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Water Use Efficiency in Common Beans Under Cool Temperatures

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Abstract: ***The common bean (Phaseolus vulgaris L.) a warm season legume, is considered the most important food legume for humans globally because it provides 30% of the protein and calories of diets in many countries. However, drought is considered a major issue affecting the world's production of P. vulgaris. Therefore, there has been a growing demand recently for improving common beans so that they become more tolerant to drought stress. Drought-adaptation mechanisms in common beans include deep root systems, increased water use efficiency (WUE), ratio between photosynthesis and transpiration, and transfer of photosynthate to seed via efficient mobilisation. WUE contributes to increasing yield under drought, and is associated with physiological processes of the plant such as leaf gas exchange, stomatal conductance, osmotic adjustment and root characteristics. Recently, breeding crops to make more efficient use of water is one of the most important strategies that has become an urgent necessity. Phaseolus beans are being proposed as a potential alternative legume crop for mild winter, rain-fed cropping seasons and the current research aims to assess their water use efficiency and drought tolerance under cool temperatures in comparison to already adapted cool-seasons legumes such as lupin.***

Keywords: Common bean, water use efficiency, cool temperature, drought stress, drought tolerance, tolerance

1. Introduction

The common bean (*Phaseolus vulgaris* L.) ($2n = 2x = 22$) is considered the most important food legume for humans globally (Guzmán-Maldonado *et al.* 2000, Schwartz and Corrales 1989, van Schoonhaven and Voysest 1991). It provides more than 30% of the protein (García-Hernández *et al.* 2010, Shellie-Dessert and Bliss 1991, Vance *et al.* 2000) and 30% of the daily calories in many countries (McConnell *et al.* 2010), and is a good source of complex carbohydrates (Reyes-Moreno *et al.* 1993). Moreover, it is produced as a major product in world trade and is widely consumed, especially by the poor of Latin America and Africa (Evans 1986, Singh 1999). It was domesticated in central and southern America more than 7,000 years ago (Gepts and Debouck 1991, Kaplan 1965, Kaplan and Kaplan 1988).

Legumes are grown in 12–15% of the world's arable land, and they constitute 27% of the production of the world's staple crops (Graham and Vance 2003). The total production of dry beans in Australia in 2010 was 43,500 tons while global production was 22,923,401 tons. In addition, the total production of green beans in Australia in the same year was 28,000 tons of the global production of 19,834,297 tons (FAOSTAT 2010). Grain legume crops in Western and Eastern Australia have been adopted as an important component of field crop rations in Australia (Brinsmead *et al.* 1991, Delane *et al.* 1989, Hamblin 1987, Marsh *et al.* 2000).

Further, legume break crops play an active role in achieving many positive aspects such as minimising the appearance of weeds, insects and diseases (Bezdicek and Granatstein 1989, Delaneet *et al.* 1989, Nemecek *et al.* 2008, Stevenson and van Kessel 1996, Unkovich *et al.* 1997). In Western Australia, some concerted efforts have been made to increase the number of crops that can be used in rotation with cereals according to the type of soil and climate in the Western Australia Wheatbelt (Robertson *et al.* 2010).

Beans are grown in many different environments (Laing *et al.* 1984; Schwartz and Corrales 1989) although they are best adapted to tropical and subtropical climates, or growing in the warm seasons in temperate regions. Moreover, beans have slow germination and therefore growth will be slow (Kooistra, 1971). Consequently, low temperatures can affect the genotypes. The minimum during germination temperature for the common bean is 12 °C, but there are some varieties that can germinate at less than 8 °C (Nleya *et al.* 2005). Otherwise, Kotowski (1926) has stated that bean seed germination under 15 °C is poor.

Drought is one of the greatest issues affecting the world's production of grain crops, especially on *P. vulgaris* (Lizana *et al.* 2006, Singh and Terán 2002) because the bean is particularly sensitive to climate changes (Konsens *et al.* 1991, Piha and Munns 1987). It is also because about 60% of bean production is in regions that are suffering from water shortage (CIAT 1980, Grajales *et al.* 2008, Lizana *et al.* 2006). Significantly, the common bean has a low tolerance to drought (Souza 2003). Therefore, brief periods of water deficiency have negative effects on both the quality and yield of common beans (Haterlein 1983, Konsens *et al.* 1991, Laing *et al.* 1984, Wallace 1980). Drought also causes a reduced amount of production. For example, Africa loses about 300,000 tones of beans annually because of drought (Wortmann *et al.* 1988).

The development of common bean cultivars that are tolerant to drought is a practical and economical approach to reducing the negative effects of drought on crop production (Ramirez-Vallejo and Kelly 1998, Xiong *et al.* 2006). Many studies have reported that drought tolerance in crops is a complex physiological process (Araus *et al.* 2002, Bohnert *et al.* 1995, Bruce *et al.* 2002, Ludlow and Muchow 1990). Finally, beans have been proposed as an alternative crop for mild winter growing seasons in Western Australia and potentially for other regions to increase food security (Jacobsen *et al.* 2012; Kharkwal and Shu 2009; van Schoonhaven and Voysest 1991). Water use efficiency and drought tolerance of beans and winter-adapted crops has not been compared before.

2. Common bean

Common bean (*Phaseolus vulgaris* L.) (2n= 2x= 22) is considered one of the most important food grains because its high protein (18 to 32%) and high levels of minerals, such as potassium, calcium and phosphorus (Ariza-Nieto *et al.* 2007; Papa *et al.* 2006; Tajini *et al.* 2012). It is also an important source of calories (Ariza-Nieto *et al.* 2007, Paredes- Lopez *et al.* 1989, Singh and Singh 1992). It represents 50% of the grain legumes consumed worldwide and is the most important food legume (McClean *et al.* 2004, Ramirez-Vallejo and Kelly 1998, Yan *et al.* 2004). In addition, it has an ability to fix atmospheric nitrogen, which is important in many cropping systems (van Schoonhoven and Voysest 1991, Wakrim *et al.* 2005).

Moreover, common beans are an inexpensive display of macronutrients and micronutrients for low-income earners (Broughton *et al.* 2003, Doria *et al.* 2012). Malnutrition in several poor countries is a serious health issue that consider as an important factor for diseases such as HIV-AIDS and tuberculosis. Common bean contains high level of zinc and iron, which are minimizing individuals with AIDS (McClean *et al.* 2012). Moreover, Common bean is a low fat and it is a good source of the important vitamins and "minerals soluble-iber starch, phytochemicals" (Meiners *et al.* 1976, Messina 1999, Reyes-Moreno *et al.* 1993).

P. vulgaris has an active role in cropping system because it is normally self-fertilized (Graham and Vance 2003). Furthermore, there is high ability to hybridized many of Phaseolus to common beans (Smartt 1976), although the hybrid seeds have an ability to survive when "embryo-cultured on synthetic media" (Graham and Vance 2003). However, common bean is widespread in developing countries, and 60% of its production occurs under drought stress conditions (Graham and Ranalli 1997, Martinez *et al.* 2007, Munoz-Perea *et al.* 2006).

3. Drought tolerance of common bean under Cool Conditions

Drought is a major constraint to *P. vulgaris* production in the world (Singh and Terán 2002), because the bean is particularly sensitive to climate changes (Konsens *et al.* 1991, Piha and Munns 1987). Therefore, brief periods of water deficiency have negative effects on both the quality and yield of common beans (Halterlein 1983, Konsens *et al.* 1991, Laing *et al.* 1984, Wallace 1980). However, the development of common bean cultivars that are more tolerant to drought is a practical and economical approach to reduce the negative effects of drought on crop production (Ramirez-Vallejo and Kelly 1998, Xiong *et al.* 2006).

Many studies reported that drought tolerance in crops is a complex physiological process involving (Araus *et al.* 2002, Bohnert *et al.* 1995, Bruce *et al.* 2002, Ludlow and Muchow 1990). However, differences have been reported in water-use efficiency among common bean cultivars (Comstock and Ehleringer 1993, Ehleringer 1990, Ehleringer *et a1.* 1991). Water use efficiency under cool temperatures has not been studied. There is scope to introduce beans to mild winter growing seasons. The current project aims to determine the water use efficiency of bean genotypes under cool temperatures relative to the cool season legume, *Lupinus angustifolius*.

Adaptation to drought

Drought tolerance in plant aims to promote and sustain the production under water-limited rain-fed conditions (Ashraf and Harris 2005). Watts *et al.* (1984) explained that some genotypes reduce 14–26% of the canopy photosynthesis when exposed to drought stress in order to retain water by reducing leaf area rather than on the response of stomata. In addition, roots may increase water absorption by adjusting the pattern of allocation (Chaves *et al.* 2003).

Drought-adaptation mechanisms in common beans include, as a minimum, (1) a deep root system with a suitable architecture that increases soil moisture and has a greater ability to extract water from the depths of the soil; (2) increased WUE in the plant for photosynthesis, development and growth; and (3) increased transfer of photosynthate to seed via efficient mobilisation (Grajales *et al.* 2008, Rao 2001, Sponchiado *et al.* 1989, White *et al.* 1994). According to Acosta-Diaz *et al.* (2009), loss of leaf area can be a result of reducing the size of younger leaves and inhibition of the expansion of the old leaves, which is considered from the mechanisms that can be adapted to drought.

Many physiological and biochemical responses such as ‘tissue water retention, osmotic adjustment and integrity of membranes can be associated with the variation in seed yield of common beans (Costa Franca *et al.* 2000, Hieng *et al.* 2004, Lizana *et al.* 2006). Biochemical mechanisms occasionally have adverse effects under different stresses. Therefore, tolerance to a specific stress may contribute to sensitivity to other stresses (Fleury *et al.* 2010). For example, some plants use evaporative cooling through ‘stomatal conductance’ to avoid heat stress. Consequently, the closing of stomata increases the ability of plants to retain water in drought conditions.

Demand has been growing recently for improvements to common beans so that they become more tolerant to drought stress (Lizana *et al.* 2006); adaptive mechanisms include modifications to growth habit, early flowering, root architecture and shoot biomass accumulation (Rosales-Serna *et al.* 2004, Terán and Singh 2002). According to Terán and Singh (2002), seed production is main factor used to a screen genotypes drought tolerance. Pimentel *et al.* (1999) have stated that there are two main mechanisms for drought tolerance in *Phaseolus vulgaris*: stomatal control (Laffray and Louguet 1990) and root development (Kuruvadi and Aguilera 1990). Generally, the progress in breeding to adapt crop varieties to drought stress has been successful

(Acevedo and Ceccarelli 1989, Blum 1996, Condon *et al.* 2002).

Pareek *et al.* (2009) have agreed with many studies that explain the methods that could improve plants' resistance to drought. They stated that there are four approaches to improving plants for drought tolerance: high root mass, smaller leaf area, osmotic adjustment (OA) and early-maturing short-duration varieties of plants. In summary‹ drought tolerance contributes to continue crop to produce under water deficiency conditions through specific mechanisms have a correlation with roots and photosynthesis. Beans respond to drought stress by leaf weak, stomatal closure, and shedding of leaves, flowers and young pods (Adams *et al.* 1985).

Tolerance mechanisms and selection criteria

According to van Schoonhaven and Voysest (1991), studies of mechanisms of drought tolerance have suggested a wide range of selection criteria, but not one of these has proved to be practical for beans. They also stated that there are many problems facing the studies of mechanisms. For example, drought causes the accumulation of the amino acid proline in plant tissue, so the tolerance can be examined by measuring proline levels (Singh 1972, Stewart 1972). However, one study showed that, despite the accumulation of amino acids caused by drought, there is no correlation with tolerance (Stewart and Hanson 1980).

Otherwise, there are some strategies, such as drought escape, that could lead plants to be more resistant to drought. 'Classically, plant resistance to drought has been divided into escape, avoidance and tolerance strategies' (Turner 1986). Fukai and Cooper (1995) added a fourth division of plant resistance to drought, which is drought recovery. This is an important mechanism when drought occurs early in crop development.

Escaping drought is very important, especially in arid areas, because plants that escape drought show a high degree of developmental plasticity and are able to complete their life cycle before physiological water deficits occur (Chaves *et al.* 2003, Martinez *et al.* 2007, Turner 1986). Moreover, these are important features that can reduce the negative effect of drought on crop production in the Mediterranean area, which has short growing seasons and high drought stress (Rajaram *et al.* 1996). Ashraf and Harris (2005) have stated that drought escape could reduce the risk of crop failure and increase yields by manipulating sowing dates and reducing the period of maturity according to the amount of rainfall in the region.

According to Chaves *et al.* (2003), breeders should examine plant phenology, because plants can avoid drought stress by completing their life cycles before they are affected by water shortage situations. A short life cycle is better than a long life cycle because plants can avert physical and chemical barriers that can inhibit the growth of roots (Fleury *et al.* 2010). The short life cycle strategy has been extremely successful in Mediterranean conditions (Araus *et al.* 2002). In addition, data indicates that reduced water potential can be avoided through minimising the turgor-loss volume of plants by shrinkage associated with adjustment of the cell walls (Fan *et al.* 1994, Marshall *et al.* 1999, Tyree and Jarvis 1982).

Ashraf and Harris (2005) cited that drought avoidance occurs by maximising the use of water when there is soil moisture by incorporating traits such as 'fast growth and well-developed root systems, rapid leaf-area expansion, and physiological efficiency'. In addition, plants can tolerate drought by avoiding dry tissue by maintaining tissue water or carrying low tissue water. In common beans, drought avoidance mechanisms principally include the development of an extensive root system, an efficient stomatal closure and increase of the tricoma density, leaf movements and leaf chlorophyllic pigmentation (Barradas *et al.* 1994, Trejo and Davis 1991). Further, drought avoidance and drought tolerance are the main ingredients for drought resistance in the common bean (Levitt 1980, Turner 1991).

4. Water use efficiency in common bean

Water use efficiency (WUE) is defined as the ratio between photosynthesis and transpiration (Caldwell *et al.* 1983; Jones 2004; Ramirez *et al.* 2011; Wright 1993). WUE is also referred to as evapotranspiration (ET) efficiency (Tanner and Sinclair 1983), which includes water loss by soil evaporation (E) (Wright 1993), while De Costa and Ariyawansha (1996) have defined WUE as the biomass increase per unit of water transpired. Figure (1) shows WUE in some cowpea cultivars under well-watered and water-stressed conditions.

According to Sun *et al.* (2006), WUE can be increased either by the transpiration being less than photosynthesis or it being greater in the intrinsic photosynthetic capacity. WUE depends on the water used for the production of biomass and growth (Liu and Stutzel 2004, Wu *et al.* 2008). WUE is considered a good trait that contributes to increasing yield under drought (Prasad *et al.* 2008). Moreover, it may be higher during drought periods (De Costa and Ariyawansha 1996). In addition, WUE in the common bean has a strong association with specific plant characteristics and soil type, which is explained in the following section.

Leaf area

Leaf area (LA) is an important part of plant that affects light interception, gas exchange, evaporation, and the growth rate (Ramirez-Builes *et al.* 2008, Boote *et al.* 1988). There is a strong relationship between WUE and leaf area. A reduced leaf area leads to reducing the rate of transpiration and water loss. Therefore, decreased leaf area is one of the most important mechanisms to moderate water loss from the canopy and minimise plant exposure to drought (Prasad *et al.* 2008). However, the minimisation of drought effect by reducing leaf area cannot sustain greater yields (Blum 2005). Leaf temperature is an important element in the rate of transpiration, so WUE can be affected by lower leaf temperature (Prasad *et al.* 2008, Tambussi *et al.* 2007). In fact, there are many morphological traits associated with lower leaf temperature, such as 'epicuticular wax, chlorophyll content, and leaf position (erect leaves)' (Prasad *et al.* 2008).

Moreover, several morphological traits in common beans were negatively affected by moisture stress these include leaf area loss which lead to declined the number of leaves, size of younger leaves and inhibition of the developing foliage expansion (Acosta-Gallegos 1988). Husain *et al.* (1990) have found that crop responds to drought stress through reducing leaf area expansion rate slightly and producing smaller leaves. Singer *et al.* (1996) have exposed common bean to drought stress by 50% of field capacity. The results were reduction of leaf area, which supports many previous studies such as Soja and Soja (1989); Husain *et al.* (1990) and Nunez-Barrios (1991). Leaf area of common bean tends to be low under rainfed conditions, and hence the levels of photosynthetic rates in a single leaf area are more important than determine of production rates (White *et al.* 1990).

WUE can be increased by a higher specific leaf weight (SLW) (the ratio of leaf weight to area) (Boote *et al.* 1996, Peng *et al.* 1993, Poorter 1990), because the increased SLW leads to increased photosynthesis in the leaf area (Tambussi *et al.* 2007). Correlation between WUE and SLW is present but it seemed to be low (Morgan and LeCain 1991). Moreover, there are several traits that may increase WUE in the common bean such as early vigour, osmoregulation and smaller photosynthetic surfaces when exposed to drought stress (Araus *et al.* 2002). In addition, Liang *et al.* (2002) demonstrated that transpiration can be reduced and WUE increased significantly via alternate drying and rewatering under drought conditions.

Further, specific leaf area (SLA), or leaf area per unit leaf dry mass (Evans and Poorter 2001), has a strong relationship with WUE (Nautiyal *et al.* 2002). It was suggested that SLA be used as an economical alternative tool to select WUE (Wright *et al.* 1994, 1996). Wu *et al.* (2008) have found in their experiment that reducing the number and leaf area with SLA and leaf area ratio (LAR) was a dehydration avoidance strategy for seedlings by reducing transpiration.

Leaf gas exchange

The measurement of leaf gas exchange (A/T) is very important because it provides a great deal of information about the activity of photosynthesis and the determination of related parameters, for example, stomatal conductance (Guidi *et al.* 1997). Therefore, the measurement of A/T can detect many processes that occur during photosynthesis, which may contribute to improving plants. In addition, it has been found that there is a high correlation between greater biomass production and higher A/T (Nautiyal *et al.* 2002, Wright *et al.* 1993). Consequently, many scientists have found that rising CO_2 contributes to rising biomass production in water-stressed plants (Centritto *et al.* 1999, Gifford 1979, Morison and Gifford 1984), which leads to increased WUE (Centritto *et al.* 1999, Eamus 1991).

Further, several studies have shown that the CO2 concentration in plants and ecosystems is very important and leads to higher crop yields (Curtis and Wang 1998, Drake *et al.* 1997, Norby *et al.* 1999). Therefore, elevated CO2 leads to reducing the negative effect of drought stress on plants by 31% (Centritto *et al.* 2002). However, Davies *et al.* (2002) mentioned that WUE could be improved by minimising gas exchange during the period of regulated deficit irrigation (RDI).

Stomatal conductance

Stomatal conductance defined as a function of both guard cell turgor pressure and its epidermis (Raschke *et al.* 1972, Franks and Farquhar 2002). Stomatal conductance controls both the rates of transpiration and CO_2 entry into the cell. There is some evidence to show that the initial reduction in stomatal conductance is higher than the reduction in carbon assimilation (Webber *et al.* 2006), resulting in an increase in the values of WUE (Chaves and Oliveira 2004). WUE is sensitive to many environmental and plant factors, which can affect stomatal conductance (De Costa and Ariyawansha 1996).

According to Tambussi *et al.* (2007), higher mesophyll conductance is associated with an increase in the rates of photosynthesis, without increasing stomatal conductance. Thus, WUE will be increased. Stomatal conductance can conserve growth and yield through control in a photosynthetically which decrease in leaf transpiration (Ehleringer 1990). In general, the characteristics of a plant’s hydraulic architecture can determine the flux of transpiration through a plant. Therefore, any change in these characteristics will lead to a change in response of stomatal transpiration rate and WUE (Bacon 2004). Figure (2) shows that the responses of stomatal conductance to increase vapour pressure deficit.

The method is thought to work via a reduction in stomatal conductance in that there are chemical signals synthesised from the root when exposed to drought (Webber *et al.* 2006), which are transferred to the transpiration stream in leaves, leading to the reduction in stomatal conductance and increased WUE (Davies and Zhang 1991, Davies *et al.* 2000, de Souza *et al.* 2003, Düring *et al.* 1996, Liu *et al.* 2001, Martinez *et al.* 2003). Moreover, it is known that mild water deficit leads to partially closing the stomata, thus improving WUE (Ashraf and Bashir 2003, Chaves 1991, Davies *et al.* 2002, Flexas *et al.* 2004, Boogaard *et al.* 1997).

The partial closure of stomata during mild drought stress leads to an increase in the concentration gradient of CO2 from the air to the leaf more than it increases concentration gradient of water vapour from the leaf to the air, resulting decrease WUE (Grimmer *et al.* 2012). Studies showed that when beans are exposed to drought there are increases the resistance of stomata and respiratory rate, and reduction in the rate of photosynthesis, plant height and leaf area (Costa *et al.* 1991). Mencuccini *et al.* (2001) found that small changes in leaf water are caused by pressurization affect stomatal aperture even when exposed to adequate water and ‘relatively mild leaf-to air vapour pressure gradients’. They also found that, during constant environmental conditions, there are diurnal changes in stomatal opening and assimilation rate of *Phaseolus vulgaris L.*

Osmotic adjustment

OA includes the solutes accumulation within a cell in response to a decline in water potential of the cell’s environment, resulting reduces the osmotic potential of the cell, which attracts water into the cell and conserves turgor pressure (Lidon and Cebola 2012). OA is an adaptive process that contributes to reducing the negative effects of water deficits (Lilley *et al.* 1996) and supports yield under drought stress (Blum 2005). OA is the most important component of drought resistance (Ludlow and Muchow 1990, Zhang *et al.* 1999). According to Zhang *et al.* (1999), OA is a key mechanism for improving WUE and yield of grain that is exposed to drought stress. In addition, OA provides two of the main tasks in the production of the plant under drought stress: (a) it leads leaf turgor maintenance for the same leaf water potential (LWP), which encourages stomatal conductance under lower leaf water status (Ali *et al.* 1999, Sellin 2001); and (b) it improves the ability of the roots for water uptake (Chimenti *et al.* 2006, Jones and Sutherland 1991, Tangpremsri *et al.* 1991).

Recently, OA has drawn much attention because its importance as physiological adaptation character that is associated with drought tolerance. Moreover, it includes the net accumulation of solutes in the cell in response to falls in water potential of the cell environment (Hessini *et al.* 2009). As a result, there is a diminished likelihood of an osmotic cell, which in turn attracts water into the cell by tending to keep the swelling pressure (Blum *et al.* 1996). Martínez *et al.* (2004, 2007) stated that these contents benefit stressed cells in two ways: (1) they work as cytoplasmic osmolytes, which facilitates the absorption and water conservation, and (2) they protect the stability of the molecules and structure from damage that is caused by stress conditions. However, OA has an energy cost that may affect plant production and WUE (Turner and Jones 1980).

The analysis of pressure-volume (PV), in one study which occurred on beans, showed an active OA in the leaves, in response to drought stress imposed slowly, 'at a rate of about 0.15 MPa day^{-1}' (Zlatev 2005). Generally, there is no difference in the effective of OA in crops. Bourgault and Smith (2010) suggested that do not investigate the difference in the OA in crops, because they did not find a difference between common bean and mungbean.

Root characterisation
Root system characterisation is important for exploring the soil and the acquisition of resources, so it is strongly associated with plant adaptation under abiotic conditions such as drought (Ludlow and Muchow 1990, Manschadi *et al.* 2006). In addition, root characteristics include morphology, root system size and root hydraulic conductivity (Sanders and Markhart 1992). The slowly dried root is one of the positive characteristics that is found in *P. vulgaris* (Trejo and Davies 1991).

In addition, roots may increase WUE through water absorption by adjusting the pattern of allocation (Chaves *et al.* 2003). Moreover, WUE has a strong relationship with biomass and root length because water uptake efficiency primarily depends on the quantity and length of fine roots (Wu *et al.* 2008). Root characteristics are the fundamental characteristics of the drought response in the common bean, while shoot characteristics are less important (White and Castillo 1989). According to Manschadi *et al.* (2006), root architectures and vertical distribution appear to be the basic characteristics of water for improved adaptation in such environments.

Root vigour and architecture is a trait that relates to faster root growth, which leads to an increase in root size colonisation in the soil to obtain more water and nutrients (Palta and Watt 2009). This trait has been successful in wheat: roots grew faster by about 40% compared with conventional cultivars (Watt *et al.* 2005). In addition, the extraction of water from the soil through improved root efficiency is one of the most important goals for genetic analysis (Fleury *et al.* 2010). According to Manschadi *et al.* (2006), the analysis of modified roots shows that an increase of 10 mm of water extracted during grain filling increases yields by around 500 kg/ha, which is equivalent to 25% of the increase in Australian wheat yield (2,000 kg/ha).

Several individual qualities in the roots can be contributed into the increase of grain production under the circumstance of water shortages by the pattern of development of water stress in the target production environments (Manschadi *et al.* 2006). For example, in environments in which crops are grown widely, such as in the north-eastern Australian Wheatbelt, water may run out before the completion of grain filling. Consequently, minimising water use during pre-anthesis by reducing the diameter of xylem vessels will lead to greater grain yield due to improved post-anthesis water availability (Passioura 1972).

5. Breeding for high water use efficiency

Improved WUE in irrigated and rain-fed land has become an urgent necessity (Hamdy *et al.* 2003), which requires several strategies (Wang *et al.* 2002). Breeding crops to be more efficient in use of water is one of the most important of these strategies (Condon *et al.* 2004). Breeding for high WUE includes three key processes: (i) transferring more of the water available through the crop rather than it being lost by evaporation or drainage beyond the root zone;, (ii) acquiring more biomass 'in exchange for the water transpired by the crop'; and (iii) dividing more of the biomass that has been achieved into the harvested product (Abberton *et al.* 2008; Condon *et al.* 2004).

Water use efficiency as a breeding target
To achieve specific objectives by breeding, the first step is to identify those objectives well, and then determine inherited traits. WUE as a target in breeding depends on many characteristics such as the size and measurement units of exchange that are being considered (Condon *et al.* 2004). According to Fischer (1981), improving agronomic traits by raising WUE in the leaves is one of the most attractive methods. Bourgault and Smith (2010) have been recommending several traits that could be used as a breeding target to improve WUE, for example, low leaf area at flower initiation, SLW when it is related to higher transpiration efficiency (TE) and using other breeding to achieve higher yields under the condition of water deficiency.

Lowering the gradient in water vapour concentration
Lowering the gradient in water vapour concentration during the crop growth is one of the simplest and the most influential means in crop breeding to improve the TE of

biomass by raising gas exchange (Tanner and Sinclair 1983, Richards *et al.* 2002). Many breeders in the past century relied on the exploitation of genetic variation associated with 'intrinsic earliness, response to photoperiod, and vernalization requirement' to generate a wide variation in crop phenology. Therefore, the higher the level of gas exchange leads to increased crop yields due to phonological variation, which has allowed crops to be grown successfully in areas and times of the year that lower the prevailing evaporative demand (Condon *et al.* 2004).

Improve WUE using biotechnology
Selection traits under drought stress may increase selection efficiency, value adjustment, high heritability and measurements. In addition, it leads to increased 'relative stem and leaf elongation', delayed aging and a reduced 'anthesis silking interval (ASI)' to increase the efficiency of the selection of cereal crops (Bolanos *et al.* 1993). The changes in tissue elasticity under water stress could lead to drought tolerance, as observed in common bean (Zlatev 2005; Martinez *et al.* 2007). Richards *et al.* (2010) summarised the most important traits recommended for improving cereal crops in water deficient conditions. These traits may not all be important in global rain-fed environments, and some may have a greater effect in specific environments. The most important traits are:

Seedling establishment
Mostly dry environments are characterised by short growing seasons, so the effective use of a full growing season is necessary to enhance the yield. This is important for wheat when the establishment is poor if the seeds of 'Green Revolution varieties containing the GA-insensitive dwarfing genes Rht-B1b and Rht-D1b' are deep (Jones *et al.* 1998). These varieties contain short 'coleoptiles', but they will not establish if they are very deep. Otherwise, there are many dwarfing genes that respond to the application of GA and that contain longer coleoptiles. Currently, these genes are not available in contemporary crop varieties (Richards *et al.* 2010).

Shoot vigour
This is a complex trait in which the interest is mainly in specific leaf areas and embryo sizes (Cooper *et al.* 1987). Generally, faster leaf growth above the ground increases plants' biomass in order to reduce the evaporation of moisture from the soil's surface and make the most of available water in the soil for growth and transpiration (Richards *et al.* 2010).

Root vigour and architecture
This relates to faster root growth, which leads to an increase in root size colonisation in the soil to obtain more water and nutrients (Palta and Watt 2009). When wheat was developed using this trait, the roots grew faster by about 40 per cent compared with conventional cultivars (Watt *et al.* 2005).

Transpiration efficiency (TE) (carbon isotope discrimination)
This complex physiological trait integrates photosynthesis into transpiration. It is also negatively associated with the concentration of carbon dioxide between leaf cells, which in turn relates to carbon isotope discrimination in wheat (Farquhar and Richards 1984). Carbon isotope discrimination has many attractive features for breeding. It is a good surrogate for TE in breeding (Richards *et al.* 2010).

Wax (glaucousness)
Glaucousness is a visual trait related to the colour of photosynthetic surfaces, which can be easily identified. Its most important feature is reducing transpiration during the night and day, thereby reducing water loss. In addition, it is important in maintaining the leaf area late into grain filling (Richards *et al.* 2010).

Other yield-enhancing traits for dry environments
Other proposed traits to increase wheat grain yield in drought conditions include (i) reducing xylem vessel diameter, (ii) increasing OA and (iii) reducing grain-filling duration and increasing the rate (Richards *et al.* 2010).

6. Conclusion

In summary, the warm-season legume common bean is the most important food legume, providing many useful features such as proteins. Moreover, it has an important role in cropping systems and break crops. Further, it is very sensitive to climate changes and abiotic conditions such as drought and cold, which may affect crop yields. However, WUE leads to minimising the effect of drought stress on plants. Additionally, beans have been proposed as an alternative crop for mild winter growing seasons in Western Australia and potentially for other regions to increase farm profitability and food security.

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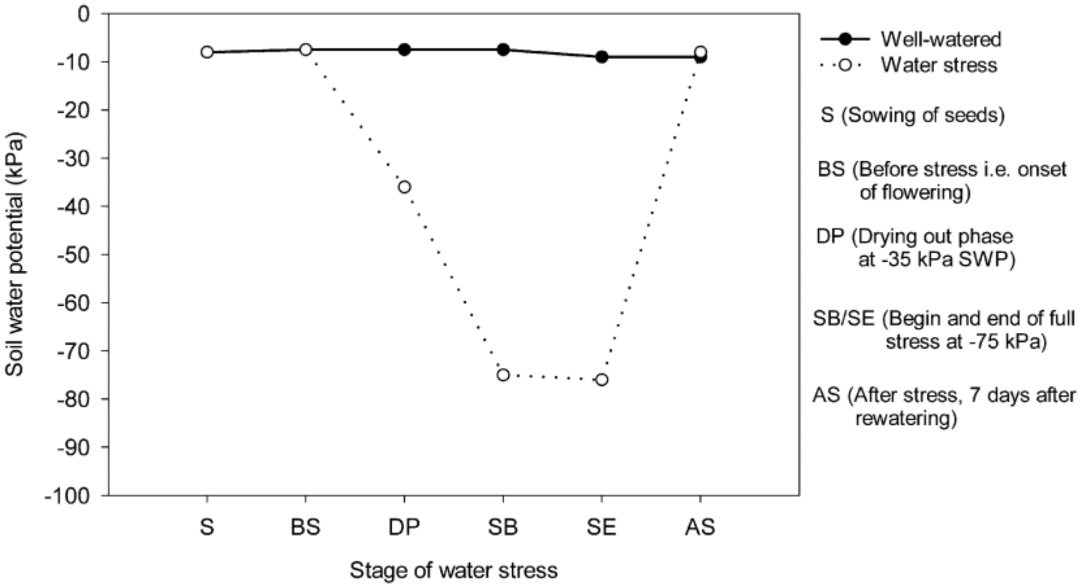

Figure 1: 'A typical soil matrix potential indicating level of water stress in the experimental pots during the course of experiment. Duration of interval S to BS was ≥70 days, BS to SB was ≈7 days while SB to SE was 10 days' (cited in Anyia and Herzog 2004).

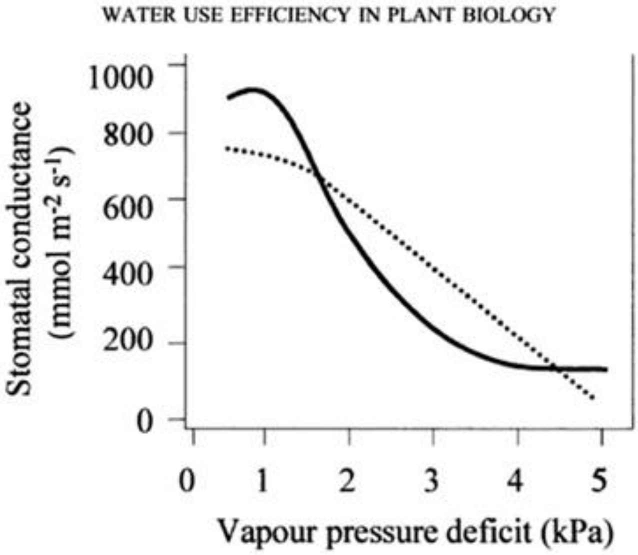

Figure 2: 'Two illustrative responses of stomatal conductance to increase vapour pressure deficit (adapted from a figure in Atwell et al. (1999) which used unpublished data of D. Eamus)' (cited in Bacon 2004).