Response of wild oats to environmental stresses

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Key words

heat stress, drought, no/minimum tillage conservation agriculture, wild oats survival

GRDC code

9175899

Take home messages

- When under heat and water stress, wild oat plants can mature 3 weeks earlier than non-stressed plants
- Stressed plants produce 30% fewer seeds; additionally, these seeds are 40% smaller and show less dormancy than seeds from non-stressed plants
- Seed dormancy can differ between biotypes and between the two types of seeds (primary and secondary) produced by wild oat plants
- Early plant maturation can cause early seed shedding depending on the severity of heat and water stress
- If the occurrence of late season environmental stresses becomes more frequent as forecast under a changing climate, the efficacy of strategies such as harvest weed seed control may further diminish for wild oats.

Background

Wild oats (*Avena fatua* L. and *Avena sterilis* (L.) *ludoviciana* (Durieu) Nyman) are one of the most economically important weeds within the Northern Grains Region (NGR) (Llewellyn *et al*., 2016). In the NGR, ~0.6 M ha of cropping land is infested by wild oats that cost growers ~$4.5 M annual revenue loss by sacrificing crop yield (Llewellyn *et al*., 2016). Wild oats possess a range of survival mechanisms to succeed in the cropping environment, such as variable seed dormancy and a persistent seed bank. In response to changing climatic conditions, where the frequency of hot and dry periods is increasing during the late winter/early spring period (CSIRO, 2011), wild oats plants can mature and shed a majority of their seeds early and before the cereal crop is harvested. These seeds can undergo rapid germination from exposure to cool, wet conditions in the following autumn/winter planting season.

The response of *A. fatua* to a range of environmental stressors has been studied a great deal. However, little research has been conducted on *A. sterilis* ssp. *ludoviciana*, which is the more abundant wild oats species within the NGR (Nugent *et al.,* 1999). The survival mechanisms of *A. sterilis* ssp. *ludoviciana* may differ between biotypes, as has been reported for *A. fatua* (Adkins *et al.,* 1987). Even the primary (the bigger sized seed of a floret) and secondary seeds of *A. sterilis* ssp. *ludoviciana* produced from the same floret may show differences in dormancy behaviour (Quail and Carter, 1968), which may help wild oats to persist in the cropping environment. This study investigated the phenology and reproductive biology of *A. sterilis* ssp. *ludoviciana* biotypes in response to environmental conditions. Specifically, we investigated the impact of heat and water stress, and a combination of both stressors, to gain insight into the potential persistence and invasiveness of wild oats within the NGR.

Objective

To determine how late season heat and water stress, individually and in combination, affect the growth and reproductive biology of *A. sterilis* ssp. *ludoviciana* when applied during the seed development stage – knowledge of which is critical to understand their persistence in NGR cropping systems under changing climatic conditions.

Materials and methods

Seeds of four biotypes were collected from four locations across the NGR: Biloela 1 (-24.35471 °S, 150.49773 °E); Biloela 2 (-24.35048 °S, 150.49767 °E); Toobeah (-28.36792 °S, 149.52197 °E) and Jandowae (-26.66727 °S, 151.02460 °E). The experiment was conducted during June to December 2019, using a completely randomized design with six replications. Three germinated seeds of each biotype were transplanted into a 20 cm diameter × 19 cm height pots each containing 4.5 kg of a black Vertosol soil (71% clay, pH 7.3) obtained from Gatton, QLD. The 96 pots (four biotypes × four treatments × six replications) were maintained at 100% gravimetric plant available water content (PAWC) and kept in a greenhouse under ambient conditions (average ~23/14°C day/night). The stress treatments were applied at panicle emergence (Biloela 1 and Biloela 2 panicle emerged at 58 days, Toobeah 63 days and Jandowae 65 days after seed germination) and were maintained until harvest. The treatments were as per Table 1 below.

Table 1. Stress treatments applied to wild oat populations

	Abbreviation	Treatment
a)	HS	Heat stress at the panicle emergence stage. Pots were moved to a temperature-controlled glasshouse set at 29/23°C 12/12-hour day/night photoperiod and maintained at 100% gravimetric PAWC.
b)	WS	Soil water stress at the panicle emergence stage. Pots were maintained at 60% gravimetric PAWC under the ambient greenhouse conditions.
c)	HWS	A combination of HS and WS. Pots were moved to the same temperature-controlled glasshouse (as mentioned in HS) and maintained at 60% gravimetric PAWC.
d)	Control	No imposed stress. Pots were maintained at 100% PAWC under the ambient greenhouse conditions.

The PAWC of pots was determined by the following equation:

100% PAWC (g H_2O/kg soil) = (water content at field capacity – water content at permanent wilting point) / dry soil weight

The field capacity and permanent wilting point of black Vertosol Gatton soil were determined as 390 and 224 g H_2O/kg soil, respectively. Soil water content of the pots was maintained according to the weight of the pot and considering the weight of the plant.

Data acquisition

The number of days taken to reach maturity, total number of filled primary seeds/plant and filled secondary seeds/plant were recorded for all plants. The 1000 primary and secondary seed weight were determined by taking five lots of 50 seeds from the bulked seed lots (combined across replicates of each stress × biotype treatment) and dried at 80°C for 96 hours. Once dry, they were weighed and values multiplied by four to reach 1000. To check the dormancy status of the freshly harvested hulled primary and secondary seeds, three replicates of 20 filled primary and secondary seeds coming from the bulked seed lots of each treatment were incubated at 9°C under 12/12 hour light/dark condition for 42 days in a germination incubator. Number of seeds germinated was recorded.

Statistical analysis

A. sterilis ssp. *ludoviciana* responses to the different environmental stress treatments were analysed by ANOVA performed in Minitab v. 8.1. Means were separated using Fisher's protected LSD test at $P<0.05$. The graphs were prepared using SigmaPlot v. 13.0.

Results and discussion

Significant two-way interactions between *A. sterilis* ssp. *ludoviciana* biotype and different environmental stressors were observed for all variables studied except for days to maturity (Table 2). Northern NGR biotypes (Biloela 1 and 2) matured in ~97 days, 6 to 8 days earlier than southern biotypes (Jandowae and Toobeah), which matured in ~105 days. However, the stress treatments had a greater impact on driving earlier maturation when compared to the control plants. The HWS treatment had much greater impact on phenology and reproductive biology of *A. sterilis* ssp. *ludoviciana* than when each stressor was applied individually. The HWS treatment resulted in plants maturing 19 days earlier than plants grown without any stress, followed by HS (17 days earlier) and WS (9 days earlier). The exposure of plants to different environmental stressors during the seed development stage stimulated plants to complete their life cycle in a much shorter time. Additionally, exposure to the environmental stressors was responsible for plants producing fewer and smaller seeds as compared to the control plants (Table 2). Primary seed production of plants was reduced by 32, 29 and 12% as compared to the control plants from the HWS, HS and WS treatments, respectively. These figures were similar for the secondary seeds, although it was observed that secondary seed production was less than primary seed production in all biotypes (Table 2). Primary and secondary seed sizes were greatly impacted by the stress treatments. Under HWS, seed size was reduced by as much as ~40% as compared to seeds produced by control plants.

Environmental stressors resulted in a reduction in the dormancy status of the wild oat seeds. The dormancy status of primary seeds produced under stress conditions was reduced from 80, 85, 90 and 87% in the control plants to 23, 45, 62 and 47% in Biloela 1, Biloela 2, Toobeah and Jandowae, respectively, under the combined HWS (Figure 1). The dormancy status of secondary seeds remained higher as compared to the primary seeds; however, HWS produced the least dormant seeds among all treatments for both seed types.

Table 2. The effect of heat and soil water stress treatments applied at panicle emergence on the time of plant maturity, the production of filled primary and secondary seeds, and their seed weight for four *Avena sterilis* ssp. *ludoviciana* biotypes collected from the NGR. Letters within biotypes indicate significant differences among the stress treatments. Main effect means for all biotypes and stress treatments (in bold text) sharing the same letter do not differ significantly. Values in parenthesis are those when compared to the control.

Treatments (applied at panicle emergence)	**Biotype**				**Mean**
	Biloela 1	**Biloela 2**	**Toobeah**	**Jandowae**	
Days to plant maturity (days earlier than control)					
Heat and water stress	87 (-20)	91 (-18)	96 (-19)	99 (-19)	**93 d (-19)**
Heat stress	90 (-18)	92 (-17)	99 (-16)	101 (-17)	**95 c (-17)**
Water stress	99 (-8)	101 (-8)	104 (-11)	108 (-10)	**103 b (-9)**
Control	107	109	115	118	**112 a**
Mean	**96 d**	**98 c**	**104 b**	**106 a**	
Filled primary seeds/plant (% reduction compared to control)					
Heat and water stress	142 d (-25)	119 d (-37)	155 d (-30)	120 c (-36)	**134 d (-32)**
Heat stress	147 c (-22)	125 c (-34)	167 c (-24)	123 c (-34)	**140 c (-29)**
Water stress	157 b (-17)	164 b (-13)	196 b (-11)	174 b (-7)	**173 b (-12)**
Control	189 a	189 a	220 a	187 a	**196 a**
Mean	**159 b**	**149 c**	**184 a**	**151 c**	
Filled secondary seeds/plant (% reduction compared to control)					
Heat and water stress	131 d (-28)	114 d (-37)	153 d (-28)	110 d (-39)	**127 d (-33)**
Heat stress	139 c (-23)	116 c (-36)	158 c (-25)	116 c (-35)	**132 c (-30)**
Water stress	150 b (-17)	157 b (-14)	188 b (-11)	167 b (-7)	**165 b (-13)**
Control	181 a	182 a	212 a	179 a	**189 a**
Mean	**150 b**	**142 c**	**178 a**	**143 c**	
1000 primary seed weight (g) (% reduction compared to control)					
Heat and water stress	18.79 c (-53)	25.65 d (-39)	29.98 d (-35)	33.44 c (-32)	**26.97 d (-39)**
Heat stress	19.84 c (-51)	28.83 c (-32)	32.68 c (-30)	33.90 c (-31)	**28.81 c (-35)**
Water stress	34.08 b (-15)	32.47 b (-23)	38.51 b (-17)	43.34 b (-12)	**37.10 b (-17)**
Control	40.19 a	42.28 a	46.36 a	49.03 a	**44.47 a**
Mean	**28.23 d**	**32.31 c**	**36.88 b**	**39.93 a**	
1000 secondary seed weight (g) (% reduction compared to control)					
Heat and water stress	10.57 c (-53)	14.43 d (-39)	16.87 d (-37)	18.81 c (-33)	**15.17 d (-40)**
Heat stress	11.16 c (-50)	16.22 c (-33)	18.38 c (-31)	19.07 c (-32)	**16.21 c (-36)**
Water stress	19.17 b (-16)	18.26 b (-24)	21.66 b (-19)	24.38 b (-13)	**20.87 b (-18)**
Control	22.61 a	23.78 a	26.08 a	27.58 a	**25.01 a**
Mean	**15.88 d**	**18.17 c**	**20.75 b**	**22.46 a**	

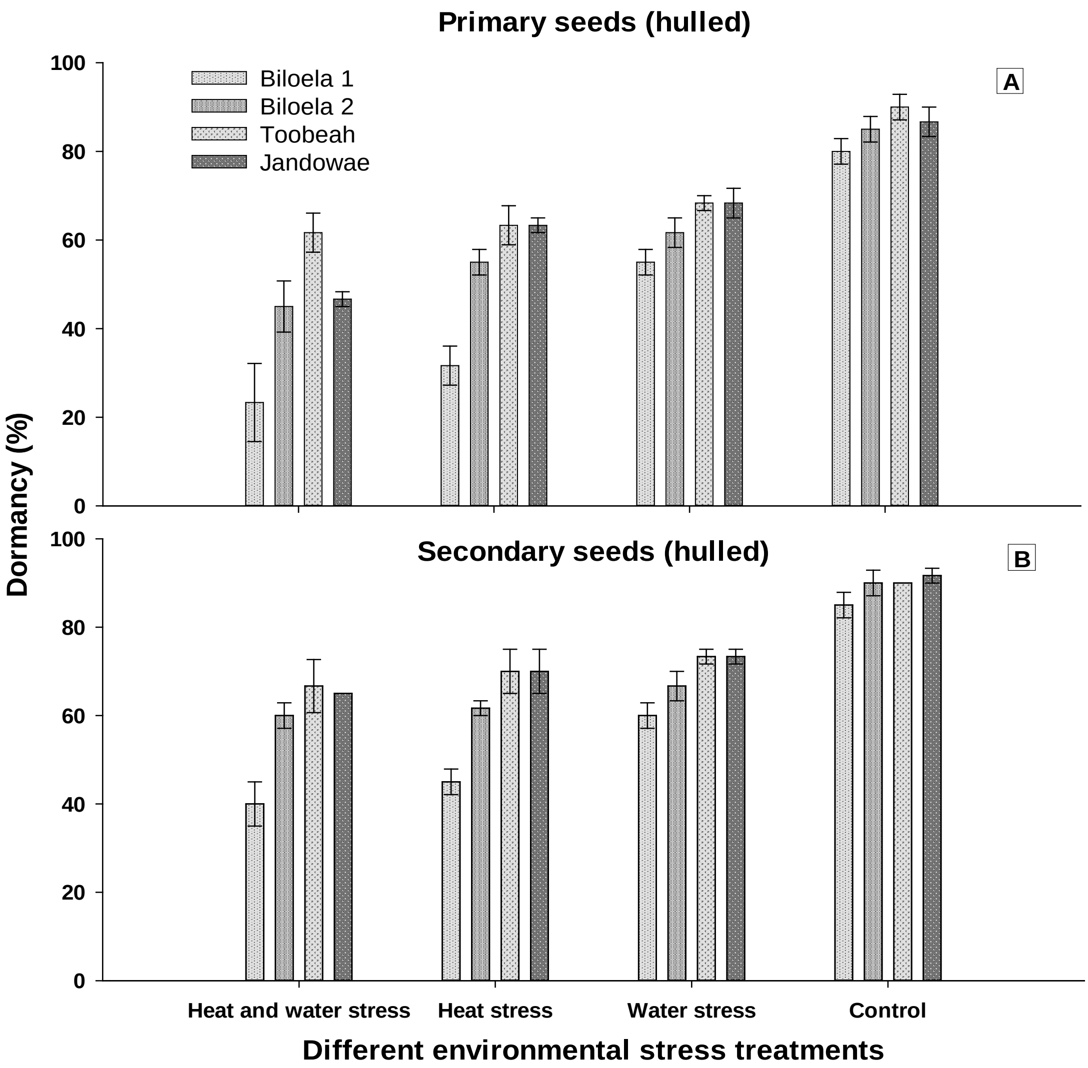

Figure 1. Effect of heat and soil water stress treatments applied at panicle emergence on percentage seed dormancy of freshly harvested (A) primary and (B) secondary hulled seeds of four *Avena sterilis* ssp. *ludoviciana* biotypes incubated at constant 9^{o}C under 12/12 hour light/dark condition for 42 days. Error bars represent ± standard errors of the mean of three replicates.

Conclusion

The various heat and water stress treatments imposed in our study showed that wild oats plants grown under these environmental conditions are likely to mature earlier and produce fewer, smaller sized seeds that are less dormant. Given climate change forecasts for the NGR are for hotter and drier growing season, this is likely to impact on the growth, seed production and seed characteristics of wild oat populations in this region. These changes in climatic conditions will, therefore, affect the population dynamics and management strategies of wild oats. For example, hot and dry conditions will shorten the maturity time of wild oats and produce seeds with less dormancy, meaning they can potentially germinate rapidly under suitable conditions at the time of next winter crop planting in no/minimum tillage-based conservation cropping systems. Additionally, early maturity can lead to early shedding of maximum wild oats seeds to the ground before crop harvest, which is a concern in terms of harvest weed seed control. Occasional non-chemical control interventions such as the use of strategic tillage may be useful by burying shattered seeds at greater depth from where they can-not emerge. This may be a useful control tactic given the data indicates that such seeds are less well adapted for long-term survival in the soil seedbank. To assess the impact of the harvest weed seed control technique for controlling wild oats, future research should be conducted on comparing the relative maturity between wild oats and crop types and crop cultivars. To improve control of wild oats and to reduce their impact on crop production, weed management tactics and strategies will need to adapt to the changing environment and changing ecology of these weeds.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

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