A chapter from

Adaptation of Chickpea in the West Asia and North Africa Region

Edited by

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5.2. Comparisons of Abiotic Constraints to Chickpea Production in WANA and SAT

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Introduction

The major objective of this section is to summarize abiotic constraints affecting chickpea production across the WANA region. These constraints will be compared with those in the SAT. For this purpose, the chickpea-growing regions of South Asia will be considered as representative of SAT environments, although it is recognized that the crop is grown, but to a much lesser extent, in other SAT environments such as in Australia, Mexico, and eastern Africa. These constraints will then be prioritized in terms of yield loss and potential for alleviation, on the basis of current knowledge. Ways of appropriately mapping these constraints using geographic information systems (GIS) technology will also be considered. It is intended that these efforts will assist in the formulation of relevant research agendas aimed at alleviation of the stresses, with rational allocation of tasks between national agricultural research systems (NARS) and international agricultural research centers (IARC).

The major difference between the chickpea-growing environments of WANA and SAT is the pattern of rainfall, temperature, and photoperiod during the year. In the Mediterranean environment of WANA, the main rainfall period coincides with the period of lowest temperatures and shortest photoperiods. Chickpea can be sown at either the beginning (winter sowing) or the end (spring sowing) of the main rainy season, but in both cases, the crop is exposed to a period of increasing drought and heat stress. Chickpea-growing areas of the SAT on the other hand, normally receive most of their rainfall during the high-temperature, long-day period of the year. Chickpea is generally sown after the rainy season on residual soil moisture in the cooler part of the year. These differences in climatic patterns and cropping systems provide the basis for differences and similarities in the moisture- and temperature-related stresses facing chickpea in WANA and SAT. Underlying these climate-based differences are the differences in soil types across regions. But in this case, similarities predominate as, across each region, chickpea cultivation is mainly confined to soils with high clay content, high water-holding capacity, and neutral to alkaline reaction.

Prioritization of Constraints

Important abiotic constraints are:

- Water deficit (drought);
- Excess of water (waterlogging);
- Low temperature (cold);
- High temperature (heat);
- Deficiencies of essential mineral elements; and
- Mineral toxicities (including salinity).

The degree to which these constraints impose a limitation to chickpea yield in each country of the WANA and SAT regions was ranked and an attempt was made to estimate the potential for alleviation of each constraint, through a concerted research and extension effort (Tables 5.2.1 and 5.2.2.).

This evaluation takes into account abiotic constraints to currently cultivated varieties that are generally adapted to the region where they are normally grown, (e.g., they have the appropriate photoperiod response and phenology). The estimates are based on both published and judgmental information, as explained by Johansen et al. (1994).

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Constraints in WANA

Drought stress, especially terminal drought stress, is by far the most serious yield reducer of chickpea across the WANA region (Table 5.2.1). It results from exhaustion of the stored soil moisture and rising atmospheric evaporative demand before the pod-filling phase is complete. Terminal drought stress and the limited wet season in Mediterranean climates dictate early flowering. Countries where terminal drought stress is not a serious problem include those where chickpea is grown in higher rainfall zones, such as Turkey and Ethiopia, or where it is widely irrigated, such as Egypt. Waterlogging damage to chickpea can occur in zones where heavy rainfall occurs after sowing and soils have a high clay content and poor drainage (Table 5.2.1).

Low temperature stress becomes increasingly severe with increase in latitude, such as in Turkey (Table 5.2.1). Cold stress (sub-zero temperatures with frost) injures or kills plants at the seedling or early vegetative growth stage, as the crop is sown either just before, during, or just after the coldest period of the year. By contrast, high temperature stress effects on chickpea become important as low latitudes are approached, unless they are moderated by high altitude as in Ethiopia (Table 5.2.1). Temperatures above 30°C interfere with pod filling (Summerfield et al. 1984). Mediterranean climates are characterized by rapid increases in temperature in spring, where chickpea faces forced maturity under the combined effects of terminal drought and heat stress. High temperature stress assumes importance as a yield reducer for irrigated chickpea at lower latitudes, as in Egypt.

Table 5.2.1. Ranking[1] of abiotic constraints of chickpea and their potential for alleviation[2] in the major chickpea-producing countries of WANA (adapted from Johansen et al. 1994). Area and yield estimates for 1990 are indicated (FAO 1991).

Production/	West Asia				North Africa			
Constraint	Iran	Syria	Turkey	Algeria	Egypt	Ethiopia	Morocco	Tunisia
Area ('000 ha)	112	55	800	60	8	130	27	45
Yield (t ha^{-1})	0.72	0.66	1.08	0.33	1.75	0.97	0.77	0.62
Drought	1C	1B	3C	1B	×	3B	1B	1A
Waterlogging	–	–	×	×	?A	?B	×	×
High temperature	3C	3C	×	2C	2C	×	2C	2C
Low temperature	3A	2A	2A	3B	×	×	3B	3B
High soil pH	×	×	×	3C	2C	?C	3C	3C
Low soil pH	×	×	×	×	×	?C	×	×
Salinity	2C	3C	×	–	–	–	–	–
N_2 fixation	?A	3A	3A	3A	3A	?A	3A	3A
P deficiency	3A	3A	3A	–	–	–	–	–

1. Ranking of constraints: 1 = Severe yield reducer (> 50% yield loss in some years); 2 = Moderate yield reducer (15–50% yield loss across years); 3 = Minor yield reducer (< 15% yield loss in any year); ? = Problem suspected but status unknown; × = Known to be not a problem; – = Inadequate or no knowledge concerning the problem.
2. Potential for alleviation: A = High (regional production breakthrough probable in the medium term, e.g., 3–7 years), B = Moderate (production breakthrough possible over the longer term, e.g., 7 years); C = Low (only marginal improvement expected or substantial improvement only after a decade or more).

Sources: Smithson et al. 1985; Saxena, M.C. 1987; Saxena and Singh 1987; Summerfield 1988, van Rheenen and Saxena 1990; Wolde Amlak et al. 1990.

Nitrogen (N) and phosphorus (P) deficiencies are the most frequently cited nutrient deficiencies for WANA (Table 5.2.1). Some deficiencies associated with alkaline soils, such as iron (Fe) or zinc (Zn), are also known to reduce chickpea yields. However, reports of yield reductions due to other nutrient deficiencies are rare, but it is not clear whether they indeed do not exist or are yet to be diagnosed. The predominant mineral toxicity stress facing chickpea in most WANA countries is salinity (Table 5.2.1). Salinity is widespread throughout the region (UNEP 1992), but chickpea cultivation is avoided in saline zones, even if the climate may be suitable, as this crop is particularly sensitive to salinity (Subbarao and Johansen 1994).

Comparison with SAT

As in WANA, drought is the major abiotic constraint of chickpea in South Asia (Table 5.2.2). In this region also, terminal drought stress is the prime manifestation and there is a clear increase in severity as lower latitudes are approached (Saxena, N.P. 1987). Waterlogging (surface soil saturation) is only an important consideration in Bangladesh, where excessive winter rainfall is received in poorly drained rice fallow fields in which chickpea is normally grown (Table 5.2.2). However, in the subtropics of South Asia, soil water close to field capacity causes excessive vegetative growth leading to crop lodging and susceptibility to such foliar diseases as botrytis gray mold or ascochyta blight.

Table 5.2.2. Ranking[1] of abiotic constraints of chickpea and their potential for alleviation in the major chickpea-producing countries of South Asia (adapted from Johansen et al. 1994). Area and yield estimates for 1990 are indicated (FAO 1991).

Production/ Constraint	Bangladesh	India	Myanmar	Nepal	Pakistan
Area ('000 ha)	100	6495	134	28	1002
Yield ($t\ ha^{-1}$)	0.65	0.65	0.75	0.59	0.54
Drought	2B[1]	1B	1C	3C	2B
Waterlogging	3C	–	–	–	–
High temperature	2C	2C	3C	×	3C
Low temperature	3C	2B	×	2C	2C
Lodging[2]	3C	3C	?C	×	3C
High soil pH	×	3C	×	×	3C
Low soil pH	3C	×	?C	3C	×
Salinity	×	2C	×	×	2C
N_2 fixation	3A	3A	3A	3A	3A
P deficiency	2A	3A	3A	3A	3A
S deficiency	2A	–	–	–	–
B deficiency	3A	–	–	–	–

1. See Table 5.2.1 for definition
2. Exacerbated by wind, heavy rain, or hail

Sources: Smithson et al. 1985, Saxena, M.C. 1987, Saxena and Singh 1987. Baldev et al. 1988; Summerfield 1988; van Rheenen and Saxena 1990; Jagdish Kumar 1991.

In chickpea-growing areas of the SAT at higher latitudes, freezing temperatures are not so frequent or severe as to cause plant death. Extremely low temperatures occur at the early reproductive stage and temperatures in the range of 0–10°C prevent or delay pod setting (Saxena 1980a). Consequently, the vegetative growth stage is extended causing the reproductive stage to be postponed to a period when conditions are more favorable for insect pest (e.g., *Helicoverpa* pod borer) and foliar disease incidence, and towards maturity, the crop is exposed to terminal heat and drought stress. This is the type of cold stress referred to in Table 5.2.2. The terminal heat stress facing chickpea in SAT environments (Table 5.2.2) is the same as in WANA. It becomes particularly important for chickpea if it is sown after the optimum sowing time, which is usually the case for chickpea grown in rice fallows, a major cropping pattern in South Asia. As in WANA, it is also an important stress for irrigated chickpea at low latitudes.

The occurrence and extent of nutrient deficiencies and salinity affecting chickpea production are similar between SAT (Table 5.2.2) and WANA (Table 5.2.1).

Representation of Constraints

Abiotic constraints to chickpea can generally be clearly depicted on GIS as they depend on climate and soil databases, which are generally more comprehensive and stable over time than those available for biotic constraints. Plots of length of growing period (LGP), calculated from rainfall, potential evapotranspiration (PET), and soil water-holding characteristics (FAO 1978), best depict zones prone to terminal drought stress. It should also be possible to depict variability of LGP across years, based on annual variation in rainfall. Areas prone to waterlogging can also be easily depicted, as indicated by excess of rainfall over PET and soil water infiltration and water-holding characteristics.

Temperature isotherms, which are generally readily available, can be used to define zones where chickpea is subject to heat or cold stress at sensitive stages of the growth cycle. Probability considerations also apply here, as temperature extremes can show considerable annual variation although mean temperatures may not vary much from year to year. It is necessary to know the probability of occurrence of temperature extremes to assess the expected impact of genetic improvements in low or high temperature tolerance.

Nutrients maps, drawn by plotting zones of similar values of soil chemical tests for nutrient availability, have been used to depict zones of probable nutrient deficiencies (e.g., Ghosh and Hasan 1979). These zones normally correspond with particular soil classes, for which soil maps are also generally available. However, it is rare that soil chemical tests have been adequately calibrated against crop yield response. Secondly, there is likely to be large field-to-field variation in crop response to nutrient application due to effects of cropping and fertilizer history. Thus, nutrient maps at a country level can only give a very approximate depiction of yield loss due to nutrient deficiency. On the other hand, soil measurements of mineral toxicities can reasonably well predict crop performance, as critical levels are more clear-cut. Salinity maps are available for the major chickpea-growing regions of the world (e.g., UNEP 1992).

Alleviation of Abiotic Constraints

Prospects for expanding the area of irrigated chickpea, to alleviate drought effects on the crop, are quite good in both WANA and SAT but the motivation to do so depends on economic considerations. As the emphasis of the Chickpea in WANA Project is mainly on rainfed chickpea, ways to maximize yield in water-limited, rainfed environments will be considered here. First of these is the use of short-duration varieties so that the crop can escape from terminal drought stress, but as the crop duration is shortened, its yield potential also declines (Saxena, N.P. 1987). The crop duration of traditional landrace varieties is such that they usually face terminal drought stress in areas where they have evolved. Fitting of appropriate crop phenology can be conveniently guided by LGP maps. In peninsular India, progress has been made in developing varieties that are better able to escape terminal drought stress and it is recommended that this approach be used more widely.

Another way to escape terminal drought stress is to advance the sowing date. This has been successfully exploited in the development of winter chickpea technology for WANA (Singh 1987). It has relied on the development of genotypes that have resistance to cold and ascochyta blight. This is a good example of a combined agronomic and genetic approach to escaping drought. Advancement of sowing date to escape drought has also been tried in peninsular India. Significant yield advantages have been obtained by advancing sowing by 1 month from the normal sowing date of mid-Oct (ICRISAT 1984). However, this has limited scope for widespread application in South Asia, because: (a) a rainy-season crop would prevent early sowing of a subsequent chickpea crop; (b) sowing is difficult in heavy soils until after the rainy season; and (c) early-sown chickpea is susceptible to high temperature and disease (e.g., *Colletotrichum* blight) stresses.

Even with appropriate fitting of crop phenology to the probable period of soil moisture availability, there are further options for minimizing effects of drought stress, by exploiting drought resistance mechanisms. These include more exploitative root systems, smaller leaf area, large seed size, and twin pods at basal nodes (Saxena and Johansen 1990). Genetic progress in yield under drought has been achieved by selecting plants with larger root systems (ICRISAT 1993).

As waterlogging is not a very widespread problem for chickpea, it does not need much attention. Agronomic methods, such as suitable drainage systems, would be effective in checking this problem wherever it occurs.

Although manipulating the sowing date would help the plant to escape from low or high temperature constraints, it is not always practical to do it keeping in view other factors such as cropping system pattern and soil-water availability. Thus, it is necessary to enhance tolerance for extremes of temperature through genetic means. Progress in genetic incorporation of cold tolerance, along with resistance to ascochyta blight, has facilitated winter sowing technology in WANA (Singh 1987), and there are prospects for further enhancing cold tolerance by transferring the trait from related wild species (Singh 1993). In SAT, genotypes with the ability to set pods at low temperatures in sub-tropical winters have been identified and are being used in breeding programs (van Rheenen et al. 1990). However, improved sources of cold tolerance for SAT conditions and their incorporation into suitable agronomic backgrounds are still needed.

Genotypes with shorter duration than locally adapted landraces will also escape terminal heat and drought stress. But sources of heat tolerance at the pod-filling stage in both WANA and SAT, and also at the seedling stage to allow early sowing in SAT environments, will have to be identified. Although field techniques for screening for heat tolerance appear simple--by growing chickpea with irrigation in such a way that the critical growth stage coincides with a hot period (e.g., maximum temperature above 35°C), little research has been reported in this regard.

Mineral imbalances are normally best tackled through management, particularly by adding fertilizers and amendments to overcome nutrient deficiencies. Some micronutrient deficiencies, such as that of Fe, can be alleviated through genetic improvement because of large genotypic differences in response and ease of screening for the distinctive symptoms (Saxena 1980b). As the cost of fertilizers and amendments will certainly go up in future, genetic improvement in the crop's ability for nutrient acquisition and efficiency of nutrient use is a viable research goal. Chickpea is adapted to alkaline soil because it can, more than many other crops, exude acids from its root system (Marschner and Römheld 1983). These acids can dissolve precipitated forms of P and perhaps other essential nutrients (Ae et al. 1991). Genetic differences with regard to this property need to be systematically explored in chickpea as well as differences in the crop's ability to access and use other nutrients that may be deficient (e.g., Zn). Aspects of N nutrition of chickpea are covered in Section 5.5.

Good sources of salinity tolerance need to be identified for genetic improvement of salinity tolerance (Saxena et al. 1993). Landrace types or related wild species that have evolved in moderately saline habitats offer the best prospects for this; but little work seems to have been done in this area.

Conclusions

Geographic information systems can adequately depict abiotic stresses of chickpea and are therefore a valuable guide to constraint analysis and formulation of research priorities. Such depiction can assist in demonstrating the extent of problems and can indicate the possible gains from research on these problems. The use of GIS can complement earlier attempts to define crop suitability in relation to soil and climatic factors, as was done in the FAO Agroecological Zones Project, on a global basis (FAO 1978). However, it is now possible to define more clearly the constraining factors to yield than in that project. For example, more sophisticated soil-water balance models can be used to more accurately calculate the period over which soil water is available for use by the crop (i.e., LGP). Analyses of abiotic stresses, aided by GIS, are perhaps best done at the country level, or separately for major agroecological divisions of large countries such as India, in order to achieve the necessary degree of precision for decision-making.

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