Adaptation to frost and drought stress in chickpea and implications in plant breeding

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Adaptation to frost and drought stress in chickpea and implications in plant breeding

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SUMMARY - Breeding for resistance to ascochyta blight and cold is an important step in the development of winter sowing of chickpea, which is key to improving yield of this crop in the Mediterranean basin. Within the available chickpea germplasm we found a large genetic variability for resistance to cold (to temperature as low as -13°C). The phenological stage is very important in determining the response of the crop to the cold as the cold resistance in field tends to decrease from germination to flowering. Significance of this observation in terms of application to plant breeding and agronomy is discussed. If we use adapted cultivars, early sowing largely improves availability of water and increases water use efficiency. Compared to spring sowing, the early sowing does not increase the total amount of water extracted from the soil. Nevertheless, spring chickpea will remain an interesting crop for the traditional wheat-based cropping systems because of its low cost and flexibility in operations. The improvement and stabilization of its yield partly depend on selection of cultivar resistant to drought. Physiological processes like escape through earliness, increase of roots density or osmotic adjustment could be improved through plant breeding.

RESUME - "Adaptation au froid et au stress hydrique chez le pois chiche et ses implications pour l'amélioration de cette espèce". L'obtention de variétés résistantes à l'anthracnose et au froid constitue une étape importante dans le développement du pois chiche d'hiver, principale voie d'amélioration de la productivité de cette culture dans le bassin méditérranéen. Au sein de l'espèce Cicer arietinum *L. il existe une grande variabilité pour la résistance au froid, et certaines variétés peuvent résister à des températures de -13°C au niveau de la culture. Cependant il existe une forte interaction avec le stade atteint au moment du froid, la résistance semblant décroître depuis la germination jusqu'à la floraison (dans les conditions du champ). Les applications à la sélection et à la conduite des cultures sont discutées; en particulier nous avons pu définir 3 types de cultures de pois chiche basés sur la date de semis et le type variétal. Grâce à ces variétés, le semis précoce permet d'améliorer très fortement l'alimentation hydrique du pois chiche, en augmentant la quantité d'eau consommée (surtout par une meilleure valorisation des pluies) et/ou l'efficience de l'eau consommée. Ces semis précoces n'entraînent pas d'augmentation des quantités d'eau prélevées dans le sol. Cependant le pois chiche de printemps reste une culture intéressante pour beaucoup de systèmes de production: culture peu coûteuse et permettant un étalement des temps de travaux. L'amélioration et la régularisation de son rendement dépendent en partie de la sélection de variétés plus résistantes au déficit hydrique. Certains mécanismes comme l'évitement par la précocité, l'augmentation du volume de sol prospecté par les racines ou l'ajustement osmotique pourraient se prêter à la sélection.*

Introduction

In the Mediterranean basin, chickpea (*Cicer arietinum* L.) is the only pulse crop which is sown in spring without irrigation. Perhaps this plant has some features of adaptation to drought which need to be analysed in order to improve our knowledge and to try to genetically improve this adaptation. However, studies on the date of sowing have led the chickpea workers to realise that yields can be considerably improved if the crop is sown in winter. This idea was first introduced by ICARDA at the end of the 1970's and is now adopted by most of the national programs of the region. The first step was to find some sources of resistance to frost in the chickpea germplasm and that was already done in 1979 by screening 3158 genotypes of kabuli chickpea in a high elevation plateau in Turkey (Singh *et al.*, 1984). But it soon became evident that the main problem to be addressed in breeding chickpea for winter sowing was to find resistance to ascochyta blight, a disease already important on spring sowing but particularly dangerous for the crop sown in winter (Hawtin and Singh, 1984).

Nevertheless the three hard winters we experienced in southern Europe, from 1984 to 1987, and the test of winter chickpea in higher elevation zones brought us the realization of the need for more attention to be paid for resistance to frost in the breeding programs. The main results obtained in research at Montpellier and in other areas in France in last 5 years on this aspect are presented in this paper. Attempt is also made to relate it to the objective of improving the adaptation of chickpea to drought. As a background to these considerations, the effect of sowing date on chickpea production, in the absence of frost and ascochyta blight is first presented.

Influence of early sowing

Figure 1 shows chickpea yield as affected by sowing date in two contrasting environments. In Trial 1 which was conducted in Montpellier during 1982/83, the temperatures did not go below -7.8°C (under screen) and the soil was deep and fertile (Boukhedimi, 1983). Trial 2 was conducted during 1986/87 at Montfort where temperature fell below -12°C with no snow cover and the soil was shallow. Cultivars used in Trial 1 were 'Turkish local' kabuli chickpea and 'INRA 199' desi chickpea. In Trial 2, in addition to this last cultivar (INRA 199) 27 lines previously selected in Montpellier for resistance to frost were also included. These two trials were conducted when there was no ascochyta blight.

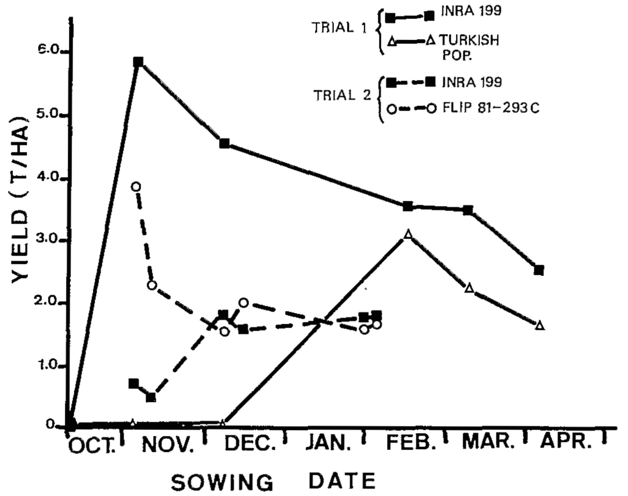

Fig. 1. Effect of sowing date on chickpea yield in two different agro-climatic conditions (Trials 1 and 2).

Trial 1 shows that traditional Mediterranean cultivar was not adapted to winter sowing because it could not survive in temperatures of -7°C which are not rare in many traditional chickpea growing zones. However, with a more resistant cultivar (INRA 199) fall sowing (early November) doubled the chickpea yield compared to the yield obtained with spring sowing (middle of March). These results are in agreement with those obtained in many Mediterranean countries with cultivars selected by ICARDA. For example, in a network of trials with 3 locations, 4 years and about one hundred of genotypes, fall sowing gave an average of 52% increase in yield over spring sowing (ICARDA, 1988). However, Trial 2 shows that a cultivar like INRA 199 cannot be considered as resistant to frost because in the earlier sowing dates (November 4 and 10) most of the plants of this cultivar were killed and the yield was lower than that from December sowing. But the same trial shows that resistance to low temperature does exist in chickpea. For example the cultivar FLIP 81-293C did not suffer from frost and showed the same beneficial effect of early sowing as previously observed (Trial 1) with INRA 199 in the absence of frost damage. Trial 1 also shows that sowing at the end of winter (middle of February) can lead to a significant increase in yield (about 30%) compared to traditional spring sowing even with traditional large seeded kabuli cultivars. For the conditions typified by Trial 1 the level of frost resistance is sufficient in many local cultivars, but unfortunately most of them are susceptible to ascochyta blight.

The beneficial effect of early sowing is mainly due to an increase in number of pods per plant (Wery *et al.*, 1988; Ayadi, 1986) created by better conditions for growth, branching and pod filling. As a matter of fact early sowing is associated with:

a) better water availability (this point will be discussed later on);

b) much longer reproductive period and better remobilization of assimilates from vegetative parts (Wery *et al.*, 1988), and

c) an improved nitrogen nutrition (Wery *et al.*, 1988).

Resistance to frost in chickpea

The previous results, confirmed by others (Wery, 1987), lead to the conclusion that resistance to frost in chickpea primarily depends on the weather conditions and on sowing date. This is already known in case of pea and faba bean. In order to explain this phenomenon and to develop a screening method, the effect of sowing date on 29 chickpea genotypes was studied at 5 locations during two severe winters (1985/86 and 1986/87) (Table 1). In each of these five trials 100 seeds of each genotype were sown in a 5 m row. A cultivar tolerant to frost was sown after each 5 genotypes and on the borders. These trials were conducted in South-Eastern France at elevations between 50 and 780 m giving a range of minimal temperatures from -10°C to -18.5°C (under climatic shelter) (Table 1). Most of the genotypes were selected

Table 1. Main features of the frost resistance trials.

Trial No.	Location and year	Elevation	Minimal temperature (under climatic shelter)	No. of cultivars	Tolerant check
1	Montpellier (1986-87)	50 m	-13.8°C (snow)	21	ILC 3279
2	Montpellier (1985-86)	50 m	-12°C (no snow)	24	ILC 3279
3	Puyricard (1986-87)	200 m	-14°C (no snow)	20	ILC 3279
4	Montfort (1986-87)	300 m	-10°C (no snow)	27	FLIP 81-269
5	La Fage (1986-87)	780 m	-18.5°C (no snow)	11	E 36

from the ICARDA International Winter Nurseries and Trials during the winter of 1984/85. In each trial and for each genotype we calculated a Frost Resistance Ratio (FRR) defined as follows:

$$FRR = PL_H/PL_E$$

PL_H = Number of plant per line at harvest

PL_E = Number of plants per line after emergence and before the first frost

Another trial was conducted to verify whether the ranking of the genotypes would change if the number of plants at harvest was replaced by the number of plants at the end of winter. There being no difference, we decided to use the ratio which was the easiest to measure. Closer the ERR to 1, better was the level of resistance to frost. Of course this ratio is only meaningful for genotypes sufficiently homogenous (most of the genotypes we tested were in F5/F6 stage). For each genotype the grain yield was also measured.

Trial 1 and 3 were not sufficiently selective for resistance to frost, the plants in the first one were protected by 20 cm of snow and the second one was sown too late (December 8). In trial 5 (located on a plateau at 780 m elevation) all the genotypes were killed

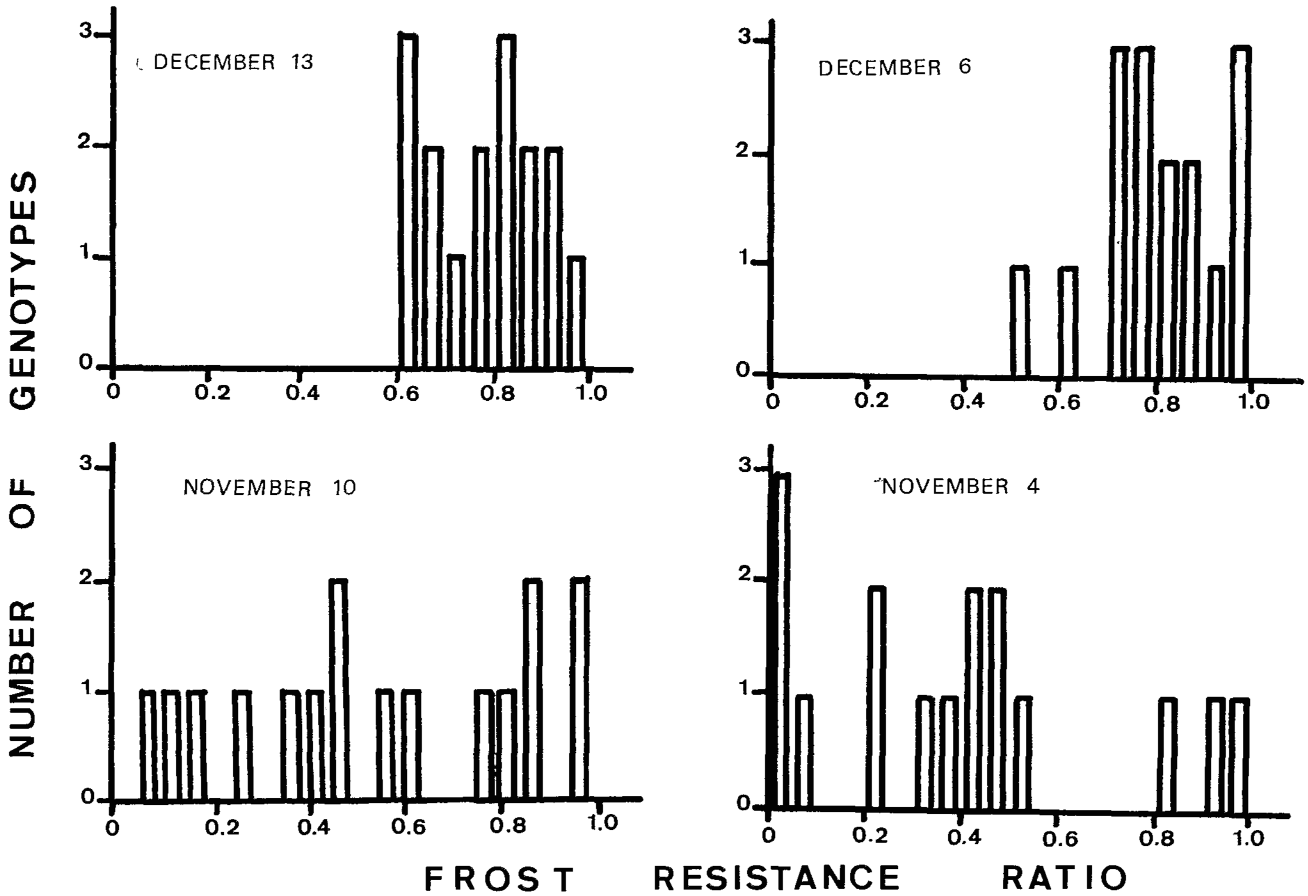

Fig. 2. Effect of sowing date on the distribution of the chickpea genotypes according to their Frost Resistance Ratio. (4 Nov. to 13 Dec.).

Table 2. Hierarchic classification of chickpea cultivars based on their frost resistance ratio.

Class No.	Number of genotypes	Name of genotypes	Frost resistance ratio			Level of resistance to frost
			Trial 2	Trial 4	Mean	
1	3	FLIP81-293C FLIP82-128C FLIP83- 7C	0.80	0.90	0.85	Resistant
2	3	FLIP83- 71C FLIP83- 48C FLIP82-172C	0.30	0.50	0.40	Tolerant
3	1	FLIP83- 98C	0.30	0.50	0.40	
4	8	FLIP83- 97C FLIP82-154C FLIP83- 41C FLIP82-232C INRA 199 FLIP82-101C FLIP82-169C FLIP82-186C	0.20	0.20	0.20	Susceptible
5	1	FLIP82-127C	0.90	0.40	0.65	Needs to be reassessed

Table 3. List of the best chickpea genotypes for resistance to frost.

Chickpea genotypes	Frost resistance ratio		
	Trial 2	CISN-W-86	CISN-W-87
FLIP81-293C	0.85	–	0.97
FLIP82-128C	0.80	–	–
FLIP82-127C	0.89	–	–
FLIP83-7C	0.72	–	–
FLIP84-46C	–	0.66	–
FLIP84-70C	–	0.68	–
FLIP84-48C	–	0.60	–
FLIP84-73C	–	–	1.0
FLIP84-176C	0.61	–	1.0
FLIP84-124C	0.66	–	1.0
FLIP85-48C	–	–	1.0
FLIP85-65C	–	–	0.99
FLIP85-73C	–	–	1.0
FLIP85-83C	–	–	1.0
FLIP85-72C	–	–	0.97
ILC 482 (as susceptible check)	0.10	0.00	0.37

by severe frost (minimal temperature -20°C at soil level without snow cover) which occurred between January and March. Trials 2 and 4 provided good screening conditions and consistent results. The results from Trial 4 (300 m elevation) in which there were 6 sowing dates are presented here in detail.

The effect of sowing date on frequency distribution of the genotypes according to their FRR is shown in Fig. 2. As one moves from the latest sowing (December 13) to the earliest one (November 4), the distribution progressively changes from a nearly normal to a bimodal-one. At the same time the average FRR decreases from 0.8 to 0.4. The earliest sowing (November 4) is the only one suitable for screening and the ranking of the genotypes based on their FRR is similar to the ranking obtained in Trial 2 (data not shown) sown on November 19 previous year in another location (see Table 1). In both trials the emergence took place than one month before the freezing period. By using the results of these two trials a hierarchic classification of the genotypes could be established based on their FRR (Table 2). The genotypes of class 1, namely FLIP 81-293C, FLIP 82-128C and FLIP 83-7C (average FRR = 0.87) can be considered as frost resistant. Genotype FLIP 82-127C which came in class 5 had different FRR in the two trials, hence its frost resistant is doubtful. A list of the genotypes found cold resistant in the trials located in Montpellier for 5 years (450 genotypes and 13 trials) is given in Table 3. All the remaining genotypes, even ILC 482 and ILC 3279, must be considered as too susceptible to frost for sowing in November in our conditions. They will fall in class 2, 3 (tolerant, with average FRR = 0.4) and 4 (susceptible, FRR = 0.2) in Table 2. The traditional large kabuli cultivars (for example ILC 1929) could be identified as a fourth group named highly susceptible (FRR = 0). This ranking based on FRR gives a better understanding of the effect of sowing date on yield. Indeed the only genotypes for which yield is increased by fall planting (early November) are those falling in class 1 (resistant to frost, Fig. 3a). For the others the yield is either unaffected (Fig. 3b) or even decreased (Fig. 3c). For all genotypes the worst sowing date was December 6, because it provided the worst soil conditions for germination (low temperature and excess of moisture).

These results and those obtained at ICARDA, clearly show that a large genetic variability exists in chickpea for resistance to frost, but its expression depends on the plant growth stages in relation to the frost environment. The effect of frost on the plant is mainly depending on

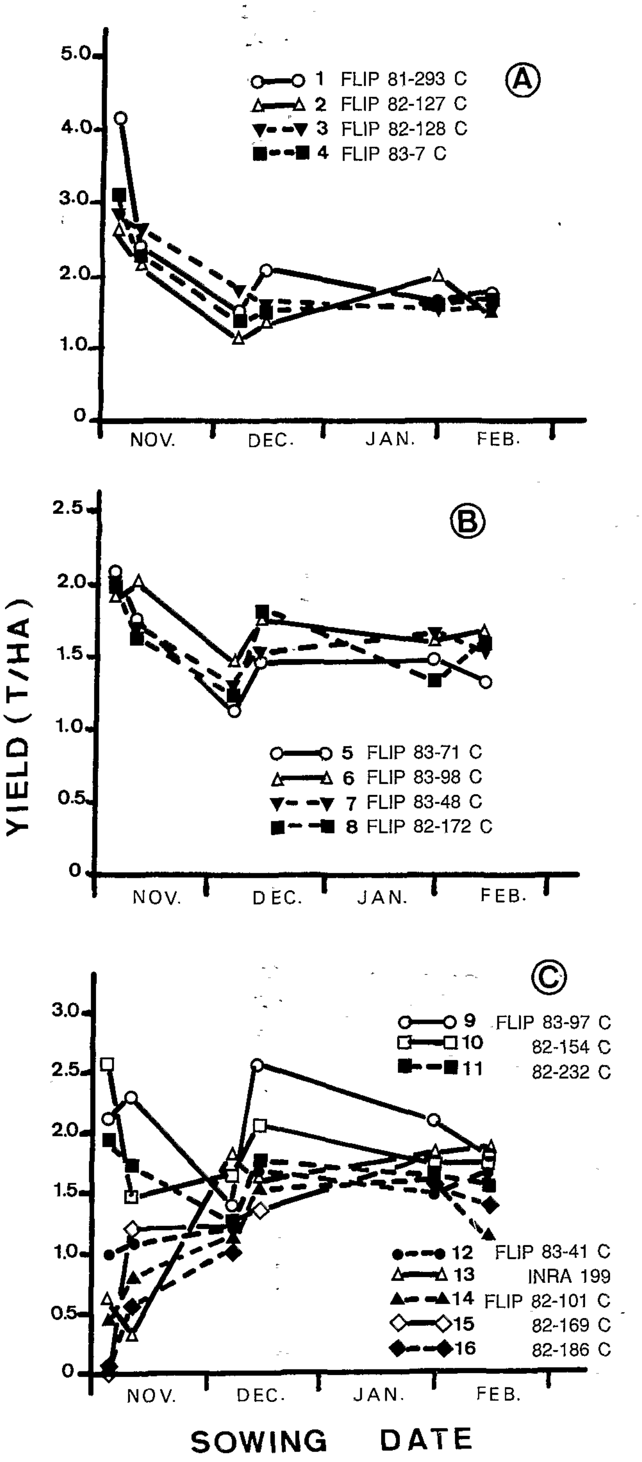

Fig. 3. Effect of sowing date on chickpea yield according to the level of resistance to frost.
a: Genotypes resistants to Frost (average FRR=0.85)
b: Genotypes tolerants to Frost (average FRR=0.40)
c: Genotypes susceptibles to Frost (average FRR=0.20)
(November to February)

two factors: phenological stage of crop and the degree of lowering of temperature.

Phenological stage

Resistance to frost seems to decrease with plant age from germination and this could explain the strong effect of sowing date on FRR previously shown. Chickpea seems to react in the same way as other grain legumes with hypogeal germination such as pea or faba bean. The results obtained on lupine (Papineau, 1987) and cereals (Couvreur *et. al.*, 1979) show that resistance to frost strongly decreases during germination and increases during tillering (cereals) or crown formation (lupine); then falls down again during stem elongation. We have no observation to prove that chickpea does not show this decrease in resistance to frost during germination, but this trait would be incompatible with our results indicating a better resistance to frost before emergence (obtained by late sowing). In fact if we compare the evolution of temperature over the soil surface and under the soil surface (data not shown) we can conclude that during the germination phase the chickpea seedlings are protected by the buffering role of soil. Indeed, even when air temperature (at 10 cm above soil surface) fell down to -12°C, it never became negative at 10 cm below the soil surface. After emergence the increase in frost resistance could be explained by the hardening process: lowering of cells' freezing point by organic (mainly saccharose and glucose) and mineral compounds storage (Couvreur *et. al.*, 1979). During the active growth associated with stem elongation the plant would become unable to maintain such high concentrations and would progressively lose its resistance. In addition frost susceptibility is probably increased by stem elongation which lets the growing points pushed up in the colder air layers. So chickpea cold resistance could be incompatible with ability to grow before and during winter. The chickpea breeders would probably have to look for genotypes with vernalization needs in order to avoid this pre-winter growth and allow the plant to harden (Couvreur *et. al.*, 1979), and perhaps to initiate more branching.

Temperature minima

For a given phenological stage and a given genotype, frost susceptibility seems to depend on the minimum temperature experienced by the crop. The traditional large kabuli types seem to resist temperatures as low as -8°C (at soil level) even at a late stage (10-11 leaves) (Montfort 1987/88 - L.R.M. Castaing, personnal communication). But they are killed at -10°C regardless of the phenological stage. The most resistant genotypes (for example: FLIP 81-293C) resisted post emergence temperature of -12°C under shelter (about -13 or -14°C at the crop level) (Trial 2). These genotypes have resisted temperatures as low as -11°C (at crop level) at a very late stage (13 leaves) (Montfort 1987/88 . L.R.M. Castaing, personnal communication). But they were killed by temperature of -18.5°C after emergence (Trial 5).We can conclude that we have today some genotypes of chickpea that can be sown in November as they can resist temperatures as low as -15°C at crop level. Of course with a snow cover they can survive much lower temperatures. Koinov (1968) cited by Van der Maesen (1972) reported that some chickpea cultivars can resist temperatures as low as -12.9°C without snow cover and -29°C with 5 cm of snow.

In addition to phenological stage and the degree of lowering of temperature, resistance to cold could also depend on temperature during the previous days because high temperature can decrease the hardening level (Couvreur *et. al.*, 1979). This phenomenon could explain the damages caused by spring frost.

Although we have still a poor knowledge of genetical and physiological basis of resistance to frost in chickpea, our results and those from ICARDA lead us to propose a simple method for screening a large number of chickpea genotypes, even at low altitude. This includes the following:

1) Nursery to be sown at 2 or 3 dates (with about one month interval), from the middle of October, in order to be sure to have each year a good screening.

2) A susceptible check (ILC 482 or ILC 1929 according to location) to be sown after each 10 genotypes.

3) Establish a ranking of the cultivars according to their Frost Resistance Ratio (FRR) in the best screening date which can be defined as the one where the average FRR of the check is lower than 0.3. The latest sowing date is used for evaluating other characters mainly those linked with productivity.

This kind of selection where the plants are facing unusual frost conditions could be also interesting for the regions having moderate frost (temperatures not falling below -8°C or -10°C) where the susceptible lines do not show clear symptoms of damage but are affected adversely enough to later show decreased yield or increased susceptibility to disease or drought. Indeed, it is interesting to notice that the 3 best genotypes we selected for frost resistance in Montpellier (FLIP 81-293C, FLIP 82- 127C, and FLIP 82-128C) were frequently ranked in the 5 best genotypes for yield in the 1985 ICARDA Winter Nurseries (CIYT-W-MR-85) (ICARDA, 1987); and the fact that ILC 482 was also in the 5 best proves that these trials were carried out in milder conditions.

These results also lead us to propose 3 types of chickpea crops for Mediterranean region where temperatures can fall down below -10°C:

1) *Fall chickpea:* The most interesting for yield (potential of 5 t/ha in good soils) but only possible with genotypes that rank resistant to frost (for example FLIP 81- 293C) and assuming that temperatures will not fall down below -15°C. The sowing must be early enough for allowing germination and emergence before the first frost (i.e. early November in Montpellier).

2) *Winter chickpea:* For this type of crop the strategy is to obtain a phenotypic resistance to frost by sowing late enough to avoid any growth before winter (i.e. from early December to early February according to the elevetion). Cultivars which are ranked as susceptible to frost such as ILC 482, ILC 3279, INRA 199 can also be used for this crop. December sowing is only interesting if emergence can take place during the winter; otherwise most of the seeds will be killed and plant population will limit yield. The only exception appears to be cultivar INRA 199 (with black and thick seed coat) which can tolerate these conditions and emerge perfectly in spring. This can explain why it ranked first for yield in December sowing in Trial 3. This strategy could be interesting for high elevation regions of the Mediterranean basin.

3) *Spring chickpea:* Sown as soon as possible between the end of February and the end of March in order to escape frost. in that case we can use cultivars which are susceptible or very susceptible to frost as long as they are productive and resistant to drought.

These 3 chickpea crops need to be compared in a range of agro-climatic conditions in order to define their suitability for the various farming systems of the Mediterranean region.

Effect of early sowing on water status of chickpea

As we have seen previously, breeding for frost resistance can allow substantial increase in chickpea yield (100% or more) with winter sowing. In order to understand the effect of these early sowings on yield their influence on the factors most limiting chickpea production in our region namely the water supply was investigated.

Chickpea water consumption was studied in 3 different trials during 3 growing seasons in Montpellier. In two of these studies there were two sowing dates. Cultivars ILC 482 and INRA 199, which have very similar growth pattern, were used (Ayadi, 1986). For each treatment the chickpea water consumption, actual evapotraspiration (AET) as the sum of rainfall (R) and soil water consumption (SWC), was measured upto 1.6 m depth at 10 day intervals with a neutron probe (4 access tubes per treatment). Yield and yield components were also studied. The data on the cumulative evapotranspiration

Table 4. Crop water balance and water use efficiency in chickpea.

Trial	Sowing date and cultivar	Water consumption (mm)			Yield t/ha		Harvest index	Water use efficiency (kg DM/mm)		Crop cycle	
		Rainfall	Soil	Total	Total	Grain		For total biomass	For grain	Emergence	Maturity
1 1985 (Deschamps, 1985)	Early spring (INRA 199)	120	100	220	(9.85)	2.71	(0.28)	(44.81)	12.3	03/26/85	07/09/85
2 1986 (Ayadi, 1986)	Early spring (INRA 199)	163	113	276	5.01	2.74	0.55	18.2	9.9	03/24/86	07/10/86
	Late spring (INRA 199)	103	118	221	4.76	2.40	0.50	21.5	10.9	04/23/86	07/15/86
3 1987 (Ayadi, pers. com.)	Winter (ILC 482)	152	116	268	5.20	2.97	0.57	19.4	11.1	02/25/87	07/15/87
	Late spring (ILC 482)	59	153	212	4.51	2.57	0.57	21.3	12.1	04/16/87	07/15/87

(CAET) between emergence and maturity and its two components, rainfall and soil water consumption are presented in Table 4. The consumption ranged between 100 mm and 150 mm of water stored into the soil confirming that chickpea has a good capability to extract stored moisture. This feature is probably the main component of chickpea's adaptation to drougt. With cultivar ILC 482, Keatinge and Cooper (1983), report soil water consumptions between 70 and 100 mm in more arid conditions and soil water consumptions of about 170 mm in conditions more similar to ours (fall sowing in northern Syria). In the earliest sowing (Fig. 4a) chickpea extracted most of its water from the first 60 cm, that is, in the soil layer where most of the roots are (Keatinge and Cooper, 1983; Gupta and Agrawal, 1977 cited by Saxena, 1987). Beyond 1 m depth water consumption is very weak but it goes on until about 1.5 m depth, mainly in spring sowing (Fig. 4b) which confirms the results of Keatinge and Cooper (1983) and Singh and Bhushan (1979) cited by Saxena (1987). That means that chickpea has deep roots but their density is too weak to allow them to sufficiently support the plant. After 1 m depth soil water consumption was about 2 to 4 mm/10 cm depth and it was between 12 and 20 mm/10 cm depth above 60 cm depth. In addition, in the drier climate the rainfall is sometimes too low to fill these deep soil layers (Keatinge and Cooper, 1983). Nevertheless this deep water consumption takes place at the end of the cycle and could play a significant role in pod filling. Indeed Fig. 4 shows that most of the water stored in the upper soil layers has already been consumed by the middle of May, that is by the beginning of flowering for spring sowing and beginning of pod filling for winter sowing. This situation is very detrimental to yield and to nitrogen fixation because most of the nodules are in the first 30cm of soil.

Late sowing changes the pattern of soil water extraction to the benefit of the deepest soil layers (down to 1.6 m depth) where more water is available for the second part of the growth cycle (Fig. 4). This means that chickpea is able to extract water from deeper soil layers, and this character induced by late sowing could probably be improved by breeding even for early sowing as well. Compared to traditional mid-March sowing, the earlier sowings studied here (mid-February for Trial 2 and early December for Trial 3) induced an increase in total water consumption: cumulative AET increased on an average

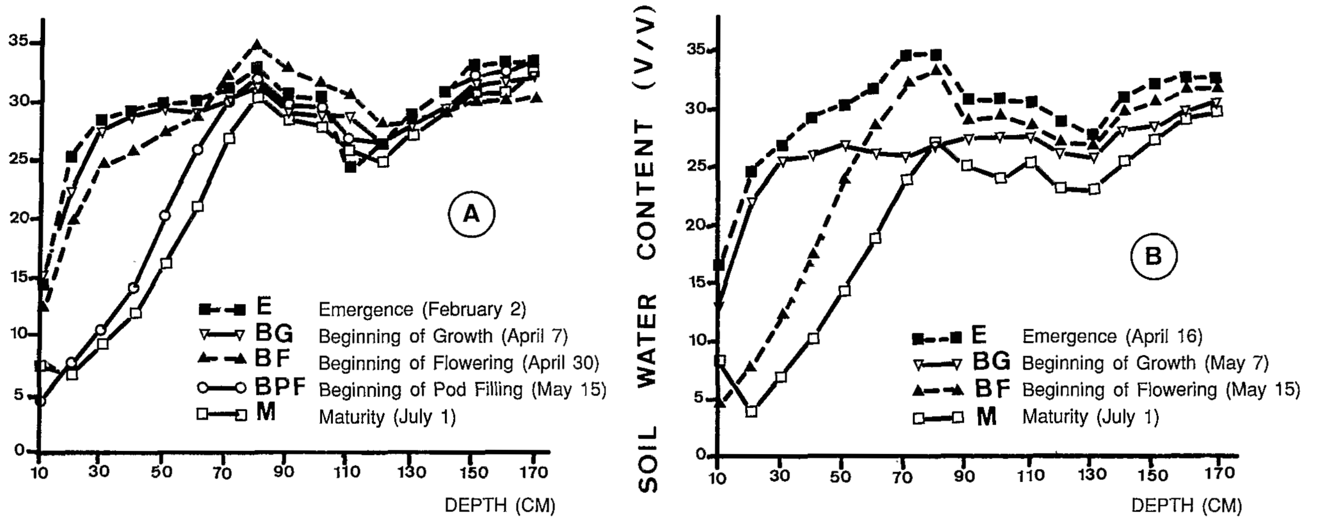

Fig. 4. Evolution of soil water content during the cycle of winter chickpea (a) and spring chickpea (b).

by 27.7% (Table 4). This increase is obtained through a better efficiency of winter and spring rainfalls because soil water extraction was lower in the earlier sowings (Table 4). Even with fall sowing in drier regions, Keatinge and Cooper (1983) arrived at the same conclusion: no increase in soil water extraction but better efficiency of winter rainfall in the earliest sowing, due to an increase in the transpiration/soil evaporation ratio. Finally these results lead to the conclusion that replacing spring by fall or winter sowing will not deteriorate the water balance of the cropping systems. In our conditions the seed yield increase induced by early sowing is only coming from the increase in amount of water used and Water Use Efficiency (WUE) is very stable (Table 4); on an average 11.3 kg seeds/mm of water used (CV = 8.6%). This value is quite similar to the one obtained by Keatinge and Cooper (1983) in fall sowing in northern Syria, and to the ones cited by Saxena (1987).

The above observations can be synthesized adopting approach suggested by Blum (1987) for the relationships between grain yield and water use:

Grain yield = (CAET) x (WUE)) x (HI), where HI is harvest index. As previously shown winter sowing and early spring sowing increase chickpea grain yield because they increase water consumption (CAET) with no influence on the other two parameters (WUE and HI)). By using our results (where WUE = 19.8 kg DM/mm, CV = 7.5% and HI = 0.54, CV =5.5%) we could propose the simplified formula for predicting the yield (g/ha) of grains of ILC 482 in winter or spring sowings as follows:

Grain yield (g/ha) = CAET (in mm) x 0.107

These experiments lead us to conclude that breeding for resistance to cold and ascochyta blight is probably one of the most efficient ways to improve drought resistance in chickpea through an increase in water use efficiency (fall sowing in dry regions) and/or an increase in water consumption (winter sowing or early spring sowing). In addition we can expect that one or two irrigations (where available) applied during the seed filling phase could greatly improve chickpea grain yield by increasing its evapotranspiration (Saxena, 1987). With an early spring sowing we obtained a 30% increase in grain yield by applying two irrigations of 35 mm after the first pod appearance (data not shown). But we have to keep in mind that chickpea is extremely sensitive to excess of irrigation at this stage, which can create lodging and excessive vegetative growth (Saxena, 1987; Wery *et. al.*, 1988). Nevertheless chickpea will essentially remain as a rainfed crop and increasing drought stress resistance of spring chickpea remains as one of the major goals for the breeders. The approach of Blum (1987) presented above could help us in defining three complementary ways for achieving this goal:

1) Improvement of AET could be obtained with an increase of water extraction in the bottom of the soil profile (under 80 cm depth) by getting a higher root density under this depth. This feature will be translated in a higher transpiration during pod filling, which could be assessed with an indirect method such as infrared-thermometry (Blum, 1987). According to Saxena (1987), this method has already been successfully tested on chickpea at ICRISAT.

2) Improvement of WUE could be obtained by looking for plants which are able to function more efficiently in dry and warm conditions. Improvement of osmotic

adjustment could be the major way to achieve this goal and the breeders could use indirect measurements, such as chlorophyll fluorescence for checking plant function under stress. In addition WUE could be improved by looking for an increase in the transpiration/evaporation ratio similar to the effect created by early sowing (Keatinge and Cooper, 1963). The breeders would look for a rapid increase in leaf are index in spring chickpea. Of course they will have to maintain the classical breeding objective of drought escape through early flowering and maturity.

3) Improvement of harvest index could be obtained by looking for plants able to remobilise more C and N from the stems, the leaflets and the pod wall, according to the approach developed on cereals by Blum (1987). A genetic variability seems to exist in chickpea for this character and it seems to be negatively correlated with response to irrigation (Khanna-Chopra and Sinha, 1987).

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