Abiotic stresses of cool season pulses in Australia

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INTRODUCTION

Pulses are widely recognised as having an important role in Australian agriculture. Unlike 15 to 20 years ago, there are now many pulse species and varieties available to farmers that are adapted to a wide range of Australian environments. The major food legume species of economic importance to Australian Agriculture are field pea, chickpea, faba bean and lentil. Considering the limited breeding effort and development of management packages for pulses, compared with cereals and canola, there is considerable scope for further improvement of pulse yields in Australia. However in recent years fluctuations in pulse yield and frequent crop failure in several regional environments caused by biotic and abiotic stresses are threatening the future expansion of the pulse industry in Australia. Currently major research and industry development efforts are addressing a number of biotic stresses, including fungal diseases of pulse crops in Australia. The relative importance of the abiotic stresses affecting pulse production in Australia is poorly understood. The major abiotic stresses of pulses in Australia are those associated with cold, frost, waterlogging, drought, heat, soil pH, salinity, sodicity and boron toxicity.

PHENOLOGY

The extent of the damage caused by abiotic stresses depends on the pulse species (Table 1), the prevailing environmental conditions and stage of crop growth.

The phenology of pulse crops varies with species, time of sowing and location. For a particular stress, the time at which it occurs in the plant's life cycle will affect plant production through its yield components (total biomass, number of pods, number of seeds, seed weight and harvest index). The pulse crop life cycle can be generally divided into the following five phases. Phase 1- from planting to seedling emergence. Phase 2- from seedling emergence to first flowering. Phase 3 - from first flowering to pod appearance. Phase 4 - from pod appearance to the beginning of seed formation. Phase 5 - from seed formation to physiological maturity. Typical phenological development of major pulse crops at Merredin, Western Australia is presented in figure 1. Faba beans and field peas were the earliest to flower and pod compared to desi chickpeas and lentils. Despite differences in flowering and podding, maturity was similar in the pulse species studied and was largely determined by soil moisture and temperature conditions at the end of the season. The duration of reproductive period (first flower to maturity) was longer in faba beans and field peas.

DROUGHT AND HEAT STRESS

The optimal temperatures for the cool season pulses range between 10°C and 30°C. Temperatures that fall outside the optimum range cause stress. Daily maximum temperature above 25°C is considered as the threshold level for heat stress in cool season pulse crops. The critical temperature for heat tolerance seems to be higher in chickpea than in faba bean, lentil and field pea crops and the reverse is true for cold tolerance.

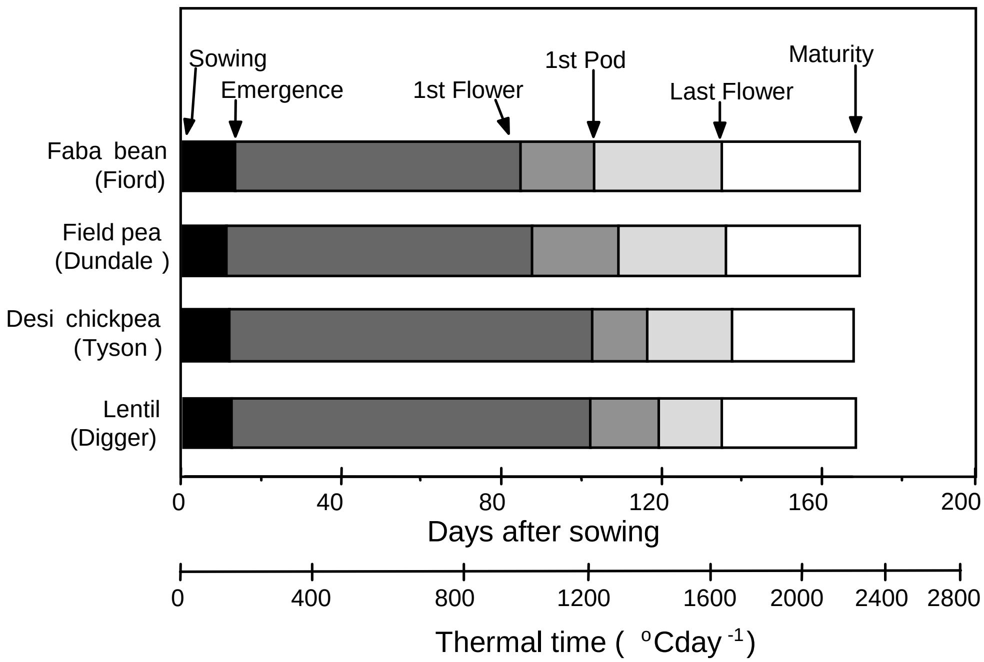
Pulses are particularly sensitive to heat at the full bloom stage. A few days of exposure to high temperatures (30- 35°C), causes heavy yield losses through flower drop and pod abortion. Marked reductions in seed yields after brief episodes of high temperatures during seed filling can diminish seed set, seed weight and accelerate senescence and reduce yield.

Table 1. Importance[A] of major abiotic stresses affecting cool season pulse crops in Australia

Stress	Field pea	Chickpea	Faba bean	Lentil
Cold	X	XXX	X	X
Frost	XXX	XXX	XX	XX
Waterlogging	XXX	XXX	X	XXX
Drought	XX	XX	XXX	XX
Heat	XXX	XX	XXX	XXX
Salinity	XX	XXX	XX	XX
Boron toxicity	XX	XXX	XX	XXX

[A] very important XXX, important XX, not very important X

Figure 1. Duration (days after sowing and thermal time, base temperature 0°C) to emergence, 50 per cent flower, 50 per cent podding, last flower and 95 per cent maturity for pulse crops sown on 16 May at Merredin in 1995 (adapted from Siddique *et al.* 1999).



Faba bean has poor tolerance to both high temperatures and drought and consequently its productivity in low rainfall areas is variable. Even in areas where conditions are favourable for vegetative development, high temperatures when pods are setting and filling can significantly reduce seed yield of faba bean.

Drought is a major constraint in all pulse growing regions of Australia, particularly in the low rainfall areas. From a practical point of view, it is difficult to separate drought and heat stress and they generally occur simultaneously. The types of drought stress which affect pulse production in Australian are: lack of or low opening rainfall at planting, intermittent drought stress by breaks in winter rainfall; and the terminal drought stress, resulting from receding soil moisture and increasing high temperature in spring.
Terminal drought is the most common form of drought stress experienced by cool season pulses in Australia. The severity of terminal drought stress depends upon the amount and distribution of rainfall, capacity of the soil to store moisture and the evaporative demand of the atmosphere. There are two major effects of drought on pulse productivity: failure to establish the desired plant stand; and reduction in growth and yield due to sub-optimal soil moisture availability.

Chickpea has higher soil moisture requirement for germination than lentil, field pea or faba bean. However the critical soil moisture required for seed germination and seedling emergence in chickpea is well below field capacity. Lentil seeds absorb water equal to their weight in less than 36 hours and germinate soon after, but germination is reduced if dehydration occurs thereafter. This makes lentil crop sensitive to early season drought, particularly when planted shallow.

Drought stress during vegetative stages of growth alone does not appear to cause a significant yield loss in chickpea or field pea. Flowering is the most sensitive stage to drought. It is probable that high sensitivity to drought during the reproductive stage is due to the lack of new root growth in pulse crops at this stage of growth. Chickpea is considered to be the most drought tolerant cool season pulse and it forms a deep taproot. Chickpea has the greatest ability to tolerate intermittent drought and respond to subsequent rainfall due to its more indeterminate growth habit when compared to other cool season pulse crops.
Seed yield loss in chickpea due to terminal drought can vary between 30 per cent and 60 per cent depending upon the location and climatic conditions during the crop season. Faba bean is very sensitive to drought and losses in potential yield can be up to 70 per cent.

Lentil is considered relatively tolerant to drought. Potential losses in yield can range between 6 per cent and 54 per cent. Field pea is also sensitive to drought and yield losses varies from 21 to 54 per cent. However field pea with the correct phenology has the ability to escape drought and produce respectable yield when compared with other pulses.

COLD

The major symptoms of cold in winter pulses are reduced leaf production, area expansion, poor dry matter production, chlorosis and, finally necrosis of the older leaves. These symptoms are generally observed in winter-sown chickpea in Australia. A daily average temperature between 0°C and 10°C is considered a threshold level for cold or chilling stress in cool season pulses. In Australia resistance to cold is greater in faba bean and lentil than field pea and chickpea. Under Australian winter conditions reproductive organs, mainly flower buds and flowers, are most susceptible part of cool season pulses to cold or chilling injury.

Chickpea is more sensitive to chilling injury than field pea, faba bean or lentil. Most chickpea cultivars grown in Australia where temperature falls below 10°C continue to flower but fail to set pods. The reduced ovule fertilisation, associated with decline in pollen tube growth and ovule viability, is the major cause for poor seed set in chickpea at low temperatures. Fortunately recent evaluation of germplasm both in Australia and overseas shows distinct differences in pod and seed set at low temperatures in chickpea. These traits are currently being exploited in the breeding programs.

FROST

The threshold level for frost injury in winter pulses occurs when daily minimal temperature is below 0°C without snow cover. Frost damage in spring (radiation frost) is a major cause of yield loss in crops including pulses in Australia. The most important stress in the freezing process is ice formation and the associated mechanical damage of the tissue. Flowering, early pod formation and seed filling are the most sensitive stages of in winter pulses. Critical temperatures for frost injury appear to be higher for chickpea than field pea, lentil and faba bean. Among the pulses field pea seems to be the most susceptible to frost injury during the reproductive stage. Chickpea is a more indeterminate species than the other pulses and will continue to produce fresh flowers and pods provided there is adequate moisture in the soil profile and the temperature conditions during this period remain favourable. This allows chickpeas to compensate for loss of early flowers due to frost or cold injury.

WATERLOGGING

Transient waterlogging is very common in winter on fine textured soils in Australia. Seed germination is very susceptible to waterlogging. Poor crop establishment is a common problem when waterlogging occurs at seedling emergence. Among cool season pulses faba bean is relatively tolerant to waterlogging at germination compared with lentil, field pea or chickpea. Waterlogging six days after germination of field pea can delay the emergence by up to five days and reduce the final plant density by 80 per cent. Waterlogging depresses vegetative growth of plants but affects root growth more than shoot growth. Roots of faba bean have greater tolerance to waterlogging than the roots of chickpea, lentil and field pea. Once seedlings are established, the sensitivity of plants to waterlogging stress is generally increases with advancing age. Thus the ability to survive and recover following waterlogging is dependent on the timing of the waterlogging event relative to the stage of growth. Ability to recover generally declines sharply as reproductive growth (flowering and pod filling stage) approaches. Seed yield loss resulting from waterlogging can be substantial. Limited data for lentil, field pea and chickpea suggest that reduction in yield can vary from negligible to almost 100 per cent, depending upon the species, stage of growth when waterlogged, duration, and the extent of root zone affected by waterlogging. Management practices to reduce the effects of waterlogging include the species choice (Faba bean tolerant; lentil highly susceptible), paddock selection, time of sowing, seeding rate and drainage. Selection for genetic variation in waterlogging tolerance within a cool season pulse species has been limited.

SOIL PH

Cool season pulses are sensitive to acid soil conditions and require a neutral to alkaline soil pH for their optimum growth and yield. Among the cool season pulses lentil is the most sensitive to low pH followed by chickpea, faba bean and field pea. A drop of one pH unit below the threshold value (pH 5.5) can cause more than 86 per cent reduction in seed yield of lentil. Cool season pulses generally appear to be more sensitive to acidity than cereals.

Nutrient availability can change dramatically with small changes in soil pH, particularly in mineral soils low in organic carbon. On such soils, toxicity of Al, Fe, and Mn occur when the pH falls from 5.5 to 4.5. Root growth of pulses is severely restricted on acid soils. Symptoms of nutrient deficiency and water stress, therefore, commonly occur in pulse crops growing on unsuitably acid soils.

Deficiencies of Fe, Zn and Mn occur above pH 8.0. There are many reports of Fe deficiency in chickpea and lentil; and Zn deficiency in field pea, chickpea and lentil. Fe deficiency is by far the most commonly occurring nutrient disorder on high pH and calcareous soils across cool season pulses. Losses in yield of highly susceptible genotypes range from 22 to 50 per cent, both in chickpea and lentil. Appearance of Fe - deficient symptoms is highly transient across cool season pulse crops appearing under wet (above field capacity) soil moisture conditions and low temperatures. Screening germplasm grown on high pH (> 8.1) calcareous soils has been very effective in identifying genotypic differences in susceptibility to Fe deficiency in cool season pulse crops.

SALINITY AND SODICITY

Cool season pulses are relatively sensitive to salinity. Salinity damage to pulse crops is shown by characteristic symptoms of excess ion accumulation. Necrosis of the outer margins and yellowing of the older leaves are the first signs of salinity. As salinity intensifies, these symptoms progress to younger leaves and older leaf die and abscise. Salinity intensifies anthocyanin pigmentation in leaves and stems in desi chickpea but in kabuli chickpea these tissues become yellow. It is easy to confuse salinity symptoms in pulses with symptoms of other nutrient disorders, disease, herbicide damage and drought.

Crop response to salinity also changes with crop age. For example, lentil, faba bean and field pea are more sensitive at germination than at subsequent growth stages and the converse is true for chickpea. To quantify the effect of salinity on plant growth it is necessary to establish critical values, relating salt concentrations and their effect on growth and yield reduction. Critical values for the major pulse crops are given in Table 2. Glasshouse studies and field observations suggest that lentil and field pea may have greater salinity tolerance than faba bean and chickpea. Salinity tolerance of field pea and lentil are comparable to wheat but less than that of barley (Table 2). The latter stages of chickpea growth, particularly flowering are more sensitive to salinity than the early vegetative stages. Scope for genetic enhancement of salinity resistance in cool season pulses is limited by the lack of variability in germplasm with the desired levels of resistance. Sensitive pulse crops (e.g. chickpea and faba bean) should not be grown on salt affected soils; other tolerant species such as barley should be considered.

Table 2. **Relative tolerance of cool season pulse crops in relation to barley and wheat to salinity**

Species	ECe (dSm-1) at 50 per cent seed yield
Lentil	12.8
Field pea	10.0
Faba bean	6.8
Chickpea	3.0
Barley	16.0
Wheat	10.0

Sodicity adversely affects cool season pulses by reducing germination and seedling establishment with increasing exchangeable sodium percentage (ESP; 15 - 20). Glasshouse studies and field observations suggest that chickpea and lentil are more sensitive to sodicity than faba bean and field pea. The level at which 50 per cent reduction of seed yield occur is about 10 ESP for chickpea and 15 ESP for lentil. As with salinity, seed yield appears more sensitive to sodicity than does vegetative growth. In lentil and chickpea, the number of pods per plant and mean seed weight were severely decreased, where as the number of seeds per pod was little affected. In comparison, canola a moderately sodic-tolerant species, can withstand 35 ESP without significant reduction of growth or yield.

MANAGEMENT OF ABIOTIC STRESSES IN PULSE CROPS

Abiotic stress can be reduced by choosing the most appropriate pulse species and adjusting agronomy (sowing time, plant density, soil management) to ensure sensitive crop stages occur at the most favourable time in the season. For example choosing the optimum sowing time, species and cultivars with appropriate phenology can reduce the effect of frost and drought in pulse crops in dryland environments with terminal stress.

One approach of dealing with stresses caused by extremes in the abiotic environment is to develop cultivars resistant to specific stresses. Breeding and selection for resistance to these stresses is often considered difficult because of the unpredicability of climatic conditions. The developmental stage of the plants and the duration of the stress have a strong influence on the effect of the abiotic stress, together with the ability of the plants to tolerate the stress themselves. Drought and heat escape through earliness in flowering and maturity is probably the characteristic most widely used by breeders for pulses and other crops to escape drought especially in low rainfall terminal drought environments.

Currently lack of simple and accurate screening procedures to screen parental genotypes and breeding population for various abiotic stresses is the major bottleneck in the development of stress tolerant cool season pulse crops. Germplasm for resistance to various abiotic stresses are not widely available to breeders. Recent studies from overseas suggest that wild species of cool season pulses posses desired traits for a number of abiotic stresses. Future effort is required to identify desirable genes from this germplasm for transfer to adapted cultivars by conventional and/or biotechnological approaches to develop abiotic stress resistant cultivars.

REFERENCE

Siddique, K.H.M., Loss, S.P., Regan, K.L. and Jettner, R.L. (1999). Adaptation and seed yield of cool season grain legumes in Mediterranean environments of south-western Australia. Australian Journal of Agricultural Research, 50: 375 – 387.