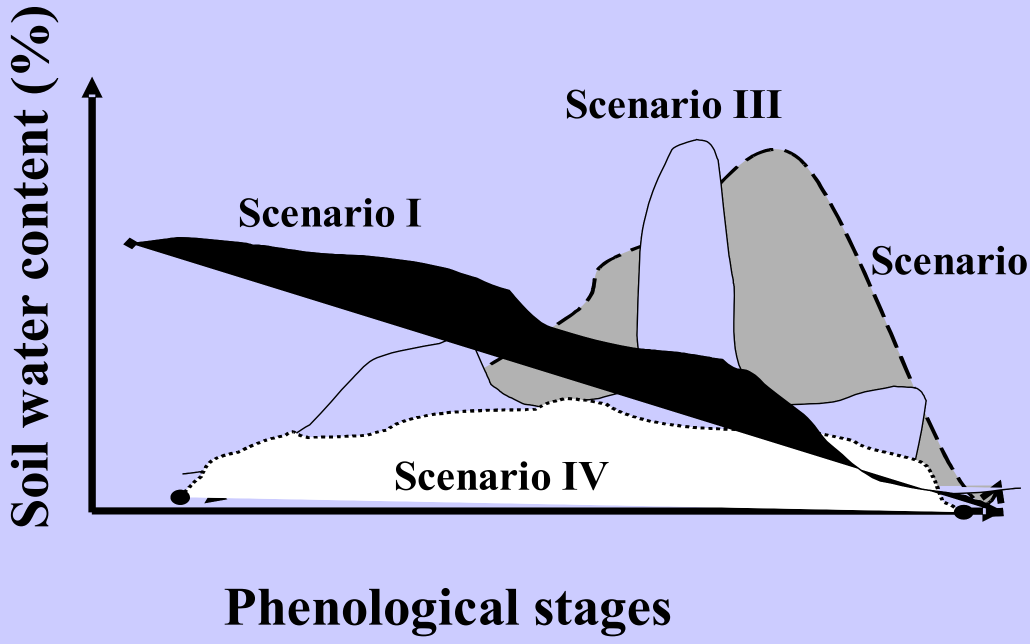
Coping with Drought:

Strategies to Improve Genetic Adaptation of Common bean to Drought-Prone Regions of Africa



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Coping with Drought: Strategies to Improve Genetic Adaptation of Common bean to Drought Prone Regions of Africa

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Table of Contents

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ACRONYMS

BIWADA = Bean Improvement for Water Deficit in Africa

CIAT = International Centre for Tropical Agriculture

RWC = Relative Water Content

DAE = Day after Emergency

DTF = Days to flowering

DTM = Days to Maturity

ECABREN = Eastern and Central Africa Bean Research Network

LWP = Leaf Water Potential

RGR = Relative Growth Rate

SI = Sensitivity Index

PREFACE

Screening bean (*Phaseolus vulgaris*) genotypes for drought resistance dates to 1980s in the regional bean networks from sub-Saharan Africa (SSA). However, no much progress has been made by scientists in identifying drought resistant bean genotypes.

In May 1999, regional scientists from Eastern and Central Africa Bean Research Network (ECABREN) initiated a working group on drought called 'Bean Improvement for Water Deficit in Africa' (BIWADA) which has been operating across bean networks working groups. The BIWADA group had difficulty in starting its activities. During several field visits to some member countries in the region, it was observed that there was lack of standardized protocol for screening bean genotypes to drought resistance. Certain parameters that were used for assessing germplasm to drought resistance had no direct correlation with drought.

This book demonstrates an important tool to develop drought resistant genotypes and covers different aspects including methodologies in breeding for drought resistance, how to develop protocols for drought resistance; indicators of drought resistance; and methodologies for determining indicators of drought resistance. I am convinced that this precious document will be used not only by bean scientists, but also by scientists working on various crops; they could adapt breeding and screening methodologies to their respective crops.

I wish to thank Dr. Tilahun Amede who accepted the responsibility of coordinating the BIWADA meeting, and the African Highlands Initiative for making him available. He also spent his efforts and time to have this document published for use by regional scientists. Let me also thank the network plant physiologists, breeders, and agronomists, for their full commitment to work harmoniously for availing this working paper to scientific community in the African regions.

Mukishi M. Pyndji, Ph.D.
Coordinator, East and Central African Bean Research Network (ECABREN)
March 13, 2003

1. INRODUCTION

Common bean is enjoying resurgence in interest and an enhanced level of consumption as a major source of protein for African households owing to an outrageous increase in price of animal products. It also serves as a break crop in Maize-based and rice-based systems to reduce decline in soil fertility. However, frequent drought and diseases limit productivity of beans in the region. It is partly because bean production in recent years has expanded into semi-arid regions, due to an increase in population pressure. While drought is yet one of the most limiting factors to bean production on a global scale, the situation will expectedly deteriorate in Africa if the current trend of land degradation cannot be reversed. In addition, climatic variability will increase as it has been postulated in a scenario of global warming.

Drought has affected bean production in East, Central and Southern Africa causing losses of more than 395,000 t each year. Drought, which includes moisture and heat stress, acts in conjunction with biotic stresses, especially diseases and pests, and other abiotic stresses. Soil fertility related stresses, the most important being low soil P and N, soil acidity and the associated aluminium and manganese toxicity, are known to aggravate drought effects. These multiple constraints are often acting concurrently with a considerable negative effect on the quantity and quality of crop production. The most efficient approach to reduce the effect of multiple stresses is to introduce resistance genes into beans to enable them withstand the major stress agents. The regional breeding programs in East, Central and Southern Africa have adopted this strategy. The need for multiple stress resistance in bean improvement is particularly relevant in this region because the farmers are resource poor. They can hardly afford expensive inputs. For low-priced crops such as beans, use of such inputs is often uneconomical.

Limited water availability to the bean crop can be caused by physical and climatic factors of the environment, the soil-precipitation relationship, the soil-plant relationship, the atmosphere-plant relationship, excessive demand by the plant, or any combination of these (Nilson and Orcutt, 1996). The major cause of water deficit in bean growing regions of Africa is low precipitation. Despite the alarming demand for drought-resistant cultivars, breeders are slow in achieving this goal due to the difficulty in identifying traits that reflect true drought resistance. There is, therefore, much interest in trying to improve bean yields under soil water deficit conditions. Although screening for potential drought resistant materials has been carried out in many national programmes and even at the regional level (for example the African

Drought Nurseries of ECABREN), these materials were often not meeting the preferences of the farmers and consumers. The methodology for screening was based only on yield and early maturity.

Drought resistance is polygenic and is commonly accompanied by negative impacts on grain yield (Amede, 1998). Grain yield formation in beans is a more intricate process than in cereals in that the development of generative organs in beans is relatively gradual and could be prolonged if the external conditions, like water and nutrients, are readily available. Therefore, selection for drought resistance based on yield alone may not bring about the required genetic shift in specific physiological attributes, as the component of genetic variance is low when compared to environmental or genetic-environment-interaction variance under stress environments (Rosielle & Hamblin, 1981).

The BIWADA team, recognising the importance of drought and its anomaly, decided to hold a meeting to discuss issues that may lead to rapid advance in achieving high-yielding varieties with stabilised yields in soil water deficit environments.

2. OBJECTIVES

The objectives of the BIWADA meeting were to:

- Characterise the incidence of drought in various bean-growing environments of East, Central and Southern Africa.
- Identify plant traits associated or correlated with drought resistance in beans
- Review and identify potential indicators of drought resistance to be used in developing drought resistant varieties.
- Develop protocols for drought resistance screening
- Review strategies for breeding for drought resistance in beans

3. BACK GROUND

3.1. Definition of Drought in Regional Context

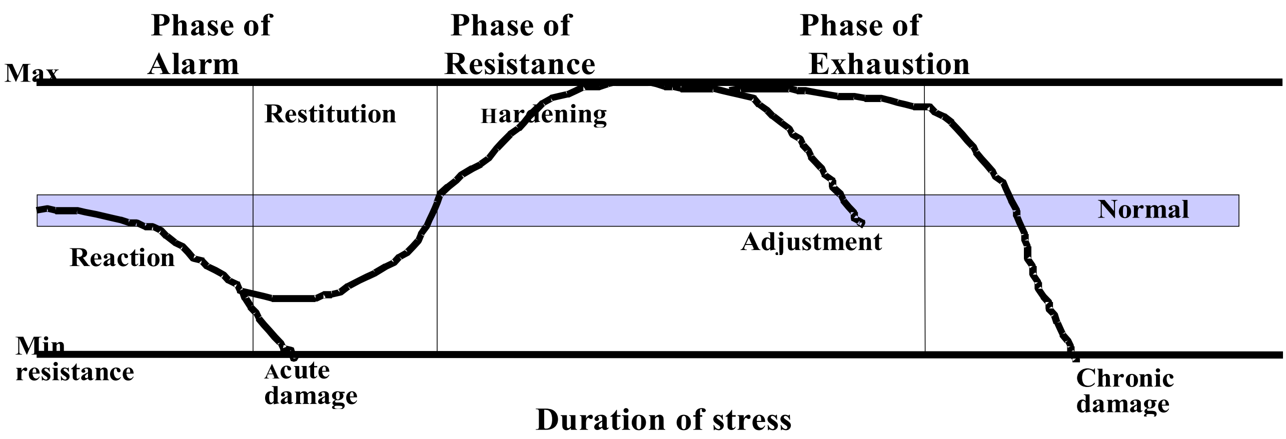
Drought denotes a prolonged period without considerable precipitation that may result in reduction in soil water content and, thus, cause plant water deficit. It can be defined in terms of either the external water status at the boundaries of the plant (soil, air) or the internal plant water status within the tissue (Tardieu, 1996). The first approach defines water stress as an imbalance between supply and demand, linked to the atmospheric saturation deficit following the water potential gradient and leaf area. The second definition associates water stress with the control mechanisms of the plant, where plant water status is regulated within the plant accompanied by changes in water flux with or without change in plant water potential under low soil water potential conditions (Amede, 1998). However, a decrease in leaf water potential or turgor of a plant *per se* may not truly indicate absolute water stress, as some plants with closed stomata and/or inhibited growth could remain without altered plant water status (Turner, 1986; Tardieu, 1996).

3.2 Response of Beans to Drought

Grain yield in beans is the product of number of plants (or fruitful axes) per unit area, number of pods per plant, number of seeds per pod and thousand seed weight. These yield factors are crucial for producing economic yield, and vary in time scale. The number of plants per unit area depends on the number of plants that emerge and/or survive till maturity. For this yield factor, drought at the beginning of the growing season is very detrimental. Number of pods per plant or seeds per pod depends on the number of branches produced and the number of well-developed pods/seeds. In this case, intermittent and terminal drought could dictate pod formation, seed setting and seed filling by altering the source-sink relationship by way of affecting assimilate production, translocation and partitioning. Number of pods per plant is the most variable trait to affect grain yield in beans, and is responsible for the significant reduction of yield during drought at or after flowering. Drought at flowering is known to cause abortion of flowers/pods, through assimilate shortage resulting in yield reduction.

Whenever bean plants experience a rapid water deficit, bean leaves are known to orient themselves parallel to the incident light, and also alarm the biochemical systems. If the time of stress is extended to hours or days, physiological activities would divert from functions of cell expansion and growth to mechanism of restitution of the physiological integrity (Fig 1). Bean plants may react to the stress through short-term strategies, like changes in hydraulic signals or stomatal adjustment. At this stage photosynthetic rate could be comparable to that in non-stressed plants but assimilation could be favoured to develop long-term stress tolerance mechanisms at the expense of growth (Amede, 1998). Bean plants exposed to water stress for days to weeks may develop long term physiological strategies such as altering the leaf area, modifying root to shoot ratio and the like. When available soil water is reduced, plants usually undergo three progressive stages of dehydration (Sinclair and Ludlow, 1986).

Figure 1. A Phase model of stress events and responses (After Larcher, 1987)



At the initial stage of mild drought, assimilation and transpiration are comparable to those of well-watered plants as long as soil water uptake meets evapo-transpirational requirements. In the second stress period, the photosynthetic capacity of the plant is reduced below the maximum potential level. This is considered to be the most dynamic stage to develop adjustment mechanisms and to regulate processes for the maintenance of metabolic activities (Amede, 1998). In the third phase, plants merely survive and delay death. Recovery after rain or irrigation depends on the duration of stress and type of species. For instance, Tepary bean (*Phaseolus acutifolius*) was more drought-tolerant than common bean (*Phaseolus vulgaris*) when grown under stress conditions (Parsons & Howe, 1984).

When crop plants are exposed to drought, they may alter cell solute concentration by re-allocating resources so that the osmotic potential of the cell is reduced, and turgor is maintained (osmotic adjustment). It allows turgor-driven physiological processes, such as stomatal movement and cell growth, to continue despite low plant water potential. It could also increase grain yield under stress conditions through modifying the soil-plant water gradient thereby increasing the amount of water transpired. Osmotic adjustment, through accumulation of effective osmotica is thus an important mechanism of drought resistance in legumes (Amede, 1998). However, accumulation of solutes in the plant cell *per se* does not guarantee osmotic adjustment. In addition to osmotic adjustment, solute deposition in plant cells under drought stress could have four principal causes (Amede, 1998). Firstly, plants may lose substantial amount of water that may lead to a reduction in the expansion rate of the tissue (reduced cell volume), and thereby to an accumulation of solutes in the cell. Secondly, some primary metabolites (proteins, carbohydrates or lipids) may be degraded at higher stress intensities, and the by-products could accumulate as secondary metabolites in the cell. Thirdly, decrease in cell elongation (growth) may cause slowing down of assimilation biosynthesis but effective import of assimilates to the sink cells could be high enough to increase the concentration of solutes and ultimately cause a reduction in the osmotic potential of the cell (Kramer and Boyer, 1995). Fourthly, under moderate levels of stress, roots may still actively absorb inorganic ions (potassium, calcium, sodium, magnesium, chloride, and others) from the soil. Nutrients may not be utilised by the plant owing to drought-induced growth inhibition but instead, translocated ions may accumulate in the cell and induce substantial reduction in osmotic potential (Munns, 1988). Therefore, distinguishing between solute accumulation due to a concentration effect and true osmotica is a prerequisite before using solute accumulation as synonym to osmotic adjustment (Amede and Schubert, 1997).

Parsons and Howe (1984) compared common bean (*Phaseolus vulgaris*) with Tepary bean (*Phaseolus acutifolius*) for their water relations, and concluded that Tepary beans were more drought tolerant than common beans due to the higher osmotic adjustment potential they possessed. They, thus, suggested a transfer of osmotic gene from tepary beans to common beans to improve drought resistance.

Mild drought favours root growth at the expense of shoot growth to enable roots to extend to the unexplored deeper part of the soil for available water. Adequate root density throughout the soil profile may increase the diffusion area, thereby improving water availability and uptake. Maintenance of water status under water limitation can be partially attributed to rooting depth and root length density (Turner, 1986; Subbaro *et al*., 1995). Thus, root depth could be considered as an alternative trait to screen drought resistant lines. Sponchado et al., (1989) compared two drought-tolerant bean genotypes (BAT 85 and BAT 477) with two drought-sensitive genotypes (BAT 1224 and A70) under drought-stress conditions at CIAT-Palmira to identify physiological differences of drought resistance. Their results showed differences in drought resistance among genotypes were associated with rooting depth, but not with root length density, as roots of drought tolerant genotypes reached a depth of 1.3 m, while roots of drought sensitive ones reached a depth of only 0.8 m. Plants often maintain higher root length density than is required by the surface area of the shoot, mainly to minimize effects of other stress factors such as pests, and nutrient deficiency (Passioura, 1983).

Water loss at the plant level largely depends not only on the size of the transpiring areas (mainly leaves) but also number and size of the stomata, and the conductivity of the cuticle. In crops, about 90% of total water loss is associated with stomatal transpiration (Monneveux and Belhassen, 1996) followed by water loss through the cuticle. The hydraulic conductivity of the cuticle depends upon thickness and the presence or absence, and the nature of cuticular wax embedded in or deposited on it. Plant transpiration loss could also be modified by the presence or absence of leaf traits such as leaf rolling ability, the colour of the transpirative organ or leaf reflectance. Moreover, early seedling establishment, early vigor, rapid canopy development in order to minimize evaporation, as well as leaf area maintenance have been suggested as potential drought resistance mechanisms of grain legumes (Subbaro *et al.*, 1995).

An experiment conducted to evaluate the effect of drought on stomatal closure in beans and chick peas showed that in beans $C0_2$-fixation decreased by about 75% after 3 days of mild stress, while in chick peas C02-fixation was not affected by drought except for 25% reduction on the sixth day of stress (Amede, 1998). In other studies, O'Toole et al. (1977) showed that photosynthesis and transpiration rates in common bean were near zero at plant water potentials of -0.9 to 1.0 MPa, showing that stomatal closure is one of the first steps of defence against drought in beans since it is a more rapid and flexible process than other mechanisms like root growth or reduction in leaf area. Thus, it could be considered as an effective survival strategy for intermittent stress (Scenario III, Fig. 1) but not important for terminal stress (Scenario I) since production of economic yield is the major goal at this stage of growth.

4. DEVELOPING DROUGHT PROTOCOLS

4.1 Characterization of Drought-prone environments in the East and Central Africa

Bean growing regions of Africa receive different amount and distribution of rainfall (Wortman et al, 1998) and hence the region experiences different drought scenarios. The BIWADA group identified four different drought scenarios (Fig. 2).

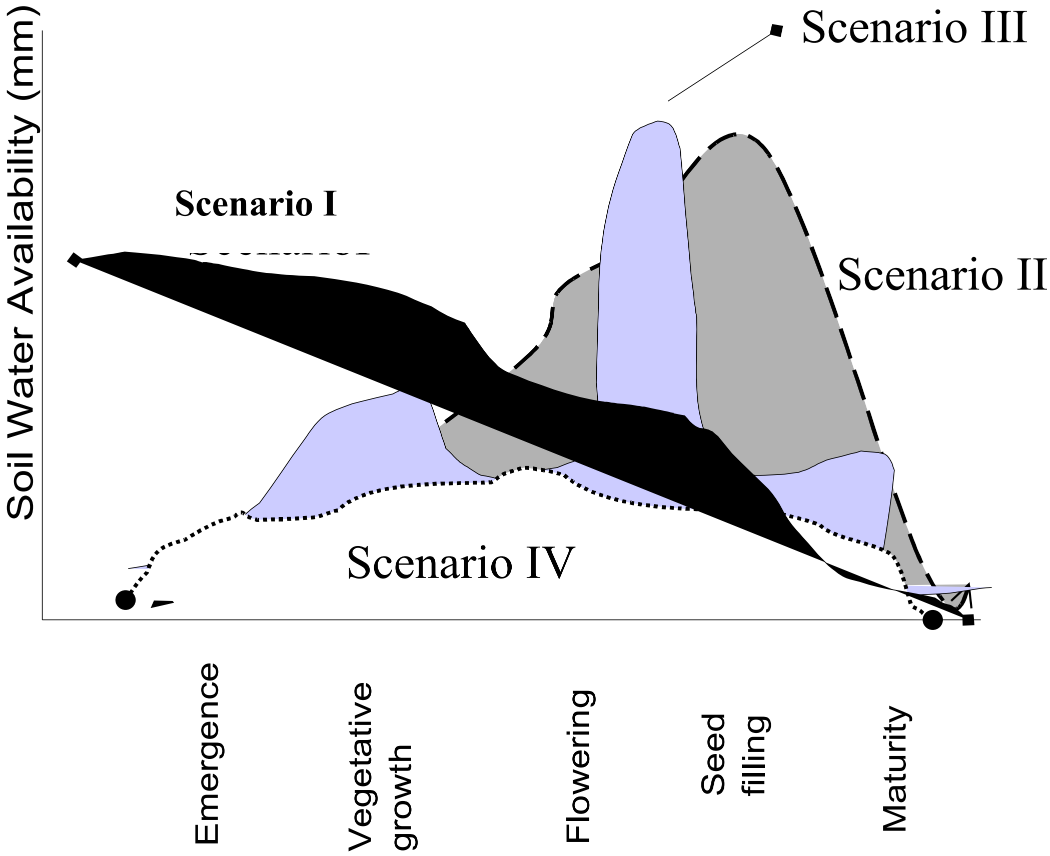
a) Scenario I represents terminal drought. In this case there could be enough water for early establishment and growth, but later phenological stages are exposed to soil water deficit. This is typically the case in relay cropped beans of the Rift Valley and in rice based systems of Africa (e.g. Madagascar). In practices of relay planting beans in the Maize field or in systems where beans should follow rice, bean crop is commonly exposed to terminal drought. It is also a common phenomenon, in regions that fully depend on irrigation to produce the major cash and food crops, to grow beans on the residual moisture. Hence beans are exposed to terminal drought starting from early pod filling stages. Sudan and Egypt could be typical examples of this scenario.

b) Scenario II represents intermittent drought: This is typical of regions with relatively good rainfall amount but poor distribution during the growing period (Fig 2). There could be enough water for the crop throughout the life cycle except for some short dry spells that may happen at any time of the year. This is very common in regions with extended growing period (e.g. Awassa in Ethiopia and Northern and Eastern Tanzania).

c) Scenario III represents relatively predictable drought. In this case the total amount of precipitation could be comparable to good years, but most of the rain falls within a short time of the growing season. Bean plants could be exposed to stress at early stage of growth but could receive enough water at later stages if the planting date is adjusted accordingly. This is a common phenomenon in most part of the Great Rift Valley of East Africa.

d) Scenario IV represents dry semi-arid climates whereby the amount of rainfall is relatively low to cover the physiological demand of the crop at any stage of growth despite its fair distribution throughout the growing period. Typical of this type of agroecology could be found in southern and South-western Africa.

Fig 2. Different scenarios of drought in bean growing regions of Africa



The following checklists were used to characterise the drought prone bean growing regions of Africa.

- Altitude
- Rainfall (Amount, distribution in 10 days interval, onset of rainfall, offset of rainfall and duration)
- Temperature (Min, Max, Avg)
- Short and long dry spells within the growing season
- Soil characteristics (Type, texture, pH, Soil Water Holding Capacity)
- Frequency of drought (across seasons and years)
- Length of growing period

- Length of maturity period and maturity classes available
- Available bean maturity classes
- Time of planting (sole and intercropping)
- Types of companion crops accompanying beans
- Traditional drought coping mechanisms
- Other observations

Wortman etal., (1998) identified fourteen African bean production environments, of which six could be categorised as drought-prone regions, as presented in Table 1.

Table 1. Characteristics of the major drought-prone bean growing environments in Africa (Modified from Wortman etal., 1998)

Bean prod. Area	Area (,000)	Major soil Types	Day length	Water deficit E M L
1. Semi-arid highlands at low latitudes, > 1500 masl, < 400 mm moisture, unimodal				
Kenya East highlands Rift valley Kajiado	 130 61 30	 Bc, Ne Bc, Bk, Tm Ne	 12.1 12.1 12.1	 M M M H H H H H H
Tanzania N. semiarid	 43	 Bc, To	 12.1	 H H H
2. Semiarid highlands at mid latitudes, >1500 masl, <400 mm moisture, unimodal				
Ethiopia Rift valley	 64	 Xh	 12.4	 L M H
Lesotho Foot hills	 7	 We, Bc	 13.6	 L M L
South Africa High veld	 45	 Lc	 13.5	 L M L
3. Semiarid at mid altitudes & low latitude, 1000-1500 masl, < 400 mm moisture, bimodal				
Kenya East,mid-alt	 60	 Lf	 12.1	 M H H
Rwanda Eastern	 60	 Fo	 12.1	 M H H
Tanzania N&E mid-alt	 14	 Nd, To	 12.1	 M H M
4. Semiarid mid-altitude & mid-latitude, 1000-1500 masl, <400 mm moisture, unimodal				
Angola Mid-alt	 30	 Lf, Fo	 12.6	 L M M
Ethiopia Haragrhe	 20	 Bd, Be	 12.6	 L M M
Zimbabwe Mid-veld	 3	 Lf	 13.2	 L H H
5. Semiarid mid-altitudes on acid soils, 1000-1500 masl, <400 mm moisture, unimodal				
Madagascar Following rice	 10	 Je	 11.0	L M H
Zambia N, central,NW	 14	 Fr	 12.8	 L M H
Swaziland	2	Ne, Lc, Fr	13.0	L M H
6. Partly arid, supplemental irrigation, residual moisture, <1000 masl, Unimodal				
Sudan, Northern	20	Jc	12.5	L M H
Egypt, Nile delta	20	Jc	12.6	L M H
Morroco, N	7	Lc	12.9	L M M

Key: Bc = Chromic cambisol, Ne= Eutric nitosol, Bk= Calcic cambisol, Tm= Mollic andosol, To= Ochric andosol, Xh= Haplic xerosol, Lc= Chromic luvisol, Lf= Ferric luvisol, Fo= Orthic ferralosol, Nd= Dystric nitosol, Bd= Dystric cambisol, Je= Euric fluvisol, Fr= Rhodic ferralsol, Jc= Calcaric fluvisol

E= early stage, M= early flowering, L= later stages
L= low, M= medium, H=high

Table 2. Agroecological traits of selected East and Central African bean growing areas

	KYA	DRC	SUD	TZA	ETH
Length of Growing season	90-100	<90 days	90 days, low temp	90-100 days	90-100
	100-150	90-100		>120 days	120-140
Maturity period	90-120	<90 days	<90 days	85-90 days	85-90
		120 days, climbers		85-90 days	
Planting time	Oct/Nov March/ April	Early March	Oct/Nov	Feb/Mar	Early June
		March		December	Feb, August
Severity	2	2-3	2-3 residual moisture	3	2-3
	4	1-2		2	2-3
Associate crops	Maize, pigeonpea, cowpea	Maize, cassava	Residual-long irrigation, faba bean, chickpea	Sorghum/ mucuna, early maize variety	Sorghum/maize, coffee, sweet potato
Copping measures	Early planting, contour cultivation-planting in furrows	Early planting, mulch with crop residue	Early planting, weed control	Deep cultivation, contour ploughing, tie ridges, int. of water harvesting	Early planting, ridges after maize
Other observations		Water harvesting not adopted	No supplemental irrigation		
Irrigation practices			Long irrigation interval (15-60 days)	Supplemental irrigation in rice system	nil

Key: KYA= Kenya, DRC= Democratic Republic of Congo, TZA= Tanzania, ETH= Ethiopia

As presented in Tables 1 and 2, common bean is exposed principally to terminal drought partly because it is grown as a secondary crop following maize or rice, and partly fertile soils of higher water holding capacity are commonly allocated to cereals. Since terminal drought often coincides with the most drought sensitive growth stages of beans (flowering, pod formation and seed/pod filling) stress effects on photosynthesis and assimilate translocation could significantly affect yield. The most important effect of drought on bean yield is not only through affecting photosynthesis but also through hindering assimilating transport from the source to the sink. Physiological/morphological mechanisms that may make the plant maintain tissue plant water potential and turgor that sustains assimilation, translocation and partitioning, are therefore of paramount importance. In regions with extremely low amount of rainfall (<300 mm) accompanied by high temperature, heat stress could aggravate water stress effects. Heat stress is known to affect the physiological integrity of the plant regardless of plant water potential.

5.2 Experimental methods in drought research

Different experimental methods could be used to compare bean genotypes at different growth stages and at different level of drought intensity. The most commonly used methods are field experimentation, pot experiments, chamber house experiments, nutrient solutions, rain-out shelters, rhizotron experiments and petridish experiments. The potential advantage or disadvantage of these experimental methods is presented in Table 3.

Table 3. Comparison of different experimental methods used to conduct drought stress research

Method	Advantage	Disadvantage
I. Field experiments	- Gives a realistic ground - Effective under characterised environments - Large no. of materials could be tested - Relatively cheap - Best to compare based on grain yield	- Hidden half (roots) are difficult to quantify - Results are complicated by other factors (soil heterogeneity, soil moisture variability, and temperature variations along the day...)
II. Pot experiments	- Uniform management of treatments possible in terms of soil fertility, water - Easy to determine plant water status - Relatively cheap - Best to compare biomass	- Labour intensive - Limited no. of treatments could be tested - Pot size restricts root growth - Does not sustain plant demand till maturity
III. Chamber houses	- Temperature, relative humidity & radiation can be controlled - Exact comparison possible - Best to measure gas exchanges	- Limited space (few treatments could be tested) - Very expensive
IV. Nutrient solution	- Relatively fast results could be obtained - Best to evaluate nutrient/water stress interaction	- Less precise (may not reflect reality) - Complications may arise due to stressor effects (Polyethylene glycol or Abscissic acid) - Labour intensive
V. Rainout shelters	- Reflects reality - Many materials could be tested - Effective to compare yield under partially controlled conditions	- Induces heat stress - Higher relative humidity (slow induction of stress) - Leaking effects
VI. Rhizotron experiments	- Side by side comparison of treatments possible - Effective to follow-up root growth, depth and distribution	- Only few treatments could be tested - Bulky, labour intensive
VII. Petri dish experiments	- Short term (minutes to hours) - Economical	- Should be supplemented by field or pot experiments - May not reflect reality

5. INDICATORS OF DROUGHT RESISTANCE

In the literature, traits that may endure drought resistance of crops are advocated based on theoretical modules, laboratory experimentation, or mathematical correlation between the presence of the trait and yield under drought, without sufficient attempt to demonstrate whether and how the particular trait contributes to final yield. Proline accumulation is a good example of such a trait, without any proof of its value as an indicator of drought resistance (Ludlow & Muchow, 1990). Some of the most probable indicators are presented in Tables 4&5.

Table 4. Potential mechanisms of drought resistance in common beans grown in intermittent or terminal stress (Amede, 2001)

Intermittent stress	Terminal stress
• Synchrony of fast growth stages to water supply • Early vigour • Stomatal regulation • Developmental plasticity • Root depth and density • Leaf area maintenance • Other survival strategies	• Synchrony of flowering/early pod filling to water supply • Mobilization of assimilates from source to sink • Rooting depth • (Osmotic adjustment of roots and shoots)

Table 5. Some indicators and methods of detecting Drought resistance in Beans (Ronno, 2001).

Indicators of Drought Resistance	**Resistance Mechanism**	**Detection Method**
a) Morphological		
1.Continued leaf expansion of primary and secondary trifoliate at lowered soil water potential (SWP)	Drought avoidance and tolerance.	Determination of leaf area following mild and moderate drought stress; determination of leaf water potential (LWP) for 50% reduction.

b. Physiological		
Decreased Stomatal transpiration at critical SWP	Drought avoidance	Determination of SWP and LWP for 50% reduction of transpiration.
Capability to osmoregulate Resulting in maintenance of turgor	Drought tolerance	Determination of SWP and LWP at decreasing relative water content (RWC).
3. Capability to be "hardened" to drought stress	Drought avoidance and tolerance	Subject plants to alternate drying and re-watering followed by subsequent testing of changes in morphological, physiological, biochemical and physical responses.
4. Response to applied ABA	Drought avoidance and tolerance	Determination of effect on membrane leakage.
c. Biochemical		
1. Maintenance of high nitrate reductase activity (NRA) at lowered SWP	Drought avoidance and tolerance	Determination of NRA in most recently expanded leaf at decreasing SWP and LWP at which NRA falls to 50% of unstressed level
Lack of proline synthesis and accumulation at lowered SW	Drought avoidance and tolerance	Determination of SWP and LWP at which proline accumulation begins
d. Cytological and ultrastructural		
1. Maintenance of nuclear and nucleolar dry masses and areas at lowered SWP	Drought avoidance and tolerance	Determination of nuclear area and dry mass in epidermal cells from drought stressed plants.
e) Physical		
Maintenance of Membrane integrity (lack of leakiness) at lowered tissue WP	Drought tolerance	Determination of release of ultraviolet absorbing solutes (220 nm from leaf discs subjected to 50% fresh weight level.
f) General		
Possession of varying low critical WP for non recovery upon re-watering	Drought tolerance	Determination of RWC and or LWP below which plants will not recover
2. Maintenance of cotyledonary function at lowered SWP	Drought avoidance and tolerance	Determination of SWP which cotyledonary abscission begins

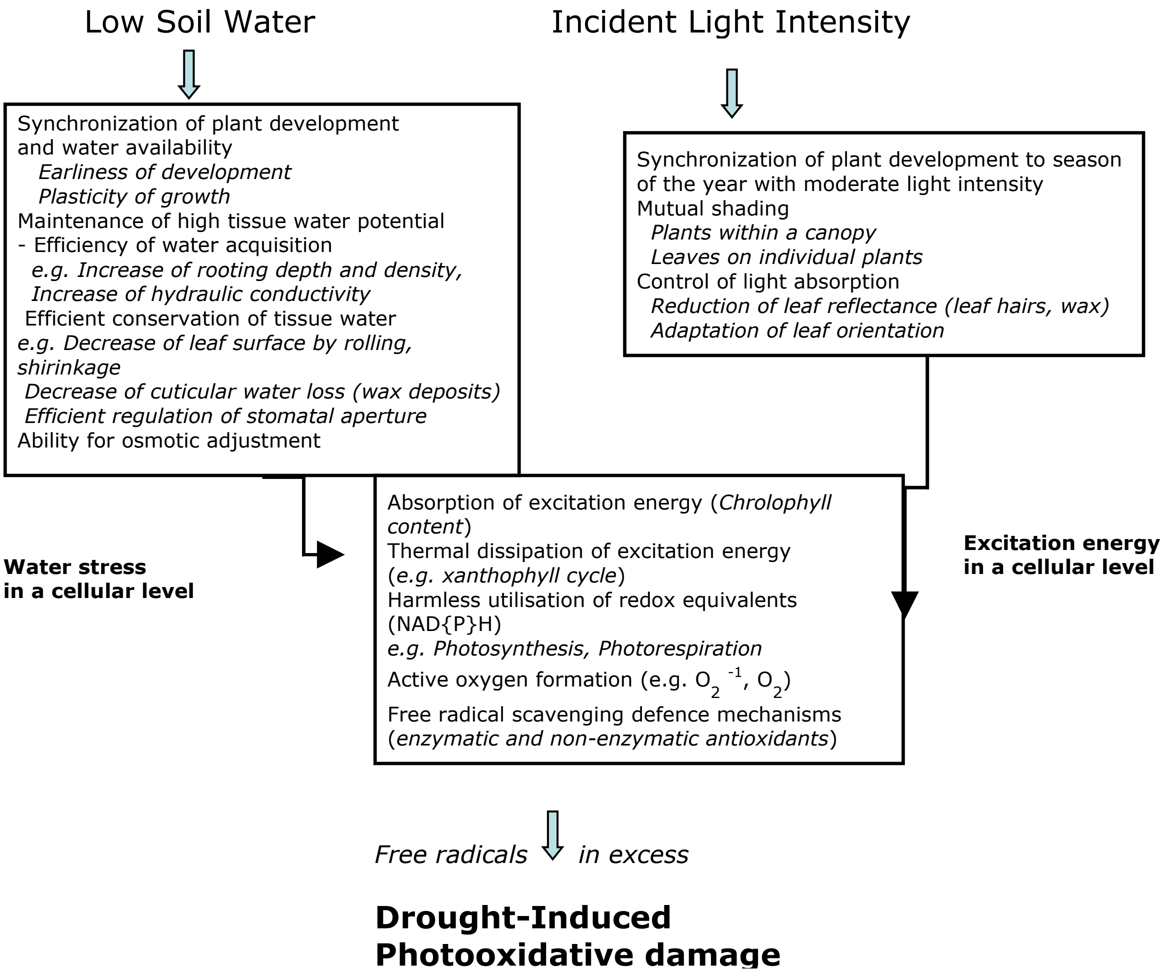


Fig 3. Causes, effects and resistance mechanisms of photooxidative stress in crop plants (After Mueller, 1998).

When crops are exposed to high light intensity in general and in combination with drought or mineral nutrient deficiency in particular, the electron flow in the photosynthesis complex could disrupted, which may lead to irreversible damage of the photosynthetic apparatus as indicated by chlorosis and necrosis of the leaves (photooxidation). Bean varieties that could decrease light absorption or dissipating energy through reflecting light and heat, changing leaf angle or possess physiological mechanisms to detoxify harmful oxidative agents could perform better under light stress conditions.

5.1 Processes in Identification of Drought Resistance Indicative Traits

The following checklists were used to monitor the type of drought environment that we are working with, and to identify plant traits that could be used by researchers in identifying drought resistant materials. The ultimate goal will be to develop bean varieties equipped with drought resistance traits and adaptable to Eastern and Central African conditions. The most important questions to consider during the process of identification of important traits that are to be used for development of drought resistant bean varieties were whether:

- There is a relationship between the trait in question and drought resistance
- The trait is expressed mainly when the crop is exposed to stress
- The timing of the trait expression coincides with the most drought sensitive stages of the crop
- The trait is responsive to changes in soil water status
- The trait is highly correlated to biomass production and grain yield
- The trait is easily measurable or observable
- The trait is highly correlated to other drought resistance indicators
- The trait has a regional value to be considered in standard protocols

About 18 potential indicators were included in the process as suggested by different authors (Turner, 1986, Singh etal, 1994, Amede, 1998). The proposed traits to be integrated into bean breeding programmes for drought-prone regions are assessed in terms of potential contributions to productivity, survival under drought, stability across years, and practical usage of the trait under the existing laboratory and capacity conditions, as presented in Table 6.

Table 6. Potential indicators as identified based on sets of criteria for use in improving drought resistance in beans

Drought Resistance Indicators	Correlation between the trait and drought resistance	Responds to changes in soil water status	Highly correlated to biomas production or grain yield	Easily measurable or observable	Of regional value for standard protocol	Total Sum	Rank
Plant WP	3	3	2	1	3	12	**9**
Osmotic potential	3	3	2	3	3.5	14.5	**1**
RWC	3	3	3	3	2.25	14.3	**2**
RGR	2	3	2.5	3	2	12.5	**8**
Biomass	2	2	2	2.5	2	11.3	**10**
Vigour	2	3	3	3	3	14	**4**
Root depth	2	2	2	1	1	8	**13**
Root density	3	3	1	1	1	9	**12**
Pods/plant	2.5	2	3.5	3	3	13.8	**6**
Seeds/pod	1	1	3	3	2	10	**10**
Seed weight	1	1	1	3	1	7	**14**
Grain yield	2	2	3.5	3	3.5	14	**4**
Early maturity	3.5	2	3	3	3	14.3	**2**
Duration of flowering	2	3	2	3	3	13	**7**
Period of seed filling	2	2	3	3	2	12	**9**
Degree of translocation	2	2	3	3	2	12	**9**
Production efficiency	2	3	3	3	2	13	**7**
Sensitivity index	3	2	2	3	3	13	**7**

Where: 0 = Irrelevant, 1 = Low, 2 = medium, 3 = High, 3.5=Very high

6. **Determination of Drought Resistance Indicators**

6.1. **Indicators of plant water status**

6.1.1. **Osmotic potential**

The commonly used techniques to measure osmotic potential of plants are cyroscopic, psychometric and pressure chamber (Turner, 1981), freezing point depression (osmometer), incipient plasmolysis, and solution equilibrium. The osmometer methods depend on the change in the freezing point while psychometric method depends on the change in the relative vapour pressure. To measure osmotic potential, the turgor pressure must be reduced to zero usually by killing the tissue by freezing or by heating. An effective and relatively cheap technique for determining the osmotic potential of tissues is the solution equilibrium method, which employs relative weight gain of samples from water uptake when placed in solutions of variable osmotic potential. The salt solution is used to calculate the osmotic potential of the solution (van't Hoff relations).

The pressure chamber technique involves the reduction of turgor pressure to zero, not by killing the tissue and liberating the solutes, but by applying pressure to the leaves and obtaining the osmotic potential from the pressure - volume relationship of the intact cells. Once the turgor pressure reaches zero, the volume of water in the cell is related to applied pressure as follows:

$$1/P_c = Vs - V/RTN$$

Where P_c = Pressure in the chamber, Vs = volume of simplistic water in the turgid leaf, V= volume of the simplistic water expressed, R = gas constant, T = Kelvin temperature and N = Moles of solute in the leaf, a plot of $1/P_c$ against V should be linear when the turgor pressure become zero. Extrapolation of the straight line, V = O given the osmotic potential at full turgor; and osmotic potential at zero turgor in the point at which the water potential and osmotic potential are equal.

If the total volume of water in the leaf (Vt) is determined from initial turgid weight (TW) and dry weight (DW)

Vt = TW - DW

Assumptions of the method are that the reflection coefficient of the membranes is close to unity and that solutes do not move from the cells to the xylem under the imposed pressure.

6.1.2 **Plant Water Potential**

Measurements of LWP are made between 1000hr and 1200 hr 2 weeks after germination and the weekly until flowering. To measure the LWP, one elegant and cheap method is a pressure chamber (Scholander probe, Scolander et al., 1965). This technique is based on the assumption that tension in the xylem stream is equilibrated with the water potential of the leaf tissue. A young fully expanded trifoliate leaf is cut quickly using a sharp razor blade. Wrap with a gluing foil and place in the chamber of the pressure bomb with cut end of the petiole just protruding from the chamber through a rubber plug which is used to seal the chamber. Pressure inside the chamber is gradually increased by using compressed gas from a cylinder until the sap exudes to the cut end of the xylem vessels. Detection of exudation of water at the end point is made using a hand lens. This operation should generally take less than 2 minutes. At least three samples are measured per plot. The readings are in bar and could be converted into Mega Pascal (MPa) units (10:1). The amount of pressure needed to press the sap out of the vessel is proportional to the water potential of plant tissue.

6.1.3 **Turgor Potential**

It is the physical pressure exerted by the water in the vacuole against the cytoplasm and the cell wall on the internal content of the cell by the walls of the turgid cells. The turgor potential can be measured directly by pressure probe technique. It can also be calculated from the difference between the total osmotic potential and water potential, if measured from the same sample at similar conditions. Replicate samples could be taken from the plant and one replicate can be placed immediately to the scholander probe for determination of water potential while the other replicate is frozen in liquid nitrogen for determination of osmotic potential. Plant sap is pressed from the frozen and thawed sample for determination of osmotica.

6.1.4. **Relative Water Content (RWC)**

Conventionally, RWC is determined as simple calculation of water content, a weight ratio between dry and wet biomass. However, there was an understanding among scientists that simple ratio of dry & wet biomass is not sensitive to evaluate cellular water relations. Instead, water content should be calculated as RWC by comparing the current hydration of a tissue to its maximum potential hydration. Five leaf discs, 7 mm in diameter are punched out from the recently most expanded leaf on each of the three plants selected in each plot. After weighing immediately using an electronic balance to determine fresh weight (FW), the discs are placed in a vial containing de-ionised water for 16h in a refrigerator at 5^0C (Turner 1981, Runkulantile *et al.* 1993) in order to regain turgor.

The discs are then removed from the vials, gently wiped using a blotting paper and then re-weighed to obtain turgid weights (TW). Each sample is again immediately replaced back in the empty vial and oven dried at 70^0C for 48 hr (to a constant weight) to obtain dry weight (DW). Estimates of RWC are determined between 1000 and 1200 h (midday). The first estimate is done 15 DAE and at bud formation.

The estimate of water content in each plant is calculated as follows:

$$RWC = [(FW - DW)/(TW - DW)] \times 100$$

6.2. Indicators of Drought escape

The most effective strategy of a drought-resistant crop should be to match the most sensitive phenological growth stage to the peak soil water availability (Richards, 1996), and drought escape could be one of the most reliable strategies of drought resistance for specific environments. However, drought escape in beans is strongly associated with low yield. A yield trial from CIAT on forty two bean genotypes with varying maturity period from 52 to 83 days showed that differences in maturity was strongly associated with a yield difference of 2000 kg ha^{-1} (White, 1988). Low yield in early maturing genotypes could be justified solely by reduced periods of photo-assimilation but also due to shortened remobilization/translocation period.

6.2.1. **Days to 50% Flowering (DTF)**

This parameter is measured as the difference in number of days from date of planting to date when 50% of the plants in each plot had one or more first flowers. This stage coincides with the initiation of developmental stage R6 (CIAT, 1987). The planting date should coincide with availability of sufficient soil moisture to allow germination of seeds. Drought escaping varieties could be identified through determination of days to flowering.

6.2.2. **Duration of Flowering (DF)**

This parameter is determined as the average number of days between the first open flower and the last open flower per plant in a plot. The population being assessed should be fairly stable and not segregating. Five randomly selected plants in each plot could be used for monitoring purposes.

6.2.3. **Days to Maturity (DTM)**

This is determined as the number of days from date of planting to date when 50% of plants in each plot attained physiological maturity R8 (CIAT, 1987). At this stage, pods are dry and brown.

As in DTF, the planting date should coincide with availability of sufficient soil moisture to allow germination of seeds.

6.3. **Indicators of Growth & Productivity under Drought**

6.3.1 Determination of Grain Yield

Plots are harvested when 95% of the pods are dry and brown (R9). Harvest areas must be identified and determined before harvest. Border rows and plants within the harvest plots must be clearly marked. Harvest area is determined as:

Harvest plot (m^2) = Total length of harvested rows (m) x space between rows (m).

After harvesting, the seed from each plot is weighed using an electronic balance that has an accuracy of at least 0.1 g and recorded. Grain yield is then determined as:

Grain yield (g/m^2) = (Seed weight/Harvest area)

6.3.2. **Plant vigour**

Each plot is assessed for general growth vigour at four weeks after germination. Scoring will be made on a scale of 1 to 5, whereby
1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = very good.

6.3.3. **Pods per Plant**

Determine the average number of pods per plant by randomly harvesting 5 plants in a plot, count the number of pods at physiological maturity (R9) and divide by 5.

6.3.4. **Production Efficiency (PE)**

This parameter is determined as:

PE = (DSD/DVP) x Grain yield

Where
DF = Duration of seed development (days between 50% flowering and Physiological maturity (R8).
DVP = Duration of vegetative period (days between germination and 50% flowering -R6).

6.3.5. **Sensitivity Index (SI)**

The SI developed by Fisher and Mauer (1978) gives a robust and extendable opportunity to compare multiple trials. This SI is therefore recommended for use in BIWADA trials.

SI = [1 - (D/C)] / [1 - (Dm/Cm)]

Where D = Drought yield,
C = Control yield,
Dm = Mean yield across all lines under drought
Cm = Mean yield across all lines under control

The following parameters were considered as secondary indicators either because they may need laboratory facilities and training or are not sensitive enough to show differences among treatments

6.3.6 **Relative Growth Rate (RGR)**

To obtain the RGR values, dry weight at seedling, pre-flowering, flowering and pod development are obtained by cutting the shoots at the ground surface. Five plants are randomly selected in each plot. The shoots are then oven-dried to a constant weight at 70°C. The average value per plant represents the mean for each plot.

The RGR is calculated as:
RGR = $\{(1/w) \times (\delta w/\delta t)\}$
Where, w = average plot dry weight (g)
δw = change in dry weight (g)
δt = time between each harvest date.

6.4 **Indicators of Developmental Plasticity**

In comparison to drought escaping types, genotypes with a potential developmental plasticity would be much preferable. Developmental plasticity means the ability of a genotype to adjust the duration of different growth phases and canopy development pattern to suit moisture availability during the growing season (Subbaro *et al.*, 1995). For instance, peg initiation and elongation of groundnut plants ceases when soil moisture is depleted to 80% of the plant-available water, and recommences when soil water is adequate (Chapman *et al.*, 1993). Pod setting and filling at lower nodes during the early growth of some chick pea genotypes ensured that at least some seed setting occurred in case of receding soil moisture (Saxena *et al.*, 1993).

6.4.1 **Root length and density**

The oldest system of studying root system was to excavate them, an expensive attempt in terms of labour and time. Currently the rhizotrons (2-3 mts long) became popular for having large underground observation tunnels, and windows large enough to follow the development of tap and fine roots. Rhizotron study is possibly one of the most reliable method to determine root length density in plants *in situ*. Another locally available method for determining tap root (TRD) and root dry weight (RDW) is a trough following procedures used by Ronno (1999). Troughs constructed using baked are filled with field soil. Each trough should measure at least 1.5 m high. All troughs are fully irrigated to field capacity prior to planting. The procedures for calculating the amount of water required per trough are adopted from Doorenbos and Pruitt (1977).

$Q\ (m^3) = 10/Ea\ (P \times Sa) \times D \times A$

Where Q = amount of irrigation required
Ea = application efficiency (assumed at 65%)
P = fraction of total available soil water permitting evapotranspiration
Sa = total available soil water
D = rooting depth (m)
A = trough size in hectares

Appropriate soil fertility and crop protection methods must be taken to maintain a healthy crop. TRD and RDW are monitored on two occasions namely seedling and flower initiation development stages. At each sampling date, troughs are well-watered about 6 hours prior to sampling to allow easy removal of the bricks without interfering with the roots. At sampling time the bricks bordering one side of each trough are carefully removed exposing the roots. Each plant is then carefully dug out and immersed in a container of water to soak and remove the soil surrounding the roots. Roots so washed are measured for length by using a ruler and subsequently severed at the stem base and oven dried to determine root weight. Five plants in each plot are harvested to obtain these measurements.

6.4.2 **Biomass adjustments**

Grain yield is a converted function of biomass accumulation, which is linearly related to cumulative transpiration (Tanner and Sinclair, 1983). Higher grain yield in legumes is positively correlated with higher plant biomass but negatively with drought resistance (Slim and Saxena, 1993). Amede et al (1999) showed that in faba beans, drought sensitivity increases with increasing plant height and the correlation was very high (r=+ 0.93). Thus, high yielding genotypes were drought sensitive and vice versa. Since genotypes that are water saving are commonly low-yielding, growing those genotypes in favourable years would lead to a considerable yield loss (Slim and Saxena, 1993). However, for agroecologies with terminal drought, as in scenario I (Fig 1), genotypes with smaller biomass production may perform better under drought as the water requirement of such materials will be low.

6.4.3 **Translocation efficiency**

Screening many lines in the field based on rooting depth or root length density is laborious and normally impractical. The simplest method suggested for screening drought-resistant lines in the field is delayed sowing (Singh *et al.*, 1994). Since legumes grown in semi-arid regions commonly encounter terminal drought, sowing a month later than normal in the spring has been effective in differentiating between drought-resistant and sensitive lines (Singh *et al.*, 1994). As translocation is less affected by drought than photosynthesis and respiration (Boyer, 1976), late sowing may help to evaluate the ability of the genotype to translocate reserves to the sink during the onset of terminal drought. The assimilates could act as a buffer against the effects of water deficits on current assimilation (Ludlow and Muchow, 1990). The assimilates could originate from pre-anthesis or post-anthesis periods depending up on the time of stress and the amount of reserve available in the stem. Varietal differences in beans for this trait has been observed (I.M. Rao & S. Beebe, CIAT, Personal communication).

6.4.4 **Stomatal regulation**

Stomatal conductance could be measured by porometers. The commonly used diffusion porometers are small cuvettes that can be attached to leaves that monitor humidity in the cuvette over time. The null porometers measure steady-state rate of transpiration of the enclosed leaves.

7. **Indicators of drought beyond the plant: The soil water**

In agricultural studies, annual or seasonal precipitation is often used as an index of plant water availability, although this index suffers from not taking the soil influences into consideration. Several physical characteristics of soils affect the quality and quantity of water available to plants. Soil texture dictates the amount of water to be retained in root zone and the functional response between soil water potential and soil water content. Following precipitation, water will drain through a soil profile rapidly in sandy soils, leaving little capillary water behind compared to clay soils. On the other hand, the soil solution will have higher water availability in sandy than clay soils.

As a response, many researchers prefer to measure soil water content as an index of plant water availability. Soil water content can be measured by percent of dry weight, tensiometers, neutron probes, pschrometery, or time domain reflectometery.

8. BREEDING FOR DROUGHT TOLERANCE

Breeding for drought tolerance is an important objective for most market-driven regional bean improvement programmes. However, most of the activities have been limited to screening for drought under field conditions. Although breeding strategies have been developed for most important biotic and abiotic constraints, efforts made to develop similar approaches for drought tolerance have been limited. This section discusses the prerequisites and strategies in breeding for drought tolerance.

8.1 Prerequisites in breeding for drought tolerance

Certain requirements should be met if worthwhile progress is to be made in breeding for drought tolerance. These are:

1. A large-scale simple and reliable screening technique to distinguish between resistant and susceptible plants/progenies should be available.
2. A suitable rating scale should be available.
3. Sources of resistance should be identified.
4. Knowledge of genetics of resistance can help the breeder decide the breeding methods which can be employed
5. Knowledge of the mechanisms of resistance is useful in handling breeding material.

8.2 Screening techniques

The first sections of this report have discussed the merits and demerits of the various techniques, and finally recommended a protocol that should be followed. Lack for such a protocol in the past made it difficult to compare results from various sites. A few additional issues related to management of drought nurseries need to be considered.
Sites which are representative of the region should be selected. They should assure adequate drought and permit proper trial management. A useful way to evaluate the representativeness of sites is to implement cluster analysis as suggested by White and Singh (1991). Sites that are very similar would appear in the same cluster (based on relative yield) and, thus, should be avoided since no new information is expected from the additional site.

Experimental design: work at CIAT-Colombia and elsewhere has shown that lattice designs are superior to randomized complete block designs. In most cases at CIAT, lattices with three replicates have been found effective to detect the desired levels of difference. For non-lattice designs, four replicates are used. For unreplicated nurseries with large numbers of entries, augmented designs (Lin and

Poushinsky, 1983), and moving averages (Knott, 1972) have been found more effective.
Plot size: With relatively uniform plant populations and soils, experience at CIAT has shown that the minimum useful plot size is about 10 m^2, with a harvestable area of 4.5 m^2. Where uniformity is a problem, plot size should be increased. Replicates (and blocks within lattices) should be distributed in relatively square formats, taking into consideration known gradients, to minimize within-block variation.

Planting dates: These should be chosen in such a way that a 20-day stress period occurs 30 days after planting and coincides with flowering and early pod fill. In cases where occurrence of drought is doubtful, replicates of a single trial at different planting dates should be considered. A 13-day difference was used at CIAT-Colombia to generate variable rainfall patterns and yield.

Trial management: In breeding for drought tolerance, agronomic management should provide conditions similar to those in farmers' fields and, at the same time, assure an appropriate and reliable level of stress for screening. Where available, irrigation provides a valuable tool to protect against failures caused by insufficient moisture and to producing a graded level of stresses according to the selection pressure needed at a given stage of genetic advancement (White and Singh, 1991). Irrigation also helps to distinguish between truly drought-susceptible genotypes (with excellent yields under irrigation and low yields under drought) and those, which are just poor materials (low yields under all conditions). Identification of such a susceptible check is an easy way to evaluate stress levels of nurseries and will strengthen conclusions from drought tolerance studies. Data from irrigated and control plots provide a means for calculating stress indices such as arithmetic mean, geometric mean, response, percent reduction, and Fischer and Maurer stress index. At CIAT, preference has been to use the geometric mean to avoid serious biases associated with the other four indices.

8.3 Rating scale

CIAT has developed standard 1-9 rating scale for drought tolerance, where 1-3 is tolerant, 4-6 intermediate and 7-9 is susceptible. No better screening criteria than yield under drought have been found. Yield values in stress and control plots are used to calculate the geometric means. Stability analyses may be used where data from more than three or four trials with the same entries is available.

8.4 Sources of resistance

Improvement of character depends on availability of useful sources of resistance. Modest efforts have been made to identify sources of drought resistance at CIAT. Several lines have been used in breeding for drought tolerance in beans. These include A54, A170, A195, BAT 336, BAT 477, BAT 1289, Bayo Criollo del Llamo, Bayo Rio Grande, Durango 5, Durango 222, Chiapas 7, Apetito, G1502, Rio Tibagi, Gordo, Mulatinho Vagem Roxa, Rim de Porco, Favinha, San Cristobal 83, ICA Linea 17 and V8025. More germplasm from the gene bank and experimental lines is being screened to identify new and better sources of drought tolerance. However, many researchers feel that genetic variability for drought tolerance in bean is low. They have suggested using genes from related species. The prime choice is tepary (*Phaseolus acutifolius*) whose superiority has been demonstrated. Although interspecific crosses with *P. vulgaris* and *P. acutifolius* have been obtained, only resistance to common bacterial blight has been transferred to the common bean. Recent studies showed that hybrids using tepary bean showed good drought tolerance in Honduras. Drought tolerance has also been reported in pinto bean. It will be necessary to screen breeding populations, landraces, advanced breeding lines and other accessions in the region to identify reliable sources for resistance. It will be prudent to exploit sources identified by CIAT-Colombia and use them in crossing programmes with tepary and local materials. Screening in adapted cultivars and advanced breeding populations should be given priority because they already contain resistances to diseases and pest, quality traits and adaptation characteristics.

8.5 Genetics of drought resistance

Little is known about the inheritance of drought tolerance in common bean. This is probably a reflection of the lack of reliable sources, screening criteria and partly lack of interest among researchers. It is, perhaps, also an indication of the complexity of this trait. Drought tolerance is associated with many morphological, physiological and chemical traits, which are probably controlled by different groups of genes. Resistance to temperature-drought stress was determined by a single dominant gene in P.I.297079 and by two complementary genes in P.I. 151062 (Bouwkamp and Summers, 1982). All three genes were inherited independently. Menosso et al (1978) found that low content of free proline (which accumulates in leaves of many crops under drought stress) was partially dominant, and about four genes were involved in its inheritance. However, Amede etal (1998) concluded that massive proline accumulation was a symptom of a severe internal water stress, and this accumulation had no survival value during drought. Therefore, proline accumulation is considered to be of no practical value in breeding for drought tolerance. Mode of inheritance of early flowering varies from monogenic, digenic to polygenic. Root characteristics show quantitative inheritance. It appears that, for breeding purposes, drought tolerance should be treated as a multi-faceted quantitative trait. The objective in a breeding programme is to increase the frequency of alleles conferring improved performance under drought stress.

8.6 Breeding Methods

Although bean breeders have been studying drought tolerance since the 1930's, hardly any commercially important variety has been developed specifically for drought tolerance. However, selection in stress environments has resulted in improved performance. In Kenya, GLP 1004 and GLP-X 92 have been reported to be drought tolerant while GLP 806 is tolerant to both heat and drought (Muigai, 1983).

In breeding bean for moisture-stress environments, it should be appreciated that the objective is not so much to maximize yield but to assure a reasonable yield, which covers production costs and provides some additional return to farmers. Harvestable yield and its reliability from year to year, rather than mere plant survival, are critical to farmers (White and Singh, 1991; Parsons, 1979). In addition, breeding for drought tolerance should not be seen in isolation. Growers will reject drought resistant cultivars if it is particularly susceptible to other major stresses on their farms. Barnes (1983) defined drought tolerant cultivars to those possessing economic levels of disease, insect, and nematode resistance; tolerance to soil, water and air problems; and insensitivity to normal temperature and photoperiod fluctuations.

Breeding methods, which can be employed for rapid incorporation of specific mechanisms of drought tolerance, such as early maturity, deep roots, small foliage, thick leaves and trichomes, include pedigree and inbred-backcross. In addition, three-way and modified double cross may be used to rapidly increase the frequency of desirable genes. A recurrent selection program using S2/S3 (equivalent to F3/F4) yield tests has also been started at CIAT for improvement of drought tolerance in common beans. Gamete selection procedure for simultaneous improvement of both qualitative and quantitative traits has been used effectively at CIAT. This procedure may be employed to improve drought tolerance and other traits.

8.7 Strategies in Breeding Bean for Drought Tolerance

Three strategies can be followed in breeding beans for drought tolerance: improvement of parental sources of drought tolerance, breeding for drought tolerance *per se*, and breeding drought tolerance into commercial cultivars. In absence of a better criterion, selection for drought tolerance should be based on yield performance.

Strategy 1: Improvement of parental sources

Parental lines with reliable drought tolerance characteristics are required in a breeding programme. Available germplasm should be screened at primary and secondary sites as identified in the protocol suggested in this report. The germplasm should include landraces, drought tolerant lines identified by CIAT-Colombia, commercial cultivars available in the region and advanced lines held by various national and regional programmes. In assembling this germplasm, care should be taken to include materials from race Durango from the highlands of Mexico and other centres of diversity, which have evolved under drought stress conditions. A critical evaluation of parental sources for their response to temperature extremes, major diseases and pests in this region should be made. Drought tolerant parents deficient in major constraints can be further improved by incorporating genes through an inbred-backcross method or its modifications. About 100 hybrid plants should be used as male parents from the first (F_1BC_1) and subsequent backcrosses. Two backcrosses with recurrent parents followed by two generations of inbreeding are often adequate before beginning single plant selections and progeny testing. This strategy will produce lines with multiple resistance, which can be tested in on-farm trials, and the best lines eventually released. Alternatively, it will provide drought tolerant parental lines for further breeding activities.

Strategy 2: Breeding for Drought tolerance *per se*

This is a medium to long term breeding programme specifically for drought tolerance. It can be justified on the basis of the large areas affected by drought in East, Central and Southern Africa, causing severe yield losses. Predicted climatic changes further justify a strategic regional breeding programme for drought tolerance. This approach involves making crosses among different sources of drought tolerance and relaxed selection for plant types, grain types and other features. The crosses should assure maximum recombination of different traits, mechanisms, sources and genes associated with drought tolerance. Genes for large root volume and deeper root growth, early maturity, tolerance to heat, poor soil fertility, small foliage, low canopy temperature, and other traits associated with drought should also be intercrossed with drought-tolerant parents. When the parents are genetically very diverse, for example for seed size, maturity, growth habit and adaptation, strategies such as recurrent selection, backcrosses, three-way crosses or modified double crosses should be used to increase the frequency of desirable genes (White and Singh, 1991). The approach followed at CIAT is shown in Table 7.

Table 7. Early generation yield test used at CIAT, Colombia for breeding drought tolerance in bean.

Month planted	Generation	Activities	Location and selection pressure
December	Parental	Intermate among selected parents	Palmira None
March	Parental and F_1	Intermate among selected parents and crosses. Save F_2 seed from selected single crosses.	Palmira None
June	Parental and F_1	Intermate among selected parents and crosses. Save F_2 seed from selected crosses	Palmira None
December	F_1	Grow out and save seed from selected crosses	Palmira None
June	F_2	Yield-test all crosses in replicated trials. Save F_3 single pod bulks from selected crosses	Palmira None
December	F_3	Yield test and save F_4 single pod bulk from selected crosses	Quilichao Drought, common bacterial blight, angular leafspot, fertility, root rots
June	F_4	Yield-test and save F_5 bulk from selected crosses	Popayan Drought, anthracnose, root rots
December	F_5	Space-plant and make single plant selection	Palmira Drought, root rots
June	F_6	Progeny test and seed increase	Quilichao Same as F_3
December	F_7	Yield-test selected lines for national programmes and other nurseries and specific physiological studies	Palmira, Quilichao and Popayan Same as in F_3, F_4 and F_5

Source: White and Singh (1991)

Strategy 3: Incorporation of drought tolerance in commercial cultivars

This strategy differs from breeding for drought tolerance *per se* because, in addition to drought, other yield-limiting factors such as diseases and pest resistance must be simultaneously bred into commercial cultivars. The main steps that can be followed are:

1. Identify the regionally important base cultivars to be improved.
2. Identify the major production constraints e.g. drought, angular leafspot, anthracnose, common bacterial blight and rust.
3. Determine the type of new cultivar to be developed and characteristics it should have.
4. Identify three to six sources of resistance to each constraint.
5. Intermate the base cultivars to produce single crosses.
6. From single crosses, intermate to create backcrosses, three-way and double crosses.
7. Intermate donor parents to combine two or more traits.
8. Intermate the three-way and double crosses with crosses from donors to create F_1 with combined traits. Base parents crosses are used as females. F_1 may be backcrossed to maintain substantial contributions from regional base cultivars or advanced to F_2.
9. F_2: yield trial under optimum management at one location to identify high-yielding crosses. Harvest best populations as single pod bulks.
10. F_3: yield-test under moderate drought pressure, low soil fertility, common bacterial blight and angular leafspot. Select and harvest single pod bulks.
11. F_4: Selected populations are grown in a replicated trial under pressure of anthracnose and drought. Harvest single pod bulks.
12. F_5: The bulks are screened under drought pressure. Make single plant selections. Note that by the time single plant selection commences, early segregating generations will have been exposed to climatic, soil and biotic stresses occurring at three contrasting sites. This allows only survival and identification of genotypes, which combine desirable traits in successive generations. When the number of traits desired in cultivars is large, extreme pressure for any single trait, especially quantitatively inherited ones in early generations, is avoided.
13. F_6-F_7: bulk families or lines from F_7 onward are yield tested under drought and nonstress environments and evaluated in separate complementary nurseries for anthracnose, common blight, angular leafspot and other constraints.

Because relatively little has been done on breeding bean for drought tolerance, BIWADA and regional programmes will have to initiate an effective programme perhaps following the experiences and suggestions outlined above. BIWADA may focus initially on strategy 1 and follow the protocol outlined in this report. Strategy 2 and 3 may be carried out as part of the regional strategic activity. There is need to study the inheritance and mechanisms of inheritance and incorporate farmer participatory approaches in all strategies.

Table 8. Site activities and standard experimental protocols for testing materials for drought resistance

Step/ Activity	Countries	Indicators to be measured	Soil Characterstics	Weather parameters	Duration of experiment	Number of Replications	Plot Size
Primary Screening	KENYA ETHIOPIA UGANDA TANZANIA SUDAN	All 9	Soil type pH SWHC N, P and K	Max & Min Temperature, 10 Year average seasonal rainfall	2 seasons	2	45cm X 15cm 2 rows, 3m
Secondary Screening	MADAGASCAR DRC MALAWI ZAMBIA SOUTH AFRICA	5 best Indicators (30% best materials)	Soil type pH SWHC N, P and K	Max & Min Temperature, 10 Year average seasonal rainfall	2 seasons	3	Local spacing 4 rows, 4m long
On-farm (breeding studies)	ALL COUNTRIE (10 Farmer/ country)	Yield Maturity Disease/ pest (5-10 best)	Soil type pH SWHC N, P and K	Max & Min Temperature, 10 Year average seasonal rainfall	3 seasons	10 (Each farmer is a replication)	Local spacing Rows 5m long Plot size at least 25 M^2

9. REFRENCES

Amede, T. and S. Schubert (1997): Solute pool enlargement in Drought sensitive or-tolerant grain legumes. Concentration effect or osmotic adjustment ? Plant nutrition for sustainable environment, Kluwer Academic Publishers, Japan. 165-167

Amede, T., E. von Kittlitz and S. Schubert (1999): Differential drought responses of Faba bean (*Vicia faba* L.) Inbred lines. J. Agronomy and Crop science 183, 35-45.

Amede, T. (1998): Analysis of drought resistance in grain legumes: The case of *Vicia faba, Pisum sativum, Phaseolus vulgaris and Cicer arietinum*.VERLAG ULRICH GRAUER publishing, Stuttgart, Germany. 135 p.

Bouwkamp, J.C. and W. Summers, 1982. Inheritance resistance to temperature- drought stress in the snap beans. J. Heredity 73:385-386.

Boyer, J.S. (1976): Photosynthesis at low water potentials. Philos. Trans. R. Soc. London Ser. B. 21:501-512.

Chapman, S.C., M.M. Ludlow, F.P. Blamey and K.S. Fischer (1993): Effect of drought during early reproductive development on growth of cultivars of ground nut (*Arachis hypogaea* L.) II. Biomass production, pod development and yield. Field Crops Res. 32: 211-225.

Fischer, R. and R. Maurer (1978): Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897-912

Hanson, A.d., C.E. Nelsen, A.R. Pedersen & E.H. Everson (1979). Capacity for proline accumulation during water stress in barley and its implications for breeding for drought resistance. Crop Sci. 19: 489-493.

Knott, D. (1972): Effects of selection for F2 plant yield or subsequent generations in wheat. Can. J. Plant Sci. 52: 721-726

Kramer, P. J. and J. S. Boyer (1995): Water relations of plants and soils. Academic Press, UK. 480p.

Lin, C.S. and G. Poushinsky (1983): A modified augumented design for an early stage of plant selection involving a large number of test lines without replications. Biometrics 29: 553-561

Ludlow, M.M. and R.C. Muchow (1990): A critical evaluation of traits for improving crop yields in water-limited environments. Advances in Agronomy, Vol. 43:107-153.

Menosso, O.G., C. Vierira, A. Bragarena, and J.C. Siva, (1978): Hereditariedade de toor de prolina em folhas turgidas e desidratadas de fejveiro (Phaseolus vulgaris). Turrialba 28: 340-342.

Monneveux, P. and E. Belhassen (1996): The diversity of drought adaptation in the wide. Plant growth regulation 20: 85-92.

Muigai, S.G.S. (1983): Breeding better beans.
Kenya farmer (August): 20-21.
Munns, R. (1988): Why measure osmotic adjustment ?
Aust. J. Plant Physiol.,15: 717-726.
Mueller, H. (1998): Drought-induced photooxidative stress and the role of antioxidative defence systems in drought tolerance of wheat genotypes development of a simple test to select for a complex trait. Verlag Ulrich E.
Grauer, Stuttgart. PhD thesis, University of Hohenheim, Germany. 181 p.
O'Toole, J.C., J.L. Ozbun and D.H. Wallace (1977): Photosynthesis response to water stress in *Phaseolus vulgaris*. Physiol. plant. 40:111-114.
Parison, L.R. (1979): Breeding for drought resistance: What plant characterstics impart resistance? Hort. Sci. 14:590-593.
Passioura, J.B. (1983): Roots and drought resistance.
Agric. water manage. 7:265-280.
Rao, I.M., (2000). Role of physiology in improving crop adaptation to abiotic stresses in the tropics: The case of common bean and tropical forages. In: M. Pessarakli, 2000. The hand book of plant and crop physiology. Marcel Dekker, Inc. New York. USA.
Richards, R.A. (1996): Defining selection criteria to improve yield under drought. Plant growth regulation 20: 157-166.
Rosielle, A.A. and J. Hamblin (1981): Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci. 21: 943-946.
Saxena, N.P., C. Johanson, M.C. Saxena, and S.N. Slim (1993): Selection for drought and salinity tolerance in cool season food legumes. pp 45-270. In:Singh, K.B. and M.C. Saxena (eds). Breeding for stress tolerance in cool season food legumes. Wiley, UK.
Sinclair, T.R. and M.M.. Ludlow (1986): Influence of soil water supply on the plant water balance of four tropical grain legumes. Aust. J. Plant Physiol. 13:329-341.
Singh, K.P., R.S. Malhotra, M.H. Halila, E.J. Knights and M.M. Verma (1994): Current status and future strategy in breeding chickpea for resistance to biotic and abiotic stresses. Euphytica 73: 137-149.
Slim, S.N. and M.C. Saxena (1993): Adaptation of spring-sown chickpea to the mediterranean basin. II: Factors influencing yield under drought. Field Crops Res. 34:137-146.
Subbaro, G.V., C. Johansen, A.E. Slinkard, R.C. Nageswara, R.N.P. Saxena, and Y.S. Chauhan (1995): Strategie for improving drought resistance in grain legumes. Critical reviews in plant sciences 14 (6):469-523.

Tanner, C.B., and T.R. Sinclair (1983): Efficient water use in crop production: Research or Re-search. In H. Taylor *et al*. (eds) Limitations to efficient water use in crop production. pp 1-28. American society of Agronomy, Madison.

Tardieu, F. (1996): Drought perception by plants. Do cells of droughted plants experience water stress. Plant growth regulation 20: 93-104.

Turner, N.C. (1986): Adaptations to water deficits: A changing perspective. Aust. J. Plant Physiol., 13:175-90.

White, J.W. and J. Izquierdo (1991): Physiology of yield potential and salt stress. In: A. Van Schoonhoven, O. Voysest, eds. Common beans: research for crop improvement. Wallingford, UK. CAB International & Cali, Colombia, CIAT. 287-382.

White, J.W., J. Kornegay, J. Castillo, C.H. Molano, C. Cajiao, G. Tejada, 1992. Effect of growth habit on yield of large seeded bush bean cultivars of common bean. Field Crops Res 29: 151-162.

White, J.W. and S. Singh, 1988. Breeding for drought resistance in beans. In White,J.W, Hougenboom, G., F. Ibarra and S.P. Singh (eds.). Bean drought workshop, CIAT, Cali.

Wortmann, C., R. Kirkby, C. Eledu and D.Allen (1998). Atlas of common bean production in Africa. CIAT publication no. 297. Cali, Colombia.

APPENDIX 1. Analysis of the strengths and weaknesses of participating countries with regard to drought research activities.

KENYA	
STRENGTHS	WEAKNESSES
Drought prone environments	Unreliable weather conditions
Technical experience and skills in research	Lack of screening equipment
Linkage with IARCs eg CIAT, ICRISAT	Limited financial and human resources
	Poor co-ordination and communication
DRC	
Drought prone environment (dry spots)	
Experience in drought research in association-CIAT	Types of drought badly defined
	Lack of equipment
	Poor communication
	Limited financial resources
	Unreliable weather conditions
TANZANIA	
Drought prone environment	Low human capacity in Drought activities
Experience people in drought area	Lack of equipments
Good networking with CIAT, ICRISAT	Badly defined drought prone areas
	Bad communication
	Limited resources
	Unreliable weather condition
SUDAN.	
Two different systems (irrigation & residue moisture)	Human capacity
Same as Tanzania	Limited machinery development
Linkage with ICARDA / CIT	Lack of equipment
	Fluctuation of floods from season to season
	Limited germplasm (early maturinga0
	Limited resources
ETHIOPIA	

Wide experience in drought behaviour	Lack of germplasm with environmental plasticity
Limited germplasm for beans	Limited germplasm
Human capacity (Senior and Graduate)	Limited research facilities
Environment - drought prone areas	Poor considerations by scientist and policy makers
REGIONAL ASPECT	
Basic information available on characterization of drought prone environment	Lack of uniform protocols
A critical mass of capacities in drought research	Limited research on drought in relation to other areas
Interregional Networking is good	Limited germplasm at region level
Information available to limited level / extent	Lack of equipment
	Limited human capacity in drought research
	Early warning system for bean production is lacking - Drought coefficient is lacking
	Absence of reliable indicators
	Lack of screening methodologies
	Reluctance to invest in drought research
	Lack of commitment from policy & donors
	Lack of infrastructure to combat drought
	Absence of defined technology from farms of different categories