Quinoa agronomy in Western Australia

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Abstract
AgriFutures Australia funded a research project with the objective of transitioning quinoa (*Chenopodium quinoa* Willd) from a niche/cottage/organic crop to wider adoption across Australian broadacre farming environments and to develop variety options. We undertook field evaluation of quinoa advanced lines in combination with different sowing dates and seed rates at Kununurra in the north, Manjimup in the south-west and at six locations in the Wheatbelt of Western Australia. Results demonstrated that quinoa could yield well in both irrigated and rainfed conditions. The line BEW performed better at Kununurra under irrigated conditions when sown in mid April with a seed rate of 1-3 kg/ha (up to 2.0 t/ha) and at Geraldton under rainfed conditions sown in early June with a seed rate of 2.5 -5 kg/ha (3.0 t/ha). BEW is expected to be released as a new variety at the national level by 2021. Medusa seems to perform better than BEW in southern WA. The varieties tested showed sensitivity to frost and high temperature (daily maximum above 35^{o}C) at flowering to seed development stages, and to head sprouting at maturity.

Key Words
Quinoa, quinua, seed yield, plant density, sowing dates, climate

Introduction
Quinoa (*Chenopodium quinoa* Willd) originates from high altitude regions of South America with the majority of the world production coming from Peru and Bolivia. Small areas near the coast in the central and southern Mediterranean part of Chile also have a history of growing quinoa (Bazile et al 2015). Quinoa is grown commercially in northern Tasmania by 'Kindred Organics' under a mixture of irrigated and rainfed systems, and near Narrogin in south-western Australia by '3 Farmers' under rainfed conditions. Attempts by Kimberley Agricultural investments (KAI) along with two other farmers to grow a commercial crop of quinoa under irrigation in Kununurra, Western Australia (WA) commenced in 2017.

AgriFutures Australia funded the quinoa research project from 2015 to June 2019 with Department of Primary Industries and Regional Development (DPIRD) as the national lead. The project aimed to investigate where and how quinoa could be grown across the country with the possible release of a new variety at the national level. Quinoa could be a high value cash and break crop in Australian cropping systems. Apart from WA, the trials were also conducted at Katherine and Alice Springs in Northern Territory, Bool Lagoon in South Australia, Leeton in New South Wales and Walkamin in Queensland. However, this paper reports on WA sites only.

Methods
In WA, quinoa was evaluated at eight locations. Different quinoa varieties/advanced lines, sowing times and seed rates were used in the treatments. Details of the varieties tested in the trials are given below:

Variety	Owner	Plant Breeders' Rights	Availability for commercial growing
BEW	DPIRD and AgriFutures Australia	Yes	Yes, once released
Medusa	Australian Grown Superfoods Pty Ltd	Yes	Contract with the owner
Regalona	Semillas Baer, Chile	No	Unsure, contact the owner
Titicaca	Sven-Erik Jacobsen, Denmark	No	Unsure, contact the owner
JC1	AgriFutures Australia and DPIRD	No	No

All field trials were conducted using a randomized complete block or a split-plot with a possible /factorial design of various factors with 3-4 replications as well as balance in 2-directions. All the data was subjected

to an analysis of variance using the procedures ANOVA/REML using in the GenStat Statistical Program (*http://genstat.com*). Further trial site-specific information is given below:
Kununurra (North, 15.653°S, 128.707°E) - winter crop under irrigation
The two trials during 2015 and 2016 were conducted on grey self-mulching clay of pH 7.4 (H2O). Plots were 21m long with 4 rows sown 22cm apart on 90cm wide raised beds using a gravity fed cone seeder. The site was irrigated using flood irrigation immediately after sowing with further irrigation applied at intervals of 2 weeks. The trials were harvested on 28 July, 18 August, 21 September 2015 and 29 August 2016.
Manjimup (South-West, 34.298°S, 116.125°E) - spring crop under irrigation and rain-fed
The trial was on a red/brown sandy loam surface over a loamy sand soil at 20-30cm. Plots were 10m long with 8 rows sown 17cm apart with 40cm buffers using a gravity fed pasture cone seeder (super seeder points without press wheels). The site was irrigated using overhead impulse sprinklers from the middle of December to the end of January according to evapotranspiration. The trial was harvested on 7 March.
Cunderdin, Mingenew, Geraldton, Eradu, Katanning and Esperance (Wheatbelt, 28.611°S, 115.025°E - 33.689°S, 117.644°E) - winter rain-fed crop
Plots were 10m long with 7 rows sown 22.5-27cm apart with 40cm buffers using air cone seeders fitted with knife points and press wheels at approximately 1cm depth (soil coverage). The trials were harvested at Cunderdin on 15 December, Mingenew on 23 September, 6 and 14 December, Geraldton on 20 October, Eradu on 13 November, Katanning in January 2018 January and Esperance on 20 December. Soil characteristics are described below.

Site	Soil type	Soil pH (water)
Cunderdin	Grey loamy sand surface over a sandy clay loam – clay loam at 30cm	6.4 – 7.0
Mingenew	Red clayey sand to 40cm	6.6 – 7.3
Geraldton	Red/brown clayey sand surface over a sandy loam at 30cm	5.4 – 6.4
Eradu	Course yellow sand (Eradu sandplain)	5.7 – 6.3
Katanning	Sandy loam	6.2 – 6.4
Esperance	Loamy sand	5.7 - 6.5

Plots were fertilised using recommendations for canola as quinoa is a non-legume broadleaf crop. Grass weeds were controlled using Dual® Gold and post-emergent grass selective herbicides, broad leaved weeds with post-emergent diflufenican (e.g. Brodal®) and/or by manual weeding. Plant density was assessed at or close to maturity using a range of quadrat sizes and expressed as plants per square metre. All plants in the plots were harvested using conventional experimental crop harvesters. Some trials were desiccated prior to harvest as required. The seed was passed through a thresher and aspirated for cleaning before weighing.

Results
The highest seed yield across winter sown quinoa varieties was recorded at Geraldton (2.2-2.9 t/ha) followed by at Kununurra (0.92-1.66 t/ha) and spring sown quinoa at Manjimup (0.53 -1.5 t/ha) (Table 1). At Geraldton, BEW yielded significantly higher than Medusa. Similarly, at Kununurra, BEW yielded significantly higher than JC1 and Titicaca during 2015 and higher than JC1 and Medusa during 2016. However, at Manjimup Medusa and JC1 yielded significantly higher than both BEW and Titicaca.

Seed yields at Kununurra were highest when sown in April and lowest in June (Figure 1). BEW sown in April yielded about 2.0 t/ha, significantly higher than the other varieties. Seed yields of quinoa grown at Cunderdin in the central Wheatbelt were very low at the three times of sowing with zero yield at the earliest sowing time of 3 May. Overall, JC1 yielded significantly lower than BEW and Medusa (Table 1).

Increasing the sowing rate did not result in higher plant density or seed yield within each variety at Kununurra (data not shown), Geraldton, Manjimup and Esperance (Table 2). However, at Eradu, BEW and Medusa had significantly higher plant density with an increase in sowing rate from 5 to 10 kg/ha and corresponded with a similar increase in seed yield. Similarly, increasing the sowing rate of quinoa at Cunderdin from 1 to 8 kg/ha also resulted in an increase in plant density (e.g. 12-52 plants/m^2 with 1-8 kg/ha seed rate in BEW sown on 25 May 2016). There were significantly greater plant densities in quinoa sown on 3 May compared with later sowing times. Seed yield increased with increasing plant density in BEW and Medusa sown on 25 May (data not shown).

BEW flowered approximately 40 days after sowing at Kununurra (across three sowing dates), 71 days after sowing at Geraldton, 78 days after sowing at Eradu, 84, 90 and 107 days after the first, second and third sowings at Cunderdin, respectively, 133 days after sowing at Esperance and 72 days after sowing at Manjimup (spring sown). Other varieties had similar days to flowering (data not presented).

Table 1. Seed yield (t/ha) of quinoa varieties (across seed rates and sowing times) at different locations.

Variety	Kununurra 2015	Kununurra 2016	Geraldton	Eradu	Cunderdin	Esperance	Manjimup
BEW	1.66	1.26	2.9	0.56	0.019	0.055	0.53
JCI	1.19	0.92	2.6	0.64	0.014	0.390	1.30
Medusa		1.01	2.2	0.59	0.019	0.428	1.50
Regalona	1.39						
Titicaca	0.98		2.7	0.38		0.038	0.67
LSD (0.05)	0.30	0.24	0.7	0.24	0.005	0.499	0.25

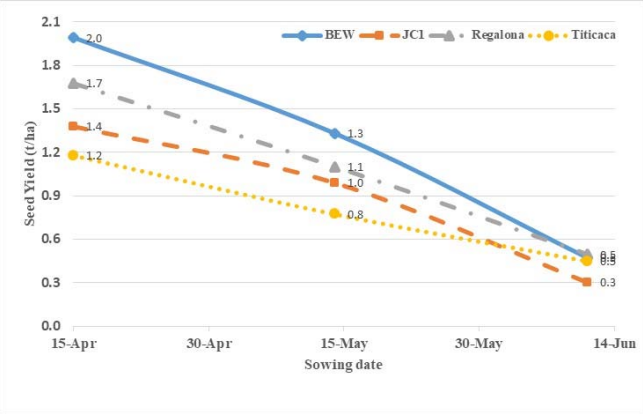

Figure 1. Effect of sowing dates (15 April, 14 May and 11 June) on seed yield of quinoa varieties at Kununurra during 2015. Gridlines are one lsd apart (0.3 t/ha).

Table 2. Effect of plant density on seed yield of quinoa varieties at different locations.

Treatments	Density (plants/m^2)				LSD*	Seed yield (t/ha)				LSD
	BEW	JC1	Medusa	Titicaca		BEW	JC1	Medusa	Titicaca	(0.05)
Kununurra – 25 May 2016						1.26	0.92	1.01		0.24
Eradu – 23 May 2017					5					0.18
2.5 kg/ha	11	13	9	18		0.37	0.58	0.47	0.38	
5.0 kg/ha	19	17	19	14		0.76	0.71	0.71	0.37	
Geraldton – 2 Jun 2017					55					0.63
2.5 kg/ha	68	99	66	108		2.73	2.52	1.99	2.66	
5.0 kg/ha	88	131	95	145		3.09	2.74	2.41	2.81	
Esperance – 26 Jun 2017					31 (NS)					0.76
2.5 kg/ha	7	14	4	-		0.05	0.34	0.10	0.04	
5.0 kg/ha	4	29	29	7		0.05	0.44	0.76	0.04	
Manjimup – 4 Oct 2016					27 (NS)					0.36
5 kg/ha	11	18	20	7		0.53*	1.25	1.47	0.56	
10 kg/ha	18	18	22	12		0.53*	1.35	1.52	0.78	

NS = Statistically non-significant. *Pre-harvest rains damaged plants and grains.

Discussion

At Kununurra, the highest yield was recorded with quinoa sown in April and yield declined with later sowing in May and June. This could be due to higher ambient temperatures during flowering and seed development associated with a later sowing time. There were 0, 4 and 19 days with daily maximum temperatures above 35□C in the 50 days after flowering commenced with the three times of sowing, respectively (BOM). Temperatures above 35□C is known to affect seed production in quinoa (Jacobsen and Stolen 1993). In addition, increased activity of insect pests, Rutherglen bug in particular, might also be implicated. As such, planting in April is strongly advised to avoid a significant yield penalty, but will depend on availability of dry paddock conditions. Sowing rate has no impact on seed yield, however higher plant density could increase crop competitiveness against weeds as there is currently no herbicide registered for weed control in quinoa.

Growing quinoa in the wheatbelt of WA is likely to have mixed results. The marked success of the trial at Geraldton can be attributed to a combination of good adaptation to climate and soil. Minimum and maximum temperatures at the Geraldton trial were very similar to those at Concepcion and Temuco, Chile and Scotia, northern California where quinoa is grown successfully under rain-fed conditions in a Mediterranean climate (Bazile et al 2015; Lundberg; DMC; NOAA). It is grown in these area over spring and early summer on 180-365mm of rainfall and stored soil moisture from winter rain of 725-1070mm. The well-drained clayey sand at Geraldton might also have contributed to the successful crop given that crop establishment was a big limitation at most of the sites.

Plant establishment was a major impediment to yield at many trial locations and reasons seem to be site-specific. For example, plant emergence at Eradu was low possibly due to the presence of water-repellent (non-wetting) soil at the site. Similarly, plant emergence at the southern trial sites of Katanning and Esperance was also poor most likely due to wet and cold weather conditions. Quinoa emerged well at Mingenew, however, plants were severely impacted by pre-emergent herbicide applied to control broad-leaved weeds.

Despite good plant emergence in most treatments at Cunderdin, seed yields were very low. Low temperatures and several severe frosts caused a total loss of seed production at the early May sowing and severely limited yield to a few kilograms at later sowing dates against an expected seed yield of more than a tonne/ha. Ten days experienced sub-zero temperatures in a 30 day period during flowering of plants sown in May. Nevertheless, 2016 was the second coldest year on record in many parts of the WA wheatbelt (BOM).

Spring sowing quinoa at Manjimup with supplementary irrigation produced reasonable seed yields between 1.2 and 1.5 t/ha in varieties JC1 and Medusa, however BEW performed poorly in comparison. Wet and cool conditions resulted in a one-month delay in harvest. Between 10 and 15 February 2017, 36mm of rain fell at the site (BOM). Before rain, hand harvested quadrat yields for BEW were 0.7 and 1.1 t/ha for sowing rates of 5 and 10 kg/ha, respectively (data not presented). As well as a reduced harvest yield, harvested seed was heavily discoloured and shrivelled, indicating that BEW is particularly susceptible to damage from sprouting. BEW is late maturing up to a week and has compact heads compared with Medusa and JC1. This might have resulted in rain water retained longer in BEW heads causing more sprouting and seed discoloration. Overall, all the quinoa varieties tested have shown some sensitivity to sprouting.

Conclusion

Seed yields of approximately 2t/ha had been achieved under irrigation at Kununurra in variety BEW when sown in April with a density of between 25 and 75 plants m^{-2}. Under rain-fed conditions in the wheatbelt at Geraldton variety BEW had yielded approximately 3t/ha of seed when sown on 2 June with a density of approximately 90 plants m^{-2}. With the current price of $1000 per ton (at farm gate), quinoa (e.g. BEW) could be a high value cash and break crop. Quinoa seed processing and marketing are the main issues that need attention for its wider adoption.

References

Bazile D, Martinez EA, Fuentes FF, Chia E, Namdar-Irani MN, Olguin P, Saa C, Thomet M,Vidal AB (2015). Quinoa in Chile. Chapter 5.4. In: FAO & CIRAD. State of the Art Report on Quinoa in the World in 2013, pp. 401-421. Rome.

BOM. Australian Government Bureau of Meteorology. http://www.bom.gov.au/

DMC. Direccion Meteorologica de Chile. http://www.meteochile.gob.cl/PortalDMC-web/index.xhtml

Jacobsen SE and Stolen O (1993). Quinoa - Morphology, phenology and prospects for its production as a new crop in Europe. European Journal of Agronomy 2, 19-29.

Lundberg. Lundberg Family Farms. https://www.lundberg.com/

NOAA. National Centers for Environmental Information. https://www.ncdc.noaa.gov/cdo-web/search

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