

## Garlic (*Allium sativum* L.) and its Wild Relatives from Central Asia: Evaluation for Fertility Potential

R. Kamenetsky, I. London Shafir and  
M. Baizerman  
Department of Ornamental Horticulture  
ARO, The Volcani Center  
PO Box 6  
Bet Dagan 50250  
Israel

F. Khassanov  
Institute of Botany  
Uzbek Academy of Science  
Tashkent  
Uzbekistan

C. Kik  
Plant Research International  
PO Box 16, 6700 AA Wageningen  
The Netherlands

H.D. Rabinowitch  
The Hebrew University of Jerusalem  
Faculty of Agricultural, Food and  
Environmental Quality Sciences  
Institute of Plant Science and Genetics in  
Agriculture  
Department of Field Crops, Vegetables and  
Genetics  
PO Box 12  
Rehovot 76100  
Israel

**Keywords:** fertility restoration, florogenesis, topsets, bulblets, *Allium longicuspis*

### Abstract

Garlic (*Allium sativum* L.) a popular condiment, is completely sterile, and thus is propagated only vegetatively. According to modern taxonomy, *A. sativum* and its closest wild relative *A. longicuspis* form a species complex. The collection of a large number of accessions of these taxa is the only means available for expansion of the genetic variability with regard to yield, quality, tolerance to biotic and abiotic traits, as well as flowering and possibly fertility restoration. A large number of garlic accessions was recently collected in Central Asia, the main center of garlic diversity. Plants were documented according to IPGRI rules, and thereafter evaluated and maintained in the field collections of vegetatively propagated alliums in Israel. The studied accessions were subdivided into two distinct sub-populations: semi-bolters and bolters. Most of flower-producing accessions produced both fertile pollen and receptive stigmas, and true garlic seeds were obtained from 5 accessions, collected in Kazakhstan in 1996-1998. The garlic inflorescence is an umbel-like structure with flower clusters (branches) arising from a common meristem. The flower morphology is typical of the genus *Allium*. Differentiation of topsets begins in the periphery of the apical surface only after floral differentiation has occurred, and the size, number and rapidity of topset development varies significantly between genotypes. Further studies of flowering physiology and fertility restoration, should focus on bolting genotypes which produce inflorescences with a high ratio of normal flowers to topsets.

### INTRODUCTION

Garlic (*Allium sativum* L.) cultivars are completely sterile and thus are propagated only vegetatively. The bulbs are used as a fresh condiment all over the world, and also as an important component in food-processing and nutraceutical industries. In addition, man consumes a number of wild relatives of the domesticated *A. sativum*, as garlic substitutes. Wild species *A. longicuspis* Regel, was considered by taxonomists as the closest relative to, or ancestor of the domesticated garlic (Regel, 1875). However, modern taxonomists suggest that garlic and *A. longicuspis* form a species complex (Maaß and Klaas 1995;

Fritsch and Friesen, 2002). In the absence of sexual processes, random or induced mutations are the main sources for genetic variation, and thus, the introduction of new accessions of garlic is a very effective approach to expand the genetic variability of economic traits, including flowering and fertility.

Garlic genotypes vary markedly in their ability to produce flower stalks, as well as in the flower to topset ratio in the umbel (Etoh, 1985, 1986; Zizina, 1956). In this context, Etoh (1985) suggested that garlic undergoes a transition from sexual to asexual reproduction, and that man, through generations of selection has accelerated this process.

Fertility restoration in garlic has been attempted by many researchers (e.g., Kononkov, 1953; Novak and Havranek, 1975; Etoh et al. 1988; Konvicka, 1984; Etoh and Simon, 2002), and it has been suggested that the presence of vegetative topsets is one of the major causes of sterility. Hence, topset removal and the application of antibiotics to the floral stems resulted in 17 viable seeds (Konvicka, 1984). Later, Etoh et al. (1988) found fertile garlic plants in the Tien Shan Mountains (between Kazakhstan and China) and were able to produce viable seeds. Pooler and Simon (1994) improved seed set by scape decapitation and the removal of topsets, but seed germination rates were low ranging between 10 and 12%.

Inaba et al. (1995) and Jenderek (1998) obtained 50,000, and 1.2 million garlic seeds, respectively. In the latter work, 27 clones were classified as highly fertile producing over 400 seeds per umbel, and seed germination ranging from 67% to 93%. The removal of topsets was necessary only in the early generations, as the strong selection pressure for flowering and seed production resulted in improved fertility. The remarkable effect of selection on the improvement of garlic seed production indicates the significance of the genetic control of this trait. Recently, 36 fertile accessions were identified in two USA public garlic collections (Jenderek and Hannan, 2000). Among seed bearing clones, the number of seeds produced in the first propagation cycle ranged from 0 to 85 per umbel, and a total of about 14,000 seeds were harvested.

Garlic clones are classified according to their ability to produce a visible scape and flowers, as follows: (1) *Complete bolters* – plants producing a long, thick flower stalk, with many flowers and topsets; (2) *Incomplete bolters* – plants producing a thin, short flower stalk, and bearing only a few large topsets, with a few or no flowers; (3) *Nonbolters* – plants which normally do not form a visible flower stalk, or produce a deformed stalk with an aborted umbel and cloves inside the incomplete scape (Takagi, 1990). In addition, bolting in garlic is strongly affected by the environment. In non-bolters or incomplete bolters, temperature and light may promote scape elongation or, under adverse conditions, scape elongation of bolting plants may be suppressed (London, pers. obs.).

Little is known of the morphological events during apical meristem transition from the vegetative to reproductive state. The first account was given by Etoh (1985) with a description of the initial stages of flower primordia differentiation and of flower-bud formation in cv. Shanhai-wase, including the development of flower meristem, flower differentiation and the concomitant initiation and development of topsets.

During 1995-2000, collection missions to Central Asia have gathered a large number of garlic landraces, as well as *A. longicuspis* accessions from natural populations. We provide detailed information on the sequence of morphological processes during florigenesis and seed development in selected accessions, collected between 1995 and 1999 in the framework of a joint Israel-Kazakhstan project (Baitulin et al., 2000). In addition, we describe a number of developmental traits, flowering response and fertility of 115 accessions collected in Central Asia in 2000 in the framework of the EU project “Garlic and Health”, and grown in Israel.

## **MATERIALS AND METHODS**

### **Collecting and Evaluation**

Plants were purchased at local village markets or collected from natural populations

in Central Asia (Kazakhstan, Uzbekistan and Kirgызstan). All records on collection sites and local environments were made in compliance with the IPGRI plant passport descriptors (Astley et al., 1982). Original records are kept in Bet Dagan, Israel.

In October-November, bulbs were stored at 5 C, RH 65-70%, for eight weeks. Thereafter, individual cloves were separated and planted at a designated plot in the Experimental Farm of the Faculty of Agricultural, Food, and Environmental Quality Sciences, The Hebrew University of Jerusalem, in Rehovot. Standard agricultural practice was employed throughout. Phenological observations were made between November 2000 and June 2001, including measurements of leaf number prior to bolting, maximal scape length at bolting; date of spathe opening; topset/flower ratio in the inflorescence and bulb structure.

Pollen germination ability was assessed in Petri dishes. Anthers were crushed in artificial medium (1% agar + 15% sucrose), and germination was determined under a light microscope after 2-3 hours of incubation at 23-26°C (Hong and Etoh, 1996).

Stigma receptivity was determined according to Dafni and Maues (1998). Macheray-Nagel Peroxtesmo Ko peroxidase test paper (15x15 mm) was soaked in 1 ml distilled water, and 1-2 droplets of the solution were applied directly onto a freshly cut stigma. The development of a blue color in the presence of peroxidases serves as an indication of stigma receptivity.

### **Floral Development**

Florogenesis was studied in 12 bolting garlic accessions, collected in 1995-1999 in Central Asia and preserved in the Field Gene Bank for Vegetatively Propagated Short-Day *Allium* spp., in Rehovot, Israel. Mature bulbs were harvested in May and the dried leaves were trimmed. Intact bulbs were stored through the summer in the shade under ambient conditions. In October, the bulbs were broken, and individual blemish-less cloves were planted at the Experimental Farm in Rehovot. Once a month, five to seven plants were randomly sampled for morphogenetic studies.

The freshly harvested plants were carefully stripped of their leaves, and the spathes removed from the developing floral buds. For microscopic observations, isolation of meristems or developing inflorescences was performed under a stereomicroscope in small Petri dishes containing distilled water. The excised meristems were fixed in a 5:5:90 (v:v:v) mixture of glacial acetic acid:formalin (40%):ethanol (70%), and dehydrated in a graded acetone series (35, 70, 90, 100%) and Freon. Immediately thereafter, the fixed tissues were dried using liquid CO<sub>2</sub> in a Biorad 750 (England) critical point dryer (Kamenetsky, 1994). Samples were then mounted on SEM stubs with double-sided tape, sputter-coated with approx. 10 nm of gold, and studied under a JSM-35C scanning electron microscope (JEOL, Japan) with an accelerating potential of 15 kV.

### **Seed Viability and Germination**

Seeds were harvested upon maturation in July 2001, threshed and kept in tightly sealed plastic bags at 20 C. In October, garlic seed viability was assessed using the tetrazolium chloride staining test. Seeds were imbibed overnight in a beaker containing tap water in the dark at 20-25 C. The flat side of the seed coat was carefully scratched with a sharp scalpel, avoiding the endosperm and the embryo. The incised seeds were placed in 1% water solution of 2, 3, 5-triphenyl tetrazolium chloride, and incubated in the dark at 30 C for 12 hours. Then, the seeds were cut longitudinally through the endosperm and the embryo was exposed. Red staining of the entire embryo, root-tip and endosperm indicated high viability (Peters, 2000). For studies on garlic seedlings, seeds were stratified prior to germination in a planting mixture containing quartz sand and peat (4:1, v:v).

## RESULTS AND DISCUSSION

### Evaluation of Garlic Collection for Fertility Potential

Phenological observations of 115 accessions of garlic collected from Central Asia in 2000 (Fig. 1), and maintained in Israel, revealed two major sub-populations of incomplete bolters (producing blind scapes) and bolters (producing flowering scapes). Three accessions produced neither bulbs nor floral scapes (non-bolters), and died at the end of the vegetative season. Under our experimental conditions, bolters and incomplete bolting accessions differed in leaf number, bulbing ability and bulb characteristics (Table 1). The mean leaf number of the incomplete bolters was significantly lower than those of bolters ( $t_{110} = 7.02$ ,  $P < 0.0001$ ). At the same time, bulb diameter and number of cloves in the outer whorl of the incomplete bolters were significantly higher than those of bolters ( $t_{109} = 2.73$ ,  $P < 0.0$ , and  $t_{109} = 2.28$ ,  $P < 0.05$ , respectively).

The 42 bolting accessions differed significantly in a number of traits, including: leaf number prior to bolting, flowering date (date of spathe opening), and final stem length (Table 2). We have further divided the 42 bolting accessions into three subgroups according to their flowering date, flower/topset ratio and pollen viability (Table 2, Figs. 2 a, b). It was evident that only the two late-flowering subgroups produced fertile pollen and receptive stigmas.

### Floral Development

In garlic plants from cloves, the transition of the apical meristem from the vegetative to reproductive state occurs during the active growing stage, after the formation of six to seven leaves (including leaf primordia). An initial elongation of the flower stalk precedes the spathe (prophyll) formation and the swelling of the floral meristem. The differentiation of floral initials begins only after the scape reaches 5-7 mm in length and the apex diameter exceeds 0.5 mm. Later, the apical meristem subdivides to form several swellings, each of which gives rise to a number of individual flower primordia. Concomitantly, leaf-like membranous bracts appear at the periphery of the inflorescence, and grow faster than the developing floral primordia. The differentiation of individual flowers begins when the inflorescence meristem reaches a diameter of about 2-3 mm (Kamenetsky and Rabinowitch, 2001).

In the individual flower, each perianth lobe and the subtended stamen arise simultaneously from a single primordium, as in bulb onion (Jones and Emsweller, 1936; Esau, 1965; De Mason, 1990) and shallot (Krontal et al., 1998, Rabinowitch and Kamenetsky, 2002). Following the differentiation of the outer perianth lobes and stamens, the inner whorl is differentiated, and the carpels are initiated when the outer perianth lobes overarch the stamens. Earlier work by Etoh (1985) indicated that floral malformations and the abnormal formation of embryo sacs occur during flower differentiation of the Japanese cv. Shanghai-wase. In our study, however, no such malformations were observed.

When the floral stalk reaches 15 cm in length, the pedicels elongate and the inflorescence becomes spherical. At this time, new undifferentiated domes, 0.15 mm in diameter, become visible at the periphery of the inflorescence, these quickly differentiate and develop into small inflorescence bulbs, i.e., topsets.

The formation of flowers and topsets was almost complete when the stalks reached about 30 cm in length. The spathe opened when the scape was 35-50 cm long. At this time, the differentiated flowers were visible to the naked eye. The growing topsets usually intermingled with the young flowers, and physically squeezed the developing floral buds, thus causing their degeneration. Therefore, in some garlic clones, the continuous removal of the developing topsets resulted in normal flowering, and provided that viable pollen was available, pollination and fertilization was followed by seed production (Pooler and Simon, 1994; Konvicka, 1984; Etoh et al., 1988; Koul and Gohil, 1970).

## Genotypic Variation

Prior to spathe opening, 12 bolting garlic clones (obtained in the 1995-1996 collection mission, and preserved in Rehovot), were studied microscopically, and consequently grouped into four distinct morphological types of developing inflorescence (Kamenetsky and Rabinowitch, 2001):

Type 1 - The inflorescence consists of many developing flowers differing significantly in their levels of differentiation. Leaf-like bracts form mainly in the periphery of the inflorescence, but a few bracts appear in the heart of the umbel. The differentiation of small topsets is first noticed when the young flowers are already formed (four accessions).

Type 2 - The inflorescence contains only a small number of flowers, and many leaf-like bracts develop all over the apical surface. The relatively small topsets are located in the axils of the peripheral bracts (four accessions).

Type 3 - The differentiated flower primordia abort. Numerous large, leaf-like bracts develop in the periphery of the apical surface, and small topsets develop in the axils of these peripheral bracts (two accessions).

Type 4 - All flower primordia abort soon after their differentiation commences. Leaf-like bracts develop on the apical surface, and large topsets differentiate in their axils (two accessions).

We propose that further studies on flowering physiology and fertility restoration of garlic should focus on clones capable of producing normal flowers (Type 1). The other types will serve as a useful research tool following the understanding of the genetic and physiological mechanisms of garlic flowering and its reversion to the vegetative phase.

## Seed Development

True garlic seeds were obtained from five accessions collected in Central Asia between 1996 and 1999. On average, 400-500 seeds were produced per umbel, without the removal of topsets. These figures are similar to those obtained with topset removal by Jenderek (1998) and following 5-6 generations of selection for fertility restoration by Jenderek and Hannan (2000). In October, high seed viability was confirmed using the tetrazolium chloride staining test. Thereafter, stratified seeds were sown outdoors in December 2001 in Bet Dagan. Germination rate reached ca 90%, and the seedlings developed normally. The young plants formed 2-5 leaves prior to bulbing and ripening in March. Single-clove bulbs with white, purple, gray and brown skins varied in size between 0.5 and 2 cm in diameter. They also differed in bulbing ability and maturation date (Fig. 3).

## CONCLUSIONS

The extreme variation in phenotypic responses of garlic accessions from a single geographical region, especially with regard to flowering traits and seed production, can be explained by the large genetic divergence of garlic species complex in Central Asia. Many alliums have been reported as cross-pollinators, but no information is available for *A. sativum* or *A. longicuspis*. However, the segregation of the seedling populations obtained in this study, indicates that the cross-pollination habit in garlic could provide a sound explanation for the high diversity in Central Asia. Karyotype, isozyme and RAPD analyses by Etoh (1984), Pooler and Simon (1993), and Maaß and Klaas (1995), as well as our observations on variation in flower/topset ratio, pollen production and viability, stigma receptivity, and inflorescences morphology (Tables 1, 2; Fig. 2a and 2b; Kamenetsky and Rabinowitch, 2001, 2002) support this assumption.

It is evident, that a number of processes are involved in garlic florogenesis. However, only little is known of the basic chain of processes, which if successful, ends in normal flowering and fertility. Microscopic studies of bolting accessions provided evidence for the presence of at least four different patterns in inflorescence differentiation (Kamenetsky and Rabinowitch, 2001). In spite of the fact that floral stalk elongation and flower differentiation occur simultaneously, the genetic regulation of the two processes is

probably different, and bolting (scape elongation) is necessary, not merely a condition for normal flowering. Full bolters from our collections varied considerably in flowering ability, i.e., almost half the accessions produced mainly topsets in the umbel, and were not able to flower (Table 2).

During inflorescence formation, topsets begin to develop at the periphery of the apical surface after flower differentiation. Following their initiation, topsets develop quickly and, in most cases, they physically squeeze the developing flowers thus causing their degradation and abortion. Size, number and growth rate of the developing topsets varied with genotype. In several clones, however, and especially in those with high flower to topset ratio, flower development reached completion and was followed by normal pollination, fertilization and seed development. A number of clones capable of producing normal flowers were able to develop normal seeds without topset removal. Better understanding of the genetic and physiological mechanisms, which control floral meristem transition and reversion from vegetative to generative state and back, will improve our ability to restore the fertility of sterile bolting clones.

In agreement with Etoh's (1985) hypothesized transitional phase of garlic plants from sexual to asexual reproduction, we observed failures at different stages of flower development and seed production, including: scape elongation, flower differentiation, alteration of floral meristem to vegetative state and extensive topset formation, production of fertile pollen or receptive stigmas in the developing flowers.

Mass production of seeds in 5 garlic accessions, the high rate of seed viability and seed germination, and the development of normal seedlings support the opinion that seed propagation of garlic may become a feasible option in the future (Etoh and Simon, 2002). Sexual reproduction can be exploited in plant breeding for improvements of yield, tolerance to biotic and abiotic stress conditions, and quality. In addition, seed (which normally do not transmit viruses) can be used for the production of virus-free propagation material.

Further studies on fertility restoration of garlic should include detailed investigations of flowering physiology of the prospective clones, as well as the molecular and genetic aspects of the regulation of meristem conversion from the vegetative to the generative state and vice versa.

## ACKNOWLEDGEMENTS

This study was performed in the framework of the EU project "Garlic and Health, The development of high quality garlic and its influence on biomarkers of atherosclerosis and cancer in humans for disease prevention" (QLK1-CT-1999-00498; [www.plant.wag-ur.nl/projects/garlicandhealth](http://www.plant.wag-ur.nl/projects/garlicandhealth)).

## Literature Cited

- Astley, D., Innes, N.L. and Van der Meer, Q.P. 1982. Genetic resources of *Allium* Species - A Global Report. International Board of Plant Genetic Resources, Rome.
- Baitulin, I.O., Agafonova, G., Rabinowitch, H.D. and Kamenetsky, R. 2000. Collection and preservation of Central Asian species from the genus *Allium* L., their biology and economic traits. In: E.I. Granovsky and E.E Fain (eds.), State and perspectives of scientific collaboration Kazakhstan-Israel. Almaty, Kazakhstan: 87-94 (in Russian)
- Dafni, A. and Maves, M.M. 1998. A rapid and simple procedure to determine stigma receptivity. *Sex. Plant Repr.* 11:177-180.
- De Mason, D.A. 1990. Morphology and anatomy of *Allium*. p. 27-51. In H.D. Rabinowitch and J.L. Brewster (eds.), *Onions and Allied Crops, I. Botany, Physiology, and Genetics*. CRC Press, Boca Raton, FL, USA.
- Esau, K. 1965. *Plant Anatomy*. 2nd ed. John Wiley, New York, London, Sydney.
- Etoh, T. 1985. Studies on the sterility in garlic, *Allium sativum* L. *Mem. Fac. Agri. Kagoshima Univ.* 21:77-132.
- Etoh, T. 1986. Fertility of the garlic clones collected in Soviet Central Asia. *J. Jap. Soc. Hort. Sci.* 55:312-319.

- Etoh, T., Noma, Y., Nishitarumizu, Y. and Wakamoto, T. 1988. Seed productivity and germinability of various garlic clones collected in Soviet Central Asia. Mem. Fac. Agri. Kagoshima Univ. 24:129-139.
- Etoh, T and Simon, P.W. 2002. Diversity, fertility and seed production of garlic. p. 101-117. In: H.D. Rabinowitch and L. Currah (eds.), Allium Crop Science – Recent Advances. CABI Publishing, Wallingford, UK.
- Fritsch, R.M and Friesen, N. 2002. Evolution, Domestication, and Taxonomy. p. 5-30. In: H.D. Rabinowitch and L. Currah (eds.), Allium Crop Science – Recent Advances. CABI Publishing, Wallingford, UK.
- Hong, C-J. and Etoh, T. 1996. Fertile clones of garlic (*Allium sativum* L.) abundant around the Tien Shan mountains. Breed. Sci. 46:349-353.
- Inaba, A., Ujiie, T. and Etoh, T. 1995. Seed productivity and germinability of garlic. Breed. Sci. 45, 310. (In Japanese)
- Jenderek, M.M. 1998. Generative reproduction of garlic (*Allium sativum*). Sesja Naukowa 57:141-145. (In Polish)
- Jenderek, M.M. and Hannan, R.M. 2000. Seed producing ability of garlic (*Allium sativum* L.) clones from two public US collections. Proceedings of the Third International Symposium on Edible Alliaceae. Athens, Georgia, USA, 2000. p.73- 75.
- Jones, H.A. and Emsweller, S.L. 1936. Development of the flower and macrogametophyte of *Allium cepa*. Hilgardia 10:415- 428.
- Kamenetsky, R. 1994. Life cycle, flower initiation and propagation of the desert geophyte *Allium rothii*. Int. J. Pl. Sci. 155:597-605.
- Kamenetsky, R. and Rabinowitch, H.D. 2001. Floral development in bolting garlic. Sex. Plant Repr. 4:235-241.
- Kamenetsky, R. and Rabinowitch, H.D. 2002. Florogenesis. p. 31-57. In: H.D. Rabinowitch and L. Currah (eds.), Allium Crop Science – Recent Advances. CABI Publishing, Wallingford, UK.
- Kononkov, P.F. 1953. The question of obtaining garlic seed. Sad i Ogorod 8:38-40. (In Russian).
- Konvicka, O. 1984. Generative Reproduktion von Knoblauch (*Allium sativum*). Allium Newsletter 1:28-37. (In German).
- Koul, A.K. and Gohil, R.N. 1970. Causes averting sexual reproduction in *Allium sativum* Linn. Cytologia 35:197-202.
- Krontal Y., Kamenetsky, R. and Rabinowitch, H.D. 1998. Lateral development and florogenesis of a tropical shallot - a comparison with bulb onion. Intl. J. Pl. Sci. 159:57-64.
- Maaß, H.I. and Klaas, M. 1995. Intraspecific differentiation of garlic (*Allium sativum* L.) by isozyme and RAPD markers. Theor. Appl. Gen. 91:89-97.
- Novak, F.J. and Havranek, P. 1975. Attempts to overcome the sterility of common garlic (*Allium sativum*). Biologia Plantarum (Praha) 17:376-379.
- Peters, J. (ed) 2000. Tetrazolium Testing Handbook 2000. Association of Official Seed Analysts (AOSA), Contribution No. 29.
- Pooler, M.R. and Simon, P.W. 1993. Characterization and classification of isozyme and morphological variation in a diverse collection of garlic clones. Euphytica 68:121-130.
- Pooler, M.R. and Simon, P.W. 1994. True seed production in garlic. Sex. Pl. Repr. 7: 282-286.
- Rabinowitch, H.D. and Kamenetsky, R. 2002. Shallots. p. 409-430. In: H.D. Rabinowitch and L. Currah (eds.), Allium Crop Science – Recent Advances. CABI Publishing, Wallingford, UK.
- Regel, E. 1875. Alliorum adhuc cognitorum monographia. Acta Horti Petrop. 3:1-256.
- Takagi, H. 1990. Garlic *Allium sativum* L. p. 109-146. In: J.L. Brewster and H.D. Rabinowitch, (eds.), Onions and Allied Crops, Volume III, Biochemistry, Food Science and Minor Crops. CRC Press, Boca Raton, FL.
- Zizina, S.I. 1956. Study of wild *Alliums* from Kazakhstan under cultivation. Thesis of Ph.D dissertation. Almaty, Kazakhstan, 1-16 (in Russian).

## Tables

Table 1. Phenological traits of bolting and incomplete bolting garlic accessions from Central Asia in Israel (means  $\pm$  SE, statistic analysis the Student t-test).

Scape performance	No. of accessions	Leaf number prior bolting	Bulb diameter, cm	Number of cloves in outer whorl
Incomplete bolters	70	10.4 $\pm$ 0.1 a	5.7 $\pm$ 0.1 a	9.4 $\pm$ 0.1 a
Bolters	42	12.6 $\pm$ 0.4 b	5.4 $\pm$ 0.1 b	9.0 $\pm$ 0.2 b

Table 2. Sub-grouping of 42 bolting garlic accessions according to physiological traits. Observations were made between May and July 2001, in Rehovot, Israel, when scapes reached their final length (means  $\pm$  SE).

Date of spathe opening	No. of accessions	Leaf no.	Scape length at flowering, cm	Flower: topset ratio	Pollen viability, %	Stigma receptivity
May 15 - June 5	18	10.6 $\pm$ 0.2	61.2 $\pm$ 1.8	Mainly topsets	0	-
June 6 - June 25	21	13.4 $\pm$ 0.5	80.7 $\pm$ 2.7	Mainly flowers	95	+
June 26 -July 5	3	15.7 $\pm$ 1.0	78.4 $\pm$ 6.8	Mainly flowers	100	+

## Figures



Fig. 1. Collecting sites in Uzbekistan, Kazakhstan and Kirgystan in 2000.



Fig. 2. Inflorescence development in two types of bolting garlic: A- mainly topsets; B- mainly flowers.

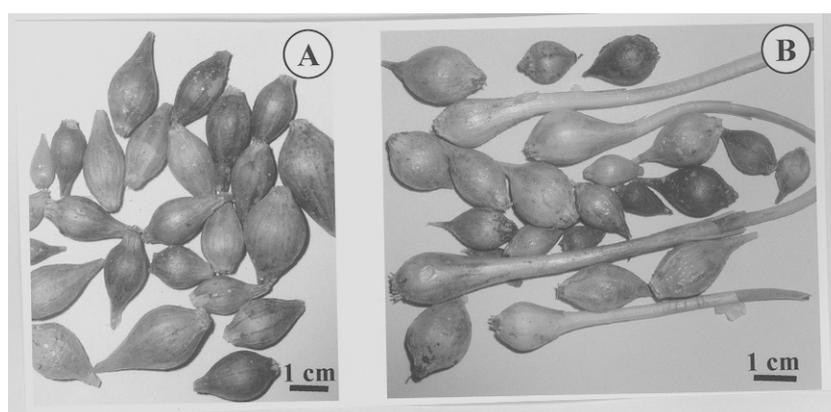


Fig. 3. One-year old bulbs from garlic seedlings: A – accession No. 3028; B- accession No. 3025 with complete and incomplete bulbing