Genotypic heat tolerance in lentil

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Abstract
Heat waves (temperatures > 35°C) during flowering and pod-filling of lentil can result in significant reductions in seed yield, quality and profitability. Preliminary research for improving adaptation of lentil to heat stress has found potential genetic variation in tolerance within lentil genotypes during the reproductive phase. A field study during the 2014-15 summer in southern Australia investigated the genotypic variation for heat tolerance of 50 lentil genotypes. Late sown crops were grown under unshaded (heat treatment) and shaded (control) conditions through the reproductive phase and irrigated to avoid moisture stress. Seed yield response to heat treatments ranged from -100% to -20% relative to controls (shade) with a significant interaction between heat treatment and genotype. Several genotypes were more tolerant to heat stress compared to the commercial varieties these being 72578 (India), 70549 (Argentina), 71457 (Jordan) and 73838 (Albania) with yields 65%, 72%, 75% and 80% of the controls respectively. These genotypes had improved heat tolerance compared with current commercial varieties and also had equivalent absolute yields. The impact of heat stress was primarily a reduction in seed number, which was reduced by 50% for commercial cultivars compared to 18% for landraces identified to have improved heat tolerance. Further controlled experimentation of these genotypes is required to validate their genetic potential. The identification of potentially tolerant genotypes to heat stress indicates there is an opportunity to utilize genetic differences to high temperatures during the reproductive phase of lentil, thereby improving their adaptation to heat waves.

Additional Key words
Climate change, genetic variation, pod filling, pulses.

Introduction

The rain-fed cropping regions of southern Australia have a Mediterranean-type climate, where crops frequently mature into terminal drought conditions. The occurrence of heat waves often coincide with the reproductive and grain filling phase of crops and can have significant impacts on their yield and quality. For southern Australia, the frequency of heat waves has been predicted to increase from a 1-in-10 to a 1-in-3 year occurrence (IPPC, 2012). Lentil crops are frequently included in cropping rotations and are particularly sensitive to abiotic stress. The potential impact of heat waves to lentil production poses a significant challenge to the grains industry. For example, a heat wave (35°C for 6 days) in 2009 across south-eastern Australia caused a 70% yield reduction in lentil crops, equating to $1000/ha loss (Brand, pers. comm).

The severity of the damage caused by heat stress depends on timing. Pulse crops including lentil are particularly sensitive to the effects of heat stress at the reproductive stages of development when plants are in full bloom. Even a few days of high temperature (30 -35°C) limits many processes including photosynthesis, metabolic pathways, electron flow and respiration rates (Redden et al, 2014), causing flower and pod abortion, resulting in yield losses by reducing seed set, seed weight and accelerating senescence (Siddique, 1999; Gaur et al., 2015). Adaptation of lentil to heat waves may be managed through avoidance (and involves selecting early maturing genotypes) or alternatively genetic solutions through identifying and breeding additional tolerance into commercial lines. Heat tolerant lentil genotypes exist and allow flexibility in sowing dates and enhance opportunities for improving yield stability and expanding areas of pulses to new cropping systems (Gaur et al, 2014). However, this genetic potential has not been fully explored in lentil for the purpose of adaptation to heat stress. The current research assesses the heat stress tolerance of a broad range of lentil genotypes and compares their response with current commercial varieties to determine if potential genetic solutions exist for increasing lentil tolerance to heat stress.

Material & Methods

Fifty lentil genotypes were tested for response to high temperature under field conditions. The study included nine commercial cultivars and 41 accessions. The accessions were selected from a range of countries and climatic zones, particularly regions where heat stress events are common in the natural growing conditions,

such as, Syria, Turkey and Pakistan (Fig 1).Genotypes (varieties and accessions) displayed a range of growth habits, flowering and maturity. These accessions were sourced from the Australian Grains Genebank, Horsham Victoria. The nine commercial breeding lines were a representation of the current cultivars commonly included in cropping rotations in southern Australia, with a range of adaptations to biotic and abiotic stresses, as a result of recent breeding. The breeding checks CIPAL0901, an early maturing red lentil breeding accession and the commercial variety PBA Giant, a large green mid/late maturing lentil were used as control lines in this experiment (checks grown every 12 rows).

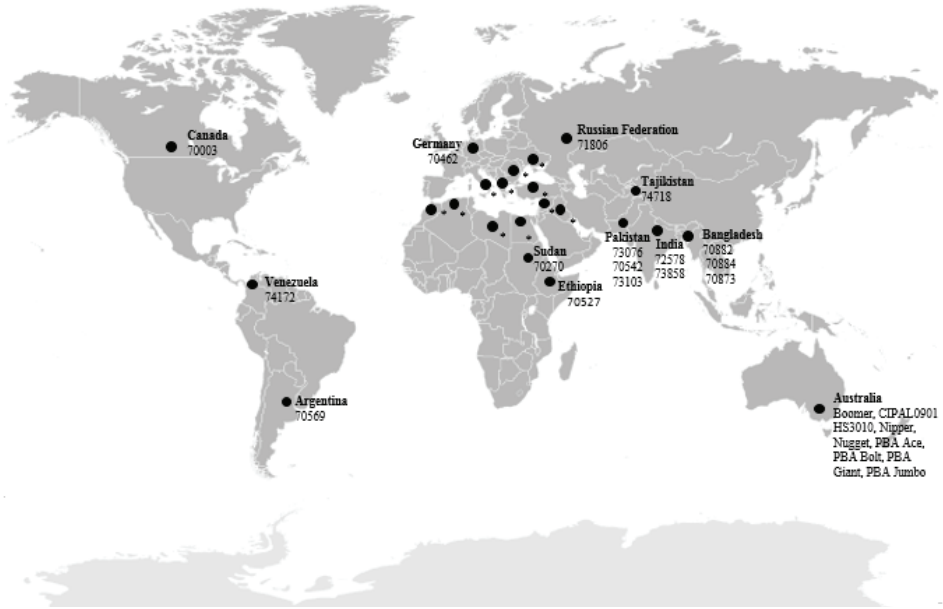

Figure 1: World map showing the origins of the genotypes included in this late sow field trial.
***Algeria (70156), Bulgaria (70951), Cyprus (71698), Egypt (73364), Greece (73580), Iran (72860), Jordan (70478), Lebanon (70118, 71456), Libya (73693), Morocco (70457), Syria (70402, 70400, 70569, 71119, 70392), Turkey (70685, 72366, 73252, 70138)**

The trial was sown under field conditions at Horsham, Victoria on a grey Vertosol soil. Sowing was delayed until 17 October to force the flowering window of lentil into hotter growing conditions (36 days >33°). The trial was a randomised complete block design with two replicates and single 1 m rows (112 rows/rep) sown, 0.65 m apart on a pre-watered irrigation bay (150 mm).Control plants were grown under a shade facility (50% shade, white UV stabilised high density polyethylene fabric, installed 0.75 m above the ground) from anthesis through to maturity, and compared with the equivalent plants grown in full sun. Between sowing and the average anthesis date (3/12/2014) there was 22 mm of rainfall and 108 mm of supplementary irrigation and in the post anthesis phase up to harvest 64.5 mm of rainfall and 36 mm of irrigation. Temperature was recorded for the canopy, soil and air for both growing conditions (unshaded and shade). Crop phenology was also recorded. At harvest, the above-ground biomass was harvested and total biomass, seed yield and seed number determined.

Results and Discussion

Lentil exposed to full heat (unshaded) had average grain yields lower (66% reduction) than those grown under the shaded control, which demonstrates the effectiveness of the shade facility in reducing plant heat stress. A similar approach has been used by Krishnamurthy et al (2011) where genotypes were grown in contrasting conditions, using sowing dates (normal and late) and different climates. For the current experiment the shade facility reduced radiant heat (non-limiting to photosynthesis) by 38.5% with a decrease in canopy temperature of 2.5°C. There was increased pod and leaf drop for plants grown in full sun, which is a common coping mechanism for pulse crops suffering from heat stress (Erskine et al, 2011).

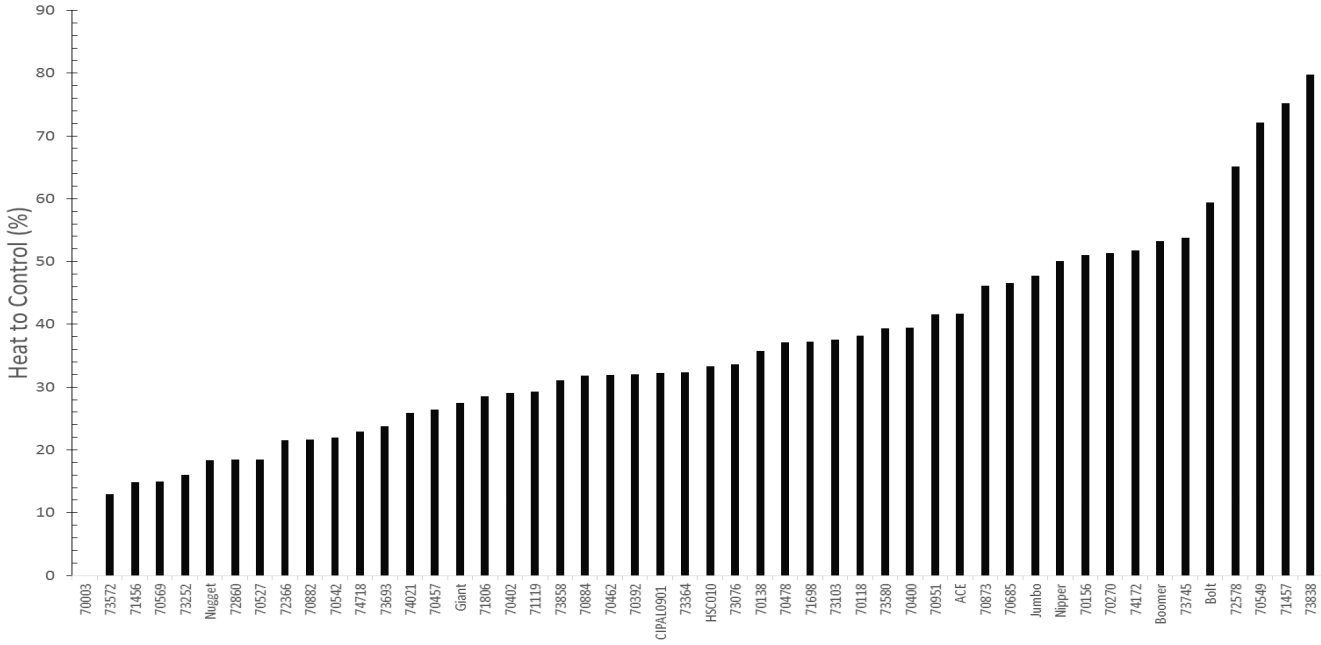

Fig 2: The response of heat stress (unshaded) crops on grain yield, relative to the control (shaded) crops for the genotypes (heat to control %).

The average yield of commercial cultivars was reduced by 41%, for heat stress plants (unshaded plots) compared with their respective controls (shaded). PBA Bolt and Boomer showed the greatest heat tolerance with yield reductions of 35 and 47%, respectively. Nugget and PBA Giant were the most sensitive to heat stress with yields reduced by 82 and 73%, respectively (Fig 2). Four genotypes, 72578 (35% reduction), 70549 (28% reduction), 71457 (25% reduction) and 73838 (20% reduction) showed improved tolerance to heat stress compared with the most tolerant commercial variety, PBA Bolt. For the four heat tolerant genotypes identified and PBA Bolt, the average seed number was reduced by 18% compared with 75% for the most sensitive genotypes (< PBA Giant). In contrast, the seed size reduction under heat stress (unshaded) for the two groups was equivalent (14%), which suggests that grain number is the major yield component being reduced by heat stress. This is consistent with Gaur et al (2015) who found that the ability to fill pods with seed is correlated with improvements in heat tolerance. The origin of the genotypes identified in this study to be more tolerant to heat stress were India, Argentina, Jordan and Albania, which have Mediterranean to Arid type climates, with a high probability of high temperature stress during the reproductive phase of crop growth (Fig 1). Genotypes from more temperate or tropical zones were more sensitive to the harsh conditions and in some instances failed to either reach maturity or produce yield.

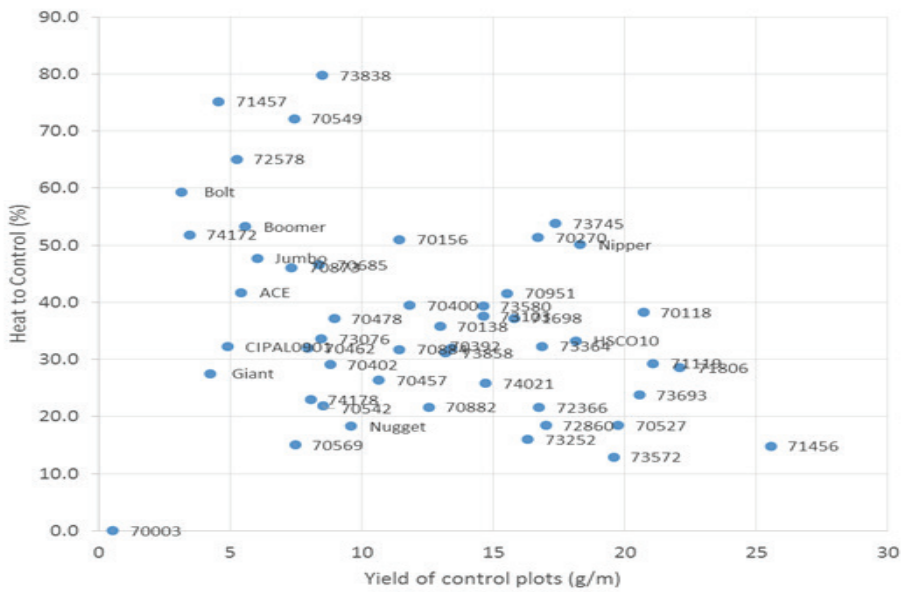

Figure 3: The relationship between the absolute yields for the control crops (shaded) and the heat to control % (increases with heat tolerance).

When comparing the absolute yield of lentil genotypes under control conditions (shaded) and the response to heat stress (heat to control %) we identified several genotypes that are both tolerant to heat stress and have an adequate absolute yield under control conditions (Fig 3). Some genotypes were high yielding, but generally had poor tolerance to heat stress. In contrast, the genotypes identified with high tolerance had a relatively low absolute yield. The majority of the commercial varieties had a relatively low absolute yield and poor tolerance to heat, the exception being Nipper, which had moderate tolerance to heat and absolute yield. The absolute yield of genotypes 72578, 70548, 71457 and 73838 was equivalent to the average commercial variety absolute yield, differing by an increase in tolerance (Fig 3). This indicates that there are lentil genotypes that have competitive agronomic yield and a greater heat stress tolerance.

The plants grown in the shade had a delayed rate of pod set and maturity, compared to the unshaded plants. The delay in maturity was likely to be due to the reduction in temperature and increased moisture conservation under the shade. There was no significant interaction in the relative delay in maturity and genotype under the two treatments (shaded/unshaded). While there was no significant correlation, the genotypes most tolerant to the heat treatment (70549, 71457 and 73838) were earlier to mature. In general, the commercial varieties had a faster rate of development compared to other genotypes, despite not necessarily having improved heat tolerance (Fig 2).

Conclusion

Genetic variability in the response of 50 lentil genotypes to imposed heat stress during the reproductive stage has been demonstrated. Four genotypes have been identified (72578, 70549, 71457 and 73838) to have improved tolerance to high temperature and absolute yield equivalent to current commercial cultivars. This provides the opportunity for breeding programs to improve the tolerance of lentil to heat stress, leading to better yield stability and profitability for growers. Further controlled studies are required to validate these early findings, refine screening methods and investigate mechanisms inferring tolerance.

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