Mutations of determinate growth and their application in legume breeding

by Andrey A. SINJUSHIN

Abstract: Mutations which cause determinate growth pattern in different leguminous species are briefly reviewed. Both their molecular basis and breeding value are in scope. With rare exceptions, the most part of cultivated legumes are characterized with an indeterminate growth pattern, when annual shoot proliferates unlimitedly producing new leaves and axillary racemose inflorescences. The presented short survey on mutations causing determinate growth type (DT) in few legume species may lead to conclusion that genetic basis for different DT types persists through evolution of the family. *TFL1*-dependent control of inflorescence structure seems conservative among Fabaceae, as mutations in *TFL1* orthologs cause similar phenotype.
Key words: inflorescence, Fabaceae, growth pattern

With rare exceptions, the most part of cultivated legumes, such as pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), vetches (*Vicia* spp.), vetchlings (*Lathyrus* spp.), chickpea (*Cicer arietinum* L.), pigeon pea (*Cajanus cajan* (L.) Huth), beans (*Phaseolus* spp.), soybean (*Glycne max* (L.) Merr.), fenugreek (*Trigonella foenum-graecum* L.) and many others, are characterized with an indeterminate growth pattern, when annual shoot proliferates unlimitedly producing new leaves and axillary racemose inflorescences. As a result, crop is usually harvested when lots of floral buds and pods remain of no practical value. A difference between potential productivity and actual yield is therefore striking.

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To overcome such disproportion and make seed ripening more synchronous, different monogenous mutations altering growth habit are being introduced into genotypes of cultivated legumes. Different cases of so-called determinate growth type (DT) are briefly described below.

Mutations in *TFL1*-like genes

Studies on a model plant species, *Arabidopsis thaliana* L. (Heynh.) (cruciferous family), uncovered a gene *TERMINAL FLOWER1* (*TFL1*) which maintains shoot apical meristem indeterminate. A terminal flower is formed in *tfl1* mutants. Three orthologs of *TFL1* were initially described in a garden pea (5). One of these orthologs, *PsTFL1a*, was found identical to already known gene, *DETERMINATE* (*DET*). Mutation *det* causes conversion of shoot apical meristem into racemose inflorescence, so the shoot ends with few-flowered raceme and no longer proliferates. Gene *DET* is tightly linked to gene *RUGOSUS* (*R*) which defines seed shape (rounded or wrinkled) and hence assignment of cultivar – grain (*R*) or vegetable (*r*). In Russia, two independently obtained mutants (*det r* and *det R*) were used for breeding new determinate vegetable and grain cultivars, respectively (6).

Combining recessive mutations *det* and *fa* results in production of weakly fasciated determinate peas which bear many-flowered apical raceme, somewhat similar to one of lupines (10, Fig. 1A). These forms were called "lupinoid" and are of potential value for breeding.

Using candidate gene approach, it was later demonstrated that mutations in orthologous *TFL1*-like loci cause DT in few other leguminous species: *Vicia faba* (1), *Phaseolus vulgaris* (8), *G. max* (11), and, recently, in *C. cajan* (9). Data on molecular basis for such mutations provides possibility of marker-assisted selection in breeding of new cultivars. Phenotypically similar forms with anomalous terminalized inflorescence were recorded in different alfalfa species, such as *Medicago sativa* (4) or *M. lupulina*. Most probably, these cases have the same molecular basis as in aforementioned leguminous taxa.

In some species, genetic control of shoot determinacy is more complicated than monogenous. For example, two non-allelic mutations, *dt1* and *dt2* (one of them disrupting a *TFL1*-dependent pathway), predispose to DT in *P. vulgaris* (3). In pea, different lines exist which have either 2 or 3-5 lateral racemes on *det* background (6). The latter phenomenon still awaits exploration.

Other types of DT

One more type of shoot determinacy is known in pea dealing with apex dying back rather than with production of ectopic terminal raceme. This DT is predisposed by mutation *determinate habit* (*deh*). Although possessing variable expression and possibly semidominant inheritance (2), this mutation is introduced into some Russian cultivars (e.g. Flagman 7).

Although species of the genus *Lupinus* L. normally have determinate shoots with multiflorous terminal racemes, a problem of breeding new cultivars with reduced lateral branching nevertheless exists. A genetic control of lateral branching is complex, but some mutations cause suppression of lateral shoots growth via conversion of axillary branch meristems into floral ones (7). As a result, single flowers are borne in axils of vegetative leaves (Fig. 1B). Similar phenotypes were discovered in *L. angustifolius* (narrow-leafed lupin) and *L. luteus* (yellow lupin) and such phenotype is called determinate in this genus.

Mutant with DT was induced in chickpea but, in addition to inflorescence determinacy, it also had floral abnormalities, sterility and reduced leaflet number (12). It has no practical value and its phenotype resembles pea mutants *unifoliata* (*uni*) more than *det*. The *uni* mutants also have flower and inflorescence distortions together with reduction of leaf complexity.

The presented short survey on mutations causing DT in few legume species may lead to conclusion that genetic basis for different DT types persists through evolution of the family. *TFL1*-dependent control of inflorescence structure seems conservative among Fabaceae, as mutations in *TFL1* orthologs cause similar phenotype. Possibly screening germplasm collections for mutations in certain loci or site-directed mutagenesis can result in breeding novel cultivars with desired inflorescence architecture.

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Figure 1. Determinate habit in pea (A) and yellow lupin (B): pea plant is also characterized with weak fasciation ("lupinoid" phenotype); single flowers in leaf axils are marked with arrows; photos were generously provided by Nina A. Vykhodova (A) and Vera S. Anokhina (B)

References

(1) Avila CM, Nadal S, Moreno MT, Torres AM (2006) Development of a simple PCR-based marker for the determination of growth habit in *Vicia faba* L. using a candidate gene approach. Mol Breed 17:185-190

(2) Belyakova AS, Sinjushin AA (2012) Phenotypic expression and inheritance of *determinate habit* (*deh*) mutation in pea (*Pisum sativum* L.). Abstracts, VI International Conference on Legumes Genetics and Genomics, Hyderabad, India, 2-7 October 2012, 353

(3) Bernard RL (1972) Two genes affecting stem termination in soybeans. Crop Sci 12:235-239

(4) Dzyubenko NT, Dzyubenko EK (1994) Usage of *ti* mutants in a breeding of alfalfa. Russ J Genet 30:41

(5) Foucher F, Morin J, Courtiade J, Cadioux S, Ellis N, Banfield MJ, Rameau C (2003) *DETERMINATE* and *LATE FLOWERING* are two *TERMINAL FLOWER1/CENTRORADIALIS* homologs that control two distinct phases of flowering initiation and development in pea. Plant Cell 15:2742–2754

(6) Kondykov IV, Zotikov VI, Zelenov AN, Kondykova NN, Uvarov VN (2006) Biology and breeding of determinate forms of pea. All-Russia Research Institute of Leguminous and Groat Crops, Orel

(7) Kunitskaya MP, Anokhina VS (2012) Genetic analysis of habit of branching determination in narrow-leaved lupine. Vestn BGU 2:46-49

(8) Kwak M, Velasco D, Gepts P (2008) Mapping homologous sequences for determinacy and photoperiod sensitivity in common bean (*Phaseolus vulgaris*). J Hered 99:283-291

(9) Mir RR, Kudapa H, Srikanth S, Saxena RK, Sharma A, Azam S, Saxena K, Penmetsa RV, Varshney RK (2014) Candidate gene analysis for determinacy in pigeonpea (*Cajanus* spp.). Theor Appl Genet 127:2663-2678

(10) Sinjushin AA, Gostimskii SA (2008) Genetic control of fasciation in pea (*Pisum sativum*). Rus J Genet 44:702-708.

(11) Tian Z, Wang X, Lee R, Li Y, Specht JE, Nelson RL, McClean PE, Qiu L, Ma J (2010) Artificial selection for determinate growth habit in soybean. Proc Natl Acad Sci U S A 107:8563-8568

(12) van Rheenen HA, Pundir RPS, Miranda JH (1994) Induction and inheritance of determinate growth habit in chickpea (*Cicer arietinum* L.). Euphytica 78:137-141