Temperature X Photoperiod Adaptation and Yield in *Phaseolus vulgaris*

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BEAN/COWPEA CRSP
MICHIGAN STATE UNIVERSITY

THE BEAN/COWPEA COLLABORATIVE RESEARCH SUPPORT PROGRAM (CRSP)

Michigan State University

The Bean/Cowpea CRSP is a program of coordinated projects in Africa and Latin America addressing hunger and malnutrition through research on the production and utilization of beans (Phaseolus vulgaris) and cowpeas (Vigna unguiculata). The goal of the Bean/Cowpea CRSP reflects the Title XII "Famine Prevention and Freedom from Hunger" mission of the US Foreign Assistance Act under which the program is funded. The goal is to establish active and vigorous collaborative research efforts that will contribute to the alleviation of hunger and malnutrition in developing countries by improving the availability and utilization of these foods. In the true spirit of collaboration, the CRSP also makes a significant contribution to agriculture in the US through the increased knowledge and materials generated by the research partnerships with Host Countries (HCs). The research findings and identified biological resources hold potential for solving or reducing important agricultural constraints to bean and cowpea production and consumption in legume producing nations.

Beans and cowpeas are dietary staples in the HCs associated with this CRSP. Among many families, these legumes provide the major source of high quality, affordable protein as well as an important source of B vitamins. Beans and cowpeas generally are grown as food for household consumption, rather than as export crops. They are typically grown on subsistence farms and, in some countries, are grown solely by women, on whose shoulders rests the major responsibility for providing the food for family consumption. CRSP research seeks to strengthen the resources available to these producers.

To support its goal, the CRSP directs its attention to:

1. Building strong and collegial professional relationships among the HC and US researchers in each project;
2. Making financial resources available for both HC and US research activity;
3. Emphasizing multidisciplinary research integrating production and non-production issues;
4. Focusing on research in traditional settings;
5. Paying specific attention to the roles and participation of women;
6. Being alert to mechanisms for information dissemination; and
7. Supporting HC educational opportunities to strengthen long-term legume research capability within the country.

CRSP research is concerned with genetics and plant breeding, agronomics, economics, nutrition and socio-cultural factors. A global research plan, developed jointly by HC and US colleagues, formed the basis for the design of the collaborative projects. These vigorous international research partnerships directly involve research institutions in thirteen HCs, two international centers and fourteen US agricultural research institutions, which include the nine having lead roles in the CRSP.

In making available to the international agricultural research and development system an avenue to the US agricultural research network, the Bean/Cowpea CRSP is making important contributions to the resolution of difficult and persistent problems associated with bean and cowpea production and utilization. Across the many participating disciplines and nations, there is emerging from this CRSP a heterogenous cadre of professional research colleagues prepared to share the unique resources of one another in addressing long-term troublesome constraints to adequate food and nutrition in poverty regions of the world. The CRSP **Vanguard** Series is a publication of the important research findings which are evolving from these collaborative professional relationships.

Temperature X Photoperiod, Adaptation and Yield in *Phaseolus vulgaris*

Dr. Donald H. Wallace
Department of Plant Breeding and Biometry
Cornell University

Dr. Porfirio N. Masaya
Bean Program Leader
ICTA

Paul A. Gniffke, PhD Candidate
Department of Plant Breeding and Biometry
Cornell University

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Extensive variations exist from one location to another in the amount of rainfall and the duration of the rainy season(s) within almost all tropical countries. High yield of quality beans requires sufficient rainfall, with maturity occurring during a rainfree period. Beans cannot be grown in dry seasons without irrigation or residual moisture, and most plantings depend on natural rainfall. For these reasons, the duration of growth, i.e., days from planting to seed maturity, is an important feature that adapts a cultivar to a geographical locality. This includes temperate locations where temperatures determine the growing season duration. Every location tends to have a specific duration of active growth that makes for maximum yield. Besides the above mentioned water and temperature relationships, the choice of crops to be grown in multiple cropping with beans can alter the required days to maturity. Also, mean and absolute day and night temperature can greatly modify the duration of growth required for a given bean cultivar. Under each temperature regime, yields are generally increased per unit land area as the duration of growth is extended. The duration may be 60 days in warm localities and up to about six months in high elevation tropical locations. Simultaneously with increased growth duration, yield per land area **per day** may be drastically reduced. Therefore, total yield may be maximized with tandem plantings of early maturing cultivars. For all these reasons, breeding for maturity, adaptation and yield are critical objectives of bean improvement programs in Guatemala and Ecuador, the project sites of the research reported here, but also in all tropical and temperate countries.

Beans express a response to long photoperiods ranging from complete insensitivity — in which photoperiod has no effect on timing or intensity of flowering, to different degrees of quantitative sensitivity — in which flowering is delayed to some extent by long photoperiods, to nearly qualitative sensitivity — in which flowering seems to be indefinitely postponed by long days. A variety's sensitivity to photoperiod may have a critical impact on its usefulness in many growing locations — particularly in mid to high latitudes. A variety's relative temperature adaptation vis-a-vis a location's growing temperatures also has great influence on flowering time and time to maturity and may interact strongly with photoperiod response.

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Three flowering responses to temperature occur in the field and in controlled environments:

1. The below-optimum temperature for flowering response of the given cultivar (genotype). This response is a change toward earlier flowering as the temperature is raised.

2. The optimum temperature for flowering as indicated by the minimum expressed days to flowering of each genotype. This minimum is called the flowering tendency.

3. The above-optimum temperature for flowering response of each genotype. This response is a change toward later flowering as the temperature is raised. These three responses to changes of temperature, with daylength remaining constant, plus simultaneous direct and interaction responses of flowering to changes of photoperiod, collectively make up three major physiological-genetic components of days to flower and consequent maturity, adaptation and yield:

   a. **The photoperiod x below-optimum temperature response.**

   b. **The flowering tendency as expressed at the optimum photoperiod-temperature.**

   c. **The photoperiod x above-optimum temperature response**

The interaction of the varied daylength-temperatures of different geographical locations divides bean production of the world into areas where above-optimum temperature, optimum temperature, and below-optimum temperature for flowering, in combination with short vs. moderate vs. long daylengths, contribute differentially to quantitative delays in days of flowering. The delay is beyond that minimal days of the flowering tendency of each genotype which is expressed only at the optimal photoperiod-temperature for the genotype, i.e., usually at 800-1000 meters in the tropics.

There is evidence for genetic differences among bean cultivars with regard to response to daylength and temperature. CRSP-sponsored research at CIAT has shown that electric-light extended, long days delay flowering of bean genotypes most strongly at high temperatures (low elevations), intermediately at intermediate temperatures (moderate elevations) and little or not at all at low mean temperatures (high elevations). This agrees with our observation in Guatemala that, contrary to possible expectation, the delay of time of flowering as temperature is lowered is attended by a lowering of node number to flower, which would tend to give earlier flowering; the change of node number is more closely correlated with temperature than with days to flowering.

Other research at CIAT has shown that, at continuous moderate (near optimal) temperature, an extension of daylength to eighteen hours delayed flowering of a sensitive cultivar by seven days and increased yield by 50 and 72% in two plantings. The same photoperiod-temperature-caused delay of flowering in temperate zones is likely to decrease yield because pod development in this case takes place during the lower fall temperatures.

International yield and adaptation nurseries of CIAT show flowering of photoperiod-temperature sensitive bean cultivars to be increasingly delayed at locations with longer and longer daylengths. Our research shows this photoperiod-modulated delay to be further increased by high temperature. This occurs because the delay is always simultaneously influenced by both daylength and temperature.

Differential cultivar adaptation to different world areas arises in part because genotype-directed potential for delay in node to flower (the second process) is always modulated simultaneously and synergistically by temperature and daylength. Number of nodes initiated per day (the first process) is only modulated by temperature.

An optimum temperature for flowering exists for each daylength and genotype. There is also an optimum photoperiod-temperature where days to flower is fewer than under any other daylength-temperature. From this optimum, all rising or lowering of temperature and extensions of daylength delay flowering.

The above described biology of maturity, components of time of flowering and responses of flowering to daylength and temperature divides bean production into zones where cultivar adaptation is achieved differently.

Regulation of Bean Maturity in Different Areas of the World

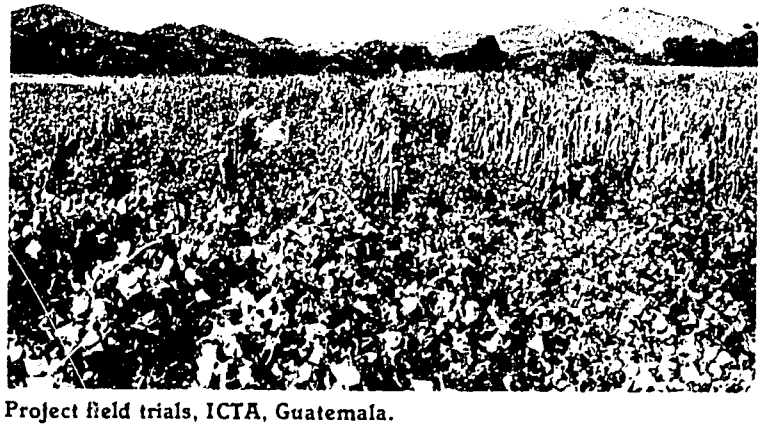
1. **Hot Lowland Tropics.** It is predominantly the above-optimum temperature for flowering component of the above-optimum temperature x photoperiod response that limits bean adaptation and yield in short-daylength (presumed non delaying), high temperature tropical locations below 800 to 1000 meters. At such above-optimum temperature locations, the change in days to flower is a delay when there is a rise of temperature, and earlier flowering when temperature is lowered.

2. **Temperate Locations.** As long recognized, daylength plus a cultivar's genotypic sensitivity to it predominantly control the time of flowering and maturity in long-day temperate locations. This control

ICTA technician evaluating and recording project intercropping trials, Guatemala.

Dr. Donald H. Wallace, US Principal Investigator, Cornell University.

Dr. Porfirio N. Masaya, Host Country Principal Investigator, ICTA, Guatemala.



Project field trials, ICTA, Guatemala.

ICTA field hands weeding bean plots, Guatemala.

Dr. Masaya at crossing block, ICTA, Guatemala.

is by precisely the same physiological-genetic process that controls time of flowering and maturity in lowland tropical locations. The only difference is that in a temperate area the days to flowering are delayed largely by the long daylength (or at least can be) rather than by high temperature. The "can be" is because, depending on genotypic sensitivity to photoperiod and consequently to above-optimum temperature, a moderate above-optimum temperature may result in a larger delay in flowering in conjunction with a long (temperate) daylength than will a very high temperature under a short (tropical) day.

3. **Highland Tropics.** Relatively few beans are grown at tropical elevations much lower (warmer) than the main bean research stations of ICTA in Guatemala (900 meters, Jutiapa) and of CIAT in Colombia (1000 meters, Palmira). Both stations are located at near optimal temperatures, i.e., at that mean temperature which gives the minimal days to flower for most cultivars. Seventy-five per cent of beans are grown at elevations higher than those with the 23-25 C that constitute the optimal temperature for flowering. Besides genotype, therefore, the main environmental factor controlling maturity and consequent adaptation and yield of 75% of tropical bean production is the below-optimum temperature for flowering. The short daylength and low temperature both minimize any photoperiod effect.

4. **Optimal Photoperiod-Temperature in the Tropics.** Such an optimum or near-optimum photoperiod-temperature is a necessary environment for expression of the flowering tendency of a cultivar. The genetic variation of the flowering tendency is the major physiological-genetic component of variable maturity at near optimal photoperiod-temperature, i.e., at tropical elevations of 800 to 1000 meters.

Influence of Diurnal Temperature Difference

Growth chamber studies show that a small difference between day and night temperatures minimizes the delay in flowering caused by long daylength plus above-optimum temperature for flowering, while a large difference amplifies the delay. Under short daylength, plus near optimal temperature, the large diurnal difference delays flowering by a mechanism other than abortion of flower buds that are only microscopically visible. The flower buds develop to a visible size and then abort a week or a day or two before anthesis, or a day or two

after anthesis at the pod setting stage. Thus, the diurnal difference modulates the stage of flower development at which abortion occurs.

Genetics of Maturity and Adaptation

Existing knowledge about inheritance of bean sensitivity to photoperiod indicates regulation by only a few genes. Studies have not adequately accounted for the simultaneous above-optimum temperature modulations through the delay in node to flowering and through the nodes developed per day, nor as through the modulation by photoperiod.

CRSP-sponsored research at CIAT has demonstrated that genotype directed, very strong, strong, intermediate, weak, and very weak sensitivities to photoperiod-temperature can be genetically associated with each of short, intermediate and long durations of the flowering tendency. No inheritance studies have clearly differentiated photoperiod sensitivity from the other physiological genetic components of maturity.

Optimal temperatures near 18 C for some highland cultivars and near 23-25 C for most cultivars have been shown by CRSP and CIAT research. Thus, genetic variability in optimal temperature for flowering exists and can be useful in breeding for cultivar adaptation. Knowledge is needed about genetics and inheritance of the flowering tendency which is expressed only at an optimal temperature. Besides being the only component of maturity expressed at optimal temperatures (moderate elevations), the minimum number of days during which a plant has a tendency to flower is the basic number of days to flowering to which all delays caused by daylength and/or temperature are added.

Applications to Breeding

Because below-optimum temperature for flowering is the major controlling environmental factor for bean production in the tropics and because every environmental factor functions through one or more of the four identified genetic systems, research on these physiological-genetic factors is essential to improving efficiency of breeding for maturity, for consequent adaptation and for yield of tropical bean cultivars. Such knowledge is most deficient for breeding cultivars adapted to the highlands.

It is necessary to identify existing genetic variation in optimal

temperature for flowering and learn about its inheritance. How does the effect of this genetically directed optimal temperature for flowering of a cultivar differ for low, moderate and high elevation locations? How does it differ for short, moderate and long day locations? What flowering tendency and what optimal temperature will give maximum adaptation and yield for the different elevations? Will a long or short duration flowering tendency combined with maximal insensitivity to photoperiod-temperature maximize yield in the lowland tropics? in temperate zones?

Use of genetic variation in flowering tendency should be tested for breeding of improved cultivars for both the lowland tropics and temperate zones, as well as for moderate elevation tropics where it is the only genetic variability that will be expressed. Depending on rainy season duration in the tropics and on fall temperatures in temperate areas, a long duration flowering potential with minimal possible sensitivity to photoperiod and above-optimum temperature would seem to be preferable over a cultivar that has its moderate or late maturity established through its gene-directed sensitivity to photoperiod-temperature. Proper flowering potential and minimal photoperiod-temperature sensitivity could facilitate bean production at low elevation, hot tropical locations. It could also minimize the large fluctuations in bean yields that occur because of year to year temperature variations in temperate locations.

THE GUATEMALA-CORNELL BEAN/COWPEA CRSP PROJECT

Agronomic, Sociological and Genetic Aspects of Bean Yield and Adaptation

Dr. Donald H. Wallace – US Principal Investigator
Cornell University

Dr. Porfirio N. Masaya – HC Principal Investigator
Instituto de Ciencias y Tecnologia Agricola (ICTA)

Collaborating researchers
Dr. Patricia Garrett, Cornell University
Dr. Roger F. Sansted, Cornell University
Ing. Selvin Arriaga, ICTA

Project Objectives

1. To determine the biological, environmental, economic and social roles of bean production in the farming systems of small farms.

2. To develop methods of determining the merit of potentially useful bean production practices using research conducted in the environment and under the management system of small farms.

3. To determine the competitive advantages of specific crops in bean intercropping systems and determine the pattern providing the highest return from the application of limited resources such as fertilizer.

4. To develop credible procedures for measuring (or estimating) the degree of acceptance of new practices by small farmers and determine the merit of feedback from such procedures for establishing research objectives.

In this project the socio-agronomic bases are sought for bean farming systems of highland Indians. Change from monocropped bush, to bush with corn, to climbing bean with corn occurs as elevation increases. The hurnan and ecological bases for the maintenance of one system over the others are investigated. Two years of field research in bean physiology has been conducted at different elevations under natural 12 hour and 18 hour electric light extended daylengths. This research, the focus of the present report, was based in part on the previous years' growth chamber research findings. Cultivator adaptation comparisons between temperate and tropical zones have also been studied.