The Performance and Feasibility of Carinata in Australia

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Abstract
Renewable diesel and biojet fuels made from fats and oils are the most rapidly growing sector in the global biofuels industry. High-erucic acid content of carinata (*Brassica carinata*) oil makes it a sought after feedstock. With growing worldwide demand for plant-based sources of protein for animal rations and human consumption, the high-protein seed meal is a co-product which, in some markets, is worth more than the oil. In the 2018 winter growing season, 20 field trials were sown across Australia to test the performance of 48 carinata genotypes against 8 commercial canolas. Site mean yield ranged from 0.11 t/ha up to 2.84 t/ha. Across all sites, carinata genotypes produced grain yields similar to Australian canola varieties. All seven of the hybrid carinatas and one hybrid canola line were in the top 10 highest yielding genotypes. Not surprisingly triazine tolerant canola lines were among the lowest yielding genotypes. Performance of these carinata genotypes selected on height, maturity and oil alone indicates that further improvements in yield and quality should be possible with future breeding efforts.

Keywords
Carinata, canola, co-products, biofuel, protein, carbon credits, regulatory controls

Introduction
Australia is renowned for its variable weather, and Australian farmers struggle with crop performance and profitability in this challenging environment. Carinata has a reputation for better heat, drought and pest tolerance than other oilseed crops such as canola. Grown as a breakcrop, brassicas provide diversification to farm income while providing benefits to the agricultural system due to their in-season biofumigation properties which actively reduce the incidence of soil-borne pathogens that can attack the following crops (Kirkegaard and Sarwar 1998). Not only that, compared to canola, carinata possesses greater resistance to some soil-borne fungal diseases (e.g. blackleg and white leaf spot) and has better shatter resistance than canola providing the opportunity for direct heading.

There are legislative mandates around the world to reduce greenhouse gas (GHG) emissions in the transportation sector. Electrical vehicle (EV), hybrid (EV and petrol) and hydrogen are logical solutions for ground transportation of freight and people but there is no practical substitute for jet fuels in the air transportation of freight and passengers. Renewable diesel and biojet fuels being made from fats and oils are the most rapidly growing sector in the biofuels industry, with CAPEX investments in place and more being made by large oil companies to produce fuels from these feedstocks (Coppola 2017). Even with installed global capacity and new capacity being brought on-line there is a chronic shortage of feedstocks, with a current unmet demand for over 6 million metric tonnes of oil to produce these fuels, and this demand continues to grow (Coppola 2017).

The aim of this study was to investigate the performance of carinata in preliminary yield trials, to identify suitable carinata genotypes for progression and to assess its potential for Queensland and Australian biofuel production.

Methods
In 2017 two thousand genotypes of carinata were supplied under a collaborative agreement with Agrisoma Biosciences of Canada (bought by Nuseed Pty Ltd in October 2019). Genotypes were grown in field nurseries at Gatton, Qld and Bordertown, SA. Eighty lines were selected based on similar height and maturity to canola and high seed oil content. In 2018, agricultural research companies were

contracted to grow field trials in regions across Australia for evaluation of 48 carinata genotypes against 8 canola varieties, the Australian brassica benchmark.

Figure 1: Map of Australia with locations of 20 field trial sites in 2018 marked.

Twenty field trial locations are shown in Figure 1 including four in Queensland, five in New South Wales, five in Victoria, three in South Australia and three in Western Australia. Locations for field experiments were chosen to represent a range of latitudes (Walkamin 17° 07' S and Ararat 37° 40' S), areas where canola is currently grown (NSW – Cowra, Greenthorpe, Temora, Marrar; Victoria – Benalla, Maryborough, Birchip, Ararat, Wonwondah; South Australia - Bordertown; Western Australia – Cunderdin, York, Kojonup), the drier fringe of the cropping zones where canola is less commonly grown (Victoria – Birchip; South Australia – Lameroo, Minnipa), locations where it is considered too hot for canola (Queensland – Cairns, Gatton, Pampas; NSW – Grafton) and locations where a breakcrop could be advantageous to the cropping system in Queensland – (Cairns, Walkamin, Gatton, Pampas, Grafton).

Statistical analyses were conducted using a two-stage approach (Cullis et al, 1996). The first stage analysis was conducted for each trial to adjust for spatial variation followed by a second stage, where adjusted genotypic means were used in a combined analysis across all trials. The combined analysis across trials was used to obtain BLUPs (best linear unbiased predictors) of genotype performance across trials.

Results and Discussion

Due to dry conditions in most areas across Australia in 2018, seven sites had a mean yield < 1.0 t/ha (Lameroo the lowest 0.11 t/ha) and only two sites > 2.0 t/ha (Ararat the highest 2.84 t/ha). Likewise a large variation for site mean oil concentration was observed, 37% (at Maryborough) to 48% (at York). Despite the dry year, only four sites (Cowra, Marrar, Maryborough and Minnipa), had mean oil concentrations < 40%. All sites showed a mean protein concentration > 24% and the mean protein at all sites ranged between 25-34%. There was a negative association between site mean oil concentration and site mean protein concentration with lower oil concentration tending to result in higher protein concentration (data not shown). Total glucosinolates (GSL's) were higher in carinata than in canola.

Our results showed that across all sites in Australia in 2018, carinata genotypes selected in 2017 at Gatton and Bordertown on the basis of height (< 170 cm), maturity (duration similar to Australian canola) and high seed oil concentration produced seed yields similar to Australian bred canola varieties (Table 1). In a scientific and breeding context, this was quite a remarkable result since canola has been bred in Australia for the past 50 years. We identified a number of carinata genotypes that are worthy of extensive pilot stage testing for potential commercial release. Performance of carinata indicates that further improvements in yield and quality should be possible with future breeding efforts. All seven of the hybrid carinatas and one hybrid canola lines were in the top 10 highest yielding genotypes. This was despite the hybrid carinata lines flowering 7-12 days later and being 7-16 cm taller than the hybrid canola. Despite the yield penalty associated with triazine tolerance, incorporation of it or other

Table 1. Across site summary for 2018 yield, quality and agronomic traits for carinata breeding lines and canola benchmarks (green) from 17 successful sites across Australia. Lines are ranked for yield from lowest to highest. Orange shaded numbers are the highest value and blue shaded numbers are the lowest value. SE is the standard error around the corresponding mean.

Name	Flower (DAS)	SE	Height (cm)	SE	Yield (g/m^2)	SE	Oil (%)	SE	Protein (%)	SE	GSL's (mg/kg)	SE
DH-145.354	110.4	4.7	115.0	10.3	97.8	18.6	35.6	0.8	33.7	0.8	108.2	5.0
Stingray	98.9	4.7	93.8	10.3	99.6	18.7	43.1	0.8	26.8	0.9	26.5	5.1
Hyola650TT	102.6	4.7	101.6	10.3	102.5	18.7	42.9	0.8	26.8	0.9	28.3	5.1
Wahoo	106.2	4.7	100.6	10.3	103.0	18.7	42.9	0.8	26.6	0.9	28.7	5.1
DH-157.541	104.6	4.7	109.5	10.4	104.3	19.0	41.9	0.9	29.0	0.9	76.4	5.4
DH-145.390	110.5	4.7	119.4	10.3	105.4	18.6	42.6	0.8	28.4	0.8	85.9	5.0
AGR945-JI32.2	104.1	4.8	111.1	10.5	106.2	19.1	38.3	0.9	33.6	0.9	124.3	5.5
DH-145.282	107.3	4.7	111.7	10.3	106.7	18.6	36.8	0.8	31.4	0.9	107.7	5.1
DH-069.485	118.2	4.7	115.6	10.3	109.9	18.6	42.3	0.8	31.0	0.8	96.4	5.0
DH-157.712	104.9	4.7	108.9	10.4	110.1	19.0	42.8	0.9	30.0	0.9	85.0	5.4
DH-157.911	107.6	4.7	113.3	10.3	111.2	18.7	42.9	0.8	29.3	0.9	86.1	5.1
DH-140.251	116.5	4.7	117.5	10.3	111.5	18.6	42.3	0.8	30.6	0.8	87.9	5.0
DH-157.516	103.8	4.7	105.1	10.5	113.9	19.1	41.0	0.9	31.4	0.9	101.2	5.4
Hyola559TT	101.1	4.7	107.2	10.3	114.1	18.6	44.1	0.8	26.0	0.9	29.5	5.1
DH-146.047	118.6	4.7	122.8	10.3	114.2	18.6	42.8	0.8	29.4	0.8	78.2	5.1
44Y90CL	97.3	5.1	107.4	11.0	114.6	20.1						
AU052	112.3	5.5	112.5	13.4	114.9	21.2	39.6	1.3	30.5	1.2	103.6	7.9
AGR945-JI33.1	106.9	4.7	115.2	10.3	115.3	18.7	39.3	0.8	32.2	0.9	115.5	5.1
DH-157.944	106.4	4.7	113.3	10.3	115.5	18.7	43.0	0.8	28.6	0.9	81.7	5.1
T4510	99.8	5.1	106.9	11.0	115.9	20.1	41.5	1.5	28.8	1.4	48.4	9.3
DH-145.290	109.0	4.7	114.8	10.3	116.2	18.7	40.4	0.8	30.4	0.9	92.2	5.1
IgniteTT	104.3	4.7	100.1	10.4	116.4	18.8	42.1	0.8	26.3	0.9	25.2	5.1
DH-157.502	105.6	4.7	108.1	10.3	117.0	18.7	40.9	0.8	31.1	0.9	96.5	5.1
DH-157.775	106.8	4.7	109.8	10.3	119.4	18.7	43.3	0.8	29.3	0.9	95.7	5.1
DH-157.534	101.7	4.7	96.7	10.3	119.6	18.7	43.4	0.8	28.7	0.9	83.1	5.1
DH-157.067	103.5	4.8	105.3	10.5	120.2	19.3	43.5	1.0	27.8	0.9	81.6	5.8
DH-157.945	104.3	4.8	108.4	10.5	120.4	19.1	40.4	0.9	28.8	0.9	96.8	5.5
DH-199.686	110.9	4.7	118.8	10.3	121.0	18.6	42.0	0.8	30.4	0.8	87.7	5.0
DH-157.834	106.0	4.7	106.9	10.3	121.5	18.7	44.6	0.8	28.5	0.8	84.9	5.1
DH-146.054	115.1	4.7	107.0	10.3	121.7	18.6	42.8	0.8	30.1	0.8	75.9	5.1
DH-209.172	116.3	4.7	115.6	10.3	122.0	18.6	40.3	0.8	32.1	0.8	106.6	5.0
DH-157.709	106.7	4.7	109.3	10.4	122.0	18.9	42.1	0.9	30.8	0.9	99.5	5.4
DH-157.021	113.0	4.8	119.6	10.5	122.7	19.2	42.0	0.9	31.1	0.9	91.4	5.6
AGR044-311E	110.7	4.7	115.2	10.4	122.8	18.8	40.5	0.9	30.3	0.9	94.6	5.3
DH-157.901	110.0	4.7	115.9	10.4	123.4	18.9	42.1	0.9	31.3	0.9	88.6	5.4
DH-129.B036	112.6	4.7	118.4	10.3	123.5	18.6	43.7	0.8	30.2	0.8	88.8	5.1
DH-056.149	115.1	4.7	121.5	10.3	123.9	18.6	39.3	0.8	31.5	0.8	108.2	5.0
DH-146.842	112.9	4.7	108.8	10.3	124.0	18.6	45.2	0.8	29.1	0.8	69.6	5.0
A120	110.8	5.5	106.7	13.0	124.1	21.0	41.3	1.2	31.2	1.2	92.8	7.6
Garnet	102.8	4.7	107.7	10.4	124.4	18.8	44.0	0.8	23.9	0.8	27.6	5.1
DH-146.205	114.1	4.7	114.9	10.3	125.2	18.6	44.4	0.8	27.9	0.8	80.6	5.1
Diamond	88.6	4.9	111.0	11.0	125.9	20.1	41.7	1.5	27.4	1.4	34.5	9.8
Avanza641	109.4	5.5	119.6	13.2	126.1	21.1	42.7	1.3	28.7	1.2	83.7	7.8
DH-215.531	116.2	4.7	123.5	10.3	126.7	18.6	41.6	0.8	29.8	0.8	84.4	5.0
DH-174.044	114.6	4.7	116.0	10.3	126.8	18.6	43.5	0.8	32.1	0.8	99.3	5.1
DH-157.501	104.5	4.7	109.1	10.3	127.0	18.7	41.7	0.8	30.5	0.8	81.1	5.1
DH-157.848	104.7	4.7	106.8	10.3	127.2	18.6	44.0	0.8	28.3	0.8	83.6	5.1
DH-146.214	113.8	4.7	123.6	10.3	128.0	18.6	44.8	0.8	29.6	0.8	68.1	5.0
45Y91CL	104.0	4.7	114.1	10.3	128.3	18.6	43.8	0.8	26.1	0.9	27.8	5.1
DH-157.509	102.4	4.7	104.0	10.3	128.6	18.6	42.6	0.8	29.7	0.8	88.7	5.0
DH-157.894	105.4	4.7	109.5	10.3	129.4	18.6	44.4	0.8	28.8	0.8	86.0	5.0
DH-174.557	112.7	4.7	111.7	10.3	130.2	18.6	44.9	0.8	29.0	0.8	95.8	5.1
HYB024	114.5	4.7	126.6	10.3	132.4	18.6	41.5	0.8	29.1	0.8	94.2	5.1
DH-157.055	103.7	4.8	106.7	10.5	134.8	19.3	41.8	0.9	29.5	0.9	95.9	5.7
HYB063	113.8	4.7	132.5	10.3	139.0	18.6	43.4	0.8	29.6	0.8	97.8	5.0
HYB054	110.4	4.7	131.4	10.3	139.1	18.6	40.1	0.8	30.1	0.8	107.9	5.1
DH-217.571	113.2	4.7	122.2	10.3	140.0	18.6	41.7	0.8	30.3	0.8	86.9	5.0
HYB019	113.3	4.7	131.3	10.3	140.0	18.6	40.2	0.8	30.5	0.8	104.4	5.0
HYB036	113.4	4.7	130.1	10.3	140.7	18.6	41.6	0.8	29.9	0.8	107.6	5.0
HYB064	111.7	4.7	129.6	10.3	142.8	18.6	41.9	0.8	29.2	0.8	94.7	5.0
HYB066	112.2	4.7	124.2	10.3	145.1	18.6	42.6	0.8	29.0	0.8	96.5	5.0
Quartz	102.7	4.7	116.8	10.4	147.6	18.8	44.9	0.8	24.0	0.8	18.1	5.1

herbicide tolerance genes into carinata would likely benefit carinata production since it would allow farmers the choice of growing carinata in paddocks where problem weeds would not normally allow the cultivation of a conventional brassica. On-farm, carinata sowing, crop management and harvest, will essentially be the same as for canola (Seepaul et al 2016) although herbicides currently used in canola production may need to be evaluated for carinata. There may be additional benefits of carinata over canola with improved disease tolerance, a reputation for drought and heat tolerance and improved efficiencies associated with direct harvesting as a result of greater shatter resistance. Carinata could "plug-in" to the existing infrastructure and supply chain of the canola oil industry with little to no technical investment required, except to segregate and scale up additional product lines.

After oil extraction with solvents, the seed meal is heat treated to capture the remaining solvent and drive off volatile glucosinolates. Carinata seed meal has lower fibre content and hence improved digestibility compared to canola seed meal. With growing worldwide demand for plant-based sources of protein for animal rations and human consumption, this is a co-product that often has a higher value than the oil. The high value of this co-product creates a revenue enhancing force multiplier opportunity.

Despite the hiatus caused by the COVID-19 pandemic, growth of air services in freight and passenger journeys are still predicted to double by mid-century. In the face of a changing climate and our need to reduce carbon emissions, the social licence for airlines to operate is currently being addressed by voluntary carbon offsetting by travellers. Member airlines of the International Civil Aviation Organization (ICAO) and International Air Transport Association (IATA) recognise that more will need to be done to ensure carbon-neutral industry growth from 2021 and reducing the 2005 total emissions levels by 50% by 2050. Airlines that fail to meet these goals will be financially penalised. All of the major global airlines are pledging to recover from the COVID-19 pandemic in the most sustainable way possible and sustainable biojet fuel is considered the anchor of this proposition heading towards 2050. Carinata based biojet fuel is fully certified and has already been used on two trans-continent passenger flights in 2018 from the USA to Australia and to Switzerland.

Due to global Indirect Land Use Change (ILUC) regulations, biofuels produced in place of a cover crop or from a waste stream produces more carbon credits and is more profitable than a dual-purpose food and fuel crop grown in place of another crop (Johnson 2011). Broadacre biofuel production under Australia's rainfed agricultural system is therefore disadvantaged by ILUC regulations because cover crops are not typically grown. A critical challenge for establishment of a carinata based supply chain in Queensland and Australia is the lack of enabling policy and legislation establishing carbon offsets or mandates for the jurisdiction. This creates specific challenges for those considering investing in infrastructure projects such as a Queensland advanced bio-refinery. Until then, Australian grown Carinata could be exported to existing refineries currently producing renewable diesel and biojet fuel in the USA, Singapore and the EU.

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