to accommodate a smaller volume of seed (https://www.graintec.com.au/products/grain-testing/quality-measurement/test-weight-chondrometer/description/). Seed volume was measured in the graduated 50ml centrifuge tube, with seed samples compacted uniformly and seed weight measure in the Ohaus adventure pro-precision balance (Model AV2102N) and the results presented as kg/m^3.

The weather data for each test site were recorded from the nearby BOM meteorological stations, and data was sourced from the Climate Data Online (http://www.bom.gov.au/climate/data/) repository maintained by BOM. The web link for each of those sites for accessing weather data are listed below:

Biloela: Station number 039269
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=039269

Rockhampton: Station number 039083
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=039083

Ayr: Station number 033002
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=033002

Tully: Station number 032167
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=032167

Kathrine: Station number 014902
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=014902

Darwin: Station number 014183
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=014183

4.2.3 Results

Weather conditions

The crop grew during hot and humid months of the year (Figure 4).

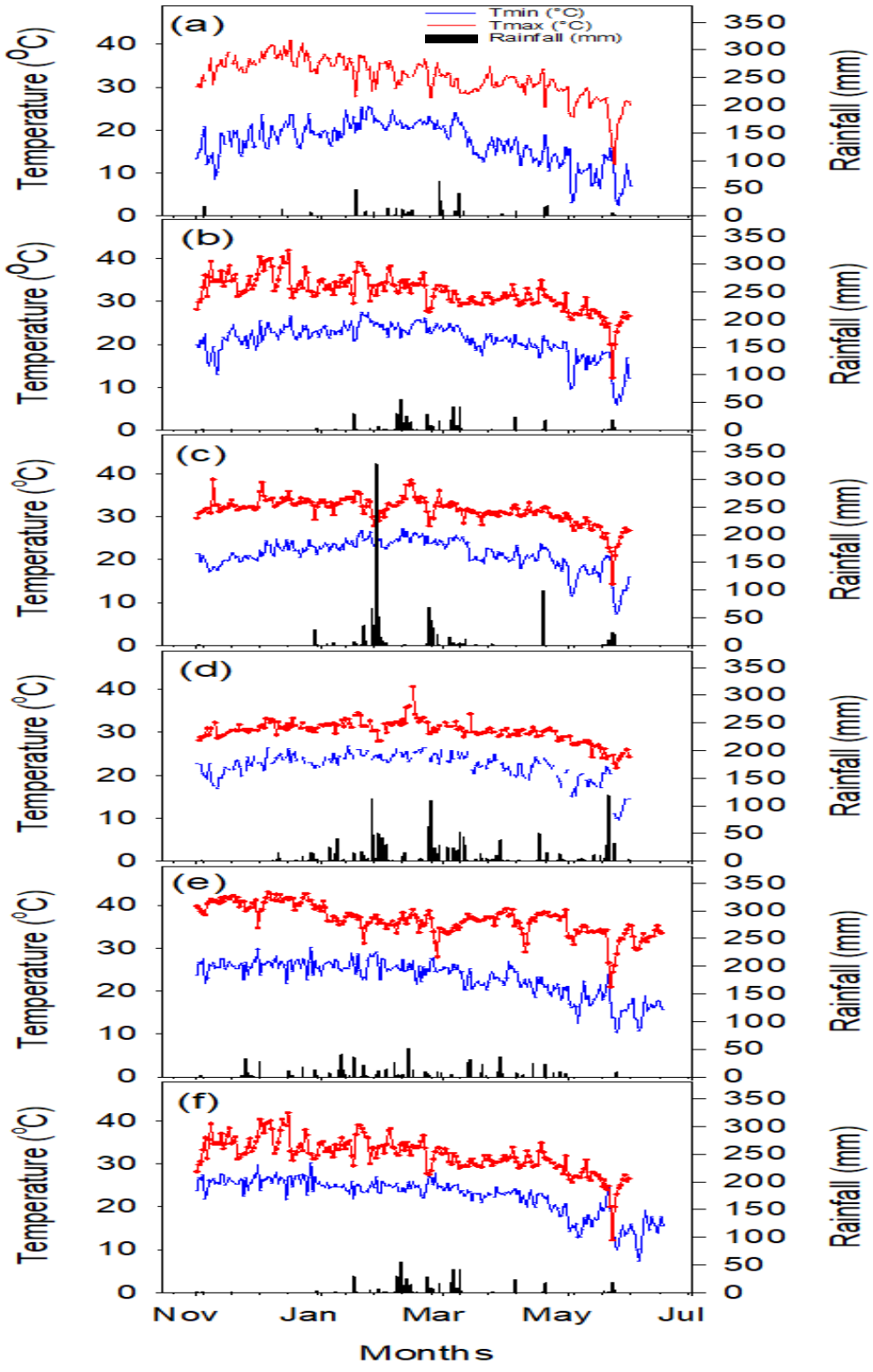


Figure 4. Weather data for the sesame crop period in different sites, a) Biloela, b) Rockhampton, c) Ayr, d) Tully, e). Katherine, f) Darwin

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The in-crop rainfall for Biloela was 136mm, Rockhampton 382mm, Ayr 805mm, Tully 996mm, Katherine 246mm, and Darwin 435mm. The crop was largely supported by rainfall, but strategic irrigation was applied to minimise the water stress on the crop. All trial sites had a drip irrigation set up that was utilised for strategic irrigation.

Crop phenology

The black sesame was planted at varying dates throughout the summer of 2019 and 2020 (Figure 5). Harvest was typically 90-120 days after planting. The average emergence for each replicate was as early as two days in Rockhampton and four to five days at the other sites. The duration from emergence to flowering ranged from 26 days (Katherine) to 38 days (Rockhampton). The flowering to maturity duration ranged from 42 days (Darwin) to 72 Days (Rockhampton). The sites were harvested manually as soon as practically feasible after maturity, with the longest delay in Katherine and Darwin of seven days post the optimal harvest date. Timely harvest upon maturity is essential in these varieties of black sesame as shattering of pods as they dry out can cause significant harvest losses.

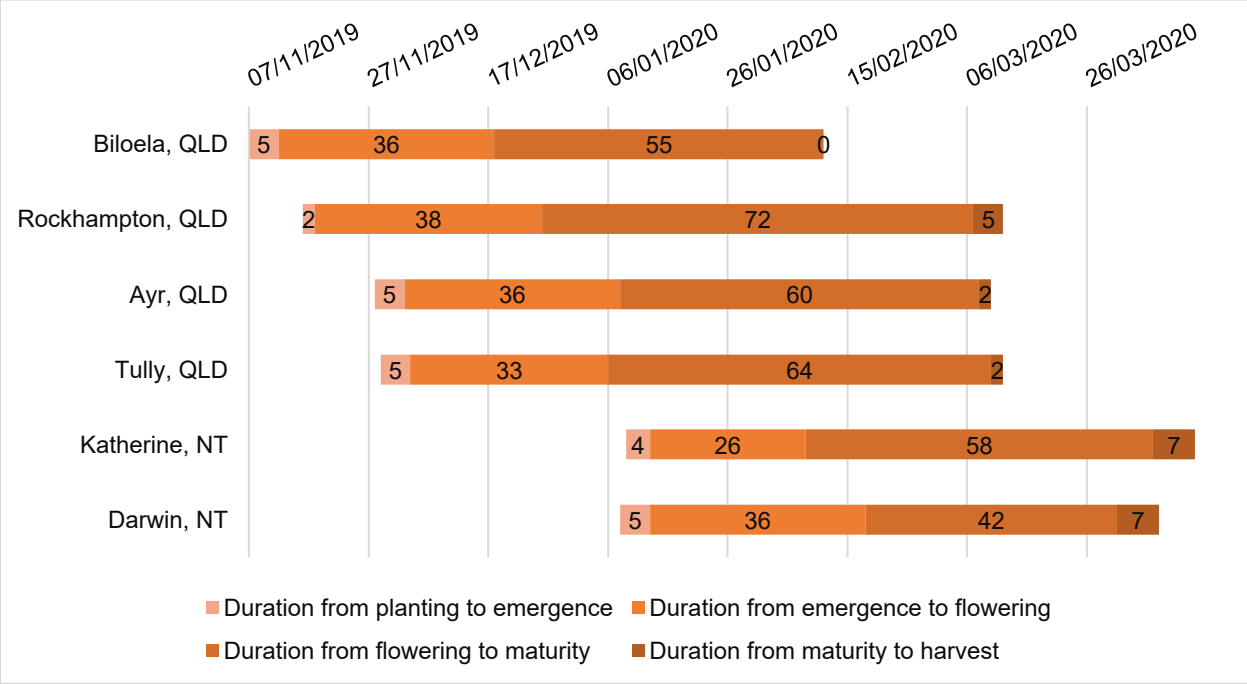


Figure 5. The growing season of black sesame from planting to harvest at the six trial locations

The black sesame crop stages at the Rockhampton site (Figure 6) were indicative of the other sites, with a healthy crop emerging and progressing through the vegetative stages to flowering and maturity.

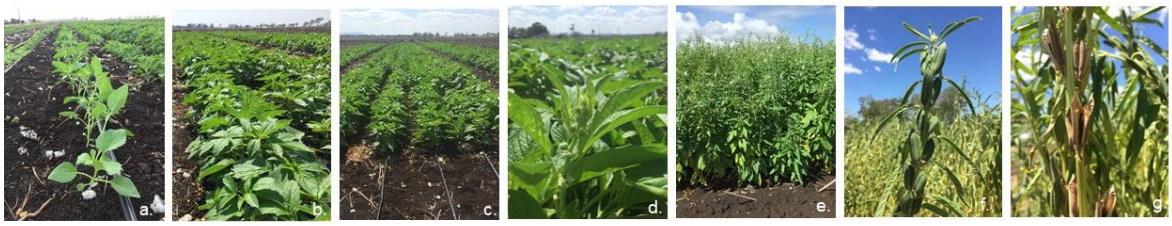


Figure 6. The growth stages of the black sesame crop at the Rockhampton site a. seedling establishment, b. vegetative growth at one month, c. vegetative growth at six weeks, d. budding, e. flowering, f. mature pods and g. dried and shattered pods (Images. T. Trotter)

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Plant height and height to first pod

The plant height of the tested lines varied between 150cm and 190cm (Figure 7) and the height at the first pod varied position at 65-110cm from the ground.

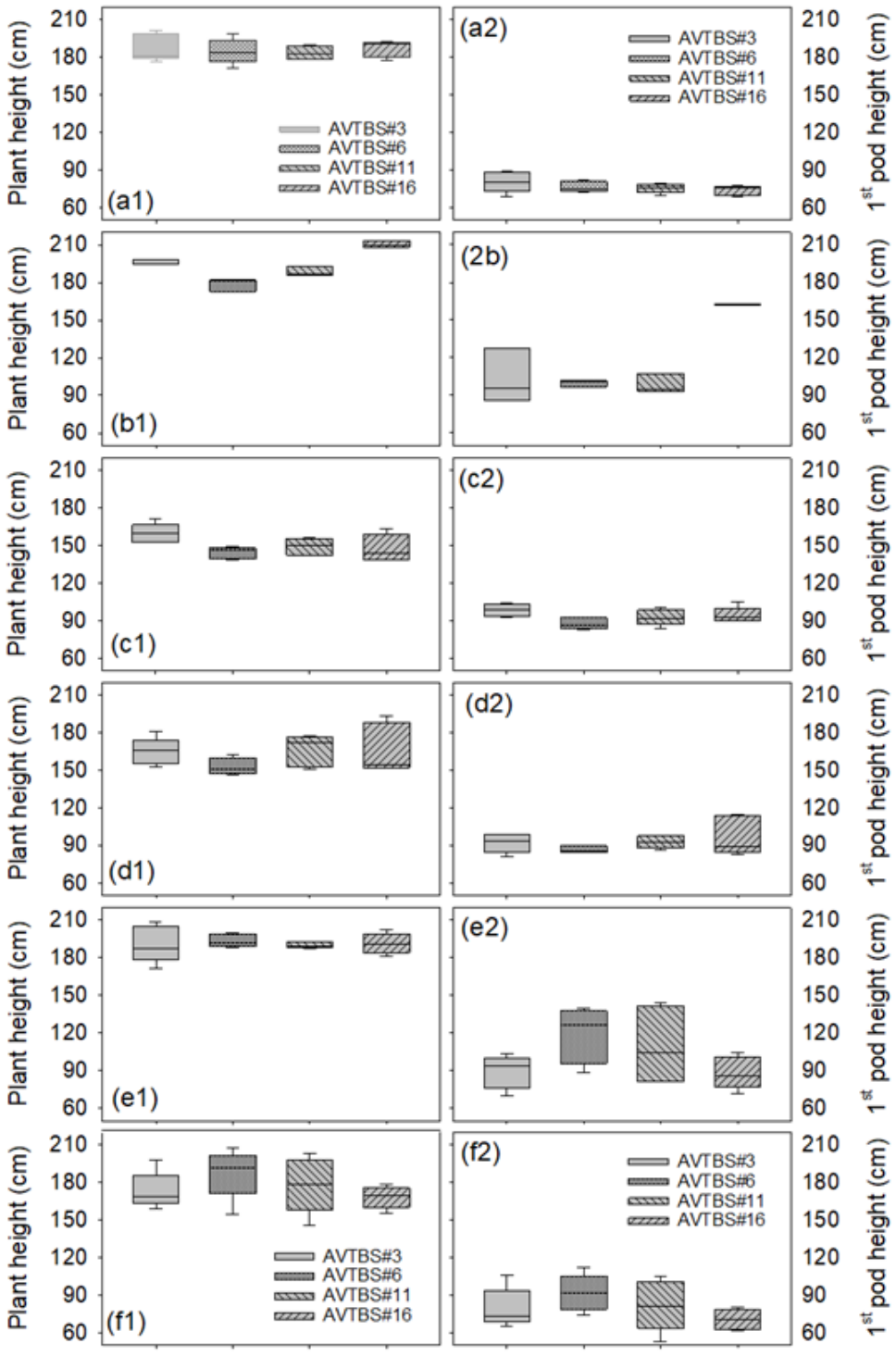


Figure 7. Plant height at harvest (column on the leaf) and height of first pod position (column on the right) for four black sesame genotypes tested at (a) Biloela, (b) Rockhampton, (c) Ayr, (d) Tully, (e) Katherine and (f) Darwin

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Yield

Seed yield

The mean sesame seed yield across the six test sites ranged from 1.37 to 3.04t/ha. The greatest seed yield was recorded in Biloela followed by Rockhampton, Katherine, Ayr, Darwin, and Tully. The seed yield between the varieties varied significantly at Biloela, Rockhampton and Darwin but did not differ between the varieties at Ayr, Tully and Katherine. AVTBS #6 and AVTBS#11 recorded higher yields compared to the other lines in Biloela and Rockhampton. In Darwin, the seed yield was greater for AVTBS#6, AVTBS#11 and AVTBS#16 compared to the yield for AVTBS#3 (**Error! Reference source not found.**).

Table 8. Seed yield (t/ha) of four black sesame varieties planted at different locations in QLD and NT during 2019-20 cropping season

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	2.748	2.83	1.578	1.392	1.076	2.011	1.826
AVTBS #6	3.315	3.23	1.596	1.393	1.687	1.991	2.073
AVTBS #11	3.177	3.06	1.786	1.569	1.672	1.714	2.045
AVTBS #16	2.933	1.81	1.424	1.111	1.682	1.926	1.750
Mean	**3.043**	**2.73**	**1.596**	**1.366**	**1.529**	**1.911**	
P value	0.064	0.032	0.395	0.435	0.009	0.498	
LSD	0.437	0.906	0.439	0.5995	0.3749	0.4570	

[P stands for probability and measures how likely it is that any observed difference between variety means is due to chance values ($p \leq 0.05$ is significant) , Least Significant Difference (LSD) calculates the smallest significant between two means as if a test had been run on those two means].

Biomass yield

The mean black sesame biomass yield across six test sites ranged from 5.05 to 7.36t/ha. The greatest biomass yield was recorded in Tully, Katherine and Darwin followed by Ayr, Biloela and Rockhampton. The biomass yield between the varieties varied significantly only in Rockhampton. Greater biomass yield was recorded by AVTBS #11, AVTBS#6 and AVTBS#3, compared to AVTBS#16 (Table 9).

Table 9. Dry biomass yield (t/ha) of four black sesame varieties planted at different locations in QLD and NT during 2019-20 cropping season

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	6.21	5.36	7.69	8.87	6.45	7.53	7.02
AVTBS #6	5.92	5.48	6.38	7.44	6.48	7.56	6.54
AVTBS #11	5.64	6.34	6.34	8.16	7.97	6.74	6.87
AVTBS #16	5.62	3.03	6.51	9.71	7.37	7.60	6.64
Mean	**5.85**	**5.05**	**6.73**	**8.54**	**7.07**	**7.36**	
P value	0.345	0.002	0.672	0.369	0.775	0.484	
LSD	0.775	1.035	2.738	2.785	3.741	1.368	

Yield attributing characteristics

Harvest index

The mean harvest index (defined as the ratio of seed yield to the total above ground biomass including seeds) across six test sites ranged from 0.106 to 0.523, showing a large difference between sites. The greatest harvest index was recorded in Rockhampton followed by Biloela, Katherine Ayr, Darwin, and Tully. The harvest index between the varieties varied significantly at Biloela but did not differ between the varieties at Rockhampton, Ayr, Tully, Katherine and Darwin. In Biloela, the harvest index was highest for AVTBS#16 followed by AVTBS#11, AVTBS#6 and lowest for AVTBS#3 (Table 10).

Table 10. The harvest index (seed yield (t/ha)/above ground biomass (t/ha) + seed yield (t/ha)

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	0.307	0.345	0.177	0.139	0.147	0.213	0.221
AVTBS #6	0.359	0.371	0.199	0.166	0.209	0.208	0.251
AVTBS #11	0.360	0.325	0.225	0.168	0.189	0.205	0.245
AVTBS #16	0.523	0.352	0.179	0.106	0.195	0.204	0.259
Mean	**0.343**	**0.348**	**0.195**	**0.145**	**0.185**	**0.208**	0.237
P value	**0.002**	0.801	0.222	0.147	0.158	0.943	
LSD	0.0252	0.1193	0.0524	0.0614	0.0568	0.0345	

Plant density (Plants/m^2)

Mean plant density across six test sites ranged from 21.9 to 44.8 plants/m^2. Plant density did not vary significantly between the genotypes in any tested site. However, the greatest plant density was recorded in Darwin followed by Ayr, and Tully. Lower plant densities (<30 plants/m2) were particularly noted in Biloela and Katherine (Table 11).

Table 11. The plant density, the number of plants per m^2

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	25.85	27.17	34.3	26.15	46.4	23.5	30.562
AVTBS #6	24.20	28.00	34.7	28.55	48.2	21.4	30.842
AVTBS #11	25.15	28.00	35.9	29.50	43.0	17.8	29.892
AVTBS #16	25.00	30.33	37.4	27.50	41.4	24.9	31.088
Mean	**25.05**	**28.38**	**35.58**	**27.93**	**44.8**	**21.9**	
P value	0.912	0.532	0.647	0.471	0.828	0.539	
LSD	5.012	5.236	5.701	4.678	17.61	10.88	

Number of pods per plant

The mean number of capsules (pods) per plant across six test sites ranged from 30 to 66 pods/plant. Pod count did not vary significantly between the genotypes. A marginal difference between varieties for pod count was noted in Rockhampton where there were more pods/plant for genotypes AVTBS#6 and AVTBS#11 when compared to AVTBS#16 and AVTBS#3 (Table 12). However, the greatest pod count was recorded in Biloela (66 pods), followed by Rockhampton (48 pods) and then by Darwin, Katherine, Tully and Ayr (30-33 pods/plant).

Table 12. The number of pods per plant

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	66.2	49.9	37.0	29.3	31.2	30.5	40.683
AVTBS #6	65.4	59.4	30.7	30.2	31.7	33.6	41.833
AVTBS #11	63.2	53.8	24.8	29.5	39.0	35.8	41.017
AVTBS #16	68.4	30.2	26.2	31.5	31.9	30.8	36.500
Mean	**65.8**	**48.3**	**29.7**	**30.1**	**33.4**	**32.7**	
P value	0.941	0.078	0.139	0.973	0.278	0.280	
LSD	18.43	22.62	11.39	11.01	9.52	6.48	

Seed test weight

Analysis of seeds for their physical (1000 seed wt, seed density, seed shape and size) and chemical properties (oil content, relative density of oil and cake contents) were assessed as a measure of seed quality parameters.

Table 13. The weight (gms) of 1000 seeds

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	3.932	4.090	3.816	3.687	3.924	3.938	3.898
AVTBS #6	4.072	4.123	3.684	3.805	4.116	3.948	3.958
AVTBS #11	4.130	4.057	3.804	3.874	4.118	3.946	3.988
AVTBS #16	3.984	3.893	3.628	3.710	4.052	3.862	3.855
Mean	**4.030**	**4.041**	**3.733**	**3.769**	**4.052**	**3.923**	
P value	0.051	0.151	0.175	0.066	0.152	0.268	
LSD	0.1465	0.2206	0.2028	0.1502	0.1930	0.1041	

The mean 1000 seed weight (g) across six test sites ranged from 3.73 to 4.05g (Table 13**Error! Reference source not found.**). There was a significant difference in the 1000 seed weight between the genotypes and locations without any significant interaction effects between varieties and locations. In Biloela, the greatest weights of 1000 seeds were recorded for AVTBS #11 and AVTBS #6 compared to AVTBS #3 and AVTBS #16. Marginal difference between varieties for 1000 seed weight was noted in Tully as genotypes AVTBS #11 and AVTBS #6 showed higher weight compared to AVTBS #3 and AVTBS #16 (Table 13). The highest 1000 seed weights were recorded in Darwin (4.05g), Rockhampton (4.04g) and Biloela (4.03g), compared to Katherine (3.92g), Tully (3.78g) and Ayr (3.73g).

Seed density (kg/m^3)

The mean seed density (kg/m^3) across the six test sites ranged from 638 to 672kg/m^3 (Table 14). Seed density varied significantly between the genotypes in Biloela and Rockhampton but not the other test sites. In Rockhampton, the highest seed densities were recorded for AVTBS #11 (678 kg/m^3) and AVTBS #6 (676kg/m^3) compared to AVTBS #3 and AVTBS #16. However, in Biloela the seed density for genotype AVTBS #11 was significantly lower (655kg/m^3) compared to all other genotypes tested at this site (Table 14). The highest seed densities were recorded in Rockhampton (672 kg/m^3) and Biloela (669 kg/m^3), compared to Darwin (657 kg/m^3), Katherine (643 kg/m^3), Tully (646 kg/m^3) and Ayr (638 kg/m^3).

Table 14. The density of seeds (kg/m^3)

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	671.1	664.07	638.6	646.5	653.2	640.5	652.3
AVTBS #6	675.2	676.50	638.4	647.0	659.2	648.2	657.4
AVTBS #11	655.0	678.21	639.0	649.7	660.9	643.0	654.3
AVTBS #16	672.7	670.98	636.9	641.6	656.3	640.9	653.2
Mean	**668.5**	**672.44**	**638.2**	**646.2**	**657.4**	**643.2**	
P value	**0.022**	**0.009**	0.896	0.583	0.451	0.345	
LSD	13.06	6.858	6.50	12.81	11.38	9.84	

Seed shape and size (mm)

The seed shape and size for the four genotypes produced from the six trial locations were measured. The seed length ranged from 3-6 mm and seed width ranged from 2-4 mm (Figure 8).



Figure 8. The seed size and colour of the black sesame seed by site and variety (Image. T.Trotter)

Oil quality

Analysis of seed for their chemical properties were assessed using indicators for seed oil content (%), relative density of the oil at 20°C and the cake outputs (%) from the oil expelling. The oil (Figure 9**Error! Reference source not found.**) and cake (Figure 10) were extracted using the oil mill for each of the replicates at each site.

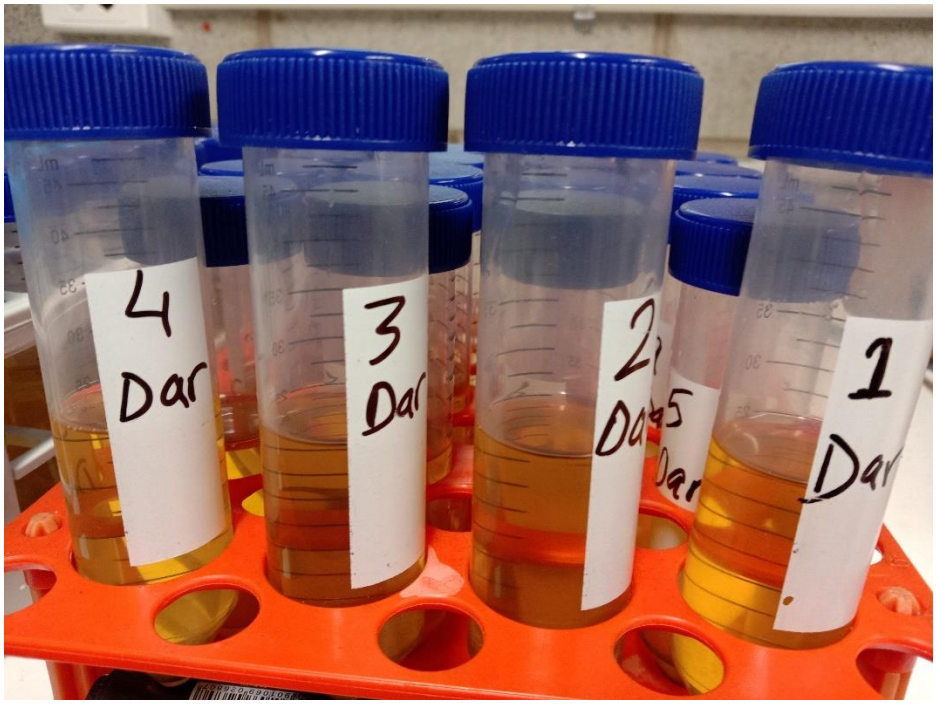


Figure 9. Oil sample extracted from each of the four genotypes from the Darwin site (Image. R. Paudel)



Figure 10. The sesame cake by-product of oil extraction, which may bring potential opportunities for extracting high value protein and antioxidants (Image. R. Paudel)

Oil content (%)

The mean oil output across the six test sites ranged from 43 to 47% (Table 15). The oil content did not vary significantly between the genotypes at any tested site. The highest oil content from the seed was recorded from the Tully samples (47%) followed by Darwin (46%), medium content from samples from Katherine (44%), Ayr (44%), Rockhampton (44%) and lowest in Biloela (43%).

Table 15. The oil content (%) of the seed

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	43.68	44.85	43.38	47.83	46.53	42.52	43.31
AVTBS #6	41.26	44.46	43.95	46.64	46.97	45.27	43.58
AVTBS #11	43.80	43.79	43.73	46.41	46.34	44.69	43.59
AVTBS #16	42.94	44.19	43.84	47.28	45.13	44.15	43.55
Mean	**42.92**	**44.32**	**43.73**	**47.04**	**46.24**	**44.16**	
P value	0.110	0.766	0.975	0.525	0.267	0.121	
LSD	2.284	2.493	2.860	2.262	1.988	2.365	

Relative density (g/cm^3) of oil (20°C)

The mean relative density of oil at 20°C across six test sites ranged from 0.884 to 0.921g/cm^3 (Table 16). This means one litre of sesame oil can vary from 884g to 921g in weight. The relative density of oil did not vary significantly between the genotypes at any tested site. The highest relative oil density (0.921 g/cm^3) was recorded from the NT (Katherine and Darwin) grown samples and the lowest relative oil density (0.88 g/cm^3) was recorded from the QLD (Biloela, Rockhampton, Ayr, and Tully) grown samples (Table 16**Error! Reference source not found.**).

Table 16. The relative density of black sesame oil taken at 20ºC

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	0.885	0.913	0.886	0.883	0.909	0.905	0.897
AVTBS #6	0.874	0.918	0.889	0.894	0.918	0.960	0.909
AVTBS #11	0.883	0.841	0.882	0.886	0.905	0.908	0.884
AVTBS #16	0.895	0.896	0.884	0.885	0.921	0.913	0.899
Mean	0.884	0.892	0.885	0.887	0.913	0.921	
P value	0.228	0.400	0.771	0.385	0.251	0.256	
LSD	0.020	0.1142	0.01743	0.01428	0.01858	0.064	

Raw cake

Cake content (%)

The mean cake turnover from expelling of seeds across six test sites ranged from 41 to 49% (Table 17). The cake contents did not vary significantly between the genotypes for any of the tested sites except Biloela. Genotype AVSBS#16 produced significantly greater cake output (50.6%) compared to other tested genotypes in Biloela (Table 12). The highest cake output from the seeds was recorded from the Biloela site (49%), whereas in all other sites, the cake outputs range between 41-43% (Table 17).

Table 17. The raw cake content (%) of the seed

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	48.77	37.51	43.80	41.86	42.44	42.29	42.78
AVTBS #6	46.84	41.05	43.60	41.84	42.53	43.82	43.28
AVTBS #11	48.84	40.81	44.93	41.79	41.91	44.80	43.85
AVTBS #16	50.60	44.84	42.41	41.22	40.34	42.92	43.72
Mean	48.76	41.05	43.68	41.68	41.81	43.46	
P value	0.019	0.105	0.460	0.975	0.141	0.226	
LSD	2.137	5.820	3.318	3.662	2.108	2.608	

4.2.4 Discussion

Varietal difference for yield

Initial results suggest that AVTBS#6 was the highest yielding variety in both Rockhampton and Biloela with AVTBS#11 performing the best in Ayr (Figure 11). The average yield was the greatest in Biloela, achieving over 3 t/ha, which was nearly double the yield in Ayr. These yields were significantly higher than the global average of 554kg/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 are generally high yielding in most of the sites. The performance of genotypes AVTBS #3 and AVTBS #16 is not consistent across Darwin and Tully, as in the former site AVTBS #3 was the lowest performer whereas, in the later, AVTBS #16 was significantly lower performer (Figure 11).

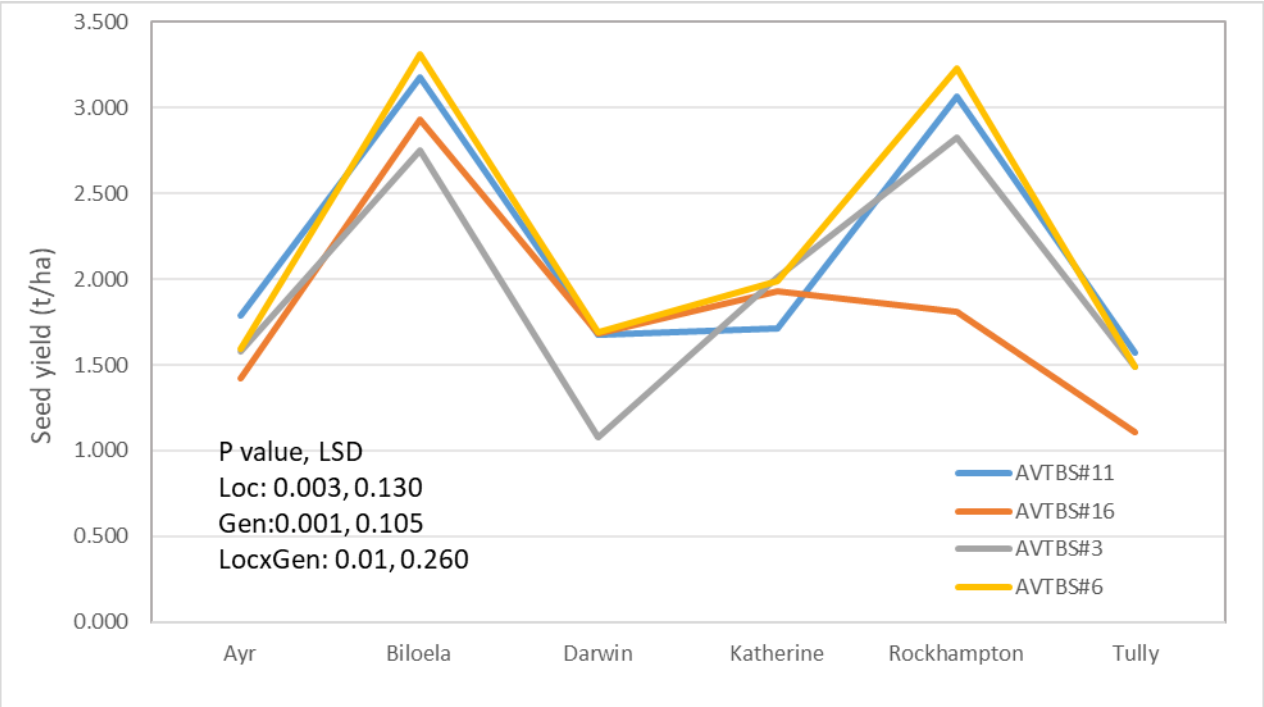


Figure 11. The genotypes x location (environment) interaction for seed yield (t/ha) for four sesame genotypes tested over six different production environments across QLD and NT

The seed yield data presented for black sesame are as much as twice the yield reported by Bennett (2014) for those white sesame genotypes tested between the 1999-2003 seasons. All yield data presented in this report are from manual hand-harvested samples. The yield data presented in the Bennett (2014) report does not include the method of harvesting employed for the trial crops.

Environmental impacts on yield

The yields in Biloela and Rockhampton are much greater than those recorded from northern QLD and NT. As the crop was planted under similar fertilizer management plans with supplementary irrigation, the low yields in northern Australia are possibly due to higher temperatures or later planting. In the early trial by Bennett (2014) the seed yield in NT was greater than the yield recorded in QLD. However, it is difficult to differentiate the effect of location on yield as the Bennet (2014) trial utilised different genotypes in the NT and QLD.

Seed quality associated with varieties and growing conditions

Seed quality assessments based on the weight of 1000 grains and oil content were significantly different due to varieties and locations. There were no significant variety x location interaction effects recorded for these two parameters. The genotypes AVTBS#6 and AVTBS#11 recorded significantly higher 1000 seed weight compared to the other genotypes. The seeds produced in Ayr and Tully recorded the lowest 1000 seed weight compared to the other locations. The lowest 1000 seeds weight could be due to fertiliser leaching associated with high rainfall in these two locations during the grain-filling stage.

The oil output across six test sites ranged from 41 to 47% (Table 15). The oil content did not vary significantly between the genotypes at any tested site. The highest oil content from the seed 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 recorded in Biloela (43%). In the previous work by Bennett (2014), the oil content of the white sesame varieties grown in the NT was 54%, much greater than the oil content of black sesame tested in this trial.

4.3 Black Sesame Verification Trials - Summer Crop (Year 2)

4.3.1 Introduction

This section describes the results of black sesame field trials undertaken over the summer of 2020-2021 season. The verification trials were grower-managed larger plots (up to 1 ha per variety) in the farmers field, with 1-2 farmers at each site. Key phenological and yield data were collected over the cropping period from the different agro-ecological zones which allowed for the evaluation of the suitability of black sesame production under farmer-managed conditions.

4.3.2 Materials and methods

Trial locations

Sesame verification field trials were conducted at seven different locations across QLD, NT and WA. The farmer-participatory trial involved evaluation of one black sesame variety per farm as a larger field trial for the verification of results from initial year 1 evaluations. The trial locations included four sites in Queensland, were planted with Jang Planter (Figure 12) two sites in the Northern Territory and one site in the western Australia were planted with cone seeder.



Figure 12. Black sesame verification trial planting at Ayr, in sugarcane-based farming system, in the summer season of 2020/21, using the four-row Jang Seeder (http://bestmadeinkorea.com//product-14511/Seeders/Jang-Tractor-Walking-Tractor-Seeder-JDT-.html) (Image. S. Bhattarai)

The multi-location (environment) trials evaluated the stability of black sesame seed yield (t/ha) for selected sesame genotypes under farmers management conditions and these data were captured over seven different production environments across three states in northern Australia (QLD, NT and WA).

4.3.3 Results

Phenology

The crop duration was shorter in the NT and WA, than the sites in QLD. There was longer crop duration in Tully and Ayr compared to Biloela and Rockhampton, which was particularly associated with longer wet weather conditions in these sites during the crop season, and delayed access to paddocks for crop harvest (Table 18).

Table 18. Crop planting, cropping system and maturity period of black sesame varieties planted at various locations in QLD, NT and WA during 2020-2021 cropping season

Site	Participant/ Grower	Cropping system	Variety	Area (ha)	Planting date	Irrigation	Date of harvest	Days to harvest
Biloela	Farm1(IK)	Melons, forage	AVTBS#6	1.0	28/12/20	Overhead/ Drip	30/04/21	122
	Farm2(ND)	Mungbean	AVTBS#11	1.0	14/01/21	Rainfed	25/05/21	131
Rockhampton	Farm1(PF)	Cotton	AVTBS#6	0.6	22/12/20	Rained	25/05/21	123
	Farm2(ARG)	Forage	AVTBS#11	1.0	21/12/20	Sprinkler	29/04/21	145
Ayr	Farm1(FM)	Sugarcane	AVTBS#6	0.6	02/12/20	Furrow	29/04/21	148
	Farm2(PP)	Sugarcane	AVTBS#11	0.6	02/12/20	Furrow	05/05/21	154
Tully	Farm1(GB)	Sugarcane	AVTBS#6	1.0	21/01/21	Rainfed	04/06/21	135
	Farm2(BD)	Sugarcane	AVTBS#11	1.0	04/12/20	Rainfed	14/04/21	131
Katherine	KRS1(Farm)	Sorghum	AVTBS#6	0.75	14/01/21	Sprinkler	13/05/21	119
	KRS2(Farm)	Sorghum	AVTBS#11	1.0	14/01/21	Sprinkler	13/05/21	119
Darwin	CPRF1(Farm)	Sorghum	AVTBS#6	0.5	21/01/21	Rainfed	20/05/21	119
	CPRF2(Farm)	Sorghum	AVTBS#11	0.5	21/01/21	Rainfed	20/05/21	119
Kununurra	Farm1(GB)	Cotton	AVTBS#6	1.0	30/11/20	Furrow	29/03/21	119
	Farm2(BD)							

Crops in the verification trials were machine harvested in most of the sites with the header available in the local area. A Kingaroy Engineering Works (KEW) research plot harvester was used for Ayr, Tully and Katherine, whereas an Wintersteiger (Austria) research plot harvester from DAF Emerald was utilised for trial harvest at one farm (IK) in Biloela and Rockhampton. The crops at Darwin and WA were hand harvested due to weather impacts on the crop and limited access to harvesting equipment in the field. A second farm in Biloela (ND) adapted commercial scale grain harvesters (CASE II) for the sesame trial harvest through the local harvest contract (CE & D Jensen grain harvesting services) from Callide, Biloela (Figure 13).

Seed and oil yield

Machine-harvested seed yield ranged from 91-1088 kg/ha. The highest yield recorded was at Biloela (Figure 13) followed by Rockhampton, Darwin and least in Tully.

The machine harvest in Ayr was impacted by wet weather, that did not allow the plot harvester access to the trial site due to excessive soil moisture.

At WA the excessive weed levels prohibited access for the plot harvester for harvesting by machine.

The hand harvested yield ranged from 306-2607 kg/ha. Significant losses were noted in the machine-harvested crops. Machine harvest loss ranged from 44% to 82% of the hand-harvested yield. Unusual wet weather, excessive vegetative growth, and header adjustments were some of the issues related to poor yield performance in machine harvest.



Figure 13. CASE II header contractor harvesting black sesame trial crop in Biloela, QLD (Image. S. Bhattarai)

Seed quality

The 1000-seed weight ranged from 3.51 - 4.22g; filtered oil content ranged from 38 - 51% (highest in WA and lowest in the Biloela samples); and cake output ranged from 43% to 49% of the seed weight (Table 19).

Table 19. Seed yield (kg/ha), seed quality and oil outputs of two sesame varieties planted at different locations in QLD, NT and WA during 2020-2021 cropping season.

Site	Participant/ Grower	Variety	Machine harvested yield (kg/ha)	Plant density (#/m^2)	Sample plot yield (kg/ha)	Loss in machine harvest (%)	1000 seed wt (g)	Oil (%)	Cake (%)
Biloela	Farm1(IK)	AVTBS#6	1088	82	2607	58	3.85	41.7	46.7
	Farm2(ND)	AVTBS#11	460	17	825	44	3.77	37.7	48.6
Rockhampton	Farm1(PF)	AVTBS#6	251	19	878	71	3.62	39.7	49.2
	Farm2(ARG)	AVTBS#11	332	98	613	46	4.16	40.2	49.0
Ayr	Farm1(FM)	AVTBS#6	NA	14	407	NA	4.22	43.6	46.8
	Farm2(PP)	AVTBS#11	NA	39	472	NA	4.08	39.7	47.6
Tully	Farm1(GB)	AVTBS#6	190	NA	341	44	4.54	40.6	44.6
	Farm2(BD)	AVTBS#11	91	NA	498	82	4.11	42.5	41.5
Katherine	KRS1(Farm)	AVTBS#6	116	33	311	63	3.51	43.6	43.1
	KRS2(Farm)	AVTBS#11	85	23	306	72	3.68	44.6	45.0
Darwin	CPRF1(Farm)	AVTBS#6	318	62	NA	NA	4.20	40.5	47.2
	CPRF2(Farm)	AVTBS#11	176	49	NA	NA	4.12	41.2	48.4
Kununurra	Farm1(GB)	AVTBS#6	NA	13	1023	NA	3.98	51.1	43.0
	Farm2(BD)								

4.3.4 Discussion

The black sesame seed yield in verification trials varied significantly between sites. The results of the verification trials also followed similar trend as in the initial evaluation trials where the highest yield was recorded in the most southern site of Biloela, followed by Rockhampton and yield decreased significantly in northern sites. In all trial sites where machine harvest was carried out, the crop was desiccated at physiological maturity with glyphosate to hasten the defoliation, synchronise the seed maturation, and dry down the moisture. The seed moisture content at harvesting was 6-12%. The machine harvesting of the crop recorded significantly higher shattering, with machine harvest loss ranging from 42-88% of the seeds in the crop.

The seeds harvested from different sites were cleaned and graded by Allenden Seeds, Goovigen, Biloela QLD using the Mungbean gravity seed separator for cleaning, grading of the seeds.

The difficulty for control moisture at harvest due to crop maturity coinciding with wet weather conditions impact greatly the postharvest seed quality.

Large harvesting loss (44-82%) due to the shattering nature of the current varieties in the trials reflects the large yield gap between hand harvested yield in year 1 and machine harvested yield in year 2.

Lack of dedicated sesame seed cleaning, grading and sorting facilities and equipment are some of the challenges for post-harvest operations for black sesame production in northern Australia.

Broadacre sesame industry in Australia requires sesame production completely mechanised. The yield recorded in some of these trials are comparable or higher than the national and farm average yield in the major black sesame producing countries, e.g Myanmar (583.3 kg/ha national average yield), where all operations are manual, and such crop are still economically viable due to low labour cost (Sirany and Tadele, 2022). However, for Australian farming system, full mechanisation options for farming and high yields are required for the sesame crop to be profitable.

4.4 Black Sesame Verification Trial - Winter Crop (Year 2)

4.4.1 Introduction

Sesame, a tropical crop, is currently grown as a summer season crop in Australia. The winter season in northern Australia remains warmer; hence, it is unlikely that the winter planted sesame crop face chilling injury. A feasibility study of growing sesame as a winter season crop was evaluated at two northern Queensland trial sites in year 2.

Northern Australia allows for planting of sesame throughout the year due to warmer temperature windows in the winter months, unlike southern Queensland and southern Australian conditions. This can bring a new opportunity for growing sesame throughout the year in northern Australia. With the wider window for planting, the crop can fit better into the wider range of farming systems, can be produced as an off-season commodity, and also minimize the pressure on the processing, cleaning, grading facilities and supply chain during the summer months.

4.4.2 Materials and methods

Black sesame was planted in north QLD (Ayr and Tully) on 21 July 2021 and 28 July 2021 respectively using AgriVentis black sesame variety AVTBS#11. The sesame at Ayr was planted as an irrigated crop, whereas the sesame at Tully was planted as a rainfed crop, both under the sugarcane-based farming system (Figure 14). The crop at Tully did not establish well due to residual herbicide usage in the previous cane crop (Pers comm with C Rixon). Therefore, the yield data for winter planted sesame crops is presented only for Ayr in north Queensland.



Figure 14. Winter sesame planted with Jang planter, double row configuration 50cm apart in a single sugarcane bed (Image. S. Bhattarai)

4.4.3 Results

Phenology

The winter-planted crop established well (Figure 15) at Ayr, producing shorter plant height and early maturity compared to summer-planted crop of sesame in the same region.



Figure 15. Early establishment of winter planted sesame showing the variable plant density, which was not due to temperature but rather the poor control of the planter (Image. S. Bhattarai)

The trial was harvested on 5 November 2021 at Ayr with a crop period of 105 days after sowing, whereas the crop at Tully was completely impacted with residual herbicide damage at the early stage of the crop hence the crop did not reach maturity.

The winter-planted crop showed greater promise in northern Queensland, particularly at Ayr, with the positive effects of cooler weather during the vegetative growth period impacting more desirable plant structure (control of height due to shorter internode lengths) and crop growth at the early establishment stage of the crop. Shorter plant height also eased header operation at harvesting stage.

Seed yield

The crop harvesting at Ayr coincided with the wet weather for this season, hence there was an effect of wet weather on the seed quality (Figure 16). Prolonged wet and humid conditions during harvesting meant that a seed moisture content of 6% could not be achieved. The crop was machine harvested with a KEW header. The machine harvested yield of sesame was 512 kg/ha. The header loss was not formally assessed but according to the operator of the header, the estimate was 30-40% of the total seed yield was harvested.



Figure 16. Winter planted sesame defoliated for harvesting. The cooler weather effects on early vegetative growth is related to reducing the internode length, therefore, it displayed reduced plant height compared to summer-planted sesame (Image. S. Bhattarai)

4.4.4 Discussion

This was the first trial of winter-planted sesame crops in northern Australia. Very low insect/pests and disease pressure were observed for winter planted crops compared to summer planted crops in the same area and other regions. The low disease and pest could also be due to the lack of inoculum from previous and surrounding crops, as there were no other sesame crops in the vicinity, and it was also the first season of sesame growing in this locality. The low pest pressure also could be due to cooler and drier weather conditions during the crop period.

Winter planted sesame crops definitely showed some promising results in terms of control of vegetive growth and plant height that have positive effects on yield formation as well as ease of harvest management by the header. Kamzaki et al (2008) in Japan also observed a similar response due to short day (10-h light/14-h darkness) treatment decreasing the final stem-length relative to the natural day length (14.1～13.4-h), without affecting the length of the stem-elongation period. The short-day treatment, however, shortened the duration to the first flower and lowered the first flowering-node position. It prolonged the flowering period, but decreased the flowering-node number on the main stem resulting from the slower rate of increase in nodes

with flowers. In our trial, the crop maturity was also enhanced for winter planted crop as the temperature sharply increased in October-November after the flowering stage.

The crop was desiccated with glyphosate at physiological maturity to ease the harvesting by machine. However, the harvesting time coincided with wet weather conditions, causing significantly higher seed moisture contents at harvest. The harvested seeds were stored in the cool room, for an extended period, at Ayr before it could be transported to Rockhampton and Biloela for general seed cleaning and grading. The harvest loss estimated by the header operator was smaller compared to the summer season crop (same header and operator were used for harvesting of summer and winter planted sesame in Ayr), but it was still up to 30-40% of the total seeds in the plants. These trial results suggest that crop management to some extent reduces the harvesting loss in these black sesame varieties but shattering resistant varieties will be of great advantage for broadacre sesame farming and improving the gross margin for the growers. Sesame can be grown in a wide range of farming systems in Northern Australia. This brings the opportunity for adapting season into various cropping systems but can also bring some challenges about the herbicides residue from the previous crop as seen in the case of Tully in verification trials and also in the widely reported literatures covering range of other cropping systems in other sesame growing regions in the world (Langham et al., 2008).

4.5 Black Sesame Commercial Crop Trials - Year 3

4.5.1 Introduction

Black sesame varieties tested in year 1 and year 2 consistently recorded very high shattering when machine harvested. Two new seed lines of non-shattering black sesame have been introduced in Australia by AgriVentis and were released for field evaluation to access the field performance and their adaptability for the machine harvesting.

4.5.2 Materials and methods

AgriVentis black sesame seed lines (AVTBS#6) were planted in Coastal Plain Research Farm in NT as late planted crop (April-May) in 2022 to evaluate the commercial yield potentials of this line.

Non-shattering black sesame line (S57B) was planted at Rockhampton (25 Jan 2022) as a commercial trial for seed bulking to support a larger area of commercial production for 2023. Similarly, another new seed line of non-shattering black sesame (S56) was planted in Biloela (28 Jan 2022) as summer season black sesame crop for major seed bulking.

AgriVentis introduced a new Monosem precision planter (Figure 17), and this planting equipment was used for planting sesame under the minimum and zero tillage system, and the crop was harvested using ZURN 150 Research Plot Combine Harvester (Figure 18).

4.5.3 Results

The crop duration for the late summer planted AgriVentis sesame variety (AVTBS#6) at Coastal Plain NT was 111 days and seed yields were 325 kg/ha. The summer season planted crop in Central Queensland, Rockhampton that received some supplementary drip irrigation whereas the crop at Biloela was grown as rainfed under the zero-tillage system. Flowering commenced between 45-55 days after sowing and harvesting commenced 122-135 days after sowing.

The machine harvested seed yield of the trial crop at Rockhampton was 653 kg/ha for variety S57B whereas a very low seed yield (28.25 kg/ha) under zero tillage rainfed systems was recorded for the black sesame variety S56 in Biloela. With respect to the physical quality of the seeds, the test weight of these two new non-shattering sesame genotypes, S57B and S56 were 3.81 ± 0.18 and 3.73 ± 0.20 g/1000 seeds respectively. Likewise, the seed density for these two lines 631 ± 12.6 and 642 ± 13.9 kg/m^3 of the seeds for varieties

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.

4.5.4 Discussion

The control of depth and singulation of seeds was excellent with the Monosem seed planter (Figure 17). Clogging of the seed plate was noticed due to debris in the seed mixture. Clean seeds and use of a pressurised air nozzle to unblock the clogged seed plate practiced to keep the planter in the correct working condition. The machine harvesting with combine plot harvester was effective and as such, there was no significant seed loss by machine harvesting. However, the seed yield was very low in Rockhampton due to significant damage by the capsule pod borer. The low yield in Biloela with a zero till system was associated with poor plant establishment/emergence, significant weed pressure and dry summer conditions with the area receiving far less than the longer-term season average during the crop growing season. The seed quality of the new non shattering black sesame lines was comparable to those of the AgriVentis lines in terms of the test weight, density and oil contents.



Figure 17. Monosem seed planter in use for planting sesame seeds under different soil conditions (Image. P. Foxwell)



Figure 18. New Zurn 150 research plot harvester with sesame header used for harvesting of non-shattering sesame lines in the trials (Image. A. McDonald)

5. WEEDS, PESTS, DISEASES & POST-HARVEST CHALLENGES

5.1 Post-Harvest Challenges

Sesame seed needs to be harvested at a low moisture content of just 6% or less. Achieving the desired level of moisture content in the seed is a major challenge for growers. The crop harvest period needs to be very dry to achieve such low seed moisture content. The amount of leaf/biomass content at harvest also influences the seed moisture content, hence, complete defoliation/desiccation is suggested for harvesting dry seed. The sesame market also demands very high seed purity - for example, in Japan Mitsui Ltd asks for 99.7% purity when exporting black sesame to their markets.

Sesame harvested under unfavourable conditions results in significant amounts of debris in the seed lots, which can create additional challenges for the seed cleaning/grading facilities. On-farm primary seed cleaning machine (Figure 19) can reduce this burden as well as reduce the transport cost of the primary cleaned seeds from the farm to the final cleaning/grading operations and pack house.



Figure 19. The on-farm seed cleaning machine, VAL-1500-6, with the capacity of cleaning 25 tonnes of seed per hour (Image. D. Frahn)

The application of Grain cleaner VAL-1500-6 (Figure 19) was assessed in the grain cleaning lab facilities of Frahn Engineering Lab at Drung VIC. The theory and operation procedure for the VAL-1500-6 grain cleaning equipment is summarised in the box diagram (Figure 20).

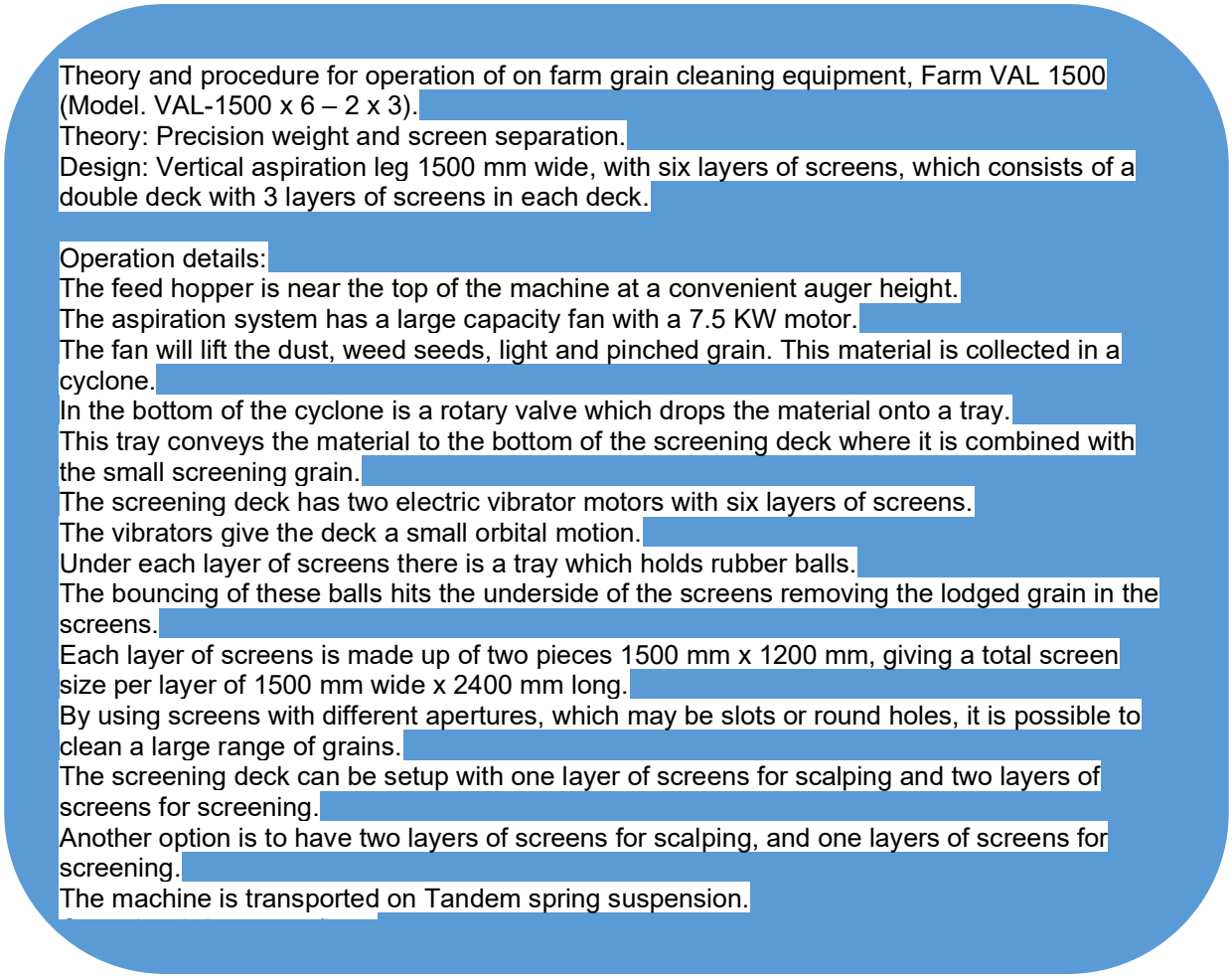


Figure 20. Theory and procedure for the operation of on-farm grain cleaning equipment, VAL 1500-6-2x3 Model

The lab grain cleaning equipment was set up with a layer of screens for scalping and layers of screens for screening that can be adopted in the field grain cleaner. The setup of the screening deck with respect to the layer of screens for scalping and the layer of screens for screening in the lab cleaning machine was as below:

Aspiration. Light materials separation.

Layer 1. Top scalper screen, 3.0 mm round hole. Coarse Scalped material.

Layer 2. Second Scalping Screen, 2.5 mm round hole. Scalp off weed seeds and large seeds.

Layer 3. Screening Screen, 1.9 mm round hole. Good grain

Layer 4. Second Screen, 1.8 mm round hole. Smaller pinched seed.

Bottom Floor. Fine losses. Visual inspection Small pinched seed and empty skins.

Alternative screen options for black sesame seeds. Layer 3, Screening screen 2.0 mm. Layer 4, 1.8mm.

5.2 Results

Table 20 summarizes the seed cleaning results for two small test batches (250-500 g) of uncleaned black sesame seeds (received directly from research plot harvester) with different scalper and screen arrangement in the laboratory seed cleaning machine.

Table 20. Laboratory grain cleaning test results of the black sesame seeds after first and second stage cleaning in the laboratory grain cleaning equipment (seed received from winter planting verification trials at Ayr)

Cleaning stage	Screen types	Weight (g)	Weight (%)	Remarks
Raw uncleaned seeds		500	100%	
Aspiration heavy materials		191	38.8%	215 Grams
Aspiration light dust		24.5	5.0%	Machine aspiration
Scalper	Above 3.00 round hole	12	2.4%	Coarse material
Screen	Below 3.00 round hole above 1.38 square hole mesh	258	52.4%	Seed still contaminated.
Fines	Below 1.38 square mesh	6.5	1.3%	Rubbish: screen plugs quickly
Sub total		492	100.0%	
Error (moisture loss?)		8	1.60%	Inaccurate scale, moisture loss?
Repeated screening of the seed cleaned from first stage cleaning as above (table 15, row 6- seed still contaminated) and seed test screen results.				
Cleaning stage	Screen types	Weight (g)	Weight (%)	Remarks
First stage clean seed		200	100%	Machines screen Layers
Aspiration			-	Aspiration. Not shown
Scalper Coarse	Above 3.00 mm round hole screen		-	Screen Layer 1. Not shown
Scalper Fine	Above 2.5 mm round hole screen	1.5	0.75%	Screen Layer 2
Top screening screen	Above 1.9 mm Round Hole screen	191	95.5%	Screen Layer 3
Bottom Screening screen	Above 1.8 mm round hole screen	3.3	1.6%	Screen layer 4
Fines	Below 1.8 mm round hole screen	4.2	2.1%	Bottom floor
		200		
Notes: Machine capacity limited by the aspiration. • The Rotary valve at the bottom on the cyclone for the Aspiration will be the limiting capacity of the cleaning process. • Approximation capacity 1 - 2 TPH of harvested product				

Data sheet for use in optimisation of the screen and aspiration settings for the on-farm seed cleaning/grading unit



Figure 21. The seed samples from the harvest header (top) and when separated into different size to remove debris (>2.4 mm), and fine debris and sub-size seed (<1.8 mm). This separation requires the correct screens in the on-farm seed cleaning machine (Image. D. Frahn).

Optimising the screen setting can significantly improve the efficiency of on-farm seed cleaning units (Figure 20). A pilot run of the seed cleaner using harvested seed from the KEW header showed that the recovery of clean seeds of about 38.2% (119g from 500g uncleaned product), as reflected in Figure 21 and Figure 22. 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 stage. The trial showed that results varied according to the incoming sample quality.



Figure 22: Cleaned seed following the correct use of screens and aspiration in the VAL-1500-6 (Image. D. Frahn).

The cleaned seed samples from the screens above will need additional cleaning with a Gravity Table and the final process being a colour sorter. The result would be high quality seeds that meet market specifications for human consumption.

For the level of cleaning required for this sample of black sesame seed, the machine capacity has been estimated to be 1-2 tonnes per hour of harvested products. The greater the debris contamination, the lower the efficiency of the cleaning equipment (Table 20). This trial data provides the guide for assessing the setting of screen size and aspiration for the VAL-1500-6 machine.

5.3 Discussion

The results from a lab-based grain cleaning machine showed that multistage cleaning is required for sesame seeds that are highly biomass contaminated at harvest. The two test results presented above (Table 15) show the clean seed recovery of only 38% for the seed lot received from winter planting verification trials conducted in Ayr during the winter season of 2021 season. The capacity rating of the cleaning machine is compromised when the seed sizes are smaller and contamination levels are very high. However, the on-farm primary and secondary seed cleaning will improve the seed presentation to grading and colour sorting stage as well as reduce the transport cost of raw seeds from the farm to the final grading/colour sorting operations.

5.4 Insect Pests

The major inspect pests recorded in different sites during the black sesame growing period includes:

- Leaf webber (*Antigastra catalaunalis*),
- Aphids (*Aphis gossypii*),
- Mealybugs (*Phenacoccus spp*),
- Thrips (*Frankinella spp*),
- Green vegetable bugs (*Nezara spp*),
- Pumpkin beetle (*Aulacophora hilris*),
- Shield bugs (*Oncocoris spp*),
- Gall fly (*Asphondylia sesami*),
- Heliothis borrer (*Helicoverpa* spp) and
- Sphinex moth (*Acherontia styx*).

5.4.1 Crop damage by insects

Mealybugs were problematic at Katherine and were also present in Biloela and Rockhampton. Insect pest pressure was greater in the northern locations compared to the southern. Most of the insect pests were identified in Darwin. Although no measures of crop damage were taken, there was no visual evidence of significant damage to the crops at any of the sites. While a wide range of sesame insect pests have been reported in sesame growing areas in the world, only the above were recorded during three years of trial crops in northern Australia.

Crop infestation by the insects was minimal in all trials during the first and second years. However, crop damage by leaf webber was severe at Rockhampton in the third year for the commercial black sesame trial on the non-shattering variety (S57B), with estimated yield loss of 25-33% by the leaf roller.

No detailed scoring for individual insect damage was carried out, therefore, the data is based on visual observations, collection of insects and crop samples and identification of the insects with the support of entomologists from Department of Industry, Tourism and Trade - Northern Territory Government (NTDITT) and Department of Agriculture and Fisheries, Queensland (QDAF).

5.4.2 Beneficial Insects

A number of beneficial insects were identified at each of the locations, including a variety of spiders in all sites. Assassin bugs were present at Rockhampton and Ayr. Butterflies, European honey bees and native bees were prevalent at all sites and were effective pollinators during flowering. Predatory shield bugs and pirate bugs were also found at the Darwin site.

5.5 Diseases

Diseases associated with black sesame recorded at different sites included the following:

- Charcoal rot (*Macrophomina phaseolina*),
- Alternaria leaf and capsule spots (*Alternaria sp.*),
- Cercospora leaf spots (*Cercospora sesami*),
- Powdery mildew (*Erysiphe cichoracearum*),
- Phytophora blight (*Phytophthora nicotianae*),
- Bacterial leaf spot (*Xanthomonas campestris*),
- Sclerotinia (*Sclerotinia sp.*),

Among these sesame diseases, charcoal rot and phytophotra leaf blight were noticed particularly in the early establishment phase at all trial sites.

Sesame is prone to root and stem diseases associated with waterlogging, while damping off diseases can also occur in humid environment. While seven diseases affecting sesame have been identified, two common diseases were *Corynespora cassiicola* (target spot) and *Pseudocercospora sesami* (large cercospora leaf spot), which severely affected seed yields when crop maturity coincided with the wet weather conditions at the Coastal Plains trial site in Darwin. Cercospora leaf spot caused large spots on the foliage which were dull brown in colour, and irregularly shaped. The spots often coalesced, collapsing portions or entire leaves on susceptible cultivars during humid conditions. Target spots first appeared as dark (often purplish) spots on leaves, stems and pods. As spots enlarge, they developed lighter-coloured centres.

The disease issues in Darwin occurred in late March and early April on Jan-Feb planted crops. Late in-season rainfall resulted in various fungal spots on the leaves and pods and some wilt due to *Sclertotium rolfsii* was noted in some plants.

Most of the foliar disease pressure was noticed with the sites experiencing wet weather conditions, as experienced in Darwin. Although no measures of crop damage were taken, nor the scoring for each of these disease symptoms were carried out, there was no visual evidence of significant damage to the crops at any of the sites. While a range of sesame diseases have been reported from sesame growing areas in other parts of the world, only those listed above were recorded during three years of trial crops in northern Australia.

5.5.1 Crop damage by diseases

Crop disease infestation and damage were minimal at all sites except Darwin during the three years of trials. However, the challenges at crop establishment impacted by charcoal rot, and other root rot diseases such as phytophthora were a concern at all trial sites for all varieties. This included the commercial Sesaco non-shattering variety, where plant loss in the early establishment stage was severe, resulting in thin canopy cover in the field influencing the weed dynamics and seed yield.

No detailed scoring for individual diseases damage was carried out, therefore, the data is based on visual observations, collection of diseased plant samples and identification of the sesame disease by the pathology lab services of Queensland's Department of Agriculture and Fisheries and the University of Southern Queensland's plant pathology team.

5.6 Other Challenges

5.6.1 Weather damage

Late season winds impacted the Coastal Plain Research Staton site in Darwin NT, causing crop lodging (Figure 23). The lodging could be permanent or temporary, but at this site, after defoliation the lodged crop recovered. The lodged crrop present challenges for mechanical harvesting, and the seed quality of the lodged crop is generally compromised.



Figure 23. Wind damage at the Coastal Plains Research Station in Darwin. (Image. C. Moore)

Wet weather damage was also recorded in the black sesame verification trials at Ayr where both summer and winter planted crops suffered significant loss of yield and quality due to wet weather conditions during harvest. The wet weather effects were more prominent in the mature crop in heavy clay soils than lighter soil, as drying out of the field was much longer and access to field for harvesting was delayed.

The year one trial at Biloela also experienced a hail storm, however, the sesame crop did not record any significant damage.

5.6.2 Other pests (Birds, Rodents and Animals)

The impact of birds, rodents, wallabies, and pigs was not noticed in the trial plots. Introduction of new grain crops in northern Australia has often been challenged by these pests but sesame appeared to be the least preferred option for these pest species.

5.6.3 Weed control and herbicides residues

Sesame is a broadleaf crop, unlike many other grain crops. Most of the herbicides applied to the previous crops generally do not cause problems, but if sesame is to follow a previous crop in the same paddock that failed, there are potential problems associated with the herbicides used in the previous crop- impact of herbicide residue (Langham et al., 2008).

No problems – Generally no problems with regular herbicides e.g., alachlor, diuron, linuron and metolachlor. Burn-down herbicides such as glyphosate and glufosinate are used widely. 2,4D and other phenoxy herbicides have been used for early burn-down, but if used just prior to planting or after planting/before emergence, they can damage the stand.

Few problems - Sesame following cotton (hailed out) planted after trifluralin, pendimethalin, and pyrithiobac. Normally, by the time of the cotton hail out, these herbicides are not as potent. Using these herbicides, just prior to planting, has been reported to reduce stands (Langham et al, 2008).

Mixed results – There have been mixed results reported after prometryn. Sesame crop following peanut that used imazapic or imazethapyr, particularly in years of low rainfall, the sesame stands was reduced substantially (Langham et al., 2008).

Poor results - Wheat herbicides (in the sulfuron family such as Amber, Glean, Ally, Finesse, and Assert) applied to control broadleaf weeds can cause injury ranging from little damage to complete stand destruction. Corn and sorghum herbicides, such as atrazine, are generally detrimental (Langham et al., 2008).

Suggested practices - Monitoring of rainfall or irrigation since the herbicide application is crucial as the use of these herbicides could have been dispersed, diluted, or moved from the sesame root zone. A rule of thumb, conduct a field trial by hand planting sesame in various locations of the herbicide treated land to test emergence before planting trials or commercial scale production if the plot is suspected to have herbicide residues (Langham et al., 2008).

As a precautionary note, it is suggested to be careful with newer, longer residual herbicides in previous crops - if cotton is NOT OK on the label, trying it for sesame is a big risk. Similar suggestions are to avoid herbicides that are very selective to specific broadleaf vegetables and lethal to other broadleaf species (Langham et al., 2008).

5.6.4 Physiological disorders

At both the Biloela and Rockhampton sites, a small number of distorted, thickened and green flowers and bunching of leaves symptoms were noticed in some plants (Figure 24). Only one plant at each site was identified with these symptoms in the first season of the initial evaluation trial. However, the intensity of these symptoms was greater in the following years in the verification and commercial trials. The disease was best described as looking like bunchy-top, associated with phytoplasma infestations. However, the diagnosis of the causal agent needs to be confirmed with laboratory tests. and leaf and plant symptoms associated with different physiological disorders



Figure 24. A flower distortion and leaf bunching found at Biloela and Rockhampton (Image. S. Bhattarai)

6. CONCLUSIONS AND RECOMMENDATIONS

The Spicing up Northern Australia project successfully carried out black sesame varietal evaluation, verification, and commercial scale production trials across various locations of northern Australia over three years of the project, following growers and industry participatory approach generating practical industry outcomes.

The major achievement of the project includes a detailed assessment of the adaptability of black sesame varieties across northern Australia that demonstrated black sesame production is technically feasible in as a summer season crop. The project also established the opportunity for winter season sesame production in Northern Australia, which brings greater market advantage and greater adaptability of sesame to different farming systems.

The research also documented key diseases, insects, pests, physiological disorders and weed challenges that provide a basis for developing a compendium of sesame insect pests and diseases.

Sesame being a small-seeded crop, faces challenges for crop establishment particularly for rainfed farming, therefore, further studies to improve sesame early establishment is suggested

post-harvest seed cleaning challenges. The research optimised the operating conditions for black sesame in mobile field grain cleaning equipment Frahn VAL-1500-6 that produces an acceptable level of seed cleaning on the farm.

An economic analysis of black sesame production in Central Queensland to evaluate its gross margin and sensitivity to price and yield fluctuations revealed that seed yields of 0.31 tons/ha, 0.27 tons/ha and 0.25 tons/ha were required to breakeven at the price of A$1600/ton, A$1800/ton and A$2000/ton of seed respectively.

In spite of the yield potentials of current black sesame varieties (AVTBS #6 and AVTBS#11), these lines showed significant shattering by machine harvest. The shattering loss of as high as 30-81% makes these varieties very susceptible to seed loss by mechanical harvester. Therefore, the search for non-shattering high yielding black and white lines and development of machine harvesting techniques for shattering sesame varieties are strongly suggested.

Sesame is considered drought tolerant crops. However, the north Australian rainfed crop often experience terminal drought stress due to longer crop duration. Focus on future variety development for greater drought tolerance or avoidance he appropriate selection of high yielding early maturity non-shattering sesame varieties for rainfed production .

The current research assessed different sesame varieties and determined suitable season for production. However, the lack of adequate agronomic tools for mechanised planting and harvest, as well as lack of postharvest seed cleaning, grading and processing facilities limit further scaling up of sesame production in northern Australia. Future research focuses on enabling agronomy is embedded in the CRNCA funded Great Northern Spices (GNS) project, along with an emphasis on mechanisation of planting and harvesting are also embedded in the GNS project (2023-2026) will fuel research translation towards commercial scale sesame production in northern Australia.

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The CRCNA acknowledges the support of its government partners.

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