SUMMER SPICE TECHNICAL REPORT

BLACK SESAME

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Contents

EXECUTIVE SUMMARY

Growing international consumer demand for sesame is delivering favourable market conditions, with the global crop valued at US$6.5 billion in 2018 and projected to reach US$17.77 billion by 2025. The Australian market is following this global trend, importing increasing amounts of both raw sesame seeds and value-added sesame products. In 2016 Australia imported 6740 tonnes of sesame and current trends indicate domestic demand will reach 9800t in 2025. The value of these sesame imports into Australia exceeded US$26.5 million in 2016 and demand since this time has been increasing.

Previous attempts in Australia to establish sesame production in the early 1990s were focused on white sesame and did not gain momentum due to the low commodity price at the time and the inability for domestic producers to compete with imported products. The lack of support for commercial production was also due to a lack of supply chain options for suppliers and distributors.

Black sesame is a high-value product returning approximately 45% more than white sesame (US $1229/t in 2018). Australia's domestic demand is consistently increasing, and this, coupled with a significant global demand for black sesame, brings a new opportunity for Australian growers to enter into commercial production of black sesame.

CQUniversity is supporting on-farm trials to evaluate the suitability of new black sesame germplasm for the sub-tropical and tropical environments of Northern Australia. This varietal material is provided by AgriVentis Pty Ltd. The CRCNA investment has enabled this work to move from laboratory trials to field trials across Northern Australia as part of multi-year project. This report provides the results of the first year of multi-location trials of four black sesame genotypes grown at six locations across Queensland and the Northern Territory. It covers the in-field crop agronomy and the results of the yield and quality analysis. The results from the first year of trials will inform the second phase of activities in the form of on-farm verification of black sesame technologies. The verification phase will be followed by commercial cropping, resulting in contract production in the third year of the project.

Black sesame is a summer crop in Northern Australia, with a 90-120 day crop duration from planting until harvest. The crop has showed wide adaptability, demonstrating its potential to fit into cotton or sugarcane farming systems. The crop is known for its drought and heat tolerance making it a desirable crop choice for the environmental challenges experienced in northern Australia.

The seed yield of the four varieties across each of the six trial locations, ranged from 1.37 to 3.04 t/ha, with the highest seed yield recorded in Biloela followed by Rockhampton, Katherine, Ayr, and Darwin, and the lowest yield recorded in Tully. This is significantly higher than the global average of 554kg/hectare. The seed yield between the varieties varied significantly at Biloela, Rockhampton and Darwin, but did not differ between the varieties at Ayr, Tully and Katherine, showing a significant genotype x environment interaction. Amongst the four genotypes tested, AVTBS#6 and AVTBS#11 recorded a higher yield compared to the other genotypes in Biloela and Rockhampton. In Darwin, the seed yield was greater for AVTBS#6, AVTBS#11 and AVTBS#16 compared to lowest yield AVTBS#3. However, it is important to bear in mind this is one year's data only.

The crop produced significant biomass in the range of 3-10 t/ha. This volume of biomass creates an opportunity for value-adding, with biomass waste being able to be used for briquettes and harvesting of antioxidants. The value of these bi-products and options for capturing this value during production, have not been examined as part of the trials to date.

The highest standards for black sesame quality are set by the Japanese, with a requirement for 99.7% seed purity and above 46% oil. Other internations markets have lesser quality requirements than Japan (Pers.Comm. Lewis Hunter 2020). The quality attributes of the sesame seeds are reflected on the 1000 grain weight and oil content. The higher yielding genotypes such as AVT#6 and AVT#11 recorded greater 1000 seed weight compared to other varieties. The 1000 seed weight was low in Tully and Ayr, which is associated with greater rainfall during grain filling stages. Unlike the 1000 seed weight, the oil content across locations ranged from 37 to 47%, with no significant difference between the tested genotypes. The highest oil content from the seed was recorded from the Tully samples (47%), followed by

Darwin (46%), a mid-range oil content was recorded in the samples from Katherine, Ayr and Rockhampton (44%), and the lowest in Biloela (43%).

The next stage of research involves on-farm verification of selected genotypes from the first year for evaluation of the adaptability of the variety to local farming conditions. The early results are encouraging, however, there are still some challenges that need to be addressed for full fledged production including weed control, optimisation of mechanical harvesting, and providing robust agronomic information especially concerning optimum planting times on the different regions and density of planting. These activities are built into a parallel project funded by AgriFutures. It is pleasing to see the coordinated and collaborative approach to this work to support a new and emerging industry for northern Australia.

The authors acknowledge the financial support of the Cooperative Research Centre for Developing Northern Australia and 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.

INTRODUCTION

Sesame (*Sesamum indicum* L.,) is one of the most ancient oilseed crops. The food industry world wide consumes sesame seeds for uses including confectionery, edible oil, paste (tahini), cake and flour and in spice mixes such as 'rubs' and dukkah. More recently sesame seeds are also increasingly being used in vegan and vegetarian dishes. This is one of the most important market trends contributing to the increased sesame consumption in developed countries. According to FAO (2019), in 2017, sesame was produced on 9.9 million hectares with an average yield of 554kg/hectare. There has been an upward trend in world sesame production over the last 50 years (FAO, 2019). Traditionally sesame is typically a crop of small farms in the developing countries of Africa and Asia. However, with its increasing market demand, production areas have expanded across the world to the USA, Europe and Australia.

The global market value of sesame in 2018 was approximately US$6.5 billion and is expected to reach to US$17.77 billion by 2025. Australia imports nearly all of the sesame it consumes domestically. In 2016 Australia imported 6740t of sesame and current trends indicate an increasing domestic demand forecast to reach 9800t in 2025 (Rahman *et al*., 2020). The value of combined sesame products (raw white and black sesame seeds plus their derived products) imported into Australia was in excess of $26.5 million in 2016 and demand has since been increasing, according to AgriFutures (FarmOnline https://www.farmonline.com.au/story/6700505/australia-well-positioned-to-make-use-of-new-sesame-seed-varieties/).

Sesame is not an entirely new crop for Australia. There were some early attempts in the 1990s to grow white sesame in Australia with some small scale production between 1999-2003 (Bannett, 2014). As a result of this early work, small commercial production progressed (~2000 ha) in NT, Southern QLD and NSW with the total production of 620t of white sesame produced in 2000-01 season. Five white sesame genotypes were evaluated over multiple years for developing higher yielding cultivars. The seed yield in the field trials ranged from 0.8-1.5t/ha in those early studies (Bennett, 2014). The crop production did not continue largely due to a lack of market coordination, as the connection between paddock and plate were not in place for the domestically produced sesame crop. In addition, the prices achieved for the white sesame at the time were less competitive compared to other cropping options.

Today black sesame returns approximately 45% more than white sesame (US $1229/t in 2018). Increasing domestic demand and a strong and ongoing growth in global demand presents an opportunity for Australian growers to enter commercial production. The viability of establishing a commercially sustainable industry is being tested through a Research–Development– Commercialisation approach. This includes seed genotype development in the first year (on-farm trials for the evaluation of new crop genetics in black sesame), followed by a year of verification where the genotypes selected from first year trials are assessed for their suitability into the existing cropping system and the overall farm conditions allowing evaluation of new genotypes under farmer-managed conditions to build confidence in the crop adoption for commercial production. Commercial contracts between growers and the seed company AgriVentis are planned for the third year, with the seed company providing both the planting material and the post-harvest value chain management..

CQUniversity initially undertook preliminary glasshouse trials and field trials in Central QLD in 2016-2018. The results showed the potential of growing black sesame varieties for commercial production in Northern Australia, paving the way for the current CRCNA multi-site project. The results to date show black sesame suitability to summer conditions. Black sesame is a drought-tolerant crop which thrives in hot climates, and is also being evaluated in higher rainfall zones. As the cropping industry develops in Northern Australia, black sesame could provide an opportunity for producers an additional break crop option within current rotations, or provide a cropping option during dry periods when the regular crops cannot be grown due to lack of moisture.

The crop is well-adapted to tropical and sub-tropical conditions; grows well on stored soil moisture with minimal irrigation or rainfall; and it can produce good yields under abiotic stress conditions including high temperatures. The seed is a high value commodity, at $A1500/t to $A2,000/t for export quality. A high-value broadacre black sesame industry in Northern Australia would both replace imports and generate exports to Asia and the Middle East, bringing new industry opportunities for Northern Australian growers.

This report describes the results of field trials undertaken for black sesame varieties over the summer of 2019-2020. Data collected over the cropping period from the different agro-ecological zones allowed for evaluation of the suitability of black sesame production based on phenology, yield, yield attributing factors (the plant physiological features which drive the yield the plant produces such as amount of biomass available to produce yield) and quality metrics for wide-scale commercial production in Northern Australia.

MATERIALS AND METHODS

Trial locations

Field trials were conducted to determine the suitability of four genotypes of AgriVentis black sesame to the climate, soils and environmental conditions in northern Australia. The trial locations included four sites in Queensland and two sites in the Northern Territory (Figure 1).

Figure 1. Trial locations in northern Australia, including Biloela, Rockhampton, Ayr and Tully in Queensland and Katherine and Darwin in the Northern Territory.

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

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

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

Planting season

The planting window varied (Table 2) from early to mid-summer depending on the availability of moisture in the soil and predictions for the onset of the wet season.

Table 2. Trial planting and harvest dates

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

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

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

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

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

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

For the weed control, at Katherine a pre-emergent herbicide Stomp (Pendimethalin A.I 440g/L) was applied at the rate 1.5L/ha two days post-sowing for weed control (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 sesame had developed a canopy, minimal weeding was required as the plant was prolific enough to outcompete any weeds.

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

Varieties, Trial Design and Planting Densities and Dates

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

Data collection

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

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

The quality assessment of the harvest seeds were undertaken in CQUni's crop science laboratory. For the quality assessment, a 100gm sample of seed was cleaned from plant trash and dust, dried in an oven at 40^{o}C and weighed for determination of seed moisture content. The weight (g) for 1000 seeds was taken for each sample using a seed counting machine (Wavwer, Model IC-VA Japan). A subsample of 50g of seed was then dried to 70^{o}C for 12 hours and the oil was extracted using a 460W automatic oil pressing machine stainless steel 304# nut oil press, and a benchtop mill that employs a screw auger oil press system for oil extraction (**Figure 2**). The cake and centrifuged filtered oil was weighed to determine % oil and % cake for each replicate for each variety.

Figure 2. The oil press used for extraction of oil from the cleaned dried black sesame seed.

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

RESULTS BLACK SESAME

Weather Data

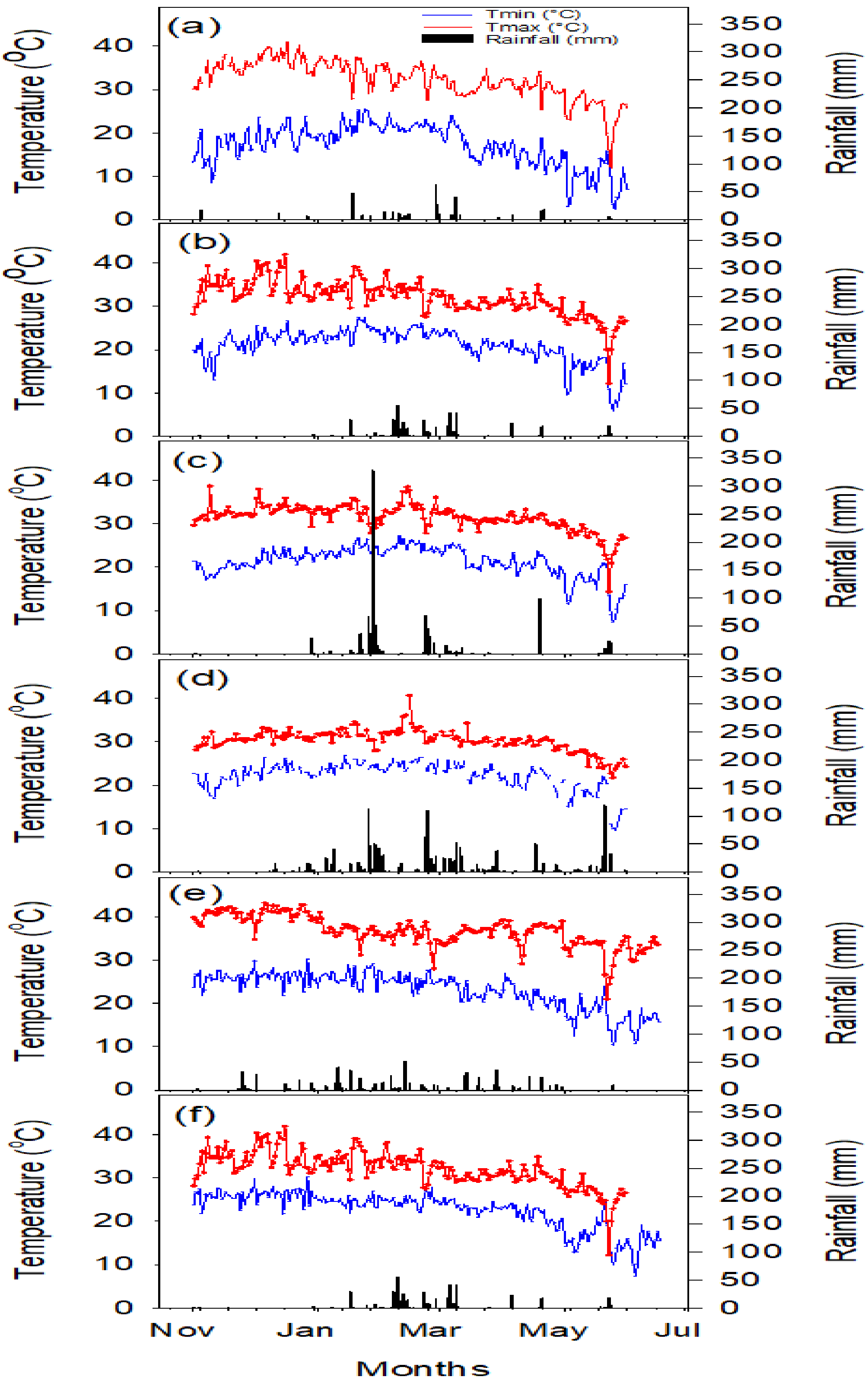

Figure 3. Weather data for the sesame crop period in different sites, a) Biloela, b) Rockhampton, c) Ayr, d) Tully, e). Katherine, f) Darwin

The crop grew during hot and humid months of the year (Figure 3). The in-crop rainfall for Biloela was 136mm, Rockhampton 382mm, Ayr 805mm, Tully 996mm, Katherine 246mm, and Darwin 435mm. The crop was largely supported by rainfall but strategic irrigation was applied to minimise the water stress on the crop. All trial sites had a drip irrigation set up that was utilised for strategic irrigation.

Crop Phenology

The black sesame was planted at varying dates throughout the summer of 2019 and 2020 (**Error! Reference source not found.**). Harvest was typically 90-120 days after planting. The average emergence for each replicate was as early as two days in Rockhampton and four to five days at the other sites. The duration from emergence to flowering ranged from 26 days (Katherine) to 38 days (Rockhampton). The flowering to maturity duration ranged from 42 days (Darwin) to 72 Days (Rockhampton). The sites were harvested manually as soon as practically feasible after maturity, with the longest delay in Katherine and Darwin of seven days post the optimal harvest date. Timely harvest upon maturity is essential in these varieties of black sesame as shattering of pods as they dry out can cause significant harvest losses.

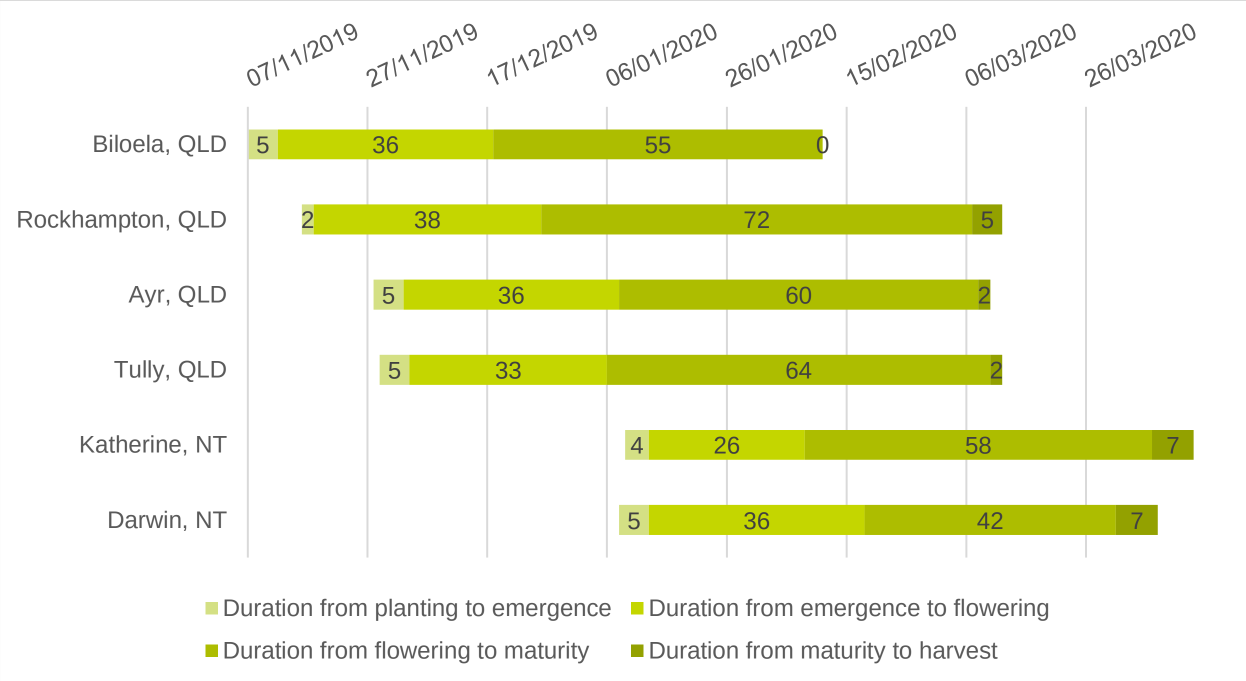

Figure 4. The growing season of black sesame from planting to harvest at the six trial locations.

The black sesame crop stages at the Rockhampton site (**Error! Reference source not found.**) were indicative of the other sites, with a healthy crop emerging and progressing through the vegetative stages to flowering and maturity.

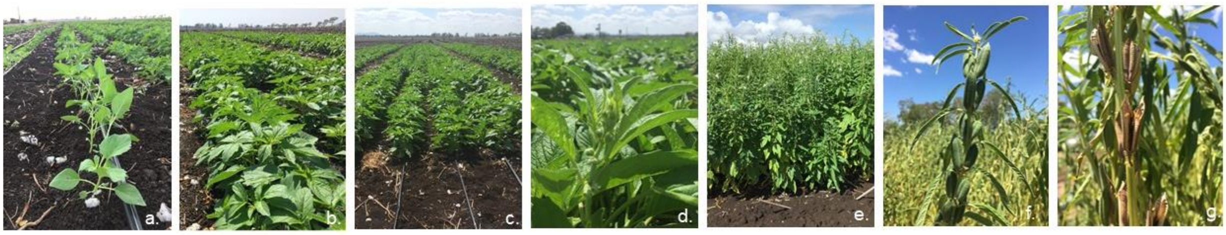

Figure 5. The growth stages of the black sesame crop at the Rockhampton site a. seedling establishment, b. vegetative growth at one month, c. vegetative growth at six weeks, d. budding, e. flowering, f. mature pods and g. dried and shattered pods (Images.T. Trotter).

Plant Height and Height to First Pod

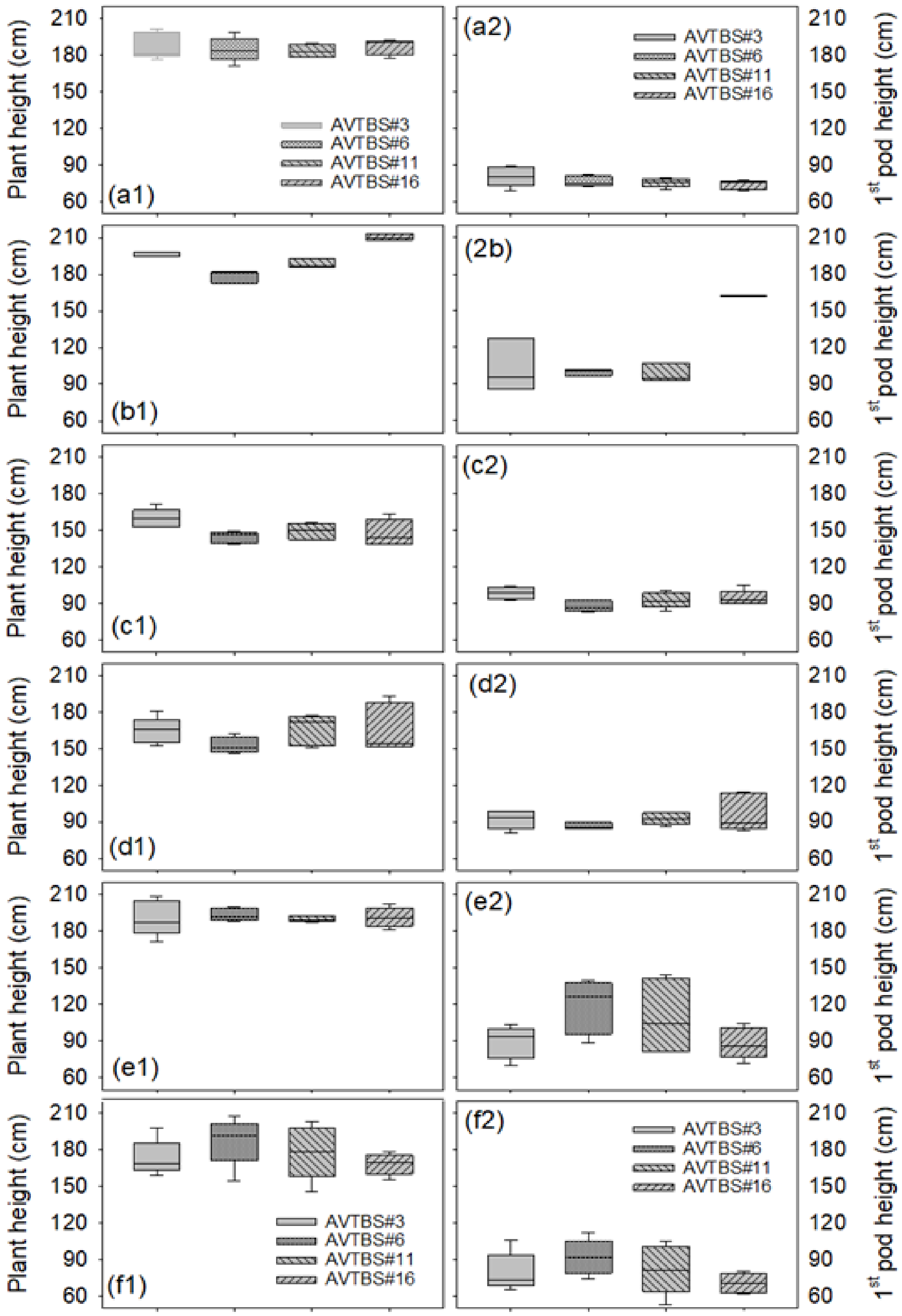

Figure 6. Plant height at harvest (column on the leaf) and height of first pod position (column on the right) for four black sesame genotypes tested at (a) Biloela, (b) Rockhampton, (c) Ayr, (d) Tully, (e) Katherine and (f) Darwin.

The plant height of the tested lines varied between 150cm and 190cm (Figure 6) and the height at the first pod varied position at 65-110cm from the ground.

RESEARCH WITH IMPACT

CRICOS: 00219C

Yield

Seed Yield

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

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

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

Biomass Yield

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

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

The mean black sesame biomass yield across six test sites ranged from 5.05 to 7.36t/ha. The greatest biomass yield was recorded in Tully, Katherine and Darwin followed by Ayr, Biloela and Rockhampton. The biomass yield between the varieties varied significantly only in Rockhampton. Greater biomass yield was recorded by AVTBS #11, AVTBS#6 and AVTBS#3, compared to AVTBS#16 (Table 4).

Yield Attributing Characteristics

Harvest Index

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

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

The mean harvest index (defined as ratio of seed yield to the total above ground biomass including seeds) across six test sites ranged from 0.106 to 0.523, showing large difference between sites. The greatest harvest index was recorded in Rockhampton followed by Biloela, Katherine Ayr, Darwin, and Tully. The harvest index between the varieties varied significantly at Biloela but did not differ between the varieties at Rockhampton, Ayr, Tully, Katherine and Darwin. In Biloela, the harvest index was greater for AVTBS#16 compared followed by AVTBS#11, AVTBS#6 and lowest in AVTBS#3 (Table 5).

Plant Density Per M^2

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

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

Mean plant density across six test sites ranged from 21.9 to 44.8 plants/m^2. Plant density did not vary significantly between the genotypes in any tested site. However, the greatest plant density was recorded in Darwin followed by Ayr, and Tully. Lower plant densities (<30 plants/m2) were particulary noted in Rockhampton and Katherine (Table 6).

Number of Pods Per Plant

Table 7. The number of pods per plant.

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

The mean number of capsules (pods) per plant across six test sites ranged from 30 to 66 pods/plant. Pod count did not vary significantly between the genotypes. A marginal difference between varieties for pod count was noted in Rockhampton where there were more pods/plant for genotypes AVTBS#6 and AVTBS#11 when compared to AVTBS#16 and AVTBS#3 (Table 7). However, the greatest pod count was recorded in Biloela (66 pods), followed by Rockhampton (48 pods) and then by Darwin, Katherine, Tully and Ayr (30-33 pods/plant).

Seed Weight and Density

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

1000 Seed Weight (g)

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

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

The mean 1000 seed weight (g) across six test sites ranged from 3.73 to 4.05g (Table 8). There was a significant difference in the 1000 seed weight between the genotypes and locations without any significant interaction effects between varieties and locations. In Biloela the greatest weights of 1000 seeds were recorded for AVTBS #11 and AVTBS #6 compared to AVTBS #3 and AVTBS #16. Marginal difference between varieties for 1000 seed weight was noted in Tully as for genotypes AVTBS #11 and AVTBS #6 showed higher weight compared to AVTBS #3 and AVTBS #16 (Table 8). The highest 1000 seed weights were recorded in Darwin (4.05g), Rockhampton (4.04g) and Biloela (4.03g), compared to Katherine (3.92g), Tully (3.78g) and Ayr (3.73g).

Seed Density (kg/m3)

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

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

The mean seed sensity (kg/m^3) across the six test sites ranged from 638 to 672kg/m^3 (Table 9). Seed density varied significantly between the genotypes in Biloela and Rockhampton but not the other test sites. In Rockhampton the highest seed densities were recored for AVTBS #11 (678 kg/m^3) and AVTBS #6 (676kg/m^3) compared to AVTBS #3 and AVTBS #16. However, in Biloela the seed density for genotype AVTBS #11 was significanlty lower (655kg/m^3) compared to all other genotypes tested at this site (

Table **9**). The highest seed densities were recoded in Rockhampton (672 kg/m^3) and Biloela (669 kg/m^3), compared to Darwin (657 kg/m^3), Katherine (643 kg/m^3), Tully (646 kg/m^3) and Ayr (638 kg/m^3).

Seed shape and size (mm)

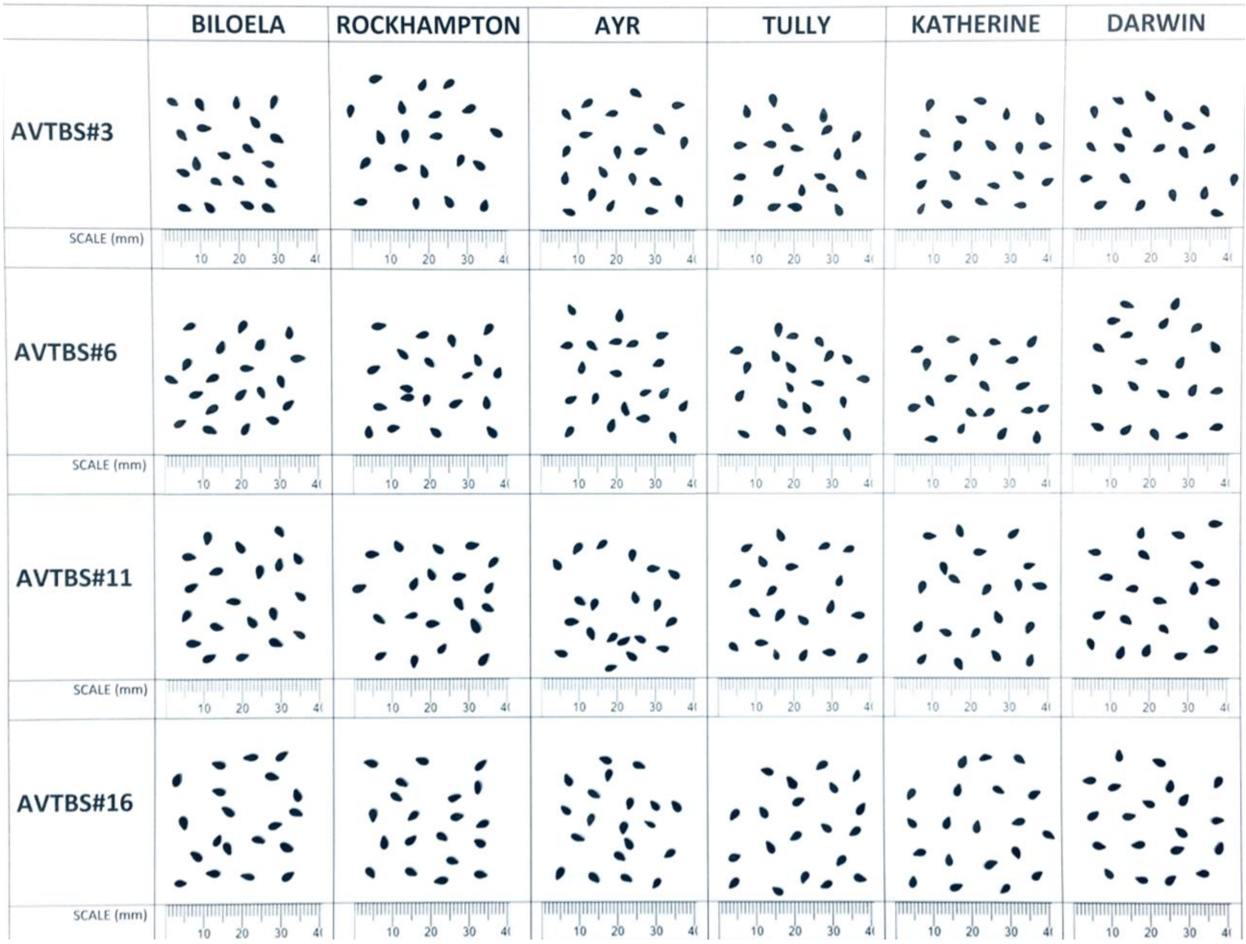

Figure 7. The seed size and colour of the black sesame seed by site and variety (Image. T.Trotter).

The seed shape and size for the four genotypes produced from the six trial locations. The seed length ranged from 3-6 mm and seed width range from 2-4 mm (Figure 7).

Oil Quality

Analysis of seed for their chemical properties were assessed using indicators for seed oil content (%), relative density of the oil at 20°C and the cake outputs (%) from the oil expelling. The oil (Figure 8) and cake (Figure 9) were extracted using the oil mill for each of the replicates at each site.

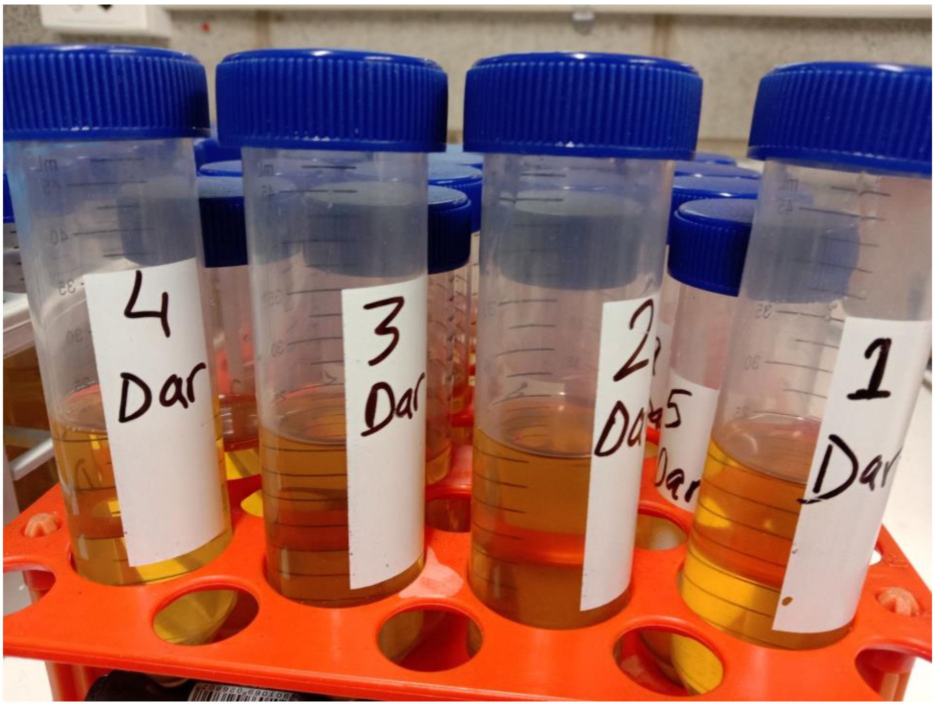

Figure 8. Oil sample extracted from each of the four genotypes from the Darwin site.

Figure 9. The sesame cake byproduct of oil extraction, which may bring potential opportunities for extracting high value protein and antioxidants.

Oil Content (%)

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

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

The mean oil output across the six test sites ranged from 43 to 47% (Table 10). The oil content did not vary significantly between the genotypes at any tested site. The highest oil content from the seed was recorded from the Tully samples (47%) followed by Darwin (46%), medium content from samples from Katherine (44%), Ayr (44%), Rockhampton (44%) and lowest in Biloela (43%).

Relative Density (g/cm^3) of Oil (20°C)

Table 11 The relative density of black sesame oil taken at 20°C.

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

The mean relative density of oil at 20°C across six test sites ranged from 0.884 to 0.921g/cm^3 (Table 11). This means one litre of the sesame oil can vary from 884g to 921g in weight. The relative density of oil did not vary significantly between the genotypes at any tested site. The highest relative oil density (0.921 g/cm^3) was recorded from the NT (Katherine and Darwin) grown samples and the lowest relative oil density (0.88 g/cm^3) was recorded from the QLD (Biloela, Rockhampton, Ayr, and Tully) grown samples (Table 11).

Raw Cake

Cake Content %

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

Varieties	Biloela, QLD	Rockhampton, QLD	Ayr, QLD	Tully, QLD	Darwin, NT	Katherine, NT	Mean
AVTBS #3	48.77	37.51	43.80	41.86	42.44	42.29	42.78

AVTBS #6	46.84	41.05	43.60	41.84	42.53	43.82	43.28
AVTBS #11	48.84	40.81	44.93	41.79	41.91	44.80	43.85
AVTBS #16	50.60	44.84	42.41	41.22	40.34	42.92	43.72
Mean	48.76	41.05	43.68	41.68	41.81	43.46	
P value	0.019	0.105	0.460	0.975	0.141	0.226	
LSD	2.137	5.820	3.318	3.662	2.108	2.608	

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

Pest and Diseases

Insect pests

Mealybugs were problematic at Katherine NT and were present in Biloela QLD and Rockhampton QLD. Most of the insect pests were identified in Darwin NT. Although no measures of crop damage were taken, there was no visual evidence of significant damage to the crops at any of the sites. While a wide range of insect pests attack sesame around the world, only the sesame leaf webber (*Antigastra catalaunalis*), Heliothis caterpillars, *Helicoverpa punctigera* and *H. armigera* and Green Vegetable Bug (*Nezara viridula*) have caused some but relatively insignificant damage at these sites.

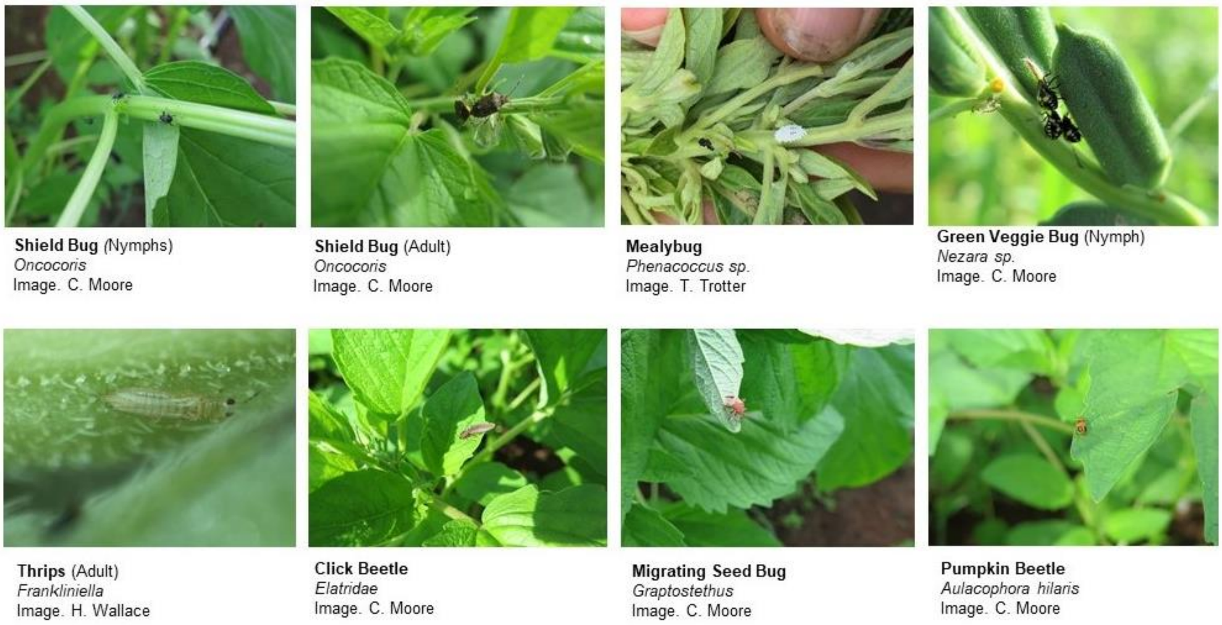

Figure 10. The insect pests identified in the crop at varying sites across northern Australia.

Beneficial Insects

A number of beneficial insects were identifed at each of the locations, including a number of spiders of several varieties at all sites (Figure 11**Figure 11**). Assassin bugs were present at Rockhampton and Ayr. Butterflies, European honey bees and native bees were prevalent at all sites and were effective pollinators during flowering. Predatory shield bugs and pirate bugs were also found at the Darwin site.

Pirate Bug (Nymph)
Orius
Image. H. Wallace

Predatory Shield Bug
Oechalia shellenbergii
Image. H. Wallace

Butterfly (Pollinator)
Image. C. Moore

Spider (Eating Click Beetle)
Image. C. Moore

Spider
Image. C. Moore

Assassin Bug (Eating European Honey Bee)
Family: Reduviidae
Image. A. Rickert

Figure 11 The insect beneficials identified in the crop.

Diseases

There were issues with disease at the Darwin site in late March and early April. Late in-season rainfall resulted in various fungal spots on the leaves and pods and some wilt due to *Sclertotium rolfsii* was noted in some plants (Figure 12). The trial site in Darwin will be fallowed to avoid further wilt issues and will not be utilised for the remainder of the trial.

Figure 12 The diseases identified in the black sesame crop.

At both the Biloela and Rockhampton sites, a small amount of distorted, thickened and green flowers and bunching of leaves were noticed in some plants (Figure 13**Figure 13**). Only one plant at each site was identified with these symptoms. The cause of this problem is unknown and plant disease testing for identification will be carried out in the future. The disease was described as looking like bunchy-top in sugarcane. Sesame is prone to root and stem diseases associated with waterlogging, while damping off diseases can also occur if humidity is high. While seven diseases affecting sesame have been identified, two common diseases were *Corynespora cassiicola* (target spot) and *Pseudocercospora sesami* (large cercospora leaf spot), which can severely affect seed yields. Large cercospora leaf spot causes large spots on the foliage which are dull brown in colour, and irregularly shaped. The spots often coalesce, killing portions or entire leaves on susceptible cultivars during humid conditions. Target spot first appears as dark (often purplish) spots on leaves, stems and pods. As spots enlarge they develop lighter-coloured centres.

Figure 13 A flower distortion and leaf bunching found at Biloela and Rockhampton.

Crop physiological disorders

Late season wind damage was experienced at the Darwin site, causing the plants to lodge (Figure 14**Figure 14**). In some cases, when the plant begins to senesce and lose leaves at maturity, the plant will begin to stand up again. If the plant lodges and doesn't recover, this will pose issues for mechanical harvesting.

Figure 14 Wind damage at the Coastal Plains Research Station in Darwin. (Image. C. Moore)

DISCUSSION

Yield acssociated with varieties

Initial results suggest that AVTBS#6 was the highest yielding variety in both Rockhampton and Biloela with AVTBS#11 performing the best in Ayr (***Table 3***). The average yield was the greatest in Biloela, achieving over 3 t/ha, which was nearly double the yield in Ayr. These yields were significantly higher than the global average of 554kg/ha. The combined analysis for the seed yield for genotype x environmental interaction suggest that the performance of the genotypes are not consistent across sites. The genotypes AVTBS #6 and AVTBS #11 are generally high-yielding in most of the sites. The performance of genotypes AVTBS #3 and AVTBS #16 is not consistent across Darwin and Tully, as in the former site AVTBS #3 was the lowest performer whereas in the later case AVTBS #16 was significantly lower performer (Figure 15).

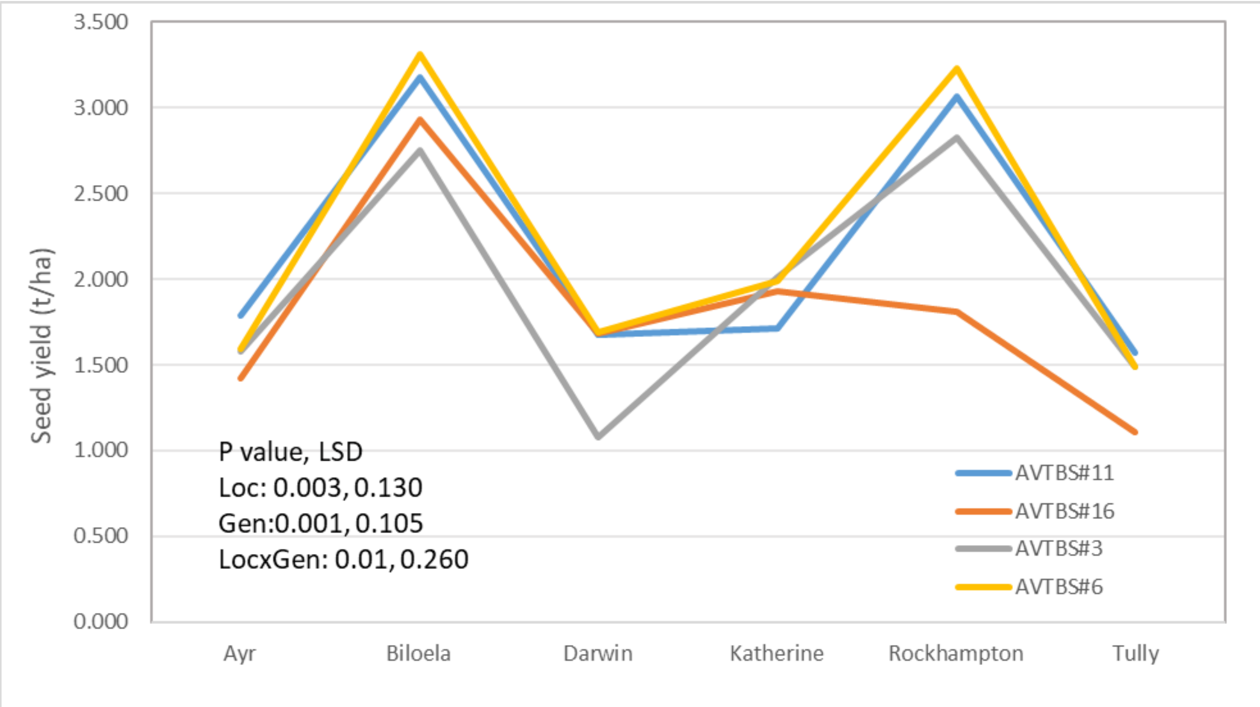

Figure 15 The genotypes x location (environment) interaction for seed yield (t/ha) for four sesame genotypes tested over six different production environments across QLD and NT.

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

Environmental Impacts on yield

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

Seed quality associated with varieties and growing conditions

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

The oil output across six test sites ranged from 41 to 47% (Table 10). The oil content did not vary significantly between the genotypes at any tested site. The highest oil content from the seed was recorded from the Tully samples (47%), followed by Darwin (46%), a mid-range oil content was recorded in the samples from Katherine, Ayr and Rockhampton (44%), and the lowest recorded in Biloela (43%). In the previous work by Bennett (2014), the oil content of the white sesame varieties grown in the NT was 54%, much greater than the oil content of black sesame tested in this trial.

Scope for yield optimisation

Before black sesame can realise its potential as a high-value crop in Northern Australian conditions, additional research is needed to adapt mechanical harvesting equipment. Due to pod shattering at maturity, there can be significant harvest losses in mechanically harvested sesame and therefore, the yield in the bin can be much less for machine harvested plot compared to the hand-harvested yields detailed in this report. However, activities are progressing for optimising machine harvesting for black sesame crops, as well as evaluation of dessication techniques in the crop at pre-maturity stage.

Two other important aspects are weed control and optimising the plant density for sesame cropping. A parallel trial funded by AgriFutures for sesame research will bring information to growers from a number of trials investigating the optimum planting date, density and weed control.

Workshop Experiences

The grower participants shared their experiences of growing black sesame during a workshop held in Rockhampton in February 2020. The following are comments are being considered for adjusting the agronomy techniques for the remaining trials.

- Non-shattering varieties will help to reduce harvest losses.
- Agronomic practices such as use of defoliant and application of pod sealants should be considered to help reduce harvest losses.
- The plants were too tall and was described as a visually unappealing crop, which may act as a psychological barrier when engaging new growers. Excessive plant height could create issues with lodging in wind or rain events and make harvesting difficult.
    - Reducing plant density might encourage the plant to branch rather than etiolate whilst trying to compete for light.
    - Allowing for moisture stress in the plant early in the season might help to reduce plant height and the height to the first pod. Irrigation might be used to support germination and then not used or used sparingly throughout the vegetative growing period.
- Suggestions were made about the effect of planting time on plant height and internode length such as trialing the impact of earlier planting dates so the crop is planted in spring during the dry season and is harvested prior to the onset of the wet season.
- Options for reducing harvest losses could include improvements to harvesters including air vacuums to draw the falling seed into the harvester, harvest upon maturity but before seeds shatter (requiring post harvest drying of pods and threshing of seeds from pods in a processing facility) or use of pod sealants to assist with keeping seeds in the pods until harvest so threshing can occur within the harvester.
- Very few pests and diseases were noted in the crop with low numbers of mealybugs, leaf weavers, caterpillars and leaf spot present in the crop. The numbers of pests and diseases increased later in the cropping season along with the increase in rainfall experienced at each site.
- Sesame can bring a number of advantages in a crop rotation system. If sown after a leguminous crop, sesame can utilise the residual nitrogen from the legume. If the leguminous crop made good growth then the residual nitrogen should meet about one-third to one-half of the sesame crop needs. Where sesame is rotated with a cereal, there can be mutual benefits in weed control. Sesame can also fit in rotation very well with sugarcane and cotton.

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Queensland Government

NORTHERN TERRITORY GOVERNMENT

Department of Primary Industries and Regional Development
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Australian Government
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