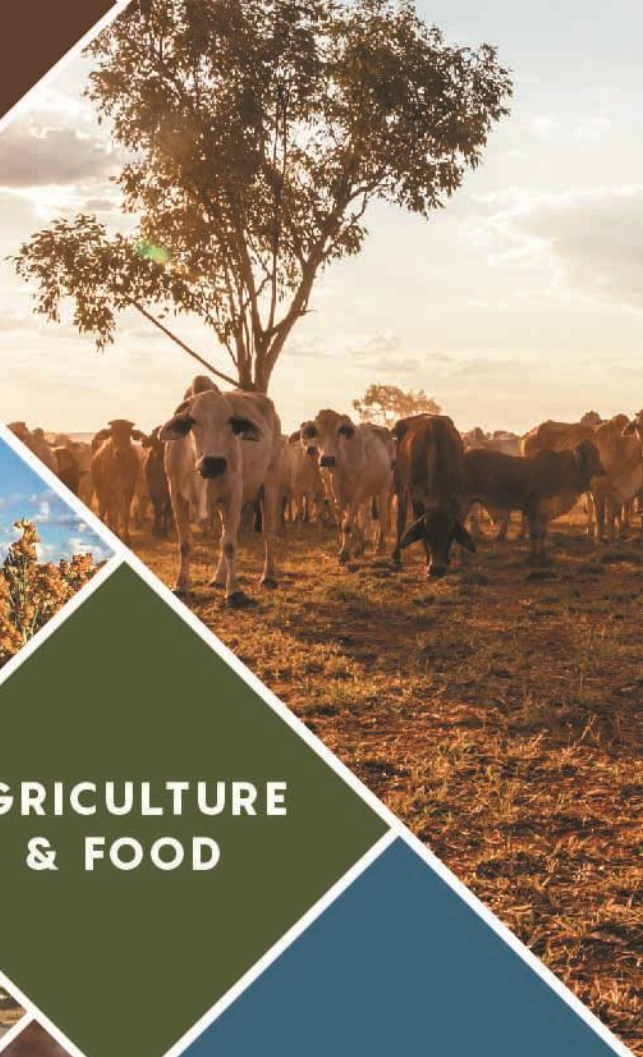
NORTHERN HEALTH SERVICE DELIVERY

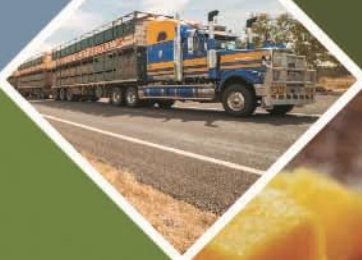






TRADITIONAL OWNER-LED DEVELOPMENT

AGRICULTURE & FOOD





PART C: KALONJI FINAL REPORT

Surya Bhattarai, Tieneke Trotter, Delwar Akbar, Azad Rahman and Michael Thomson

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.

Disclaimer

Any opinions expressed in this document are those of the authors. They do not purport to reflect the opinions or views of the CRCNA or its partners, agents, or employees.

Central Queensland University (CQU) has made every attempt to ensure the accuracy and validity of the information contained in this document, however, CQU cannot accept any liability for its use or application. The user accepts all risks in the interpretation and use of any information contained in this document. The views and interpretations expressed in this report are those of the author(s) and should not be attributed to the organisations associated with the project.

Peer Review Statement

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

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

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

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

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

© 2023. This work is licensed under a CC BY 4.0 license.

Table of contents

List of Tables 4
List of Figures 5
EXECUTIVE SUMMARY 6
1.INTRODUCTION 8
2.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 11
3.3 Results and discussion 12
3.4 Summary 15
4.AGRONOMIC CROP ASSESSMENT 16
4.2 Kalonji Initial Evaluation Trials (Year 1) 16
4.2.1 Introduction 16
4.2.2 Materials and methods 16
4.2.3 Results 20
4.2.4 Discussion 22
4.3 Verification Trial - Winter Crop (Year 2) 22
4.3.1 Introduction 22
4.3.2 Materials and methods 22
4.3.3 Results 23
4.3.4 Discussion 26
4.4 Commercial Crop Trials 2022 (Year 3) 28
4.4.1 Introduction 28
4.4.2 Materials and methods 30
4.4.3 Results 30
4.4.4 Discussion 40
5.PRODUCTION AND POST-HARVEST CHALLENGES 42
5.1 Post-Harvest Challenges 42
5.1.1. Introduction 42
5.1.2 Materials and methods 44
5.1.3 Results 46
5.1.4 Discussion 50
5.2 Insect Pests 50
5.2.1 Major Insect Pests 50
5.2.2 Crop damage by insects 51
5.2.3 Beneficial Insects 51
5.3 Diseases 51

5.3.1 Major diseases 51
5.3.2 Crop damage by diseases 51
5.5 Other Challenges 51
5.5.1 Weather damage 52
5.5.2 Other pests (Birds, Rodents, Animals, Parasites) 52
5.6 Weed control 52
5.6.1 Herbicide residues 52
6.CONCLUSIONS AND RECOMMENDATIONS 53
REFERENCES 54

List of Tables

Table 1. Mean annual rainfall, maximum temperature, and minimum temperature for chief locations in Central Queensland 10

Table 2. Fixed cost, variable cost and revenue for rainfed kalonji farming during 2020, 2021 and 2022 in Central Queensland under model 1. 11

Table 3. Sensitivity analysis of the average gross-margin from three years of kalonji production (Model 1). 12

Table 4. Fixed cost, variable cost and revenue for rainfed kalonji farming during 2020, 2021 and 2022 in Central Queensland under model 2. 12

Table 5. Sensitivity analysis of the average gross-margin from three years of kalonji production (Model 2) 13

Table 6. Gross margin of the dryland high value crops in Central Highlands region. Sources: (AgMargins, 2023, Qld Government). 13

Table 7. Geographic location, in-crop rainfall, soil types and cropping systems of the small plot trial locations. 16

Table 8. Kalonji trial planting and harvest dates 16

Table 9. Description of trials sites, and crop details for the Kalonji verification trials in 2021. 21

Table 10. Crop reproductive performance and yield of kalonji varieties at different locations in Qld under verification trials in 2021. 22

Table 11. Kalonji phenological and reproductive on growth performance at Rockhampton and Biloela in 2022. 34

Table 12. Laboratory grain cleaning test results of the kalonji seeds after first- and second-stage cleaning using seed received from winter verification trials at Rockhampton. 44

List of Figures

Figure 1: Kalonji trial locations: Biloela, Rockhampton, Ayr and Tully in Queensland and Katherine and Darwin in the Northern Territory. 15

Figure 2. The oil press used for extraction of oil from kalonji seeds. 18

Figure 3. Kalonji phenology (from planting to harvest) for winter season kalonji production at the four trial locations in Northern Australia. 19

Figure 4. Kalonji seed yield (kg/ha) for four kalonji varieties planted at different locations in Qld and NT for winter 2020 winter. 20

Figure 5. Kalonji verification trial planted with Jang planter, in three rows configured 50cm apart in flat bed in a pasture-kalonji system in alluvial soil at Gracemere North, Central Qld. 22

Figure 6. Early establishment challenge in kalonji as shown by the variable plant density, 25 days after sowing (6a), slow canopy growth, 50 days after sowing (6b); leading to strong weed competition, during the reproductive phase (6c). 24

Figure 7. Wintersteiger plot combine harvesting kalonji seed from verification trial at Gracemere North in 2021. 25

Figure 8. Winter planted kalonji defoliated for harvesting. 26

Figure 9. Longer term montly maximum, minimum, average temperature and rainfall for Rockhampton. 28

Figure 10. Longer term montly maximum, minimum average temperature and the rainfall record for Biloela. 28

Figure 11. Monosem precision planter used for zero tillage planting of kalonji seeds at Biloela. Inset is a closeup view of the Monosem seed disc ((DN12010) adapted for kalonji seed. 30

Figure 12. Kalonji seedling emergence and early-stage crop canopy development for zero tillage crop at Biloela. 31

Figure 13. Kalonji crop 45 DAS at Rockhampton under conventional tillage system showing slow initial establishment and challenges for uniform cover even with precision planter. 32

Figure 14. Kalonji crop at full bloom stage at Biloela in the rotation with horticultural crops (melons/pumpkin) with strategic irrigation. 33

Figure 15. Kalonji crop at full bloom stage at Biloela in the zero-tillage planting in a rotation with a pasture crop of barley without irrigation. 34

Figure 16. Kalonji crop at Biloela with supplementary irrigation, at capsule filling stage 35

Figure 17. Irrigated kalonji crop at Biloela grown outside the trial area of rainfed crop, for informal observation by grower, and desiccated for combine harvesting. 36

Figure 18. Zero till rainfed kalonji crop at Biloela desiccated for combine harvesting. 37

Figure 19. Kalonji crop at harvesting. Kalonji trial sites were harvested with the Zurn 150 research combine plot harvester. 38

Figure 20. Kalonji seed specification sheet from an importer/exporter. 41

Figure 21. The on-farm seed cleaning machine, VAL-1500-6, can be adapted for kalonji. The equipment has a cleaning capacity of up to 25 tonnes of seed per hour (Photo: D. Frahn). 42

Figure 22. Theory and procedure for the operation of the on-farm grain cleaning equipment, VAL 1500-6-2x3 Model (Source: D. Frahn, 2022). 43

Figure 23. The uncleaned seed samples from the plot harvester header (left) and cleaned seed using VAL -1500-6 screen sets matched for the current harvest lot of kalonji.. 45

Figure 24. The seed harvested in 2021 by the research plot header and sieved by different sized screens to sperate seeds from debris (>3 mm), and fine dust and sub-size seed (<1.6 mm). 45

Figure 25. The seed samples screened with 1.9-2.5mm mesh. 46

Figure 26. Seed samples screened with 1.8-2.2mm mesh. 47

EXECUTIVE SUMMARY

The Spicing Up the North project contributed knowledge to the development of a high-value broadacre spice industry in Northern Australia. The research focused on production of key spices (black sesame, fennel, kalonji, cumin, caraway and kalijiri) currently not commercially produced in Australia. The objectives were to identify suitable spice crop varieties and investigate agronomic practices underpinning production.

The project involved an initial multilocation varietal evaluation in the first year, followed by variety and agronomic verification trials in the second year, and scaling up to commercial production in the third year. Market analysis was conducted for black sesame, fennel, kalonji, cumin and caraway, and gross margin analysis was undertaken for the crops which progressed through all three years of assessment, namely sesame, fennel and kalonji were also performed. The final report provides a summary of the whole project, whereas detailed, crop-specific technical reports are separately presented for black sesame (Part A), fennel (Part B), kalonji (Part C), and the results of the initial evaluation trials for cumin (Part D) and kalijiri (Part E). Due to germination issues, caraway's assessment did not progress beyond the market analysis and planting stage, with kalijiri selected to replace it in the field trials in year one.

Kalonji (*Nigella sativa*) had a global market value of US$18.35 million in 2021. This is projected to reach US$34.71M by 2030. Australia imports kalonji for processing and raw seed markets. Suitable kalonji varieties and agronomic supports are required for successful production in Northern Australia. To achieve this the project employed a participatory research model to maximise grower and industry insight and adoption of new recommendations.

This report present the results of the on-farm evaluation of kalonji cultivars across six locations to find varieties suitabel for Northern Australia. The initial variety evaluations recorded hand harvested seed yields of up to 3197 kilograms per hectare, with the highest yields recorded in Biloela followed by Rockhampton, Ayr and Katherine, and the lowest yields in Darwin and a failed crop at Tully, indicating greater adaptation of kalonji for southern regions. Among the four cultivars, AVTKS#1 and AVTKS#2 consistently produced higher yield across all sites, hence these lines were progressed for verification and commercial trials in the following years. Kalonji verification trials (2021) recorded machine harvested seed yields of 47.2-342.5kg/ha in Rockhampton region, where the hand harvested yields were 1.5 to 2 times higher than the machine harvested yields, suggesting significant harvest loss. The commercial crop trials in 2022 at Rockhampton and Biloela matured on 178 and 137 days after sowing respectively, with machine harvested seed yield of 1,076 and 926.2 kg/ha respectively for a supplementary irrigated crop. The low seed yield (258.6 kg/ha) for a rainfed zero till crop at Biloela reflected kalonji's succeptibility to drought stress, therefore, the identification of an early maturing variety for rainfed production is recommended.

Kalonji showed slow emergence and crop establishment, and hence became susceptible to weed competition. However, the crop experienced low insect pests and diseases pressure, indicating opportunity for low-pesticide or organic production, provided alternative weed control methods are identified. Being a new crop in Australia, no current economic data exists within Australia. The average seed yield from this project's three-year trial was 780kg/ha with an average gross margin of A$644/ha in model 1 (highly volatile fertilizer price) and A$866/ha in model 2 (usual price of fertilizer). In both models, a seed yield over 550kg/ha would attract reasonable profits for the producers. The current results indicate potential for kalonji cultivation in the Central Queensland region. However, growers in the north indicated a willingness to further evaluate kalonji as winter crop within cotton and sugarcane farming systems.

New grower was engaged by AgriVentis for commercial contracting of 100t kalonji seed, to supply Australian importer, Hab Shifa in 2022.

The project generated data on kalonji yield potential, and preliminary agronomic tools and guidelines for kalonji production. However, there are still major challenges including: slow crop establishment resulting weed control challenges; mechanisation of planting and harvesting; robust agronomic practices for optimum planting times and density of planting for different regions; and post-harvest processing of the seeds. These issues need to be addressed for commercial production of kalonji by growers in different farming systems to harness the potentials. The outcomes of the Spicing up Northern Australia project have informed the scope of work for a follow up project, Great Northern Spices (GNS) 2022- 2026, which aims to support commercial kalonji production in Northern Australia.

1. INTRODUCTION

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

- "Market Analysis of Kalonji" (2020) - https://crcna.com.au/resources/publications/market-analysis-kalonji
- Webinar event – Spicing up northern Australia with high-value condiment crops - https://www.crcna.com.au/events/webinar-event-spicing-northern-australia-high-value-condiment-crops
- "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.

The "Market Analysis of Kalonji Seeds 2020" reports the global kalonji markets, and identifies major global producers and importers of kalonji seeds. The report also analyses current demands and forecasts future demands of kalonji seeds from within Australia.

The initial evaluation trial data was presented at a CRCNA-organised webinar on 7 April 2021. The webinar session is recorded and accessible at:

"Ag Webinar 2020: Spicing up the North" https://www.youtube.com/watch?v=LzdLCW-nEs4

The "Broadacre Cropping in Northern Australia Newsletter 2021" also presented the results of the initial variety evaluation trials for five spice crops, including kalonji, cumin and kalijiri as winter season options, whereas sesame and fennel were presented as summer crops. These trial results presented hand-harvested yields to showcase the potential of these crops in various locations, which were selected to represent the different farming systems in Northern Australia.

There were eight key deliverables for achieving the project objectives and purpose. Five deliverables related to spice crop production, quality assessment and economic analysis for each individual crops; while common deliverables across the crops, were extension, complementary activities, and research insights and future directions. Therefore, the reporting on deliverables 6-8 are presented in the overarching Final Report to minimise the duplication of information across the commodity reports.

This report presents the brief market and economic analysis relevant to Australian kalonji production, and the detailed reporting of the three years of kalonji research including initial varietal evaluation, verification trials and commercial trials, with documentation of production, harvest and post-harvest challenges, and the different aspects of the kalonji seed quality assessment.

2. MARKET ASSESSMENT

The market assessment undertaken in 2019-20 investigated the current and future trends of the global kalonji markets and explored the market opportunities for Australian-grown kalonji. The following extract from the report summarises the key findings. The full report is available at https://crcna.com.au/resources/publications/market-analysis-kalonji. The report provides a current assessment of the global industry based on available information and identifies areas for further research to address gaps in market information.

India is known to be the largest producer of kalonji seeds in the world. The other leading producers are Sri Lanka, Bangladesh, Nepal, Egypt, Iraq, Pakistan, Turkey, Syria, Saudi Arabia and Ethiopia. The estimated area of kalonji production in India was about 9000ha, with a production of about 7000-8000 tonnes (t) in 2019 (Huchchannanavar et al., 2019). Turkey produced about 3,300t of kalonji with an average yield of 980kg/ha in 2018. According to Global Market Insights, the demand for kalonji increased among consumers in the developed world, including Australia, during the Covid-19 pandemic due to its medicinal qualities. In 2020, the global market for this product exceeded $17.5M, and is forecast to rise to more than $30M by 2027. According to Global Market Insights, Inc, the US kalonji oil market is predicted to hit US$25M by 2025. It is also expected that the demand for kalonji oil in the USA will exceed 130t by 2025 (Globe Newswire, 2019). Another report predicted that the demand for kalonji oil in the UK will be over 35t by 2025 (Market watch, 2019). The same report also predicted the increasing demand for kalonji in Saudi Arabia and Italy.

Australia is a net importer of kalonji seeds. The current demand for kalonji seeds in Australia is not documented or available in open online sources, however, a secondary data source indicated that in 2016 from 16 February to 15 October, Australia imported about 70.3t of kalonji from India, with the unit price ranging from A$4,000/t to $10,000/t (Zauba, 2018). Several trading companies in Australia import, distribute and wholesale kalonji and kalonji oil. Hab Shifa, an Australian kalonji processor, alone imported about 600-800t of kalonji seeds annually for health food, supplements, and wellness products (per personal communications with Agriventis CEO Mr Lewis Hunter). Processors like Hab Shifa are looking for Australian-grown supplies to replace these imports.

Currently, kalonji is only produced as a trial crop in Australia with no established commercial production. However, the opportunity for the Australian industry to expand production is favoured by a combination of several factors such as growing market demand, price, suitable climatic conditions, geographic proximity to Asian markets, supply chain logistics, and input supplies. Australia has free trade agreements in place with the major markets of India, China, Japan and Korea, giving Australia a potential competitive advantage over other producers and exporters. The export standards of kalonji seeds include 99-99.8% purity (machine clean and sortex clean), not genetically modified, moisture 6%, oil content minimum 30% (https://www.jalaramagri.com/product/nigella-kalonji-seeds/).

However, high labour costs are a competitive disadvantage and a barrier to the growth in Australia if the crop requires manual production techniques. Therefore, completely mechanised production and processing systems are required for establishing a commercially viable kalonji industry in Australia. The crop is relatively easy to manage with existing farm equipment and supply chain logistics for the raw seed sales, and the commercialisation opportunities are stronger for kalonji than the other spice crops evaluated in this project.

Technological innovation, the adoption of high-yielding and high-quality kalonji 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, access to suitable land and kalonji varieties suited to Australian environmental conditions – place Australian-grown kalonji in a strong position to establish a viable long-term industry generating revenue through import replacement and export sales.

3. GROSS MARGIN ANALYSIS

3.1 Introduction

The international trading price is variable with only a few studies mentioning an indicative price. The trading price of Indian kalonji ranges from US$2,258/t to US$2,750/t (Engels & Brinckmann, 2017). Egyptian kalonji attracts a slightly higher trading value with US$2,900/t for conventional kalonji and US$3,000/t for organic kalonji (Engels & Brinckmann, 2017). AgriVentis and a grower signed a contract for organic kalonji production in 100 ha during 2022 demonstrate growers' willingness to consider planting commercial crop of kalonji on broadacre scale.

There have been some studies analysing the profitability of kalonji farming conducted in South Asian and African countries. Yimam et al. (2015) investigated the effect of fertilizer on the growth, and yield of kalonji production in Ethiopia. As a part of their study, they undertook some benefit analysis and found that with appropriate usage of fertilizer, the net benefit could be A$427/ha (about 15,000 Birr/ha). The price of kalonji is very high in some European countries - for example, the retail price of kalonji in Greece is about 12 Euro/kg, which is approximately equivalent to A$18,000/t. One study indicated that the net profit for kalonji production in Greece was E5,000/ha (approximately A$7500/ha) (Stefanopoulou et al., 2020). Literature on profitability analysis of kalonji production in Australia has not been found in any of the databases or any published literature. Therefore, this case study undertaken to determine the gross margin analysis of kalonji production will fill this gap.

3.2 Methods and limitations

Kalonji (*Nigella sativa L.*) is a new crop in the Australian farming system and therefore, the economic feasibility studies for kalonji are non-existent in the Australian context. This study was designed as a case study to assess the economic feasibility of kalonji in subtropical Australia and gross margin analysis was chosen as a method of economic assessment.

Three years of cost and revenue data from kalonji production from a field trial site at Rockhampton were used to evaluate its gross margin and sensitivity to price and yield fluctuations. Kalonji production costs and revenues from three years (2020, 2021 and 2022) were collected to analyse the farm operation profit and sensitivity analysis. Data was collected using a quantitative questionnaire attached in the appendix, supplemented with a phone interview. 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

The following limitations are applicable to the study:

- The scenario assumes kalonji 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 cropping are suitable for spice production as well, the focus has been put on gross margin analysis instead of whole-farm profit analysis. The 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 three years of production was 0.1ha, 0.3ha and 0.1ha for 2020, 2021 and 2022 respectively. Given the availability of only three data points, it has been judged best not to extrapolate the findings for broadacre kalonji farming or a generalised indication of profit.
- Only the direct revenue of seed sales has been included in the benefits. Value-added products including kalonji oil with other indirect benefits from crop rotation on the farm are beyond the scope of the study.
- Kalonji production has been assumed as an incorporation into the existing farming system as a rotation crop, so kalonji 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 kalonji feasibility study is targeted for a rainfed production system in prime vertisol agricultural land. The semi-irrigated and fully irrigated production system is beyond the scope of the study.
- The report focuses on the gross margin and sensitivity analysis of the gross margin of kalonji production. While gross margin analysis helps compare similar enterprises, caution is advised when comparing with farming enterprises which require different resources input in the form of capital costs.

3.2.2 Case study area

The case study was carried out in an area of prime agricultural land located in the Lower Fitzroy agricultural basin, Central Queensland. Central Queensland is a planning and administrative region in Queensland primarily including regions surrounding Biloela, Emerald, Gladstone, Rockhampton, Yeppoon and Woorabinda covering a total area of 117,588 square kilometres (QGSO, 2023). The region has a sub-tropical climate with hot humid summers and dry mild winters (Bureau of Meteorology, 2001 and 2021). The mean rainfall, average maximum temperature, and average annual minimum temperature for the chief locations in Central Queensland have been presented in 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

Data Source: (BoM, 2021)

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

Labour costs are included in the fertilizer application and harvesting costs. The costs for vehicle rego, insurance and maintenance of the farm equipment are included in the fixed cost. To calculate the farm equipment repair and maintenance cost, the 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 per 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 cost calculation has not been disclosed in this report as per the non-disclosure agreement with the farm owner. Herbicides and insecticides cost have been included in the variable cost calculation as weed management. All the capital costs incurred in the farm were halved, assuming two crops cultivated per year in rotation. Finally, all capital costs were adjusted to per hectare basis for all the years. The kalonji farmgate price was collected from a trading company involved in spice and grains trading, but not disclosed due to ethical reasons.

In this study, we have considered two models based on the fertilizer market scenario. The first model considered the highly volatile fertiliser price during the COVID-19 pandemic situation for the observed three years. The second model considered the normal market situation with fertiliser cost at about A$170/ha before COVID at the CQ farm.

3.3 Results and discussion

The kalonji crops of 2020, 2021 and 2022 incurred total cost per hectare of A$1,496, A$1,495 and A$1,756 respectively under model 1. Variable costs accounted for most of the costs, sharing on average 80% of the total cost (Table 2). Since the kalonji was used as a rotation crop, growing two crops per annum, the total annual fixed cost was halved to share the annual fixed cost between the two rotating crops. Fertiliser cost is one of the main variable costs in cropping industries, as is the case in kalonji.

Kalonji yield during the observed three years was 908kg/ha, 343kg/ha and 1,076kg/ha respectively. During the first year of trial, the yield was hand-harvested, which therefore shows the yield potential, but it is less realistic for growers using fully mechanised planting and harvesting equipment. The farmgate price of kalonji was set at A$2,600 leading to a gross margin of A$1,073/ha, -A$395/ha and A$1,256/ha in 2020, 2021 and 2022 respectively (Table 2).

Table 2. Fixed cost, variable cost and revenue for rainfed kalonji farming during 2020, 2021 and 2022 in Central Queensland under model 1.

Item	Cost ($/ha) 2020	Cost ($/ha) 2021	Cost ($/ha) 2022	Average cost / hectare
Fixed cost				
Land rent + rates	47	47	48	47
Office cost	15	15	16	15
Depreciation	85	85	85	85
Insurance + rego +repair	61	61	65	62
Total fixed cost	208	208	214	210
Variable cost				
Land preparation	70	70	75	72
Planting	25	25	30	27
Fertilizer	385	385	560	443
Fertilizer application	55	55	55	55
Water & irrigation	550	550	550	550
Weed management	30	30	60	40
Harvesting	120	120	160	133
Post-harvest (freight and cleaning)	53	52	52	52
Other (in-kind labour)				
Total variable cost	1288	1287	1542	1372
Total expenses	1496	1495	1756	1582
Revenue Segment				
Global Kalonji price/tonne	$2,600			
Production (Tonnes)	0.908	0.343	1.076	0.78
Total revenue	$2,361	$892	$2,798	$2,017
Gross margin	$1,073	-$395	$1,256	$644
Gross margin ratio	45%	-44%	45%	32%

NB: Fixed cost considered of half a year to represent crop rotation.
Red cells indicate the negative gross margin and not profitable option, while green cells indicate the profitable options.

Under model 1, which considered the highly volatile fertiliser price, we ran a sensitivity analysis on kalonji farming to observe the effect of price fluctuation and crop performance on gross margin. The results are presented in table 3. The average variable cost per hectare incurred during the three years was used for the sensitivity analysis. A seed yield of 0.55t/ha and over would be required to secure some profit at the minimum price of A$2400/t (Table 3).

Table 3. Sensitivity analysis of the average gross-margin from three years of kalonji production (Model 1).

	Yield (tonne/ha)				
Price (A$/tonne)	**0.15**	**0.25**	**0.35**	**0.45**	**0.55**
2400	-$928	-$688	-$448	-$208	$32
2500	-$913	-$663	-$413	-$163	$87
2600	-$898	-$638	-$378	-$118	$142
3000	-$838	-$538	-$238	$62	$362
4500	-$613	-$163	$287	$737	$1,187
5000	-$538	-$38	$462	$962	$1,462

The same gross margin analysis was undertaken in model 2, where we considered the usual price of fertiliser before the COVID-19 pandemic. With the same trial run, the total costs incurred were A$1,303.5/ha, A$1302.5/ha and A$1,476/ha in 2020, 2021 and 2022, respectively. With the given farmgate price of kalonji at A$2,600/t, the gross margin of kalonji production was A$1,265/ha, -A$203/ha and A$1,536/ha in 2020, 2021 and 2022, respectively (Table 4). Table 4 summarises all variable and fixed costs with gross margin calculation.

Table 4. Fixed cost, variable cost and revenue for rainfed kalonji farming during 2020, 2021 and 2022 in Central Queensland under model 2.

Item	**Cost ($/ha) 2020**	**Cost ($/ha) 2021**	**Cost ($/ha) 2022**	**Average cost / hectare**
Fixed cost				
Land rent + rates	47	47	48	47
Office cost	15	15	16	15
Depreciation	85	85	85	85
Insurance + rego +repair	61	61	65	62
Total fixed cost	208	208	214	210
Variable cost				
Land preparation	70	70	75	72
Planting	25	25	30	27
Fertilizer	192.5	192.5	280	222
Fertilizer application	55	55	55	55
Water & irrigation	550	550	550	550
Weed management	30	30	60	40
Harvesting	120	120	160	133
Post-harvest (freight and cleaning)	53	52	52	52
Other (in-kind labour)				
Total variable cost	1095.5	1094.5	1262	1151

Total expenses	1303.5	1302.5	1476	1361
Revenue Segment				
Global Kalonji price/tonne	$2,600			
Production (Tonnes)	0.908	0.343	1.076	0.78
Total revenue	**$2,361**	**$892**	**$2,798**	**$2,017**
Gross margin	$1,265	-$203	$1,536	$866
Gross margin ratio	54%	-23%	55%	43%

NB: Fixed cost considered of half a year to represent crop rotation.
Red cells indicate the negative gross margin and not profitable option, while green cells indicate the profitable options.

With a lower fertiliser price in model 2, the gross margin analysis looks very promising. The sensitivity analysis on kalonji farming for model 2 are presented in Table 5. The results indicated that a seed yield of 0.45t /ha and over would be sufficient to secure profits at the base price of A$2600/t (Table 5).

Table 5. Sensitivity analysis of the average gross-margin from three years of kalonji production (Model 2)

	Yield (tonne/ha)				
Price (A$/tonne)	**0.15**	**0.25**	**0.35**	**0.45**	**0.55**
2400	-$736	-$496	-$256	-$16	$225
2500	-$721	-$471	-$221	$30	$280
2600	-$706	-$446	-$186	$75	$335
3000	-$646	-$346	-$46	$255	$555
4500	-$421	$30	$480	$930	$1,380
5000	-$346	$155	$655	$1,155	$1,655

Table 6 presents the average gross margin of the rainfed summer crops in the Central Highlands region of Queensland. The table is to be used as an indication of the performance of the crops in the region, rather than exact figures. These data were collected from the Queensland Government and DAF-hosted AgMargins websites.

Table 6. Gross margin of the dryland high value crops in Central Highlands region. Sources: (AgMargins, 2023, Qld Government).

Crop	Calculation for year	Gross margin (A$/ha)
Mung bean	2020	$164.35
Faba bean	2020	$565.92
Chickpea	2020	$251.47
Lentils	2020	$406.18
Soybean	2020	$180.86
Sunflower	2020	$396.76
Peanut	2020	$435.40

Central Queensland (CQ) is one of the major agricultural regions in Queensland. Thus, the given figures are applicable for comparison with the gross margin from kalonji in CQ. No other profitability analysis of dryland farming of mainstream crops was found in the literature sources. From Tables 2 and 4, kalonji provides a average gross margin of A$644.0/ha in model 1 and A$866/ha in model 2 at a farmgate price of A$2600/t.

This gross margin of Kalonji is higher than the gross-margin value of most of the high-value dryland cultivated crops presented in Table 6. The kalonji field trial yield was high in the third year at 1.076t/ha. Any yield above this threshold would generate more profit for the producers. The long-term future of the kalonji industry in Australia lies in the development and usage of high-yielding varieties and access to the export markets.

3.4 Summary

The seed yields recorded for strategically irrigated kalonji at Rockhampton was 0.908t/ha, 0.343t/ha and 1.076t/ha in the years 2020, 2021 and 2022, respectively. The machine harvested yield in 2022 was at par with or higher than the world average, which is 0.8t/ha. The gross margin analysis showed a potential for this spice in the CQ region. The gross margin under model 1 with highly volatile fertiliser prices for the years 2020, 2021 and 2022 were A$1,073/ha, -A$395/ha and A$1,256/ha respectively. Sensitivity analysis under the same model revealed that a seed yield of 0.55t/ha and over would generate profit for the producers at a base farmgate price of A$2600/t. Under model 2 with baseline fertiliser prices, the producers would secure some profit even with a yield of 0.45t/ha. The results presented in this report are based on field trials on a small plot, so these results should be used with caution. Future field trials with larger plots would ascertain the findings of this report. The result presented in this study indicates a high potential for kalonji cultivation in the CQ region. However, further research on larger trial plots is required to ascertain the current findings and to develop a business case.

4. AGRONOMIC CROP ASSESSMENT

This section covers the results of the kalonji field trials over 2019-2022, covering the initial variety evaluation trials in six locations in 2019/20, verification trials over four locations in 2020/21, and commercial crop trials over two locations in 2021/22. The crop phenology, seed yield and seed quality data are presented.

4.2 Kalonji Initial Evaluation Trials (Year 1)

4.2.1 Introduction

The trial work in the first year focused on performance evaluation of four different AgriVentis kalonji varieties across six different locations - Biloela, Rockhampton, Ayr and Tully in Qld, and Darwin and Katherine, NT - representing various climatic conditions and farming systems in Northern Australia. The multilocation trial was designed to assess the general and specific adaptability of the different genotypes in the various environments when planted as winter crop.

4.2.2 Materials and methods

Trial locations

The trial locations are presented in the Figure 1.

.



Figure 1: Kalonji trial locations: Biloela, Rockhampton, Ayr and Tully in Queensland and Katherine and Darwin in the Northern Territory.

Site descriptions

The trial crop was planted during winter, coinciding with the generally dry weather in Northern Australia. The in-crop rainfall was generally very low during the winter months. The yearly rainfall, however, is significantly varied for different sites (from 686mm at Rockhampton to 4,000mm at Tully) and soil types unsurprisingly equally varied from alluvial and sandy loams, to vertisols and ferrosols. Farming systems were just as diverse (Table 7).

Table 7. Geographic location, in-crop rainfall, soil types and cropping systems of the small plot trial locations.

Location	Latitude	Longitude	Annual rainfall (mm)	Soils	Cropping system
Biloela, QLD	24º26'32S	150º31'53E	685.9	Alluvial loam	Forage- Kalonji-Forage crop
Rockhampton, QLD	23º18'24S	150º21'35E	800.0	Vertisol	Cotton- Kalonji - Cotton
Ayr, QLD	19º37'8S	147º31'52E	952.9	Sandy loam	Melon - Kalonji-Melon Sugarcane- Kalonji-Sugarcane
Tully, QLD	18º7'23S	145º31'14E	4000	Sandy loam	Sugarcane-Kalonji -sugarcane
Katherine, NT	14º28'12S	132º18'28E	967.2	Ferrosol	Sorghum-Kalonji-sorghum
Darwin, NT	12º35'38S	131º18'16E	1711	Ferrosol	Sorghum-Kalonji-sorghum

Planting

The planting window varied (Table 2) from mid-May to mid-June depending on the availability of paddocks from the previous crop in the rotation, and preparation of the soil for planting kalonji seeds.

At each site, soil preparation followed existing grower practices. At Biloela, Rockhampton and Tully, the kalonji seed was planted in plots 1.5m wide and 2m long. Each plot had three rows of cumin planted 2m long. The two outside rows were guard rows and the one central row (data rows) were used for data collection.

Raised beds 1.5m wide were prepared in Darwin and Katherine and the kalonji planted in four rows 2m in length. The outside two rows were guard rows, and the inside two rows were used for data collection.

In Ayr, 1.5m-wide raised beds covered in plastic mulch were prepared and three rows of kalonji seedlings were planted in 2m lengths with the centre treated as the data row and one additional row on each side planted as guard rows. Seedlings were raised in a local nursery in tube stock and were transplanted into plastic lined beds. This practice was undertaken at Tully as it is a practice familiar to local producers who use transplants for field vegetables and melon crops. The seedlings were transplanted when they were about 6-10cm in height, achieved about 40-45 days after seeding. 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 and seedling establishment. One line of drip tape was installed along each of the guard and data planting rows. Irrigation was applied only to supplement rainfall to the refill point.

Table 8. Kalonji trial planting and harvest dates.

Sites	Planting	Emergence	Flowering	Maturity	Harvest	Crop duration
Biloela, QLD	14/5/2020	23/5/2020	17/7/2020	1/10/2020	9/10/2020	147
Rockhampton, QLD	27/5/2020	7/6/2020	10/8/2020	8/10/2020	15/10/2020	141
Ayr, QLD*	13/6/2020	19/6/2020	10/8/2020	6/10/2020	12/10/2020	121
Katherine, NT	29/5/2020	8/6/2020	20/7/2020	5/9/2020	11/9/2020	105

*NB: At the Ayr site, the Kalonji was transplanted as seedling (40-50 days old) raised in nursery trays.

For 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 (http://www.herbiguide.com.au/labels/pen33_61322-1209.pdf).

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 kalonji crop developed canopy cover, minimal weeding was required due to the plant suppressing weed growth.

Varieties, trial design, planting densities and planting dates

Four varieties of kalonji seeds (screened from germplasm assessment carried out in earlier years at Rockhampton) were grown in small plots, independently randomised for each site, following the randomised complete block design (RCBD), with multiple replications within the same farm at each selected location. The between-row spacing was 50cm and the plant spacing within the row was about 4-6cm with an aim to achieve the target population of 30-50plants/m^2. The planting date varied between sites (Table 8).

Nutirent management

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 an NPK rate of 81:40:63kg Ha^{-1} at planting as a basal application. No additional fertiliser was applied during the growing season.

Data collection and analysis

Crop phenological and reproductive data were collected at each site at key phenological stages throughout the growing season. The date of planting, emergence, emergence count, flowering, maturity and harvest, and the number of plants per hectare at harvest were recorded. At maturity, the plant height, number of capsules per plant and height at the position of the first capsule were recorded from six plants selected as representatives of the plot. The data rows (middle rows between two guard rows in the bed) 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 characteristics were made to explain the seed yield. Harvest Index (HI) was calculated as the ratio of seed yield (t/ha)/above ground plant weight (seeds + biomass weight t/ha).

The quality assessment of the harvested seeds was undertaken in CQUni's crop science laboratory. The quality assessment included the preparation of a 100g sample of seed, 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 2). The oil press was used for extraction of oil from kalonji seeds, with pressed oil centrifuged to determine the clean oil contents (%).



Figure 2. The oil press used for extraction of oil from kalonji seeds.

The seed density was calculated using the principal 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 sites were recorded from the nearby BOM meteorological stations, and data 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

Climatic conditions

The trial crop emerged and established during the cooler period of the year and the seed development and maturity occurred during the warmer period (Figure 3). As the crop growth, development and maturation coincided with the dry season, the crop received supplementary irrigation (applied when soil moisture reached deficit to refill point) to minimise the water stress on the crop.

Crop phenology

The kalonji crop was planted at varying dates throughout the winter months of 2020 (Figure 3). The days to emergence for each site varied, ranging from six to 11 days. Very early emergence at Ayr within six days was due to seed being planted in a nursery tray inside the nursery house, and not directly in the field as for the other sites. Days of planting for Ayr is referring to the date of transplanting the seedlings in the field.

The duration from emergence to flowering ranged from 42 days at Katherine to 64 days at Rockhampton. The flowering to maturity duration ranged from 47 days at Katherine) to 76 days at Biloela. The sites were harvested manually (hand harvested) after maturity, with the longest maturity recorded in Biloela (Figure 3). Timely harvest upon maturity is essential as delayed harvest of kalonji seed can cause seed losses in the field from radiation related breakdown of the capsules and increasing susceptibility to wind damage.

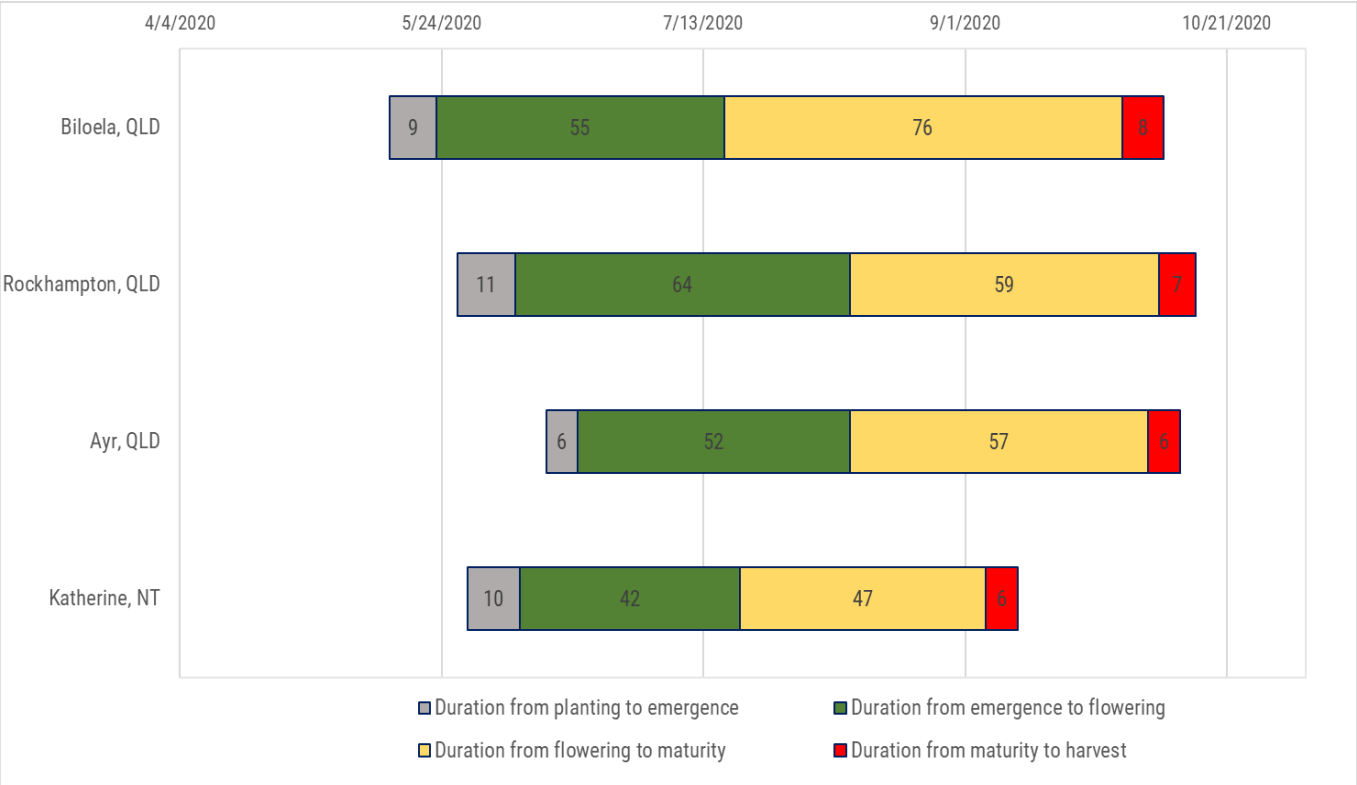


Figure 3. Kalonji phenology (from planting to harvest) for winter season kalonji production at the four trial locations in Northern Australia.

Yield

Seed yield

The mean kalonji seed yield across the six test sites ranged from 7kg/ha to 3107kg/ha. The greatest seed yield was recorded in Biloela (3107kg/ha), followed by Ayr (914kg/ha), Rockhampton (908kg/ha), Katherine (247kg/ha), and Darwin (7kg/ha). Tully did not produce a harvestable crop. The seed yield between the

varieties did not vary significantly and there was no significant interaction effect of Variety x Location (Figure 4).

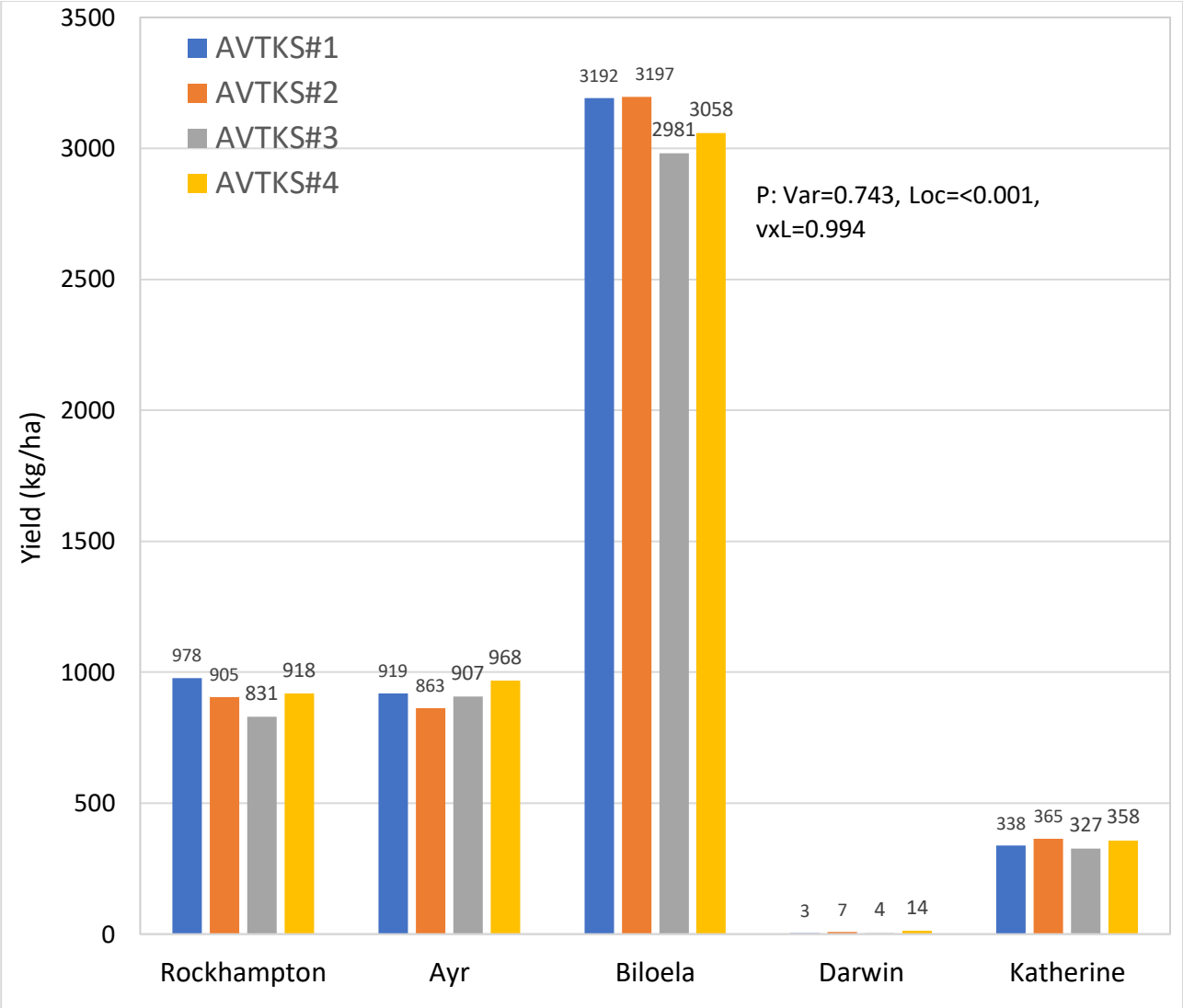


Figure 4. Kalonji seed yield (kg/ha) for four kalonji varieties planted at different locations in Qld and NT for winter 2020 winter.

4.2.4 Discussion

The first-year varietal evaluation trial consisted of a small plot trial where all plots were manually planted and hand-harvested. The kalonji crop at all sites showed slow emergence and slow early growth that exposed the crop to severe weed competition at the early stage. The trial plots were manually weeded to keep the weed growth under control for the comparison of the yield potential of the kalonji varieties. The trial across all sites showed that kalonji is weakly competitive to weed species, which will have significant implications for crop management. Therefore, future research for improving early emergence and canopy establishment, as well as effective weed control methods both for conventional and organic production system, is suggested.

The seed yield performance of kalonji was encouraging, particularly from southern locations such as Biloela, which recorded a maximum seed yield of 3197kg /ha for a hand-harvested crop.

This level of yield is about four times the average yield recorded for Turkey, which is currently the leading kalonji producing country and has an average yield of 800kg/ha. Similarly, the yield potential demonstrated in the initial evaluation trials are higher than the national average yield in other major kalonji producing countries. For example, seed yield of 1.04t/ha was reported in Bangladesh and higher yield of 1.71- 2.1 t/ha was reported in Iran (Karim et al., 2017).

The noticeable yield gap - the difference between the plot and paddock level yields - are well documented, resulting in a higher plot yield relative to paddock yield. The yield gap generally decreases when the agronomic and crop management aspects for growing crops under larger scale are better developed.

4.3 Verification Trial - Winter Crop (Year 2)

4.3.1 Introduction

This section describes the results of kalonji field trials undertaken in the winter season of 2021. The verification trials were grower-managed larger plots (up to 1ha per variety), with one farmer at each of Biloela, Ayr, and Tully, and three growers at Rockhampton (referred to in Table 9 as Rockhampton, Gracemere North and Gracemere South). Key phenological and yield data were collected over the cropping period from different farms, representing different farming systems from which the suitability of kalonji production was evaluated under farmer-managed conditions from range of agro-ecological zones.

4.3.2 Materials and methods

Kalonji was planted between 12 May to 28 July 2021 using different varieties from AgriVentis Technologies Ltd (Table 9).

Table 9. Description of trial sites and crop details for the Kalonji verification trials in 2021.

Site	Farming system	Variety	Area (ha)	Seed (kg)	Planting date	Planter	Harvester	Weed control
Biloela (ND)*	Mungbean	AVTKS#3	1.0	3.5	1/7/ 2021	Jang	CE&D Jenson Callide harvester	Manual
Rockhampton	Cotton	AVTKS#2	0.5	3.5	12/5/2021	Jang	Wintersteiger	Manual
Gracemere north (ARG)*	Pasture/hay	AVTKS#1	1.0	3.5	14/5/2021	Jang	Wintersteiger	Manual
Gracemere south (BP)*	Pasture/hay	AVTKS#1	1.0	3.5	13/5/2021	Jang	Wintersteiger	Manual
Ayr	Sugarcane	AVTKS#4	0.1	3.5	22/7/2021	Jang	KEW	Manual
Tully	Sugarcane	AVTKS#3	0.1	3.5	28/7/2021	Cone planter	KEW	Manual

*NB: Biloela (ND) refers to N Dudarko's farm at Callide; Gracemere North (ARG) refers for AR Graham farm in Gracemere north and Gracemere south (BP) refers for B Pacey farm in Gracemere south.

Kalonji was planted at Biloela in a rainfed mungbean system. The crop at Rockhampton was planted into a cotton system. The two sites near Rockhampton (Gracemere north and south) were planted as a sprinkler irrigated crop in pasture/hay system (Figure 5). The crop at Ayr was planted in a furrow irrigated sugarcane system, whereas the kalonji at Tully was planted as a rainfed crop, also under a sugarcane-based farming system (Table 3). The crop at Tully did not establish well due to impacts of residual herbicide (the block was sprayed with 0.4L/ha of Implode on 23 February during the previous cane crop – Implode carries 240g/L of Imazapic) (personal communication with C Rixon). Therefore, the yield data for winter-planted kalonji is presented only for Ayr in North Queensland.



Figure 5. Kalonji verification trial planted with Jang planter, in three rows configured 50cm apart in flat bed in a pasture-kalonji system in alluvial soil at Gracemere North, Central Qld.

4.3.3 Results

Phenology

The seedling emergence took place 9-26 days after sowing (Table 9). The earliest emergence was noted at Ayr (nine days), whereas a very slow emergence was recorded in Biloela (26 days). In other sites, the emergence of seedlings occurred 12-14 days from sowing.

Table 10. Crop reproductive performance and yield of kalonji varieties at different locations in Qld under verification trials in 2021.s

Site	Name	Date of emergence	Date of harvest	Crop duration (days)	Sample area (m^2) and # of samples	Estimated yield (kg/ha)	Machine harvested yield (kg/ha)	Estimated harvest loss (%)
Biloela	ND	26/07/2021	19/11/2021	141	2.5 (3)	379	a*	a*
Rockhampton	PF	26/05/2021	20/10/2021	161	1 (3)	532	342.5	35.6
Gracemere (north)	ARW	26/05/2021	19/10/2021	158	1(3)	274	123.2	55
Gracemere (south)	BP	27/05/2021	20/10/2021	160	1(3)	101	47.2	53
Ayr	AW	31/05/2021	22/12/2021	153	2(3)	503	a**	a**
Tully	BD		Crop failed due to herbicides residue from previous crop in rotation					

a*Hand harvest only at the Biloela due to extreme wet weather at harvest time and field not permissive for header.
a**Hand harvest only at Ayr as the kalonji was only planted in a smaller area and a header was not available locally.

The emergence of seedlings was patchy (Figure 6a). As in the other trials could be associated with the weak control depth of seeding and weak singulation of the seeds by the Jang planter. The early growth of seedlings, even in the well-irrigated alluvial soil at Gracemere North, was slower for kalonji compared to other larger seeded crops associated with limited seed reserve (Savaedi et. al., 2019). Both the slow rate of seedling emergence and subsequent slow growth of kalonji at the early crop stage, resulted in less canopy cover in the early stages and allowed the establishment of weed competition (Figure 6b). Thus, weed interference is an important factor affecting nutrient uptake, growth and seed yield of kalonji. It has been reported that weed competition through growth periods could decrease kalonji seed yield by 69% (Seyyedi et al., 2016).





Figure 6. Early establishment challenge in kalonji as shown by the variable plant density, 25 days after sowing (6a), slow canopy growth, 50 days after sowing (6b); leading to strong weed competition, during the reproductive phase (6c).

The crop duration ranged between 141 and 161 days from the date of sowing, resulting in harvest between October and December 2021. The crop matured in Biloela earliest (141 days), followed by Ayr (153 days) and Rockhampton (160 days).

All trial sites were harvested by research plot combine harvesters, except for Biloela and Ayr. In Biloela the crop was impacted by drought at the early stage, and excessive wet conditions at the later stage of harvesting resulting in the field not permitting use of the plot harvester. In Ayr access to the small plot header proved cost prohibitive, and hence it was only hand sampled. The crops at Rockhampton, and Gracemere North and South were harvested by the QDAF Wintersteiger plot combine harvester (Figure 7).



Figure 7. Wintersteiger plot combine harvesting kalonji seed from verification trial at Gracemere North in 2021.

Seed yield

The machine harvested seed yield was highest for Rockhampton (345.5kg) and was lowest for the Gracemere sites (47.2-123.2kg/ha). The hand harvested yields were 1.5 to 2 times greater than the machine harvested yield, suggesting that a significant amount of harvest loss still exists even though the capsules are tolerant to shattering. Crop harvesting at Ayr coincided with the wet weather for this season, hence there was an effect of wet weather on the seed quality. Prolonged wet and humid conditions during harvesting meant that a seed moisture content of 6% could not be achieved.

4.3.4 Discussion

The kalonji verification trial involved multilocation farmers managed non-replicated field trials (0.1-1ha), all planted by a Jang planter. Although no formal measurements were taken, very low insect/pest and disease pressure was observed on the crop at all sites. Visual observations at Ayr where the fennel and sesame crops grown at the same time were severely affected by aphid, the kalonji crop was not impacted to the same degree. The low pest and disease incidence could also be due to a lack of transmission from previous and surrounding crops, as there were no other kalonji crops in the vicinity, and it was only the second season of kalonji growing in this locality. The low pest pressure also could be due to the inherent insecticidal properties in the nigella plants (Ali and Mazhar, 2018).

As in the initial variety evaluation trials, the verification trials of kalonji showed promising results in terms of crop adaptation for winter production.

Kalonji took 140-160 days from sowing to maturity, with no significant difference between varieties. Unlike in other emerging crops in the region such as sesame, kalonji had the longest growing season. Slow crop emergence and long duration for establishment allowed for weeds to become competitive (Figure 8). As in the initial evaluation trials, weed competition is one of the greatest challenges to commercial cultivation of kalonji.



Figure 8. Winter planted kalonji defoliated for harvesting.

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 higher seed moisture content (>6%), particularly for the crops at Gracemere which needed post-harvest seed drying to bring the moisture to about 6%. The preparation of the crop by desiccation treatment also allowed lodged crop to be lifted smoothly by the header at the Rockhampton site.

The estimated harvest loss was about 48%. The harvest loss estimate for Biloela was much higher (54%) than Rockhampton (35%). Kalonji capsules, in these tested lines, did not show shattering properties, therefore, it is implied that the harvest loss was due to header performance. Optimisation of the header settings to suit to kalonji harvest is recommended as the separation of seeds from biomass and efficient screening without seed loss with biomass is required in the combine harvester. As kalonji seeds in other countries are manually harvested (Behara, 2023), there is no published literature available to the authors, for header setting for Kalonji seeds to minimize the harvest loss.

The seed yield in the Biloela site was almost three times that of Rockhampton in the initial evaluation trial but was significantly lower in Biloela compared to Rockhampton in the verification trials in 2021. The verification trial in Biloela was planted in a broadacre rainfed farming system following a mungbean crop. The crop was planted in vertisol soil, in a profile full of moisture, and therefore, the emergence and vegetative growth phase of the crop was not limited by moisture stress. However, the crop experienced severe water stress at flowering stage causing a terminal drought-stress effect. Severe yield penalty has been noted in other winter crops in these regions due to terminal drought (Senapati et al., 2019). Further research into the selection of an early maturing variety could help to improve yield by avoiding the terminal drought, which is common in rainfed winter crops in Northern Australia.

The crop at Rockhampton also showed a distinct variation in capsule morphology, with short thick capsules instead of long cylindrical types on some plants (130 plants) out of the 0.50ha of the crop planted area. Such off-type of plants were all marked individually and harvested manually prior to whole plot harvesting by the header. The seeds from the off-type selection were separately threshed and processed for new planting in the following season at Rockhampton. The large capsule size character often positively contributes to the yield, hence a favourable trait if it proves to be distinct, uniform and stable in the following generation, warranting for new line selection from AVTKS#2, as a new variant. The grower and industry partner suggested planting this new off-type as a commercial crop trial in the same farm the following season to

further evaluate the trait (short-thick capsule) for its impact on yield and quality performance as well as the inheritance in terms of distinctness, uniformity, stability (DUS).

4.4 Commercial Crop Trials 2022 (Year 3)

4.4.1 Introduction

The major challenges for scaling up to commercial production of kalonji are related to slow early establishment leading to weed competition, harvest loss in conventional grain harvesters, and post-harvest management. Of particular importance for post-harvest management is the control of seed moisture, cleaning, grading and seed sorting particularly because of the small seed size.

The commercial crop trials were planted in Rockhampton and Biloela during the winter season of 2022, where a small amount of winter rainfall was experienced at both sites, with the onset of the wet season evident at both locations from October 2022 (Figure 9 and Figure 10). The trial was planted using the Monosem precision planter and harvested with a ZÜRN150 research plot combine harvester. Preparation for harvest involved crop desiccation using glyphosate seven days prior to harvesting, at the rate of 1.5L/ha in 60L of water.

Commercial contracts were arranged between the seed company AgriVentis Technology Ltd. and growers participating in the commercial crop trials of the kalonji line AVTKS#2. The conventional AVTKS#2 was planted in Biloela and the new selection of AVTKS#2 (off type for short-thick capsule) was planted in Rockhampton. The seed harvested from these trial crops were to be used as foundation seeds for the future commercial production of kalonji for the Australian domestic market.

Kalonji, particularly under dryland farming systems, faces challenges at establishment in dry years where maintenance of good soil moisture at the surface during seed germination is essential. Cropping and pasture areas with plant stubbles and zero till can conserve and protect surface soil moisture better compared than conventional tillage during the dry season. Based on the reflections from the verification trials where kalonji emergence was variable, the growers and industry partners suggested evaluating the zero-till planting options for kalonji in order to improve the crop emergence and early establishment for in dryland farming environments.

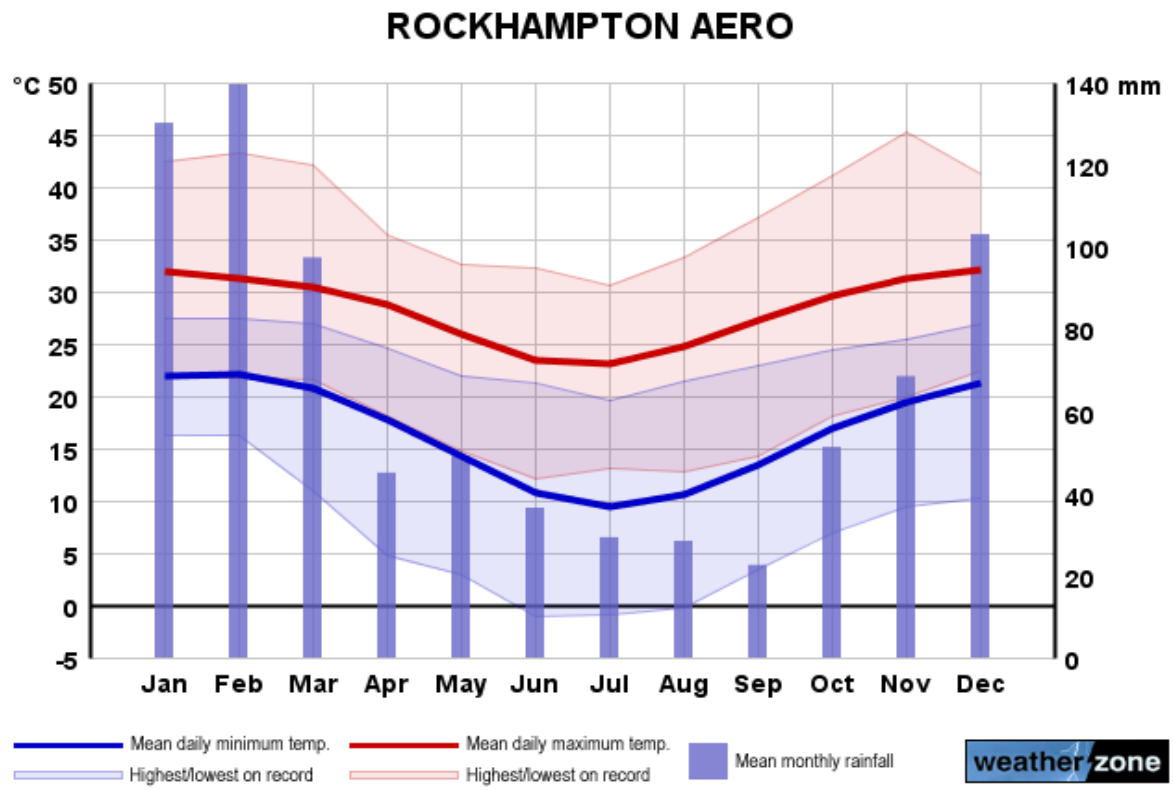


Figure 9. Longer term montly maximum, minimum, average temperature and rainfall for Rockhampton.

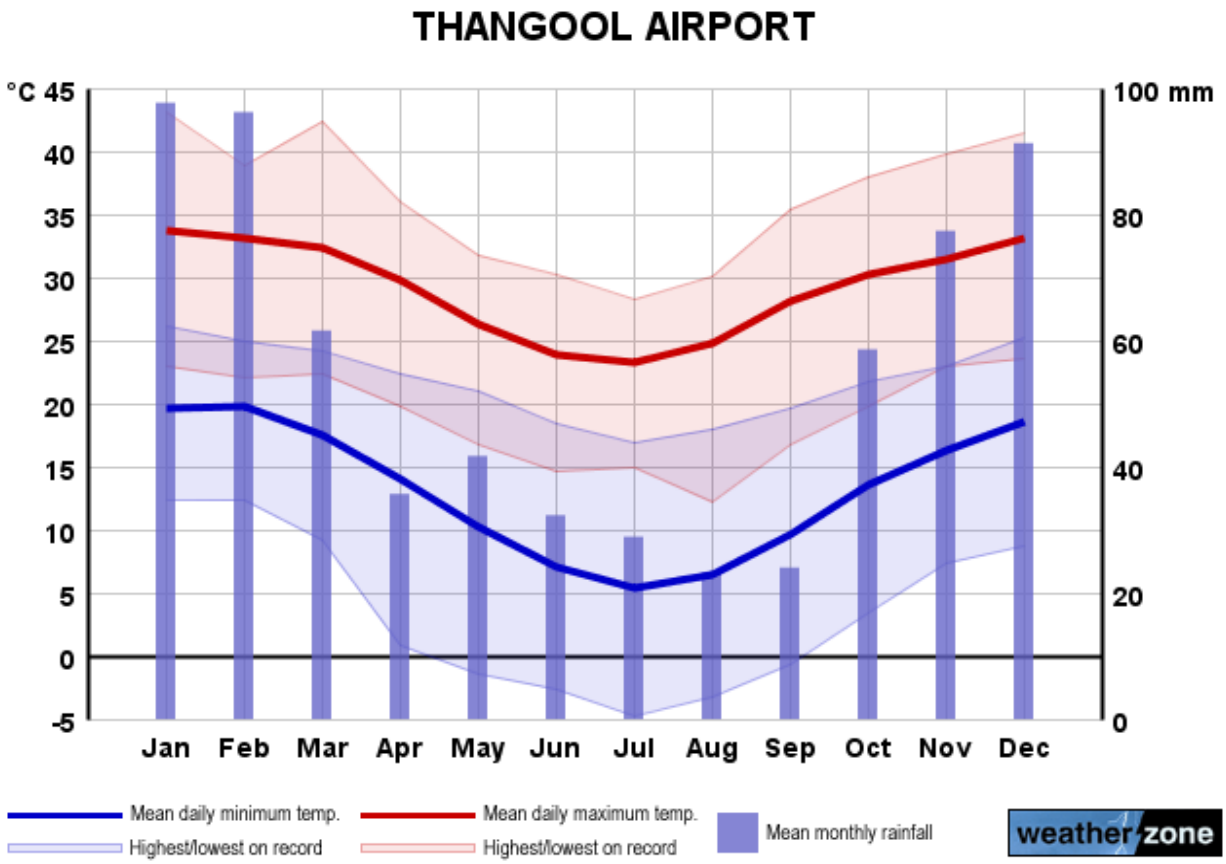


Figure 10. Longer term montly maximum, minimum average temperature and the rainfall record for Biloela.

4.4.2 Materials and methods

The crop at Rockhampton was planted on 6 May 2022 and harvested by October. The long-term minimum temperature during the season at this site is 5-15°C, with the max range 23-30°C and rainfall in season is about 210mm (Figure 9). The kalonji seed line planted at Rockhampton in 2022 was selected as off-type from the AVTKS#2 variety planted in the verification trial in Rockhampton in the 2021 season. The 'off-type' was identified based on a clear difference in the capsule morphology (short-thick capsule types) as described in the discussion section 3.4.3. The kalonji plot at Rockhampton was grown on a 0.04ha block with five beds (1m x 80m) each accommodating four rows of kalonji. The crop was planted in the cotton fallow in well tilled and pulverised soil in flat beds using a Monosem precision planter at a seed rate of 2.5-3 kg/ha. The Monosem single row disc (Model MONOSEM DN12010 D21) is known for precision planting of smaller seed crops.

The crop was irrigated using a drip irrigation system with two drip lines per bed following seeding and when soil moisture at the root zone reached the refill point. The irrigation water was pumped directly from the Fitzroy River. The plot was fertilized with NPK blends from Incitec Pivot supplying about 60kg N at pre-planting, as a basal application into the soil underneath the rows. The crop received seven irrigations, each run for eight hours and delivering about 0.96ML per irrigation. These occurred at fortnightly intervals from seeding until defoliation/desiccation. The weed control for these sites involved inter-row cultivation and manual weed chipping to keep the weed pressure under control. The crop was desiccated a week before harvesting using glyphosate (450g/L), with 1.5L mixed in 60L water, and harvested 178 days after planting using ZÜRN150 plot combine harvester.

The kalonji crop at Biloela was planted in mid-winter on 12 July 2022 and was harvested in late spring on 26 November 2022. The long-term minimum temperature range was 5-17°C, the maximum temperature range was 23-33°C, with in-season rainfall of 240mm (Figure 10). At this site, a 0.81 ha plot was planted in a zero-tillage rainfed production. The grower also planted a smaller plot (12 rows of about 80m long beds totalling 240m^2) outside the trial area under conventional tillage with supplementary drip irrigation set up for the commercial pumpkin and melon crops.

The crop was sown in rows, 25cm apart and four rows per bed (flat beds) with a seed rate of 2.5-3kg/ha. Weed control in the crop was managed with a pre-planting application (two weeks prior to planting) of glyphosate (Roundup Ultra Max) at the rate of 570g/L for burn out of existing weeds. The crop was desiccated a week before harvest using glyphosate (450g/L), with 1.5L mixed in 60L water. The trial crop was harvested 137 days after planting using the ZÜRN150 research plot combine harvester (Table 5).

4.4.3 Results

Seed germination and emergence

The Monosem planter could reasonably handle kalonji planting in zero till soil for delivering the targeted seeding rate of 3 kg/ha.



Figure 11. Monosem precision planter used for zero tillage planting of kalonji seeds at Biloela. Inset is a closeup view of the Monosem seed disc ((DN12010) adapted for kalonji seed.

The seedling emergence and crop establishment under the zero till soil was encouraging as rows with seedlings were clearly visible within 30 days of planting (Figure 12).

Patchiness in emergence and slow early canopy cover, however, was also noted for the fine tillage seed bed planted with Monosem precision planter in Rockhampton (Figure 13), as slow emergence (12-14 days) and seedling growth is typical in kalonji.



Figure 12. Kalonji seedling emergence and early-stage crop canopy development for zero tillage crop at Biloela.

The Rockhampton crop was planted into vertosol soil in fine tilth, with a similar seed rate to Biloela. It also showed patchiness even under secured soil moisture and favourable soil temperatures (16-18°C). The emergence count 30 days after sowing showed a large variation in the plant count (Figure 13), ranging from 9 to 52 plants/m^2.



Figure 13. Kalonji crop 45 DAS at Rockhampton under conventional tillage system showing slow initial establishment and challenges for uniform cover even with precision planter.

Low germination, slow emergence and slow initial seedling growth produced weak canopy cover at the early establishment phase (<20% canopy cover by 45 days after sowing) (Figure 13), therefore, weed competition was one of the major challenges experienced in this kalonji trial.

Flowering

The peak flowering of the crop commenced 91 days after sowing on 5 August 2022 in Biloela (Figure 14).



Figure 14. Kalonji crop at full bloom stage at Biloela in the rotation with horticultural crops (melons/pumpkin) with strategic irrigation.

The crop water demand peaks at flowering and moisture stress during this period can have significant impacts on seed yield and quality. The crop at Rockhampton did not face water stress whereas the crop at Biloela, particularly in the zero-tillage rainfed system, was impacted significantly by the lack of water at the reproductive stage (Figure 15). The Biloela crop faced terminal drought stress when winter-spring rain inputs were low.



Figure 15. Kalonji crop at full bloom stage at Biloela in the zero-tillage planting in a rotation with a pasture crop of barley without irrigation.

Crop maturation

The kalonji crop reached maturity 137 days after sowing in Biloela and 178 days after sowing at Rockhampton (Table 10).

Table 11. Kalonji phenological and reproductive on growth performance at Rockhampton and Biloela in 2022.

Site	Variety	Irrigation	Days to harvest	Machine harvested yield (kg/ha)	Clean out (%)	Clean seed yield (kg/ha)	Hand harvested yield (kg/ha)	Oil (%)	Test weight (g/1000 seeds)	Seed density (kg/m^3)
Rockhampton	AVTKS#2	Drip	178	1317.5	14.4	1076	1616.8	26.7	2.3	519.2
Biloela	AVTKS#2	Rainfed	137	308.6	16.2	258.6	935.3	28.6	2.8	538.7
Biloela	AVTKS#2	Drip	137	1083.3	14.5	926.2	2267	27.8	2.8	536.6
Mean			151	903.1	15.0	753.6	1606.4	27.7	2.6	531.8
SE			13.7	304.7	0.6	251.2	384.5	0.6	0.2	6.4

NB: Date of sowing (DOS) for Rockhampton: 6 May 2022; date of emergence: 20 May; Days to harvest: 178 days.
NB: DOS for Biloela rainfed: 12 July;, date of emergence: 26 July; days to harvest: 137 days.
NB: DOS for Biloela drip irrigated: 12 July; date of emergence: 26 July; days to harvest: 137 days.

The crop was almost defoliated at seed maturity, but the stem remained green and wet (Figure 16), hence, chemical desiccation with glyphosate was carried out at maturity, seven days prior to harvesting of the crop.



Figure 16. Kalonji crop at Biloela with supplementary irrigation, at capsule filling stage

The seed moisture content was monitored for the determination of harvesting date. The crop was harvested when the seed moisture content reached 6-8% (Figure 17).



Figure 17. Irrigated kalonji crop at Biloela grown outside the trial area of rainfed crop, for informal observation by grower, and desiccated for combine harvesting.

The drying down of the crop was faster in zero till plots compared to drip irrigated conventional tillage plot (Figure 18).



Figure 18. Zero till rainfed kalonji crop at Biloela desiccated for combine harvesting.

Seed yield

The position of the lower most capsule in the plant is about 10-15cm above the ground, therefore, the header can pick up most of the capsules (Figure 19).



Figure 19. Kalonji crop at harvesting. Kalonji trial sites were harvested with the ZÜRN150 research combine plot harvester.

The header front was positioned low in the ground to collect any lodged plants and even cutting height for maximising the capture of capsules and seeds.

The machine-harvested yield at Rockhampton was 1,317.5kg/ha and the machine harvested seed contained 14.4% debris. The final clean seed yield for the site was 1076kg/ha. The hand harvested yield of 1,616.8kg/ha was recorded for Rockhampton. Therefore, there was machine loss of 540.8kg/ha (Table 5).

The machine-harvested yield for the zero-till crop at Biloela was 308.6kg/ha and the seed contained 16.2% debris. The final clean seed yield for the site was 258.6kg/ha. The hand-harvested yield was 935.3kg/ha for a machine loss of 676.7kg/ha (Table 5).

The machine-harvested yield for conventional tillage and irrigation crop at Biloela was 1083.3kg/ha and the seed contained 14.5% debris. The final clean seed yield for the site was 926.2kg/ha. The hand-harvested yield was 2,267kg/ha for a machine loss of 1,340.8kg/ha (Table 5). The difference between hand-harvested yield and machine-harvested yield suggests a significant loss of seeds by machine harvesting.

Seed quality

The oil content in the seed ranged from 26.7% to 28.6%. The oil content in the seeds from Rockhampton was 1-2% lower than the seeds from Biloela. The test weight range was 2.3-2.8g/1000 seeds. The seed test weight from Rockhampton was lower than that of the Biloela. The kalonji seed density ranged from 519.2-539.7kg/m^3. The seed density was lower for Rockhampton seeds compared to Biloela (Table 5).

4.4.4 Discussion

Mechanisation of sowing and harvesting

The use of the Monosem planter demonstrated the success of kalonji seed planting for both conventional and zero tillage systems at Rockhampton and Biloela respectively. The crop was successfully harvested at both sites using the ZÜRN150 research plot combine harvester. The kalonji plant and capsule structure are well adapted for machine harvesting. Therefore, the kalonji commercial trials at Rockhampton and Biloela have demonstrated the complete mechanisation options for kalonji farming.

Some of the major challenges associated with use of planter are related to patchy emergence, which could be associated with the control of depth of seeding, as well as effective singulation of the seeds at planting. Smaller seeded crops often face the challenge of maintaining uniform plant stands in the field. Optimising the application of the planter for seed and soil type, better preparation of seeds (priming, coating, seed treatment) and preparation of seed beds for moist soil and seed contact during imbibition and germination, plus early stage weed control measures, could all improve kalonji emergence and establishment.

Kalonji has non-shattering properties and compatibility for machine harvesting. However, large yield gaps (44%) between hand-harvested and machine-harvested yield has been recorded in the trial crops. This shows opportunities for optimising the machine harvesting process as well as improving crop readiness for machine harvesting, so that holistic approach for machine harvest management is adopted. A similar problem for high header loss was reported in Canadian canola (Canola Research Hub, 2023) and different options that were suggested for optimising the use of headers might be considered for kalonji:

- Using extendable knife and draper headers over rigid headers to reduce header losses for straight combining.
- Selecting the harvest method that best suits field conditions.
- Using Flexxifinger crop lifters that fits into combine header for easy pickup flat crops on the ground.
- Growing a shatter-resistant variety will mitigate risk under ideal and adverse environments.

Machine-harvested seed yield

The seed lines planted in Rockhampton and Biloela for the 2022 trials had same the lineage (AVTKS#2) but the Rockhampton seed was selected as off-type (short-thick capsules type) from the AVTKS#2 planted in the verification trials in 2021 at Rockhampton. The comparison of the whole plot machine harvested yield between the two sites, representing AVTKS#2 and the new selection, with a number of underlying limitations for the yield comparison (lack of replications, different soil and planting time), shows higher seed yield (16%) for Rockhampton than Biloela (1076kg/ha vs 926.2kg/ha) for supplementary irrigated crop. The yield results recorded in this trial compared favourably with the yield (697.2-906.5kg/ha) reported by Ghamarnia et al (2017) for drip-irrigated (75-100% ET) kalonji in Iran.

Although the seed yield increased by 16% in Rockhampton compared to Biloela, this could not be confidently attributed for the effects of seed selection for off-type (short-thick capsule). An objective comparison between these two seed lines via replicated smaller plot field trials is required to address this question.

Hand-harvested yields were 44% higher than the machine-harvested yield (1606kg/ha vs 903kg/ha), which shows the opportunity for increasing the seed yield by improving the machine harvesting process.

Seed oil quality and processing

Seed quality is important for processors. The oil content when extracted using a warm press (70°C) was 27.8 – 28.6%. AgriVentis's kalonji seed lines have also shown high thymoquinone (TQ) content (1-2.8%) in the oil (Mani et al., 2022), when compared to large number of marketed kalonji oil samples (0.07-1.88%) in Malaysia (Alkhatib et at., 2020).

Kalonji seeds are processed for a wide range of health food, wellness products, supplements, and alternative medicinal products. The Australian processor, Hab Shifa, is a major global processor and supplier of kalonji-based health products (https://habshifa.com.au/) and is now working with AgriVentis Technologies to develop Australia's homegrown kalonji seeds for processing in Australia.

5. PRODUCTION AND POST-HARVEST CHALLENGES

5.1 Post-Harvest Challenges

5.1.1. Introduction

Kalonji seeds in the traditional growing regions (Africa and Asia) is manually cleaned by removing any debris with hand winnowing and washed by water into fine mesh strainer to remove dirt and rinsed for final cleaning. Any excess water is shaked-off and placed on towel/tarp for air drying of seeds. Kalonji being small-sized seeds, present challenges for seed cleaning. Commercial production of kalonji seeds in Australia need mechanisation options for seed cleaning and grading. The existing seed cleaning and grading equipment available in northern Australia for pulses and grains can't be utilised directly for the Kalonji seed cleaning. However, these existing cleaning grading facilities can be adapted if adequate seed pre-cleaning is carried out. Seed pre-cleaning option was evaluated in the seed cleaning machine, VAL-1500-6 for Kalonji seeds. VAL 1500-6 has been used for on-farm seed cleaning/grading for wide range of grains and pulses in Australia.



Natural
Egyptian Herbs

Specification Sheet

Nigella seed (Black Cumin)

1- General Characteristics

Product Name: Nigella seed
Supplier: Natural Egyptian Herbs Farms
Origin: Egypt.
Description, Composition:
Nigella seed is made from the flowers of Nigella Sativa .Only healthy raw material is cleaned, dried. It's free from stalks.
Labeling: Product Name / Date of Production / Lot No / Net weight / Gross weight / Origin / Exporter Name.
Packing: Plastic Package.
Shelf – Life from Date of Delivery: 18 months.

2 - Visual and Physical Inspection

Purity:	99,9 % Purity.
Colour Appearance:	Black
Odour:	Typical, aromatic, not mouldy or old.
Taste:	Typical, aromatic, not mouldy or old.
Consistency:	seeds whole
Net Weight:	25 kg
Particle Size:	seeds whole
Foreign Bodies:	Negative / the Product is metal detected and sieved for Safety

3- Analytical Instructions

Water / Moisture: Max 8 %.
Residues: Free from any detergent and disinfection agent. The product is free of pesticide residues and complies with the Organic Quality Standards.

4- Microbiological Instructions

Total Plate:	< 10^7 cfu / g.
Yeasts:	< 10^3 cfu / g.
Moulds:	< 10^3 cfu / g.
E-Coli:	< 100 cfu / g
Salmonella:	Negative.

Note: The above product complies with the Organic Standards and it does not subject to any kind of GMO's or Irradiation.

Figure 20. Kalonji seed specification sheet from an importer/exporter.

Kalonji seed need to be harvested at a low moisture content of 6-8%. 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 wet plant material (leaf/biomass contents) at harvest also influences the seed moisture contents. Complete defoliation/desiccation is suggested for harvesting dry seed. The kalonji market also demands very high seed purity, and markets set specifications that need to be

met for purchase (Figure 20). The details of a sample specification (as below) can be also be downloaded from the link - https://naturalherbs-egy.com/wp-content/uploads/2019/07/nigella.pdf

Kalonji seed harvested under unfavourable conditions results in significant amounts of debris in the seed lots, which can create additional challenges for the seed cleaning and grading facilities. On-farm primary seed cleaning machines (Figure 21) can reduce this burden, as well as reduce the transport cost of the primary cleaned seeds from farm to the final cleaning/grading operations and pack house.



Figure 21. The on-farm seed cleaning machine, VAL-1500-6, can be adapted for kalonji. The equipment has a cleaning capacity of up to 25 tonnes of seed per hour (Photo: D. Frahn).

5.1.2 Materials and methods

The application of grain cleaner VAL-1500-6 (Figure 21) was assessed at the grain cleaning lab facilities of Frahn Engineering Lab at Drung VIC Australia. The small batch of test seeds was processed through the lab unit that operates under similar principles of mobile field grain cleaner VAL-1500-6 (in terms of scalper, aspirator, and screens). The theory and operation procedure for the VAL-1500-6 grain cleaning equipment is summarised in box diagram (Figure 22).

In the field, harvested seeds is fed into machine by bucket elevator, the dust and light impurity are removed by air aspiration system, and then materials enter to sieving trunk which has multi sieve layers. Finally the material is graded to different levels by size, at the same time all the oversized and under-sized impurities are removed. The grain cleaner is customised with various sieve's size and amount of sieve layer that make the seed cleaner & grader applications suitable for different crops and maintain high grading efficiency. Specific cyclone dust separator protects working environment by control of dust spreading.

Theory and procedure for operation of on farm grain cleaning equipment, Farm VAL 1500 (Model. VAL-1500 x 6 – 2 x 3).

Theory: Precision weight and screen separation.

Design: Vertical aspiration leg 1500 mm wide, with six layers of screens, which consists of a double deck with 3 layers of screens in each deck.

Operation details:

The feed hopper is near the top of the machine at a convenient auger height.

The aspiration system has a large capacity fan with a 7.5 KW motor.

The fan will lift the dust, weed seeds, light and pinched grain. This material is collected in a cyclone.

In the bottom of the cyclone is a rotary valve which drops the material onto a tray.

This tray conveys the material to the bottom of the screening deck where it is combined with the small screening grain.

The screening deck has two electric vibrator motors with six layers of screens.

The vibrators give the deck a small orbital motion.

Under each layer of screens there is a tray which holds rubber balls.

The bouncing of these balls hits the underside of the screens removing the lodged grain in the screens.

Each layer of screens is made up of two pieces 1500 mm x 1200 mm, giving a total screen size per layer of 1500 mm wide x 2400 mm long.

By using screens with different apertures, which may be slots or round holes, it is possible to clean a large range of grains.

The screening deck can be setup with one layer of screens for scalping and two layers of screens for screening.

Another option is to have two layers of screens for scalping, and one layer of screen for screening.

The machine is transported on Tandem spring suspension.

Capacity: 6-25 tonnes/hour

It is very easy to operate, and the adjustments are simple and responsive.

Figure 22. Theory and procedure for the operation of the on-farm grain cleaning equipment, VAL 1500-6-2x3 Model (Source: D. Frahn, 2022).

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

Aspiration. Light materials separation.

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

Layer 2. Second Scalper, 2.0 mm round hole. Scalp of weed seeds.

Layer 3. First screen, 1.8 mm round hole. Good seed.

Layer 4. Second screen, 1.6 mm round hole. Smaller pinched good seed.

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

The pre-cleaned seed samples need additional cleaning with gravity table and the final process being a colour sorter for the high purity kalonji seed required by the market.

5.1.3 Results

The results of seed cleaning from two small test batches (250-500g) of uncleaned kalonji seeds (received directly from the research plot harvester) passed through different scalper and screen arrangements in the laboratory seed cleaning machine are summarised in Table 12. Primary cleaning of the kalonji seeds resulted into the clean seed recovery of only 47% (227 g of clean seeds from 500g of sample), suggest the need for rigorous cleaning. A second pass of primary cleaned seeds results into clean seed recovery of 98%.

Table 12. Laboratory grain cleaning test results of the kalonji seeds after first- and second pass of cleaning using seed received from winter verification trials at Rockhampton. s

Cleaning stage	**Screen hole size and types**	**Weight (g)**	**Weight (%)**	Screen Layers
Raw uncleaned seeds		500	100%	
Aspiration heavy materials		198	41.4%	
Aspiration light dust		30	6.3%	
Scalper	Above 3.00 mm round hole	15	3.1%	
Screen	Below 3.00 mm round hole above 1.38 mm square hole mesh	227	47.5%	
Fines	Below 1.38 mm square mesh	8	1.7%	
Sub total		478	100.0%	
Unaccounted weight (moisture/dust loss?)		8	1.60%	
Repeated screening of the seed cleaned from first stage cleaning as above [table 12, row 6 (227g)- as this seed still has contaminants] and seed rescreen test results.				
Cleaning stage	Screen hole size and types	Weight (g)	Weight (%)	Remarks
First stage clean seed		200	100%	
Aspiration			-	Aspiration Layer
Scalper Coarse	Above 3.00 mm round hole screen	0	-	Screen Layer 1.
Scalper Fine	Above 2.0 mm round hole screen	21	10.5%	Screen Layer 2
Top screening screen	Above 1.8 mm Round Hole screen	141	70.5%	Screen Layer 3
Bottom Screening screen	Above 1.6 mm round hole screen	34	17%	Screen Layer 4
Fines	Below 1.6 mm round hole screen	3.5	1.75%	Bottom Layer
Sub total		199.55		
Error-unaccounted weight (moisture loss?)		0.45	0.225%	
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*

The seed samples for cleaning, collected from the harvester contains a mixture of seeds with different sized and shaped plant debris. Such mixture of seeds and debris are separated by several moving screens and aspirators into different size and class materials. In the case of kalonji, six different size-class materials were produced. Thus separation required the correct screen size for the on-farm seed cleaning machine to match the size distribution of the bulk uncleaned seed in the bin. An example of kalonji seed harvested from Rockhampton in 2021 is presented as before cleaning and after cleaning in Figure 23.



Figure 23. The uncleaned seed from plot harvester (left) and cleaned seed using VAL-1500-6 screens for kalonji seeds.

The seeds are separated in different levels of aspirators and scalping screens to show the visual of different size class distribution and its application in seed cleaning.

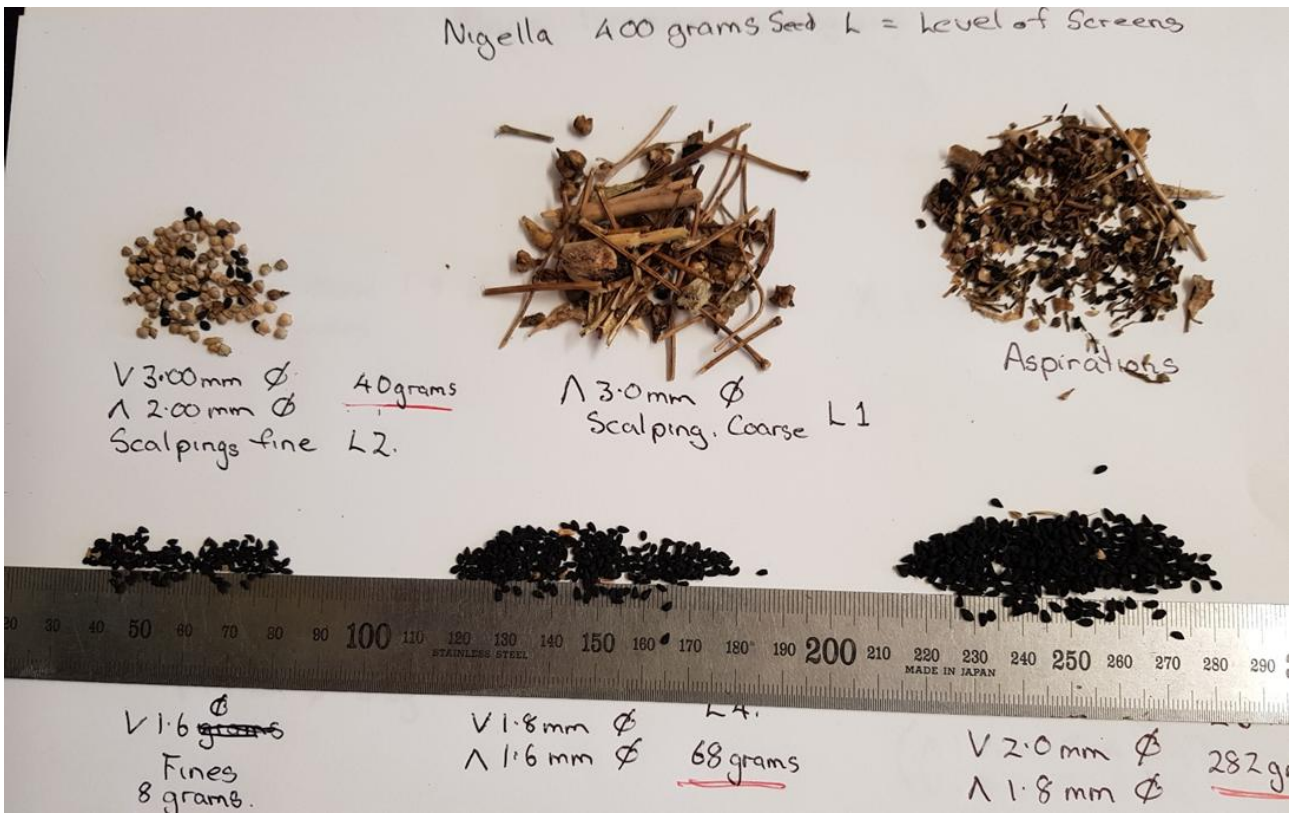


Figure 24. The seed harvested in 2021 by the research plot header and sieved by different sized screens to sperate seeds from debris (>3 mm), and fine dust and sub-size seed (<1.6 mm).

The optimisation of the cleaning process involves analysing the samples with different mesh size screens accommodating the higher and lower size ranges in the seed mixture so that all extreme particle sizes other than seeds are removed. Figure 24 shows the seed cleaning output with different screen size combinations between 1.9mm and 2.5mm.

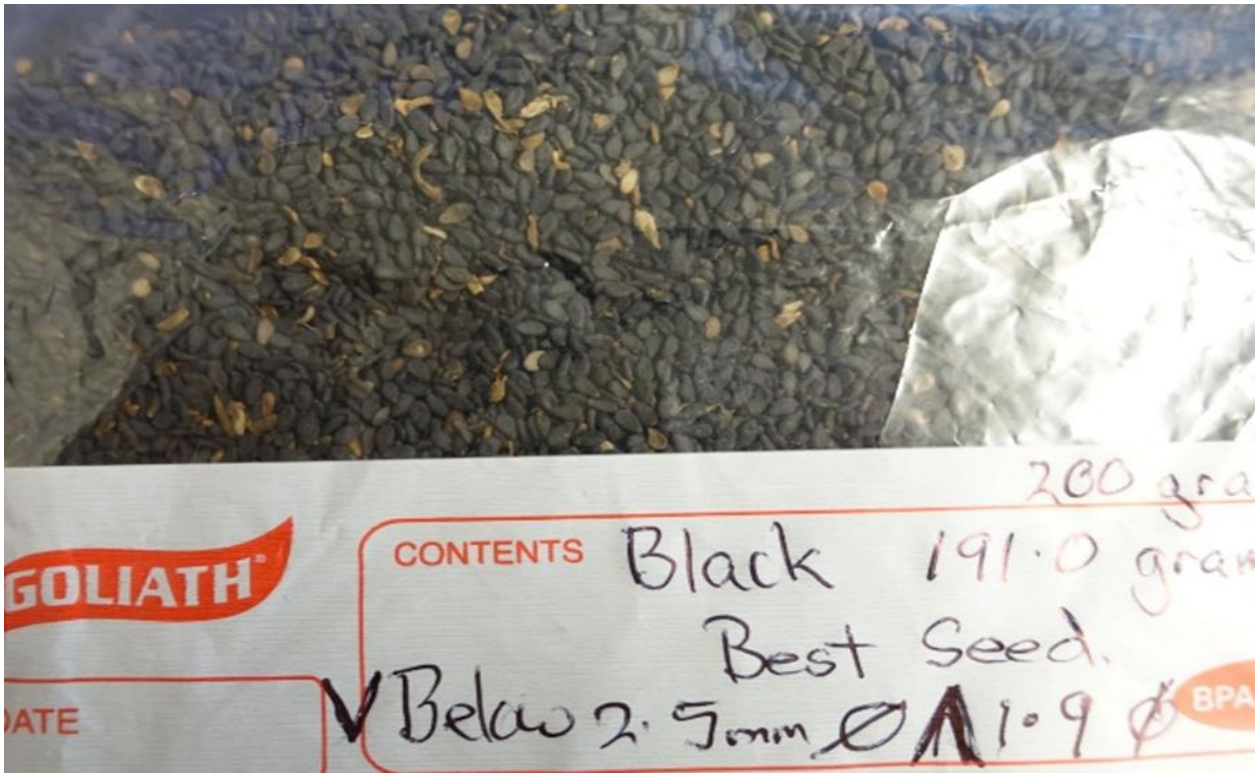




Figure 25. The seed samples screened with 1.9-2.5mm mesh.

The efficiency of cleaning seeds by matching the correct screens and aspiration combination to the harvested seed for the VAL-1500-6 operations improves the result. Therefore, correct setting for the VAL specific to the crop, variety and season is suggested.

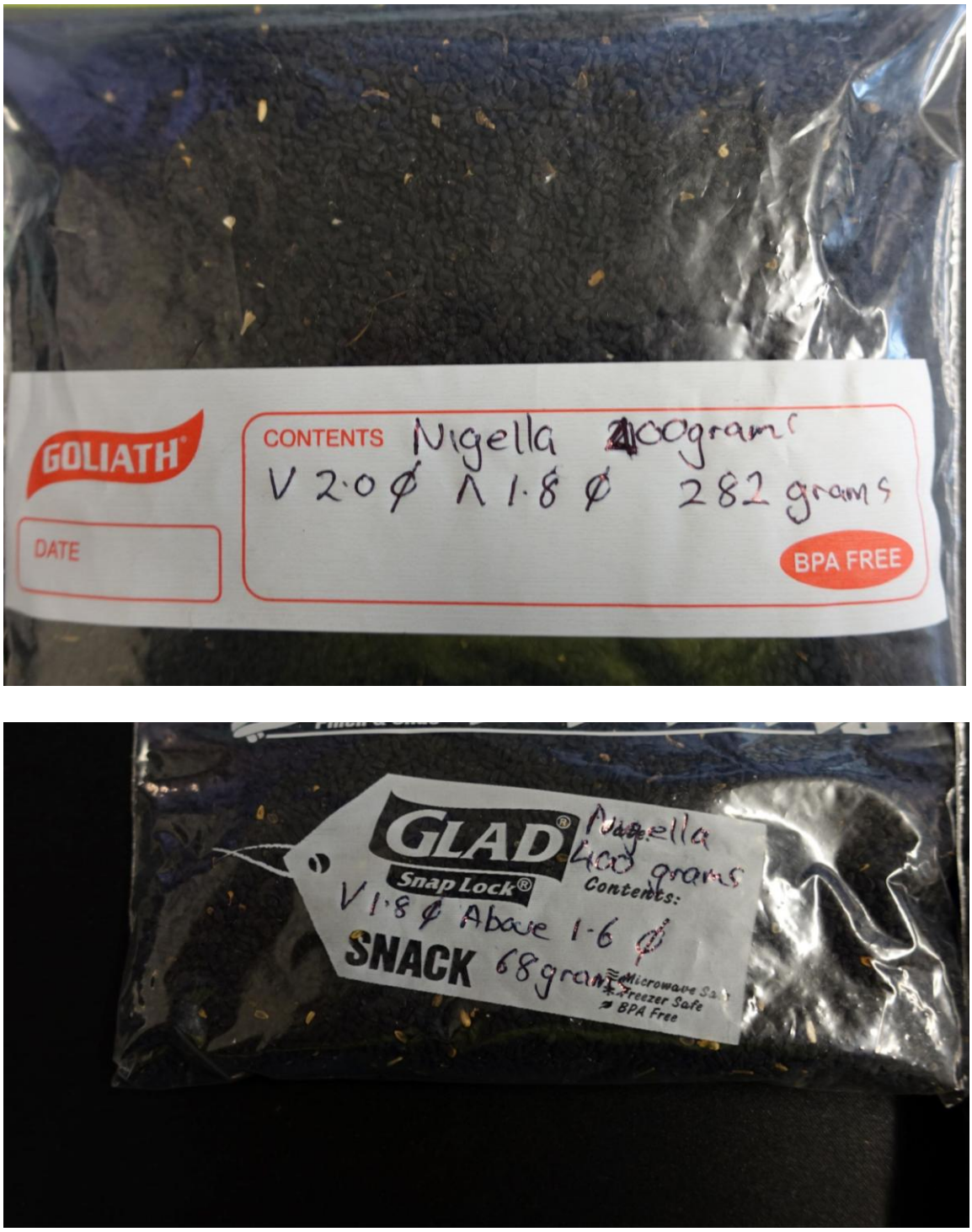


Figure 26. Seed samples screened with 1.8-2.2mm mesh.

Optimising the screen settings can significantly improve the efficiency of on-farm seed cleaning units. A pilot run of the seed cleaner using harvested seed from the KEW header showed that the recovery of clean seeds is about 47% (Figure 26). Low recovery of the clean seed was due to higher moisture and excessive

biomass debris due to wet weather impacts on the crop at the late maturity stage during the 2021 season. The trial showed that the clean seed recovery varied according to the incoming sample quality.

5.1.4 Discussion

The results from a lab-based grain cleaning machine showed that multi-stage cleaning is required for kalonji seed that is heavily contaminated with biomass at harvest. The two test results presented above (Table 12) show the clean seed recovery of only 47% for the seed lot received from the 2021 winter planting verification trials in Rockhampton.

The second stage cleaning is more efficient and faster with the recovery of 98% clean seeds.

The VAL-1500 is rated for cleaning up to 8t/hour for larger seeds such as mungbean and chickpea. For the current sample of kalonji seeds, the machine capacity has been estimated to be 1-2 tonnes per hour, as the capacity of the cleaning machine was greatly compromised due to smaller seed size and excessive biomass contamination.

This trial data provides the guidelines for assessing the settings of screen size and aspiration for the VAL-1500-6 machine for on-farm primary seed cleaning process. The on-farm primary and secondary seed cleaning will improve the seed presentation for final cleaning as well as reduce the transport cost of raw seeds from farm to the final cleaning, grading and colour sorting operations.

The cleaned seed samples from the screens above will need additional final cleaning with a gravity table and the final process through a colour sorter. The result would be the high-quality seed that meets market specifications (Figure 20).

On-farm seed cleaning are also increasingly adopted by grain industry. Various alternative options, in additions to the trial unit of VAL 1500 used in this experiment, are available to growers for on-farm seed cleaning. For example, using a two-stage cleaning process grain cleaner designed by Farm King (https://www.burandohill.com.au/graincleaners) allows separating dockage, rocks and other unwanted contaminants from grain before it is shipped or stored. Similarly, Grain Cleaning Solution USA (https://gcsgraincleaner.com/), manufacture wide range of grain cleaning options and GCS grain cleaner have been successfully adapted for cleaning smaller seeds such as canola through the cleaner at its max capacity and have been reported for successful results for cleaning smaller seeds.

5.2 Insect Pests

5.2.1 Major Insect Pests

Insects pest problems were not a major issue in the kalonji trial crops. This report documents a list of insect pests sighted in the trial crops during the project period. As the insect pest damage was not alarming, the enumeration and scoring of the insect pests damage on crops was not carried out.

The inspect pests were identified with the support of entomologists from QDAF and included:

- Aphids
- Whitefly
- Pod borrers
- Caterpillars
- Mites
- Thrips
- Green vegetable bugs
- Pumpkin beetle
- Shield bugs
- Gall fly
- Heliothis borrer

- Sphinex moth

5.2.2 Crop damage by insects

Crop infestation by the insects was minimal in all trials during the first and second year. However, some minor damage by pod borers was noted at Rockhampton and Biloela during the third year for the commercial trials. The estimated yield loss was negligible as many infested pods, when cut open, showed only minor damage to a few seeds inside the capsules, while the remaining infested capsule developed seed to maturity and harvest.

5.2.3 Beneficial Insects

A number of beneficial insects were identifed at each of the locations. A variety of spiders was observed at all sites; assassin bugs were present at Rockhampton and Ayr; and butterflies, European honey bees and native bees were prevalent at all sites and were effective pollinators during flowering.

5.3 Diseases

Not many diseases were noted in the trial crops over the three years of research. However, the root rot symptoms at the seeding stage were common across all sites, and some sporadic wilting of the matured plants was also noted in the verification and commercial scale trial sites at Rockhampton and Biloela.

5.3.1 Major diseases

The major diseases noted during the kalonji growing period include:

- Root rot
- Wilt
- Blight
- Powdery mildew
- Leaf spots

5.3.2 Crop damage by diseases

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

5.4. Physiological disorders

Plant yellowing symptoms, similar to that reproted by Jibat et al (2018) in the major kalonji production areas of Ethopia, was observed on only a few plants.

No other physiological disorder was noted during the project period.

5.5 Other Challenges

5.5.1 Weather damage

Wet weather caused crop lodging at the trial crops in Rockhampton, Biloela and Ayr. Lodging affected the machine harvesting of the crop as the header was unable to pick the lodged crop efficiently. The lodged crop at maturity stage until harvesting was also vulnerable to damage by mice and rodents.

Wet weather impacted mature crops, particulary those in heavy clay soils, and limited access to the paddock for harvestand for field equipment. Constant wet weather during harvesting stage of the crop in Biloela during winter 2021 resulted in the inability to harvest the crop.

Wet weather can also affect seed quality, particularly at harvest. The verification crop at Biloela and Ayr experienced extended wet weather causing excessive mositure on plant biomass, capsules and seeds. This interfered with the desiccation process at harvest. The crop at both sites was abandoned from harvesting due to the excessive moisture challenges.

5.5.2 Other pests (Birds, Rodents, Animals, Parasites)

The impact of birds, rodents, wallabies, and pigs were not noticed in the trial plots. Introduction of new grain crops in northern Australia has often resulted in damage a from these pests but kalonji appeared to be unaffected duing the trial period. Some mice damage on the mature crops was noticed in the initial varietal evaluation trial at Biloela in 2020 prior to harvesting.

The parasitic plant, Orobanche, has caused yield loss in other major kalonji producing countries, including Ethiopia (Jibat et al., 2018). However, the association of parasitic plants with kalonji was not noticed in any of the trial sites during the project period.

5.6 Weed control

Weed competition, particularly during the early establishment stage was recorded as a major challenge for kalonji production at all trial sites. Kalonji being a new crop, has only a limited number of chemicals registered for use through the APVMA.

Overseas work in Germany by Schmatz et al (2008) showed that the pre-emergence treatment with Bandur, Boxer and Butisan, and post-emergent treatment with Tramat 500, were effective herbicide options for kalonji. Likewise, the control of weed grasses and weed cereals with Fusilade MAX or Targa Super were found to be effective without problems. The results also showed that the observed residues in the dried seed samples complied with the legal maximum residue level of the investigated herbicides (Schmatz et al., 2008).

In another experiment conducted in Iran, post-emergent application of foramsulforon, oxadiazinon, niclosulfuron, rimsulforone, sulfosulfuron, Atlantis, Othello, and pre-emergent application of pendimethaline, showed a significant effect on the density and biomass of weeds. All herbicides except Atlantis and foramsulforon decreased grass weed biomass. Biomass of broadleaf weeds was reduced significantly by Atlantis and Othello. Pendimethaline, rimsulforone, Othello and Atlantis controlled total weeds by 60, 59, 57 and 50%, respectively, whereas oxadiazinon and foramsulforon caused the lowest injury to the kalonji plant (Vahid et al., 2020). Further experiments are necessary to optimise chemical weed control specific to Australia's northern environments and farming systems.

5.6.1 Herbicide residues

Herbicide residue management is as important as the use of herbicides for control of weeds for kalonji production. An understanding of the effects of herbicide residues in the soil from previous cropping practices on kalonji germination and growth, is important for kalonji production to be integrated into existing farming systems in Northern Australia. The role of post-emergent and desiccation herbicides is also crucial as the dried seed samples of kalonji should strictly comply with the maximum legal residue levels for the investigated herbicides.

6. CONCLUSIONS AND RECOMMENDATIONS

The Spicing Up Northern Australia project was successful in carrying out grower and industry participatory kalonji crop research over three years and six locations in Northern Australia. Four kalonji varieties were tested as initial evaluation trials in the first year in all sites, followed by variety verification trials of selected varieties by growers in the second year, and commercial-scale production trials in the third year.

The kalonji seed yield for the four varieties, in the initial variety evaluation trials, did not vary significantly between varieties but varied between the sites. The crop recorded a maximum hand-harvested yield of 3197kg/ha at Biloela, followed by Ayr (914kg/ha), Rockhampton (908kg/ha), Katherine (247kg/ha), and Darwin (7kg/ha). Therefore, the year 1 results by site established that the kalonji is more suited to Central Qld than the NT and NQ.

The verification trials were planted with a small mechanical planter (Jang planter) and harvested with a plot combine harvester. Verification trials recorded a machine-harvested yield of 342.5kg/ha in Rockhampton, followed by 123.2kg/ha in Gracemere north and 47.2kg/ha in the Gracemere south. The verification trials demonstrated options of adapting existing small plot planter and harvester for kalonji production. Kalonji is relatively tolerant to shattering, however, there was still a large machine harvest loss (35-55%), suggesting further investigation for optimisation of header use for kalonji harvest.

The commercial crop trial in third year, with supplementary irrigation in Rockhampton recorded machine harvest yield of 1076kg/ha and 926.2kg/ha in Biloela. However, the seed yield for the rainfed crop in Biloela was only 258.6kg/ha, showing high response to irrigation and weak drought tolerance. Therefore, variety selection for improved water use efficiency and early and synchronous maturity, high yield and seed quality is suggested. The project also established the opportunity for the kalonji crop integration into existing farming systems in Northern Australia and undertook market and gross margin analysis to assist in decision making by growers. Growers interest for contractual production of commercial kalonji crop, has been reflected by an agreement between grower and AgriVentis for contract production of Kalonji seeds in 100 ha for the domestic supply to HabShifa.

Kalonji being a small-seeded crop, presents post-harvest seed cleaning, grading and sorting challenges as the bulk harvest contained significant amounts of biomass. The operating conditions for mobile seed cleaning equipment (Frahn VAL-1500-6) were optimised, that produced an acceptable level of primary seed cleaning. Further work for final cleaning and colour sorting is needed to assist growers and processors to meet strict market specifications. The kalonji research also documented challenges for crop establishment, and identified key diseases, insects, pests and weed challenges that require further research.

In undertaking a market and gross margin analysis, the crop currently presents low gross margin (max $1256/ha in 2022), however, further increases in gross margin could be achieved by improving the machine-harvested yield of kalonji. The lack of adequate agronomic tools limit scaling up of kalonji 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. Similarly, other impediments for the production associated with crop protection, nutrient and water management, farming system adaptation, crop establishments, harvesting, seed cleaning-grading and post-harvest storage are also embedded in the GNS project (2023-2026).

REFERENCES

ABARES n.d., About my region - Central Queensland, viewed 01 Oct, https://www.awe.gov.au/abares/research-topics/aboutmyregion/qld-central#references

AgMargins (2023), Agricultural Gross Margin Calculator, QLD Government, Viewed, 4 January 2023, https://agmargins.net.au/

Ahmad, A., Husain, A., Mujeeb, M., Khan, S.A., Najmi, A.K., Siddique, N.A., Damanhouri, Z.A., Anwar F., (2013). A review on therapeutic potential of Nigella sativa: A miracle herb. *Asian Pacific Journal of Tropical Biomedicine*, 3:337–352.

Ali Z, Mazhar U. (2018). Toxic effects of *Nigella sativa* against *Rhyzopertha dominica* (Coleoptera: Bostrichidae). *J Agric Sci Bot,* 2(4):3-6.

Alkhatib H., Mawazi S.M., Al-Mahmood S.M.A., Zaiter A., Doolaanea A.A. (2020). Thymoquinone content in marketed black seed oil in Malaysia. *J Pharm Bioallied Sci.* 12(3):284-288. doi: 10.4103/jpbs.JPBS_208_20. Epub 2020 Jul 18. PMID: 33100788; PMCID: PMC7574749.

Ariafar, S., & Forouzandeh, M. (2017). Evaluation of humic acid application on biochemical composition and yield of black cumin under limited irrigation condition. B*ulletin de La Société Royale Des Sciences de Liège*, 86(special issue), 13–24.

Behara, S. (2023). Step by step guide to grow black cumin (kalonji). https://krishijagran.com/agripedia/step-by-step-guide-to-grow-black-cumin-kalonji/. Accessed on 8 March 2023.

Bureau of Meteorology (2001). Map of Climate Zones of Australia, http://www.bom.gov.au/climate/how/newproducts/images/zones.shtml

Bureau of Meteorology (2021). Annual climate statement 2020, http://www.bom.gov.au/climate/current/annual/aus/#tabs=Rainfall

Canola Research Hub (2023). Combine settings, harvest timing and genetics can optimise canola yields. Accessed on 27 Feb 2023. https://www.canolacouncil.org/research-blog/combine-settings-harvest-timing-and-genetics-can-optimize-canola-yields/

Engels, G., Brinckmann, J., (2017). Nigella, Herbal Gram, *The Journal of the American Botanical Council,*114:8-16.

FAO n.d., Crops and livestock products, viewed 10/09, https://www.fao.org/faostat/en/#data/CP

Ghamarnia, H., Khosravy, H., and Sepehri, S. (2017). Yield and water use efficiency of (Nigella sativa L.) under different irrigation treatments in a semi-arid region in the West of Iran. I*nternational Journal of Irrigation and Water Management.,* 4(12): pp.001-005.

Gilani, A.H., Aziz, N., Khurram, I.M., Chaudhary, K.S., Iqbal, A. (2001). Bronchodilator, spasmolytic and calcium antagonist activities of Nigella sativa seeds (Kalonji): a traditional herbal product with multiple medicinal uses. *Journal of Pakistan Medical Association,* 51(3):115-120.

Globe Newswire, (2019). Black Seed Oil Market to hit $25mn by 2025: Global Market Insights, Inc., available at: https://www.globenewswire.com/news-release/2019/01/21/1702692/0/en/Black-Seed-Oil-Market-to-hit-25mn-by-2025-Global-Market-Insights-Inc.html.

GRDC (2023). Minor use permits, viewed 27 Feb, https://grdc.com.au/resources-and-publications/minor-use-permits

Huchchannanavar, S; Yogesh, L.N., & Prashant S.M. (2019). The black seed Nigella sativa: A wonder seed. *International Journal of Chemical Studies*, 7(3):1320-1324. https://icarkvkballari.org/wp-content/uploads/2022/06/SH1.pdf

Jibat, M., Getachew, W., Ommit A., Kifelew, H., Getu, A. (2018). Survey and Identification of Black Cumin (Nigella Sativa L.) Disease in Ethiopia. *International Journal of Research in Agriculture and Forestry*, 5 (11):31-34

Khodadadi, V., Yousefi, A. R., Shahbazi, S. (2020). Evaluation the possibility of chemical weed control in black cumin (*Nigella sativa* L.). *Iranian Journal of Weed Science*, 16 (1):15-26. DOI: 10.22092/IJWS.2020.1601.1306

Karim M., Himel, R. M., Ferdush, J., and Zakaria, M. (2017). Effects of irrigation levels on yield performance of black cumin. *International Journal of Environment, Agriculture and Biotechnology (IJEAB)*, 2(2): 960-966. http://dx.doi.org/10.22161/ijeab/2.2.52

Kifelew, H., Getachew, W., Luleseged, T., Mitiku, H., Bekele, D., & Fikere, D. (2017). Seed spices production guideline: Ethiopian Institute of Agricultural Research. http://www.ublication.eiar.gov.et (pp. 1–36)

Hunter, L. Personal Communication. (2020).

Mani, J., Johnson, J. B., Bhattarai, S. P., Trotter, T., and Naiker, M. (2022). Phytochemistry and Therapeutical Potential of New Nigella sativa Genotypes from Australia. *Journal of Herbs, Spices and Medicinal Plants.* https://doi.org/10.1080/10496475.2022.2140738

Market watch, (2019). Black Seed Oil Market 2019 Trends, Industry Projections, Regional Analysis and Forecast to 2025, available at: https://www.marketwatch.com/press-release/black-seed-oil-market-2019-trends-industry-projections-regional-analysis-and-forecast-to-2025-2019-08-14.

Queensland Government n.d., Common soil types, viewed 2 Oct, https://www.qld.gov.au/environment/land/management/soil/soil-testing/types

Queensland Government Statistician's Office (QGSO), Queensland Treasury, (2023) Queensland Regional Profiles: Resident Profile for Central Queensland Statistical Area Level 4, viewed 3rd January, 2023, https://statistics.qgso.qld.gov.au/qld-regional-profiles.

Schmatz, H., Taubert, K., Ormerod, C. and Biertümpfel, A. (2008). Experiments with herbicides in black cumin (Nigella sativa L.) in Thuringia. *Journal of Medicinal and Spice Plants.* 13. 121-126.

Senapati, N., Stratonovitch. P., Paul, M. J., Semenov M. A. (2019). Drought tolerance during reproductive development is important for increasing wheat yield potential under climate change in Europe. J Exp Bot. 2019 Apr 29;70(9):2549-2560. doi: 10.1093/jxb/ery226. PMID: 29901813; PMCID: PMC6487587.

Stefanopoulou E, Roussis I, Tsimpoukas K, Karidogianni S, Kakabouki I, Folina A, Bilalis D (2020), A comparative techno-economic analysis of organic and conventional Nigella sativa L. crop production in Greece. Bulletin UASVM Horticulture, 77 (1), pp. 150–153. https://doi.org/10.15835/buasvmcn-hort:2019.0018

Savaedi, Z., Pramoon, G., Moosavi, S. A., Bakhshande, A. (2019). The role of light and gibberellic acid on cardinal temperatures and thermal time required for germination of Charnushka (*Nigella sativa*) seed. *Industrial Crops and Products*, 132:140-149.

Seyyedi, S. M., Moghaddam, P.R. and Mahallati, N. (2016). Weed competition period affect grain yield and nutrient uptake of black seed (*Nigella sativa* L.). *Horticultural Plant Journal,* 2(3):172-180.

TurkStat (2019). Turkish Statistical Institute, http://www.turkstat.gov.tr/PreTabloArama.do

Yimam, E., Nebiyu, A., Mohammed, A., and Getachew, M., (2015). Effect of Nitrogen and Phosphorus Fertilizers on Growth, Yield and Yield Components of Black Cumin (Nigella sativa L.) at Konta District, South West Ethiopia. *Journal of Agronomy,* 14: 112-120. DOI: 10.3923/ja.2015.112.120

Zauba (2018), Detailed Export Data of nigella seeds, Available at: https://www.zauba.com/exportNIGELLA+SEEDS/fp-australia-hs-code.html.

The CRCNA acknowledges the support of its government partners.







