Education of the Next Generation of Plant Breeders for Horticultural Crop Improvement

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Abstract
Crop improvement powered through plant breeding is critical for sustainable production of horticultural crops that contribute to healthful diets and enhance quality of life for people around the world. Currently there are too few breeders to satisfy global demands and opportunities in the public and private sectors of developing and developed countries. In order to meet future needs, it is important that educational programs incorporate rapidly changing new technologies along with classical content and methods in order to meet professional needs for cultivar developers, researchers, teachers and support scientists. Information from a broad based study at the University of California, Davis that sought input from expert stakeholders about breeding knowledge, experiences and skills can be used by educators, employers and students to provide diverse training opportunities to support ongoing professional development for future success in horticultural crop improvement.

INTRODUCTION
Horticultural crops contribute materially to the health, well-being and livelihood of people across diverse social-economic strata in all parts of the world. In addition to widespread hunger and malnourishment, in some areas there are rapidly increasing levels of childhood and adult obesity that also pose severe health problems. A well-balanced diet with abundant servings of fruits and vegetables that provide energy, protein, macro- and micro-mineral elements, and essential vitamins and growth factors will help alleviate both those situations. Although some dietary components can be enhanced through supplements, the most wholesome effects usually come from fresh and minimally-processed products. Herbs and spices provide flavor enhancement that gives increased acceptability and pleasure to many foods. It is difficult to imagine food security and healthy people without abundant horticultural products in the diet.

Horticultural plants in our everyday surroundings add beauty and pleasure to both interior and exterior landscapes. Visual and sensual pleasures from a wide array of plants can enhance a healthy life style, speed recovery of patients from surgery and illness and prolong the life of senior citizens. Although more traditionally recognized as sources of income to rural farmers, horticultural enterprises in urban areas offer expanding opportunities for entrepreneurs in villages, towns and cities. While the virtues and value of horticultural crops are well known, their potential often is not fully realized. Wise investment in human resources is needed to capitalize on the rapid changes in science and technology that can unlock that potential.

CROP IMPROVEMENT
Crop improvement began with people domesticating wild plants by selecting those that met their needs for sustenance and derived products. While some domestication is
still ongoing, most contemporary crop improvement results from planned intervention by people interested in developing plants for specifically defined needs. Most commonly those people are amateur and professional plant breeders. Agriculture must meet the needs of growing populations amid dwindling arable land and formidable challenges from land degradation and environmental changes that negatively affect plant growth and productivity. Along with reversing practices that adversely affect the land and environment, these challenges can also be met by breeding new horticultural crop cultivars that are productive under less than optimal conditions.

Plant breeding is the engine that powers crop improvement through manipulation of the genetic makeup of selected plants. Studies have shown that about one half the increases in crop productivity are attributable to genetic improvement and a similar proportion to improved production practices compatible with the cultivars. In addition to increasing overall productivity, incorporation of genetic resistance to diseases and pests has been important for horticultural crops where product quality is paramount for consumer acceptance. Genetic resistance is a key component of integrated pest management practices aimed at either minimizing or optimizing use of chemical pesticides to reduce production costs and alleviate potential negative effects on the environment.

Natural and induced mutants with easily discernable effects have provided important new plant products especially in horticultural crops where novelty of appearance and/or use has resulted in new consumer demand. A prime example is sweet corn where mutant alleles at several loci have been combined to dramatically modify wild types high in grain starch content to cultivars with sweet, tender kernels more desirable for human consumption. Although most commonly grown in temperate regions of North America, sweet corn cultivars are now being bred for and gaining wide acceptance in tropical and sub-tropical regions of Asia, Central and South America. In order for sweet corn production to flourish in tropical climates of the low latitudes extensive breeding is underway to develop cultivars well adapted to prevailing edaphic conditions and able to withstand local insects and diseases.

Some of the many other examples of new products arising through alteration of effects of a few genes including edible pod types of garden bean and of garden pea that includes the immature berries as well as the snow peas and snap pea types. Many of the wide array of stone fruit cultivars are mutants or sports that have a significant effect on color, time of ripening and other easily discerned traits of consumer interest. There is considerable interest in modifying not only appearance and quality traits but also properties affecting nutritional value including so-called nutraceutical properties. For floral and landscape plants, manipulation of appearance and fragrance controlled by genetic factors is of major importance for developing new cultivars.

PLANT BREEDERS

Definitions of plant breeding and of a plant breeder often vary. Clearly, people developing cultivars and those engaged in pre-breeding and breeding research are viewed as plant breeders. However, some still debate whether scientists developing and using transgenics and genomics for crop improvement should be categorized as a plant breeder. Job descriptions are often good indicators, but compared to the past when many job titles included “plant breeder”, today similar positions may be labeled differently e.g., crop specialist-leafy vegetables, or research scientist. I favor defining plant breeding and plant breeders quite broadly and consider all who are engaged one way or another in crop
improvement as a plant breeder. Most surely, needs of and opportunities for crop improvement as well as enabling science and technology will change in unforeseen ways. Educational programs and curricula should be broad enough to prepare professionals for a wide range of not only predictable but also currently unforeseen demands and opportunities in plant breeding.

**Plant Breeding Capacity**

The capacity required for a successful research program includes social-, organizational- and tangible capital in addition to human capital (Brennan and Quade, 2004). Human capital for successful plant breeding includes skilled breeders, assistant breeders, technical support for lab and field activities, specialists in foundation and stock seed production, curators and evaluators of plant genetic resources held in germplasm collections. Also important to a breeding program is participation of people skilled in genetics and genomics, data management and genomics tools to utilize information from associated model plants. An important but often overlooked human resource for successful plant breeding is access to and interaction with allied professionals in other disciplines, e.g., phytopathology, physiology, cell biology, post harvest biology and production science that complement work in crop improvement. To foster this type of interaction, it is important to have curricula and activities in education programs that integrate those disciplines into a breeding context so that future scientists can understand breeding and become interested in collaborating with breeders.

**Employment Opportunities for Plant Breeders**

Information about breeders in industrialized countries was summarized by Bliss (2007), with the primary source for the U.S. being papers by Frey (1996) and Traxler et al. (2005). They identified 2205 and 2156 total breeders in 1994 and 2001, respectively with approximately 70% working in the private sector. About three fourths of the jobs were related to agronomic crops while the remainder dealt with horticultural, forestry and specialty crops. In the 1994 survey about 80% of the breeders were involved primarily with cultivar development compared to less than 40% in 2004. However, direct comparisons may be misleading because the category “biotechnology,” which was added in 2004, may have contained some breeders using biotechnology for cultivar development. Although comparable data are not available for other industrialized countries and most have considerably fewer breeders than the U.S., the distribution among crop categories and between public and private sectors are likely similar (Bliss, 2007).

Quantitative and qualitative data about plant breeding capacity in 70 or more developing countries can be found on the web site of the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB) (km.fao.org/gipb/pbbc). While it is difficult to generalize about location and types of breeding programs in developing regions, usually the majority are in the public sector, often in government departments and institutes where some cultivar development is ongoing. Programs in colleges and universities are primarily for teaching with some breeding research, pre-breeding and population development along with occasional cultivar development. So too, most will be dedicated to agronomic food crops and relatively few to horticultural crops. In most developing countries there are few private companies engaged in plant breeding, especially local and regional enterprises. Sometimes regional or multinational companies may have breeders
posted locally often but that is more for testing, sales and distribution of seeds rather than new cultivar development targeted for local production areas.

Countries transitioning from developing to more advanced agricultural sectors are somewhat in between industrialized and developing regarding numbers and types of programs and plant breeders. For those such as Brazil, China, India and the Philippines, most plant breeding positions are still in the public sector working on agronomic food crops. In Brazil it is estimated that there are about 350 plant breeders of which 95% are in the public sector and 5% with private companies (Bliss, 2007). Seed sectors in countries such as Thailand and Bangladesh are developing rapidly with opportunities for breeders in the private sector emerging as demand for their skills and expertise grow along with local and regional seed sector development.

In most developing countries, farmer-saved seeds often predominate and demand for improved vegetable seeds is met through importation of cultivars created for production areas elsewhere. Because seed prices are low, markets variable, and growers small and dispersed, developing areas are often neglected. Grower needs for improved cultivars are met, if at all, by offering cultivars often poorly adapted to local conditions. There is great need for breeders dedicated to developing locally adapted cultivars, but resources are insufficient to hire personnel or support viable breeding programs after they are established. In both temperate and tropical regions, tree fruits and nuts are often important dietary components, but crop improvement is usually confined to testing new cultivars for adaptation and use of tissue culture for rapid, clean propagation.

In most countries regardless of development level, horticultural plant breeders are far outnumbered by those working on agronomic crops. More troubling, the U.S. data show that number of horticultural crop breeders declined from 653 full time equivalents (FTE) in 1994 to 425 FTE in 2001. Of the latter, 203 worked on vegetables, 122 on ornamentals, 76 on fruit and nut crops and 24 on lawn and turf (Traxler et al., 2005). I imagine that a similar mix of plant breeding positions among different horticultural crops is common in other countries where an individual breeder is likely to be responsible for several crops.

**Demand for New Breeders**

It is difficult to predict with confidence the number of new breeders required annually to meet the needs in various sectors of different countries as many factors influence movement of breeders during their careers. In developing countries it is common for well qualified breeders to be promoted rapidly to administrative positions. Although that may be desirable for personal career advancement, it often leads to a chronic gap in breeding program leadership resulting in low productivity. Breeders become discouraged by lack of program support, inadequate resources, professional isolation and promotion based on longevity rather than merit. Such disincentives prompt moves to a breeding job in another country, international institute or the private sector, or even changing to a more welcoming profession with greater resources and career opportunities.

In developed countries there is less likelihood of movement as resources and support for individual programs are usually greater. Breeders are unlikely to make more than two or three job changes during their career if they stay engaged in active breeding because continuity is important for success. Some will move to administrative positions and others from active breeding activities to related positions such as seed production, product development, marketing, sales etc. in addition to retirement, sickness and deaths.
For the sake of estimating number of new breeders required in the U.S., at a 5% annual turnover rate and with about 2200 breeders (1500 private and 700 public), about 75 new breeders will be needed in the private sector and 35 in the public sector annually (Bliss, 2007).

Gunar and Wehner (2003) reported that during a five year period, an estimated 360 Ph.D. and M.S. degrees were awarded to domestic students by U.S. universities. At an average of 72 per year that would be insufficient to replace the 110 breeders required at a 5% turnover rate. Others have suggested that there are insufficient numbers of plant breeding students being produced globally (e.g., Morris et al., 2006) and discussions with private company recruiters indicate a general shortage of skilled professional breeders for the jobs available in most sectors around the world. Information on the GIPB website and from Guimaraes et al. (2006) indicates a chronic shortage of breeders in most developing countries.

**Horticultural Plant Breeders**

Not only are there considerably fewer horticultural plant breeding positions than in field crops, but breeders are often required to be knowledgeable about a more diverse group of crops. Horticultural crops include many different crops types with great diversity within, so careful consideration must be given to the type of graduate education appropriate for preparing new breeders, as well as continuing education to keep them current and productive. Since many breeders will work on different crops during a career, how can they be prepared for inevitable change, the types of which are difficult to imagine? Who would have predicted in 1990 that a mere 20 years later, many plant genomes are sequenced and DNA-based selection methods linked with phenotypic selection and electronic data handling are becoming standard practice? Few of the plant breeders beginning their careers two decades ago had much knowledge about and experience with DNA technology, but in order to be productive and competitive today they have had to learn about and integrate new technology and methods. There is no reason to suppose that changes will be any less dramatic for future breeders.

**Needs of Horticultural Breeders**

As with other courses of study, plant breeding graduate education must strike a balance between broad preparation and specialization. The number of horticultural breeders is small compared to other crops, therefore few if any graduate programs will be designated solely for horticultural crops. So too, limited number of university faculty working on horticultural crops will make it challenging to assemble a critical mass of faculty with research and teaching appointments and interest in a range of horticultural crop areas. It is more likely and probably advantageous to have horticultural breeding as part of a broader general program with attention given to particular needs of specialty crops.

Pertinent questions for preparation of horticultural breeders should include: What types of new positions will be available in horticultural crop breeding; what level of formal education will be appropriate; what skills will be needed for success; what crops should graduates be knowledgeable about; are there educational knowledge, experience and skills that differ for horticultural vs. other crops; how should preparation differ for global careers that may be in developed and developing regions; what is needed to prepare breeders for career changes not only among different horticultural crops but also non horticultural crops; how much and what type of non-science (e.g., soft skills and
business) content should be provided during preparation; and what continuing education should be available for practicing breeders throughout their careers? One additional consideration might be how to link amateur and professional horticultural breeders, since there are probably more of the former working in horticultural crops than on agronomic and forestry crops.

EXPERT OPINIONS ABOUT GRADUATE EDUCATION FOR PLANT BREEDERS

A research team composed of faculty, staff and students from the School of Education, Department of Plant Science and Seed Biotechnology Center at the University of California, Davis conducted a survey to garner information from expert stakeholders in the plant breeding community about how best to prepared future plant breeders (sbc.ucdavis.edu). A web-based Delphi study approach was used to determine what knowledge, experiences, skills and special areas are important in a course of study at the graduate level. This approach is a group process technique used to gain a consensus of opinion that allows for input of geographically dispersed individuals with no opportunity for face-to-face exchange and avoids issues of dominance of one or a few participants.

About 400 individuals were invited to participate in this survey. Participants were identified based on their involvement in plant breeding and a broad diversity and range of ideas were sought. The stakeholders comprised four groups; private sector individuals associated with developed countries, public sector individuals associated with developed countries, individuals working in either the private or public sector in developing countries, and recent graduates of plant breeding programs with any affiliation. A total of 208 people began Round I of the survey and the participation rates through the final round were: private respondents (59%), public respondents (53%), respondents from developing countries (69%) and recent graduates (61%), all high rates for social science research.

The study, which involved three rounds, helped gather ideas to develop a list of important concepts and critical education components for themes, needs, directions and predictions about knowledge, experience and skills for preparation of future breeders. The components and process for the study are shown in Fig. 1.

Fig. 1. Schematic showing the process and components for the study using the Delphi approach to garner opinions from stakeholders about preparation of future plant breeders.
In Round I participants were asked to respond in short answer form, with up to ten responses, to four open-ended questions:

- What knowledge (topics or subject matter) is essential to have obtained at the completion of a graduate degree in plant breeding?
- What experiences should a student have while pursuing a graduate level plant breeding degree that will contribute to his/her future success?
- What skills and competencies should a student obtain by the completion of a plant breeding graduate program?
- What specialties within plant breeding (or to complement plant breeding) should be developed over the next 10 years?

The responses were distilled and clustered into broad categories which the respondents were asked in Round II to rate on importance using a 1–5 Likert-type scale (1=unimportant, 2=somewhat important, 3=neither important nor somewhat important, 4=important and 5=very important). Suggestions with a mean of at least 3.75 in Round II were presented to participants in Round III to build consensus. They were asked if they still agreed with their initial ratings, and if not, to adjust them. Data were collected and analyzed in Microsoft Excel. Initial analyses of the information provided by the stakeholder respondents can be found at: sbc.ucdavis.edu/education/delphi_study.html.

**Knowledge**

There were 17 knowledge categories that included 198 unique responses rated as important (3.75 or higher) with plant breeding, genetics, statistics, experimental design, computer proficiency and plant pathology rated important or very important by all four participant groups. Other topics important to several groups were plant reproductive biology, plant diversity and evolution, biological science, policy and law, ethics and scientific communication. In each knowledge category there were a variable number of detailed topics that provide information to program planners about potential courses and course content considered important by the different groups. For example in the plant breeding category, suggested topics included classical plant breeding, genotypic selection, inbreeding depression and heterosis, lab and field methods for plant breeding, molecular techniques for selection, phenotypic selection, plant breeding methods for selfing-and outcrossing systems, selection theory and techniques, resistance breeding, etc. In depth analyses of the number, type and importance of responses from each stakeholder group provide insight and ideas about ways graduate programs and short courses can provide breadth and depth of knowledge that is important for the diverse needs of students preparing for careers in plant breeding. There was limited mention of knowledge categories specific for horticultural crops except for production science which should include specific crop groups, e.g., horticultural crops.

**Experiences**

There were 141 unique experience responses distributed in 14 categories rated as important (3.75 or higher). All groups of respondents rated experiences in the following categories as important or highly important; practical aspects of plant breeding, data management, scientific communication, interaction and networking, collaboration and teamwork, and teaching and mentorship. Other experiences rated important by several groups included experimental design, work with plant germplasm, field visitations, and program and personnel management.
Skills

There were 301 unique skill responses rated important (3.75 or higher) in 24 categories, with the categories of practical breeding, experimental design, analytical aptitude, field work, data management, statistics, computer proficiency, intrapersonal, communication, and collaboration and teamwork rated very important. Two general skill types felt to be important for plant breeders were those that are science related and others that influence professional effectiveness. Skills in the first group were associated with practical breeding, field work, experimental design, statistics, computer proficiency and molecular manipulations. Skills related to the latter were analytical aptitude, communication, collaboration, teamwork and leadership, program and personnel management, and intrapersonal skills.

Consideration of topic suggestions in each skill category provides an indication of the types respondents feel are important for good preparation of plant breeders. These suggestions range from skills that are quite general for many scientific studies (not only related to plant breeding) to others quite specific, e.g., selection protocols and methods for specific traits such as biotic and abiotic stresses. Faculty and students interested in horticultural crops and crop specific programs will suggest appropriate skills needed for future work on those crops. Skills that can be applied to multiple breeding contexts may require integration of experiences with classroom learning in order to fully take advantage of the knowledge acquired in more formal settings. Often the context of problem-solving situations may be complex and require careful integration of information and experience along with interaction with skilled practitioners in order to become effective.

Apart from the knowledge and skills that are science-related, stakeholders emphasized so-called soft skills relating to interpersonal and intrapersonal abilities. These topics are often not found in individual courses of breeder training programs such as communication, collaboration and teamwork, but are frequently needed in interdisciplinary settings. Other areas included ethics, policy and law relating to resources and germplasm, and program and personnel management.

Although many important knowledge, experiences and skills categories were common for breeders in general, stakeholders from different perspectives emphasized importance of some different categories for future work in public vs. private and developing vs. developed settings. Those familiar with the private sector gave more importance to field oriented knowledge and skills, and to teamwork, interaction and networking, and program and personnel management (Miller et al. 2010). Stakeholders with developing country context aligned more with views of those from public sector developed affiliation.

Specialties and Specialization

Many suggested specialty topics were group specific, but those with very important rankings by all groups were breeding for biotic and abiotic stress tolerance (separate categories) and plant molecular breeding. Among the specialties mentioned, some such as breeding for health and nutrition and novel trait development are especially relevant to horticultural crops around which areas of specialization within a general program can be developed.

Optimal balance between general instruction and preparation versus specialization in graduate programs is difficult to attain and often is a sharply debated topic. With too little in-depth knowledge and too few specific skills, a new breeder may find it difficult to secure a position, but with over-specialization some prospective employers may view
them as too narrowly prepared to deal with a range of crops and breeding requirements. It will be important to have a carefully integrated program where multiple experiences and skills can accrue from a few well chosen activities to complement a well-conceived and accomplished set of courses and research activities during the normative time to complete the degree. Furthermore, it will be important to have an achievement based means of demonstrating that a student has attained various levels of proficiency in the areas that they and the program deem important for their future success. Bliss (2007) suggested that students may find it beneficial to be able to attain varying levels of proficiency for different areas of knowledge and skill of their choice rather than attempt to become an expert in all areas of breeding.

**DISCUSSION AND CONCLUSIONS**

Information from the diverse groups of expert stakeholders indicates that much of the knowledge and many of the experiences and skills students need to become successful breeders of horticultural crops will be similar to those required for other crop groups. Findings from this current study were agreed with those reported elsewhere (Duvick, 1998; Baenziger, 2006; Bliss, 2006, 2007; Gepts and Hancock, 2006; Lee and Dudley, 2006; and Ransom et al. 2006). Similar to the situation today, more in depth knowledge about horticultural crops and approaches to breeding peculiar to those crops will be acquired by working with faculty dedicated to fruit, vegetable, ornamental and specialty crops. This approach will become more challenging if the number of horticultural crop breeding programs at colleges and universities continue to shrink. In order to expand capacity for preparing students to work with horticultural crops in different regions of the world, consideration should be given to strengthening collaborative programs on a geographic/agroecological basis (e.g., tropical fruits, vegetables, etc.), on a crop or family basis [e.g., Rosaceous (see: www.rosbreed.org), Solanaceous (see: solcap.msu.edu/), Phaseolus (see www.beancap.org) crops], or by general needs categories (e.g., biotic resistance and abiotic tolerance of horticultural crops) in order to assemble a critical mass sufficient for research and education of a sufficient number of students to meet future needs.

The first step is to attract outstanding students into horticultural breeding programs with modern, exciting and relevant curricula that provide clear paths for obtaining knowledge, experience and skills needed for success in attractive jobs that are available in plant breeding globally. For all countries, horticultural products are critical for good nutrition, healthy living and a dynamic business sector. Development of new, genetically improved cultivars that are profitable for growers and that meet the needs of consumers will contribute to a vital, dynamic horticulture industry world wide.

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**Literature Cited**