Proceedings of the 7th International Conference on Functional-Structural Plant Models, Saariselkä, Finland, 9 - 14 June 2013. Eds. Risto Sievänen, Eero Nikinmaa, Christophe Godin, Anna Lintunen & Pekka Nygren. http://www.metla.fi/fspm2013/proceedings. ISBN 978-951-651-408-9.

Analysis of hybrid vigor for cucumber with Functional-Structural plant model Greenlab

Xiujuan Wang[1], **Mengzhen Kang**[1,*], **Lili Yang**[2], **Baogui Zhang**[2], and **Philippe de Reffye**[3]
[1]*State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, 100190 Beijing, China,* [2]*China Agricultural University, 100193 Beijing, China,* [3]*CIRAD, UMR 51 AMAP 34398 Montpellier cedex 5, France*
**correspondence:* mengzhen.kang@ia.ac.cn

Highlights: To analyze the hybrid vigor between parent and hybrid plants, three cucumber cultivars were used (Parents: A, B; F1 hybrid: C). Continuous observations and destructive samplings were made throughout the growth of plants. Experimental results indicate that cyclic changes occur in the dry weights of organs (internode, leaf and petiole) of different positions along the stem. The yield, organ sizes and fruit numbers of the three cultivars were different. To analyze these differences, a Functional-structural model 'Greenlab' was applied to compute the parameters of source sink for organs. The results demonstrate that plant architecture plays an important role in heterosis breeding. This study is a first step to build a tool to provide the guidance of heterosis breeding for breeders on cucumber.

Keywords: Hybrid vigor, Cyclic variation, Greenlab model, Cucumber, Sink-source ratio, Fruit set

INTRODUCTION

Hybrid vegetable technology is one of the better options to improve cucumber yield, particularly because the full potential of hybrids has not been completely exploited in vegetable crops, as compared to several cereals. Hybrid vigour can be expressed by total yield and the increased yield due to larger number of fruits/plant. Yield and fruit quality are some of the most frequent traits influenced by heterosis. In cucumber, Hayes & Jones (1916) first observed heterosis for fruit size and fruit number per plant. The highest yielding hybrids gave higher yield and showed an increase in fruit size compared with corresponding parents.

In recent years with the rapid development of molecular biology and genomics progress has been made in the study of characters of high yield and the mechanisms for high yielding and their related genes. Plant type is one of the important factors to determine the yield (Du et al., 2007). The length of internode, the size and angle of leaves are three most characters of agronomic importance in cucumber. Ghaderi & Lower (1978) suggested that heterosis in yield components such as number or weight of leaves, branches, and roots should have a direct effect on fruit yield. F1 hybrids may have greater photosynthetic activity than their parents leading to higher yield. It is well known that the yield depends on the production and allocation of assimilates of plants, which is linked to source-sink ratio (Marcelis, 1994). The aim of the current study was to quantify the link between source-sink ratio and fruit-set for cucumber plants with different cultivars, compare the difference of organ growth, photosynthesis and biomass production between the F1 hybrid and parent plants using the Functional-Structural model 'Greenlab' to compute the source sink parameters of organs for cucumber plant. Thus, the model can analyse the heterosis and provide a virtual experimental tool for breeding.

MATERIALS AND METHODS

1. Experiment setup and measurements

The experiment was carried out in the greenhouse of China Agricultural University from April to July 2010. Plant material was cucumber (three cultivars: A, B and C). The cultivar C is F1 hybrid of A and B. Seeds of the three cultivars were sowed on March 9 2010. Cucumber seedlings with four leaves were implanted into 25-cm pots at April 10. The pots were filled with 70% peat, 20% vermiculite and 10% pearlite. 20, 20 and 10 pots of plants were planted for A, B and C, respectively. There were no water and fertilization stresses. Destructive measurements and continuous observations were made. In destructive measurements, 2 plants were selected to measure the dry weight of organs (internode, blade, petiole and root) and blade surface for three cultivars, at six stages along the growing period (10 April, 26 April, 17 May, 31 May, 16 June and 3 July. The measured data of the last four stages were used to estimate the source sink parameters of model for each cultivar. Continuous observations were made on 6 plants for each cultivar, twice per week. Detailed topological observations included the number of metamers (internodes, leaves and flowers and fruits), and the stage of development (flower bud, flower and fruit or abortion) for each position for the three cultivars.

2. Greenlab model

GreenLab (Yan et al, 2004) is a generic plant model simulating two basic processes of plant: development (organogenesis) and growth (organ expansion). The organogenesis is simulated with a dual-scale automaton, which gives the number of organs that participate in biomass production and allocation. At each time interval, called Growth Cycle (GC), plant structure is updated according to the organogenesis model. Biomass production *Q(i)* is calculated according to the initial biomass from the seed, total leaf area and ground projection area of plant at each GC. Biomass is distributed into growing organs according to their sink strengths. The ratio *Q(i)* and the total demand of plant *D(i)* represents the biomass availability for each organ, called source-sink ratio. The total biomass of organs can be computed by summing up the biomass of all individual organs of the same property, which can be measured in reality.

RESULTS

1. Experiment results

The phyllochron has no significant difference for the three cultivars. Thus, we can use the same time step in the model to compute the source sink parameters. The biomass and sizes of organs, biomass allocation at the plant level, total plant biomass, organ number and position changed for the three cultivars. Plants of cultivar A had larger biomass and organ sizes for internode, blade and petiole. By contrast, the cultivar B had less biomass and smaller organ sizes than A, while the cultivar C showed intermediate values (Data not shown). To take an example for fruits, total mean fruit dry weight per plant was C>B>A, while the maximum individual fruit dry weight was A>C>B at final harvest (Table 1).

Table 1 Comparison of fruit number and average weight per plant and standard error between the three cultivars.

	Mean No. Fruits	Mean total fruit dry weight (g)	Maximum individual fruit dry weight (g)
A	1.0±0.0	12.1±3.5	14.6
B	6.0±0.8	22.8±9.0	7.64
C	3.5±0.6	31.5±0.9	12.9

2. Estimation results

Target data for one plant from different sampling dates were fitted simultaneously, including the dry weights of individual internode, blade, petiole, fruit, and the total dry weight of each component. Following our observations, the maximum duration of expansion was set to 30 growth cycles for leaves and internodes, and 35 cycles for fruits. The duration of function was set to 40 growth cycles for each organ. An example for Cultivar A of fitting results on organ-level data is shown in Fig. 1.

A set of source sink parameters was identified for each cultivar, as shown in Table 2. Petiole and internode sink strength (P_i, P_p and P_b) was similar for cultivars A and C. The same trend appeared for the sink variation parameters of blade, petiole, internode and fruit (B_b, B_p, B_f and B_i). Only fruit sink strength (P_f) differed. These parameters for cultivar B were smaller than the cultivar A and C. The estimation results are consistent with that of experiments (Table 1). A had larger individual fruit and B had smaller one. Regarding source parameters, the projection area (S_p) were stable for the three cultivars. The light use efficiency (r_P) was larger for the cultivar B.

Table 2 Estimated parameter values for three cultivars

	A	B	C
P_i	0.37	0.25	0.33
P_p	0.19	0.18	0.18
P_f	22.1	8.69	11.9
B_i	4.78	3.00	5.47
B_b	3.52	3.47	3.84
B_p	3.01	2.93	2.87
B_f	3.08	0.93	2.85
S_p	139.0	142.8	154.5
r_p	125.7	226.4	154.0
R^2	0.984	0.942	0.932

P_o is the coefficient of sink strength, B_o is the parameter of the beta function for organ expansion, S_p is the projected surface area of the plant, *o*=i(internode), b(blade), p(petiole), f(fruit).

Using these parameter values, the ratio between biomass supply and demand (Q/D) was computed, as shown in Fig. 2. The Q/D ratio of A and C was larger than that of B, and all three values decreased after their peak values when the fruit appears. This indicates that the growth of organs is influenced by the source sink ratio.

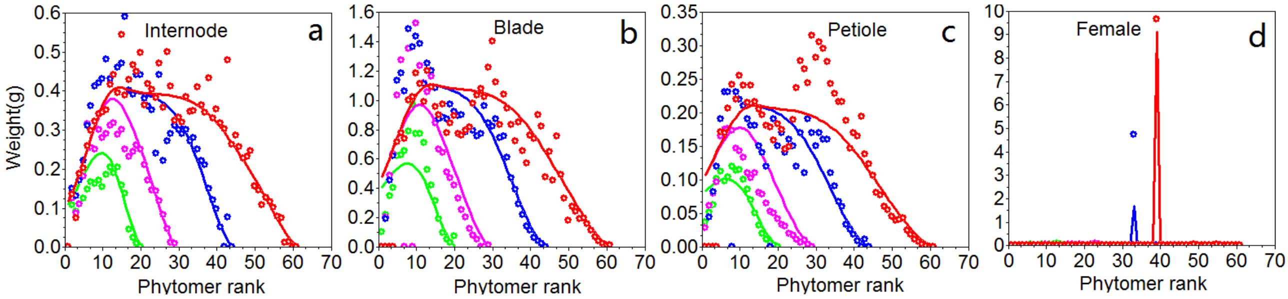

Fig. 1 Multi-fitting on plant data from four samplings. All data were fitted simultaneously, including the dry weight of individual internodes (a), blades (b), petioles (c), and fruits (d), shown with cultivar A. Dots represent the measured data, lines represent the computed data, respectively.

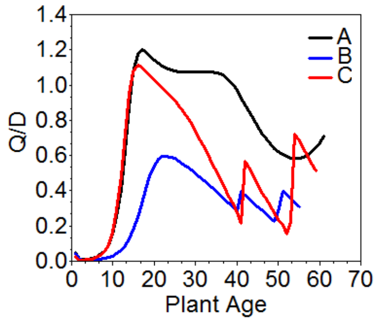

Fig. 2 Computed evolution of plant demand per cycle for the three cultivars.

DISCUSSION

The aim of the current study is to quantify the link between source–sink ratio and fruit-set for cucumber plants for different cultivars. Our model can compute the source sink parameters of organs per plant. The model results are consistent with the experiments. Cultivar A has larger leaves and individual fruit, but fewer fruits, in contrasts, cultivar B had smaller leaves and individual fruits, but more fruits; the F1 hybrid C had large leaves and fruits, also more fruits. The total yield of cultivar C is larger than A and B (Table 1). As shown in Fig.2, the fruit sink strength of F1 hybrid (cultivar C) may depend on the parent A, while the fruit sets depend on the parent B. Although source–sink ratio has been regarded as the principal factor determining fruit-set and organ growth, the cyclic pattern cannot be fitted very well using our model, as shown in the Fig. 1. Moreover, the cyclic pattern still exists even if fruits aborted there. This could result from flower bud differentiation, which may influence the cell number of organs, and in turn, its size (Ramirez-Parra et al, 2005) at the flowering stage for cucumber. The development of fruit relates to cell division and cell expansion. Factors affecting cell division before and after anthesis can bring about a failure of fruit-set. For modelling it is necessary to distinguish the time period which factors influence the size of organs during the growth.

The model can simulate the difference of organs and yields between cultivars by computing the source sink parameters of plant organs. The F1 hybrid can obtain the heterosis by combining the advantages of the parents. The model is helpful for breeders to understand the mechanism of hybrid vigor.

LITERATURE CITED

Du Y, Wang Y, Wang XH, Sun LL, Yang JC. 2007. Comparisons of plant type, grain yield, and quality of different japonica Rice cultivars in Huanghe-Huaihe River Area[J]. Acta Agronomica Sinica **33(07)**: 1079-1085.

Ghaderi A, Lower RL. 1978. Heterosis and phenotypic stablility of F1 hybrids in cucumber under controlled environment. Journal of the American Society for Horticultural Science 103: 275-278.

Guo M, Rupe MA, Dieter JA, Jijun Z, Spielbauer D, Duncan KE, Howard RJ, Hou Z, Simmons CR. 2010. Cell Number Regulator1 Affects Plant and Organ Size in Maize: Implications for Crop Yield Enhancement and Heterosis. The Plant Cell, 22: 1057-1073.

Hayes HK, Jones DF. 1916. First generation crosses in cucumbers. Connecticut Agricultural Experiment Station Annual Report: 319-322.

Marcelis L. 1994. A simulation model for dry matter partitioning in cucumber. Annals of Botany, 74: 43-52.

Ramirez-Parra E, Desvoyes B, Gutierrez C. 2005. Balance between cell division and differentiation during plant development. Int Journal of Developmental Biology. 49: 467-477.

Yan H, Kang M, de Reffye P, Dingkuhn M. 2004. A dynamic, architectural plant model simulating resource-dependent growth. Annals of Botany **93**: 591–602.