17

Biodiversity and Vegetable Breeding in the Light of Developments in Intellectual Property Rights

João Silva Dias
Technical University of Lisbon, Instituto Superior de Agronomia, Tapada da Ajuda, Lisboa
Portugal

1. Introduction

Farming and plant breeding have been closely associated since the early days when crops were first domesticated. Plant breeding was built on biodiversity and on the work of 10,000 years of farmers's selection and some generations of breeders. Without understanding the science behind it, early farmers saved the seed from the best portion of their crop each season. Over the years, they selected the traits that they liked the best, transforming and domesticating the vegetable crops they grew. Every vegetable product we see on the market has benefited from plant breeding in one way or another. New varieties were created by breeders by making use of the total genetic information that was present in a gene pool. Access to that genetic variation, the biodiversity, was required to achieve variety improvement.

In the 18th and 19th centuries the Vilmorin-Andrieux family, owner of the first commercial seed company, played an important role in a number of theoretical and technical advances in commercial vegetable breeding, such as producing the first vegetable seed catalog for horticulturists, developing the principles of genealogical breeding programs, improving seed quality through cross-breeding initiatives, and creating disease-resistant and hybrid varieties of vegetables (Gayon & Zallen, 1998). In 1856 Louis Vilmorin published "*Note on the creation of a new race of beetroot and considerations on heredity in plants*" establishing the theoretical groundwork for the modern vegetable breeding industry. The first suggestion to exploit hybrid vigor or heterosis in vegetables was made by Hayes & Jones (1916) for cucumber. Commercial hybridization of vegetable species began in the United States in the middle 1920s with sweet corn, followed by onions in the 1940s. Since that time, private breeding companies have been placing more and more emphasis on the development of vegetable hybrids, and many species of vegetables have been bred as hybrid varieties for the marketplace. Besides heterosis, hybrids also allow breeders to combine the best horticultural traits and multiple disease and stress resistances. Furthermore, if the parents are homozygous, the hybrids will be uniform, an increasingly important trait in commercial vegetable market production. The creation of vegetable hybrid varieties requires homozygous inbred parental lines, which provide a natural protection of plant breeders' rights without legal recourse and ensure a market for seed companies.

In the 1970's breeders' rights protection has been provided through International Union for the Protection of New Varieties of Plants (UPOV), which coordinates an international common legal regime for plant variety protection. Protection was granted for those who develop or discover varieties that are new, distinct, uniform, and stable. Varieties may be either sexually or asexually propagated. Coverage is for 20 years for herbaceous species. Protective ownership was extended by UPOV in 1991 to include essentially derived varieties. At the same time, the farmer's exemption (that permitted farmers to save seed for their own use) was restricted, giving member states the option to allow farmer's to save seed. In addition, after 1998 in Europe, and 2001 in the United States plant breeding companies can take advantages of patent laws to protect not only the variety itself but all of the plant's parts (pollen, seeds), the progeny of the variety, the genes or genetic sequences involved, and the method by which the variety was developed. The seed can be used only for research that does not include development of a commercial product i.e., another variety, unless licensed by the patent older. The patents are considered the ultimate protective device alowing neither a farmer's exemption nor a breeder's exemption (that permitted that the protected variety could be used by others in further breeding to create new varieties).

Research and development (R&D) for improved seed development is expensive. Such product protection has presented a business incentive to corporations to invest in the seed industry, which supported an enormous increase in private R&D leading to strong competition in the marketplace between the major seed companies. The majority of current vegetable varieties sold nowadays are proprietary products developed by private R&D. A significant consequence of this increase in R&D has been a reduction in public breeding programs. As a result, the cost for R&D to develop new varieties is shifting from the publicly supported research programs to the customers of the major seed companies.

One of the main factors that determine success in vegetable production is biodiversity and genetic capacity. No practical breeding program can succeed without large numbers of lines (genotypes) to evaluate, select, recombine and inbreed (fix genetically). This effort must be organized, so valid conclusions can be reached and decisions made. Scientists, breeders, support people and facilities, budgets, and good management are requirements to assure success in the vegetable seed business. Science must be state-of-the-art to maximize success in a competitive business environment. Since the continued need for fundamental breeding research is critical to support development of new technology and expansion of the knowledge base that supports variety development, competition among proprietary varieties results in owner-companies striving to do the best possible research to develop their own products and to compete on genetic and physiological quality of vegetable seed in the marketplace. Reasonable profit margins are necessary to pay back the R&D costs to the owner and to fund future research on developing even better vegetable varieties to stay competitive. There is considerable genetic variation within the various vegetable species, which can be exploited in the development of superior proprietary varieties. The consequences of this dynamic situation will mean relatively short-lived varieties replaced by either the owner of the variety or a competitor seed company. This intense competition means constantly improved and more sophisticated varieties for the vegetable industry. Seed companies are in the business of manipulating genes to improve plant variety performance for a profit. The success of the research is judged by the success of the product in making a reasonable profit. The research must improve economic performance starting with the seed production costs and include the grower-shipper/processor and the end user. If any link in this sequence of events is weak or broken, the new variety will likely fail.

Biotechnology is a new, and potentially powerful, tool that has been added by all the major seed corporations to their vegetable breeding research programs, and is part of ongoing public research for developing transgenic vegetable projects. It can augment and/or accelerate conventional variety development programs through time saved, better products, and more genetic uniformity, or achieve results not possible by conventional breeding.

In 2008 the global vegetable seed market was estimated at US$3.5 billion with the following shares of vegetables: solanaceous (30%), cucurbits (21%), roots and bulbs (16%), brassicas (13%), large seed (13%), leafy and other (7%) (Monsanto, 2009). In the last 8 years global commercial vegetable seed sales had an annual growth rate of 5.8% (Dias, 2010). This expansion of seed market is due to globalization of commercial seed market (more countries using commercial seed), more farmers within these countries purchasing seed and gradually increasing prices of seeds.

There are now over 6.8 billion human beings inhabiting this planet, and it has been projected that world population growth may exceed 70 million annualy over the next 40 years. It is expected to reach approximately 9.5 billion by 2050, when approximately 90% of the global population will reside in Asia, Africa and Latin America countries. With the increase in world population and consumption, and the advent of a high degree of added value through biotechnology, the global market of vegetable seeds is expected to expand in future years.

In recent times, there have been new challenges in the vegetable breeding and patenting domain. The objective of this paper is to discuss these challenges and to highlight the importance of biodiversity, plant breeding and improved vegetable varieties as key to modernize the vegetable production and to alleviate some protective measures that can create obstacles for innovation, and risks for biodiversity and food security.

2. World importance of vegetables

Vegetables make up a major portion of the diet of humans in many parts of the world and are considered essential for well-balanced diets since they supply vitamins, minerals, dietary fiber, and phytochemicals and have been associated with improvement of gastrointestinal health –good vision, and reduced risk of heart disease, stroke, chronic diseases such as diabetes, and some forms of cancer (Keatinge et al., 2010).

"Hidden hunger" or micronutrient deficiency is a pernicious problem that is caused by a lak of vitamins and minerals such as vitamin A, iodine and iron in the human diet and affects the health of between 2 and 3.5 billion people in the developing world (Pfeiffer & McClafferty, 2007). The consequences of micronutrient deficiency are: higher mortality, higher morbidity, lower cognitive ability and work productivity, and impaired growth and reproduction. Vegetables, due to their biodiversity, with increased available iron, zinc, and caroten, and enhanced protein quality could greatly improve the nutrition, health, and quality of life of these people. Diversifying diets with vegetables is a potent weapon in the current global battle against malnutrition. Food security and nutrition is not only about solving the urgency in the short-term; it must also address the long-term issue of poverty alleviation and economic growth. Greater investment in agriculture, including breeding and variety development, more effective development aid, and reforms to trade and domestic policies are all part of the solution.

Vegetables are grown worldwide, on large and small farms, on good and marginal land, and by large commercial growers and small subsistence farmers. According to FAO statistics, the production of vegetables in the world in 2007 was almost 900 million tons (FAO, 2009). Asia produced 74.7% of the world's vegetables (671 million t) on 72.8% of the world's vegetable production area (52.7 million ha). China has always been a large contributor to world vegetable production, and currently produces over 50% of the world's vegetables, which translates to 313 kg per capita. India is the second largest producer of vegetables in the world but at almost a six-fold lower level than China. Worldwide the area of arable land devoted to vegetables is expanding at 2.8% annually, higher than fruits (1.75%), oil crops (1.47%), root crops (0.44%) and pulses (0.39%), and at the expense of cereals (-0.45%) and fiber crops (-1.82%) (FAO, 2009).

The worldwide consumption and importance of vegetables in the diet is difficult to estimate owing to scant production statistics. Even where crop reporting services are an integral part of the agricultural infrastructure, information is available on only a small percentage of the vegetable crops grown. The consumption and caloric contribution of vegetables to the diet varies widely with geographical region, nationality, local customs, and cuisine. China is the largest consumer of vegetables in the world. Vegetables make up about 35% of per capita food consumption in China, a much higher share than the world average (Dias, 2011). Besides India, other southern Asian countries such as Bangladesh, Cambodia, North and South Vietnam, Laos and Philippines are also high producers and great consumer of vegetables. For example, vegetables comprise 40% of the Bangladeshi diet (Dias, 2011). Many vegetables are consumed near where they are produced, especially in Asia. The per capita consumption of vegetables in Asia has increased from 41 kg to 141 kg between 1975 and 2003 (FAO, 2009). Particularly in China the per capita consumption has increased from 43 kg (1975) to 154 kg (2003).

Rapid growth in mean per capita incomes in developed countries during the 1990s enabled consumers to purchase a broader range of relatively expensive vegetable commodities such as off-season produce, relatively new or renewed vegetables, and organic produce. Higher incomes of consumers in developed countries have also raised the demand for other attributes such as better quality vegetables and more variation in the daily menu. In developing countries consumption and domestic vegetable markets are also expanding because of an emerging educated middle class with increasing incomes. As worldwide health awareness increases and household income grows, an increasing global demand for vegetables is expected. At the same time, available arable land and a suitable water supply are lessening, so energies should be directed to enhance vegetable productivity and quality. Increasingly, consumers in developed and developing countries are also concerned about the quality and safety of their food, as well as the social and the environmental conditions where it is produced. It is expected that the assurance of safe vegetable products will become increasingly important. Food safety legislation in the European Union, in the United States, and in Japan is introducing increasingly stricter standards.

Desire for year-round availability and increased diversity, and growing health awareness, have also been important reasons for increased consumption of vegetables in developed countries. For example, the dietary benefit of fresh produce is the major reason for the 25% increase in fresh vegetable consumption in the United States during the 1977–1999 period (Regmi & Gehlar, 2001). On the other hand, factors such as increased participation by women in the labor market have created demand for processed, ready-to-eat convenience vegetable products.

A world vegetable survey showed that 392 vegetable crops are cultivated worldwide, representing 70 families and 225 genera (Kays & Dias, 1995, 1996); non-cultivated species, lower organisms (e.g. fungi), most trees and woody shrubs, and plants grown in or gathered from salt water were excluded. Vegetable crops, of which the leaves or young leafy shoots are consumed, were the most common group of vegetables utilized (53% of the total), followed by vegetable fruits (15%). Below ground crop vegetable organs ranked as follows in frequency of use: roots>tubers>rhizomes>corms>stolons, and together comprised 17% of the total number. Many vegetable crops have more than one part used. Most of the vegetables are marketed fresh with only a small proportion processed. Of these marketed vegetables, only 67 (17%) have attracted great breeding attention by international seed companies, due to their large area of production and substantial consumption, 52 (13%) were considered minor, and 85 (22%) were considered rare.

3. Vegetable marketing

Vegetables typically are perishable products that are of specific high value and that usually are sold through specialized markets. Currently more than 60% of the vegetables produced in the world are sold by vegetable growers to wholesale dealers or huge supermarket chains. Relatively few growers sell their product at retail prices to consumers in farm markets. Globally the horticultural product markets are still dominated by a large number of wholesalers or middlemen, which means not only that the producers have a lower profit but also the consumer often does not have access to lower-priced vegetables. Globally growers receive only 30% or less of the retail price. This situation is a serious problem for growers.

Domestic and international markets for vegetables are changing rapidly all over the world, partially fueled by the spread of supermarkets (Dias, 2011). Consumers increasingly purchase their vegetables and other foods in large convenience stores such as supermarkets and hypermarkets. The proliferation of supermarkets in developed and developing countries creates both challenges and opportunities for vegetable producers (Shepherd, 2005; Dias, 2011). Indeed, supermarkets may contribute to a higher demand for horticultural products and increase expectations for quality, safety, and presentation while simultaneously excluding small growers from participating in procurement and contracts. The growing importance of supermarket outlets has implications of its own regarding methods of procurement and quality standards. Supermarkets in the cities bring quality to the shelves. Vegetables are well packed and presented, providing scope for premium quality as well as novelty items. The difficulties that growers can experience is reflected in fairly rapid declines in the numbers of growers involved, as companies tend to delist suppliers who do not meet expectations in terms of volume, quality, and timely delivery. The standards of quality, safety, and presentation make it difficult for the small producers to compete. The market is getting more refined in terms of quality and yield expectations, and there is a clear demand for excellent hybrid vegetable varieties. Success for vegetable growers will depend on their ability to access diverse markets and respond promptly to changes in market conditions. Growers grow vegetables for immediate marketing, and their produce is subject to competition to decide the prices. Hence they cannot compromise the quality of the seeds they use for fear of rejection of their produce. They buy the best seeds, mainly hybrids, and frequently try new products to remain successful. The seed companies in turn get instant response and success if they develop new promising hybrids. Price of seeds is a more critical factor in marginal vegetable areas, where capital and spending input regimes are low, but is less important where high yields can be obtained and the grower's produce can be sold profitably. Providing that the benefits of the hybrid seed are understood, the price of seeds is less important than other factors, such as availability of capital, confidence in the produce market, and ability to buy other inputs, such as fertilizers and pesticides.

The increase in total volume of vegetables traded worldwide has been dramatic. Still, compared to overall exports of agricultural products, the importance of vegetable exports remains minor, comprising less than 10%of the total value. However, in recent years, the share of vegetables traded worldwide has been rising and is projected to continue to rise faster than other agricultural products. During the 1990-2010 period, the value of fresh and processed vegetables imported by developed countries surpassed all other categories. Growth in these commodities is also linked to changing trends in consumer preference and food retailing. In this situation, many vegetable growers are eager to produce value-added horticultural crops as compared to field crops and to obtain higher yields of high-quality products. International supermarket chains and large processors are becoming the main buyers of exported fresh vegetables, and small-scale growers worldwide need to be trained and organized to meet the challenge of supplying these international players. The major constraints against the participation of small-scale growers in international vegetable exports are the increasing attention that food quality and safety are receiving in food trade and an expansion in the number of nontariff measures that developed countries apply to horticultural products (Henson & Loader, 2001; Dinham, 2003; Henson et al., 2005).

Vegetables belong to the class of food items most frequently affected by sanitary and phytosanitary measures. Sanitary issues refer to ensuring a safe food supply for consumers, while phytosanitary issues concern the protection of domestic crops from imported pests and diseases. The Sanitary and Phytosanitary Agreement (SPS) of the World Trade Organization specifies that countries can pursue their own levels of food safety standards. However, SPS issues sometimes are used as a protectionist tool against imports since multilateral trade agreements have reduced the ability to protect domestic production with tariffs and quotas (Henson & Loader, 2001). SPS regulations may be the most important barrier to international trade in fresh vegetables. Thus exporters from less developed countries must be provided training opportunities and information access on how to produce and supply safe products to developed countries. Traceability, phytosanitary, infrastructure, and productivity issues will continue to be a barrier for participation in the vegetable trade for most of the developing world. Application of agricultural chemicals is often poorly regulated, and industrial pollutants are common hazards in the soil, water, and air of developing countries. In the future, the inability of these countries to meet increasingly strict phytosanitary and traceability requirements for food products will constrict exports to developed countries. Small-scale growers and processors in developing countries thus will have to learn to supply safe products with traceability labels, if their participation in global trade is to continue and expand. Technologies for safe and environmentally friendly vegetable production as well as capacity building should therefore gain particular attention for training to enable small-scale growers to participate in vegetable production for international markets.

Horticultural production, particularly in Mediterranean, subtropical, and hot-wet tropical environments, is severely constrained by postharvest losses, which have been estimated as 15%, depending on the crop and season (Kader, 2003). Vegetables often are highly perishable, restricting the ability of producers to store them to cope with price fluctuations. Reducing postharvest losses would make diversification into vegetable production less risky and more attractive. Postharvest-related quality losses also reduce opportunities for export and export revenues. Improved vegetable varieties subject to fewer postharvest losses can help improve this situation. Competitive participation in international markets requires relatively sophisticated marketing, information, and transportation networks as well as improved varieties, quality control, product standardization, and, for some future markets, traceability.

4. Biodiversity, vegetable migration and vegetable breeding

4.1 Introduction

Breeders play a key role in determining what we eat, since the plant varieties (=cultivars) they develop begin the dietary food chain. Vegetable breeding is the development of new vegetable varieties with new proprieties. Innovation in vegetable breeding is dependent on biodiversity and access to genetic resources, on specific knowledge, on the development and application of new technologies, and capital to utilise those factors. Access to genetic biodiversity as well as to technology is essential for the development of new vegetable varieties. The impact of vegetable breeding on vegetable production is dependent upon the complex relationships involving the growers, the varieties available to them, and the developers of those varieties. Vegetable growers consist of commercial producers with varying size land holdings ranging from moderately small farms to very large ones, and poor growers many of them subsistence farmers with small farms often on marginal lands. The subsistence farmers are usually also poor. Several types of varieties are available. The least sophisticated in terms of the method of development are landraces, also known as local varieties. Modern varieties consist of those developed by crossing and selection alone, those developed by crossing and selection but with specific important improvements often obtained from crosses with wild species or by transgenic methods, and F1 hybrids between desirable inbred lines. The developers of landraces are usually the farmers themselves, and are obtained by repeated simple selection procedures generation after generation. Improved varieties and hybrids are created either by public sector breeders or seed companies.
Farmers in some cases can plant and save their own vegetable seeds, but there are real problems in this system in commercial production, where typically many different species may be grown. In farmer-grown seeds, viability may be low, due to poor seed storage environment, pollination is often uncontrolled, genetic improvement is lacking and seed born diseases including virus may be a problem. Thus, in modern vegetable production the seed business is most efficiently conducted as a distinct industry dominated by international private seed companies.
The consequences of these relationships may be quite profound for the farmers at each level, the seed producers, the availability of food worldwide, and the future of crop biodiversity and sustainability. Therefore, it is worthwhile to examine international policy with regard to genetic resources genetic resources, vegetable breeding and its connections with commercial breeding industry to assess our future expectations.

4.2 Biodiversity

As stated biodiversity is the basis for plant breeding. Selection is impossible without diversity and new varieties for farmers and growers cannot be developed without it. This makes access to this variation essential for breeders.

Biodiversity of crops is characterised by a number of historical bottlenecks, i.e. critical moments diminishing this diversity. The first bottleneck was the result of domestication of crops in which only a subset of the diversity of the wild species remained after repeated selection for desired traits, e.g., non-shatering, plump seeds, etc. This was followed by a dispersal bottleneck which arises when only a subset of the crop was exported to another region, in which diversity was further reduced through adaptive selection to the new conditions (Zeder et al., 2006). This last case led for example to the famine in Ireland caused by potato blight exerting its disastrous effect as result of the narrow genetic base of the cultivated potato in comparison with those in the Andes areas of origin. The last bottleneck is the result of the modern scientific plant breeding that replaced genetically diverse landraces by uniform varieties, mainly F1 hybrids in vegetables. Besides recently "trait breeding", i.e. introducing a new trait in an existing variety through genetic modification or repeated backcrossing in combination with the use of markers, genetic biodiversity could also decrease. Where in the past conventional breeding introduced a much wider load when farmers' landraces or wild relatives were used to introduce such traits, a much more precise introduction of the desired trait alone is now possible. This may lead to a narrower genetic base of crops. Other modern bottlenecks such as "molecular bottleneck" and "cooporation companies bottleneck" are a risk and are discussed later.

The modern selection of uniform varieties from a wide biodiversity and the resulting fear of global genetic erosion led to the establishmemt of international, national and corporate genebanks. International policy with regard to genetic resources started in 1983 with the adoption of the "International Undertaking of Plant Genetic Resources for Food and Agriculture" of the UN Food and Agriculture Organization (FAO). This agreement primarily treated genetic resources as a "Heritage of Mankind" that should be freely available for all. The Convention on Biological Diversity (CBD) which came into force in 1993 put genetic resources under the sovereignty of the nations where such resources have obtained their distinctive character. Countries can, since then, make access to their genetic resources subject to mutually agreed terms. Countries differ in their implementation of the CBD and in their policy regarding access to genetic material. In some countries it is very difficult to gain access, e.g. because consent of the farmer, the land owner, the local community leader, local administrators and national authorities is required (e.g. Philippines). Such problems led to the development by FAO in 2001 of the "International Treaty for Plant Genetic Resources for Food and Agriculture" (see www.planttreaty.org). An important novelty of this International Treaty is the "Multilateral System" that should facilitate both the collecting and the sharing of benefits originated from the use of the genetic resources. Although most of the vegetables are not included in this International Treaty that applies to almost all crops and forages important for global food security. Materials of crops to which the Multilateral System apply that are under the control of the signatory governments are available under a single Standard Material Transfer Agreement (SMTA). The terms of the SMTA include a mandatory payment of 1.1% of the value of the seed sales in the case that a crop variety is produced using genetic resources from the Multilateral System, and if that variety is not freely available for further research and development. Alternatively, breeders can contribute with a flat rate of 0.5% of their gross sales for use of all genetic resources of the crop.

4.3 Vegetable migration

The introduction and trade of crops and seeds from one region to another has been continuous throughout history due to the migration of people, conquests, discoveries, and development of commercial trade routes. The ''Silk Route,'' for example, was responsible for many plant exchanges and trades between the West and China. As people immigrated to new countries, they carried not only languages, religions, and traditional customs but foods and seeds. Vegetables, in particular, are attractive candidates for introduction into a new environment, as most vegetables tend to be fairly short-season crops and, as a consequence, lend themselves for cultivation in many diverse areas. Thus, the tropical tomato has been transformed to a temperate annual. Superior vegetable crops and varieties often are assimilated into the cuisine of the indigenous populations.

Worldwide there has been, and continues to be, substantial emigration of peoples from a diverse range of countries. In western Europe and in the United States, immigration has had a pronounced effect on the vegetables consumed. For example, in the 1960s, southern Europeans immigrated to work in the northwestern European industrial zone, bringing with them their distinct consumer behavior patterns and vegetable preferences. They were responsible for the introduction of broccoli, eggplant, pepper, and fennel. Portuguese immigrants carried tree kales and tronchuda cabbages to Brazil in the 16^{th} century and to France and Germany in the 1960s. The introduction and popularity of a small number of new vegetable crops in some countries have resulted in a steady increase in their utilization. For example, Chinese cabbage and pak-choy were novelties in much of the United States in the 1970s but are now widely consumed due to the immigration of Asiatic people. Likewise, since the 1970s, sweet corn consumption has increased in several European countries. Nowadays many cities in the United States are excellent examples of increasing ethnic diversity and its impact on the vegetables available. Ethnic markets sprang up followed by shopping malls catering to Chinese, Korean, Vietnamese, or Hispanic populations. Vegetables such as Thai eggplant, tindora, parval, cactus leaves, and others are now readily found in ethnic American markets. New vegetables also have moved into traditional markets, as superior crops are accepted by the general public, greatly enriching the biodiversity of vegetables grown and consumed.

As a result of the increased frequency of world travel, a substantially greater variety of vegetable crops is available worldwide in many local markets. However, the number of new crops that become mainstream vegetables remains relatively small. Examples are rocket (*Eruca vesicaria* syn. *E. sativa*), lamb's lettuce (*Valeriana olitoria*), physalis (*Physalis peruviana*, *P. pruinosa*, *P. ixocarpa*), and pepino (*Solanum muricatum*). The number of crops that can be utilized within a local area will depend on the ethnic diversity of the location, affluence of the population, production and marketing constraints, and other factors.

Consumers also want more vegetable diversification and a continuous supply. Vegetables are purchased based partly on eye appeal, which means that the development of desire to consume increases market demand. Diversification also tends to increase consumption. Product differentiation, including new or renewed product introductions, is still a key strategy for expanding sales in vegetable markets. For example, the fresh tomato category has been differentiated to more than 10 offerings (beefsteak tomato, Roma-type tomato, vine-ripe tomato, cocktail tomatoes on vine, tiny-plum tomatoes, mini-plum tomatoes, red cherry tomatoes on vine, attractive yellow and orange cherry tomatoes, mini San Marzano–type tomatoes, teardrop or pear-shaped tomatoes, super or premium taste tomatoes). The introduction of specialty fresh baby leaf vegetable salads and fresh-cut products has opened new opportunities for domestic producers. The increased production of baby leaf vegetables in the world is intended to increase desire among elite consumers and is also an excellent way of supplying micronutrients. For example, baby leaf curly kale, as well as other dark green leafy vegetables, is a rich source of lutein and zeaxanthin carotenoids and, when cooked, contains seven times as much vitamin A as cooked broccoli and provides more calcium per 100 g than milk, yogurt, cooked broccoli, or cooked spinach. Until recently, kale was not a particularly popular vegetable in Europe (except Portugal), but as a baby leaf vegetable with 5 leaves, it is now accepted by many European consumers. An example of diversification in peas is the pea shoot. It is a nutritious leaf vegetable with high levels of vitamin C, folic acid, and vitamin A. To exploit such opportunities, it is important to continue research in biodiversity and to disseminate information regarding the benefits of vegetables, develop new improved vegetable varieties and processed products, evaluate the economic opportunities and the market scope of these new products, and identify marketing trends and alternatives.

Increasingly more wealthy and healthy people will demand greater vegetable dietary diversity in a global bio-based economy, which means that biodiversity will be crucial for the future. Besides biodiversity remains the main raw material for vegetable agricultural systems to cope with climate change because it can provide traits for plant breeders and farmers to select resilient climate-ready crop germplasm and release new varieties. Thus collecting samples of endangered vegetables to be preserved in genebanks is the first step, but also protecting the agricultural systems where those vegetables are produced is also important to ensure the *in situ* evolutionary processes.

4.4 Objectives of vegetable breeding

The genetic improvement of vegetables through breeding has to address and satisfy the needs of both consumers and growers. The general objectives for farmers are good yield, disease and pest resistance, uniformity and abiotic stress resistance. Objectives for consumers are quality, appearance, shelf life, taste, and nutritional value. Vegetable product innovation is necessary for maintaining the interest of today's consumer. Quality in vegetable crops, in contrast to field crops, is often more important than yield. For farmers to survive, varieties must be accepted by the market. Thus, color, appearance, taste, shape, are usually more important than productivity. For example, tomatoes to be used either fresh or in processing must have distinct quality characteristics. Fresh tomatoes must have acceptable flavor, color, texture, and other taste parameters to satisfy consumer demands and handling requirements. Processing tomatoes, on the other hand, must have intrinsic rheological characteristics that make them suitable for various processing applications, such as juice, ketchup, or sauce production. Traditional breeding requires the selection of a tomato genotype or a related wild species that has a desirable trait, such as early ripening or disease resistance, and crossing it with another tomato variety that has a good genetic background. The desired result is an earlier ripening tomato that makes it to the market sooner, or varieties that resist pathogen attack. In this way, several thousands of tomato varieties have been developed over the years. The final goal of vegetable breeding programs is then to release new varieties having elite combinations of many desirable horticultural characteristics. Plant breeding for improved taste, convenience, and consumer appeal has already contributed to increased per capita vegetable consumption with the development of products such as baby carrots, yellow and orange peppers, cherry and pear tomatoes, non-bitter cucumbers, mild tasting eggplants, seedless watermelons, and lettuces with different colors, textures and flavors for baby leaf and precut salads.

Other important objectives of vegetable breeding are disease and pest resistances. Since the early days of the 20th century, traditional breeding for disease resistance in vegetables has been a major method for controlling plant diseases. Varieties that are resistant or tolerant to one or a few specific pathogens are already available for many vegetable crops. Resistant hybrids with multiple resistances to several pathogens exist and are currently used in vegetable production. For example, in tomato, the genetic control of pathogens is a very useful practice and most resistances are monogenic and dominant. So far, tomato breeding has resulted in varieties with resistance to at least 15 pathogens, although with varying stability and level of expression (Grube et al., 2000). Tomato varieties with some resistance to fungi or oomycetes (*Alternaria alternata* f. sp. *lycopersici*, *Cladosporium fulvum*, *Fusarium oxysporum* f. sp. *lycopersici*, *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Phytophthora infestans*, *Pyrenochaeta lycopersici, Verticillium dahliae*), bacteria (*Corynebacterium michiganense*, *Pseudomonas solanacearum*, *Pseudomonas syringae* pv. *tomato*), virus (beet curly top hybrigeminivirus, tomato mottle bigeminivirus, tomato spotted wilt tospovirus, and several variants of the tomato yellow leaf curl bigeminivirus), and nematodes (*Meloidogyne* spp.) are available (Lacerrot, 1996). Many open-pollinated varieties of tomato presently cultivated possess genetic resistance to three or four pathogens. With the increasing use of F1 hybrids it is possible to use varieties combining from four up to six resistances (Grube et al., 2000).

Pest resistance is essential in vegetable production but is marginal in vegetable breeding research. There are few vegetable varieties resistant to insects. Resistance may be unstable due to genetic variants of the insect that are able to overcome that source of resistance. Depending on the complexity of the interaction between the pest and the vegetable plant, plant resistance may break down rapidly or be long-lived. Insects, including aphids, whiteflies, thrips and leafhoppers, are also very important in vegetables because they vector many viruses. Viruses can substantially reduce production and quality and are becoming increasingly problematic worldwide due to the absence of virus resistant germplasm for many important vegetable crops. Aphid vectored viruses are particularly problematic because many are transmitted in a non-circulative and non-persistent manner (Zitter et al., 1996). This means that a very short time, i.e. a few seconds or minutes, is sufficient for aphids to acquire virus particles when probing on infected plants. A similarly short time period is enough for aphids to release virus particles when probing on healthy plants. The primary injury caused by aphid-vectored viruses arises not from direct feeding damage by the aphids, but from their ability to allow the virus to enter the plant and initiate the disease.

The economic return of investment in breeding for disease and pest resistance may be low because it is dispersed among many different vegetable crop types. Also resistant varieties compete directly with non–resistant ones that may still be used by growers with minimum problems. Therefore vegetable disease resistance is most important when the disease is a limiting factor in production, and is especially important for many virus diseases. The high interest in, and the increasing present demand for breeding for disease and pest resistance is related to a generalized interest in releasing "environmentally friendly" vegetable varieties requiring sparse or no use of pesticides.

Breeding for postharvest traits, mainly transport quality, shelf life and cosmetic problems, is of increasing importance in vegetables. For example, in tomato, textural properties of fruits are important contributors to the overall quality for the fresh market and to the properties of products processed from tomatoes. Because cell wall disassembly in ripening fruit contributes to fruit texture, modification of cell wall proteins and enzymatic activity during ripening can impact cell wall polysaccharide metabolism and influence texture. Lettuce and other leafy vegetables used for salads deteriorate rapidly following harvest, requiring a considerable investment of effort to maintain quality and shelf life of cut material.

Harvesting increases respiration, stimulating deterioration, with increase in the synthesis of phenylalanine ammonia lyase and phenolic compounds, such as chlorogenic acid, which cause tissue browning. Consequently, delaying leaf senescence is an important target for breeding of leafy vegetables. Also in lettuce, breeding efforts have targeted tipburn, marginal browning, and rib discoloration, which detract from overall appearance. Vegetable products with good transport quality, better shelf life and good appearance will be preferred by traders and also by consumers.

Since vegetables are rich in vitamins, minerals and other micronutrients, and therefore vital for health, breeding objectives should include improving their nutritional value. Historically vegetable breeders have applied selection pressure to traits related to agronomic performance, particularly yield and quality, because these are the traits important to the producer. Rarely have growers been paid for nutritional factors, so there have not been economic incentives to pay much attention to these traits. However, consumers are becoming more aware of these traits.

Vegetable breeding for nutritional quality was not mentioned as a primary goal in plant breeding text books through the mid-20th century. However vegetable breeding efforts targeting improved micronutrient content and composition had begun in the 1940s and 1950s with research describing the inheritance and development of tomato breeding stocks and lines high in provitamin A carotenoids and vitamin C (Lincoln et al., 1943; Lincoln & Porter, 1950; Tomes et al., 1953). Lincoln et al. (1943) noted a fourfold variation in vitamin C among commercial varieties and up to 1194 ppm in red-fruited tomato interspecific crosses with *Solanum pimpinellifolium*. Similar research leading to the development of darker orange, and consequently high provitamin A, carrots began in the 1970s (Gabelman & Peters, 1979). Yellow core color occurs only in older open-pollinated carrot varieties since uniform orange storage root color has been a trait of interest in carrot for over a century. Similar studies were made in squash where rapid gains in carotenoid content have been made with phenotypic selection for orange color versus green and cream (Sudhakar et al., 2002). Genetic improvement to increase levels of specific micronutrients has been pursued in several other vegetables such as melon, spinach, sweet potato, potato, lettuce, broccoli, pepper, watermelon, collard, kale, peas, and bean. This field of study is relatively new, and also complex because of mineral interactions with each other, and numerous other compounds in the soil and in the plant. There is usually a large environmental effect, when the component is present in tiny amounts, such as for some micronutrients and phytochemicals. Success in vegetable breeding for higher vitamin and mineral content must consider not only substance concentration but also organic components in plants that can be abundant and either reduce or increase bioavailability. With these numerous considerations, breeding vegetable plants for improved nutritional value is a complicated goal that needs expertise in many disciplines such as plant breeding, nutrition, and soil science. When a vegetable compound (micronutrient or phytochemical) is found to be important for human health, and growers, vegetable markets and seed companies can capitalize on the value of the compound, there may be an opportunity for vegetable breeders to increase the amount of this compound. Breeders can be successful in reaching this goal, if the vegetable crop contains genetic variability for the compound, if selection is effective without detrimental pleiotropic effects, and if there is an easy method to measure the compound.

Enhanced nutritional content would add value for poor, malnourished populations. Breeding for provitamin A carotenoids, iron, and zinc is of keen interest as a strategy to alleviate nutrient deficiencies in developing countries (Graham et al., 2007; Hotz &

McClafferty, 2007; Pfeiffer & McClafferty, 2007). An example is the "golden tomato" which contains three to six times more provitamin A carotenoids than standard tomatoes. Developed at World Vegetable Center (AVRDC) with conventional breeding techniques after evaluation of tomato biodiversity, these improved nutritionally-rich tomato lines could help prevent many children of developing countries from going blind, since vegetarians and populations with limited access to animal products depend on provitamin A carotenoids for vitamin A. One "golden tomato" can provide a person's full daily vitamin A requirements. Tomato fruit and its processed products are the principal dietary sources of carotenoids such as lycopene. Lycopene is a potent antioxidant with the potential to prevent epithelial cancers and improve general human health. Therefore, there is considerable interest in elevating the levels of carotenoids in tomato fruit and thereby improve the nutritional quality of the crop. The B gene from *Solanum hirsutum* shifts tomato carotenoid accumulation from lycopene almost entirely to β-carotene and results in orange fruit color (Premachandra, 1986). This consequently dramatically increases the provitamin A carotenoid content. β-carotene content of commercial varieties, as mentioned, is of interest and several high β-carotene orange cherry tomato breeding lines have been bred (Stommel et al., 2005). Rainbow carrots, which are super sweet and crunchy, have multi-pigmented roots that naturally contain several antioxidants, such as lycopene, lutein, and anthocyanin. Similarly, yellow sweet potatoes are much more nutritious than white ones since they are high in provitamin A carotenoids. Unfortunately, the popularity of white fleshed sweet potato varieties in many tropical regions may complicate the acceptance of more nutritious orange ones. Recent studies across a range of Andean potato varieties show wide variation in calcium, iron and zinc content (Andre et al., 2007) as well as anthocyanins (Brown et al., 2005; Reyes et al., 2005) due to the existence of red-, blue- and purple-fleshed potatoes.

A vegetable, in order to have impact for its nutrient content, must be appealing to consumers. Sensory appeal, including color, is an attribute important to consumers when selecting many vegetables. Enhanced pigmentation of carrot, potato, tomato, and pepper, for example, is considered a quality factor. In peppers carotenoid content of green, yellow, orange and particularly red peppers can be relatively high. Selection for high pigment is an important goal because these carotenoids are important for visual appeal in many markets but until now didn't have any specific nutritional impact (Biacs et al., 1993; Hanson et al., 2004). In the past yellow or orange tomatoes could not compete with red tomatoes because they were unfamiliar to consumers, but now they are commercialized, and are challenging the market. This fact and recent development of orange colored cauliflower and orange flesh cucumbers reflect a new direction in vegetable breeding: nutritional quality. The white versions of these two vegetables lack carotenoids present in high enough concentration to alter their appearance. As nutritional quality becomes a more common breeding goal, and the novelty of unusual colors brings added value to seed companies and vegetable growers, unusual colors will quite certainly become more available and perhaps more widely consumed. But consumer requirements for quality: appearance, shelf life, and taste, must be met. Breeding to increase consumer appeal by improving convenience and the quality factors of a moderately nutritious crop often can be a more effective approach to increase intake of shortfall nutrients (Simon et al., 2009). Nutritional quality identifiable by the consumer and available at a moderate price might induce increased consumption and thus confer an important marketing incentive for breeding activity.

4.5 The commercial breeding industry

In the case of most vegetable crops, biodiversity and genetics are delivered in a marvelous package known as the seed. The special techniques of seed production, such as seed treatment for the control of planting diseases and viruses, and the combination of breeding improvement program such as development of hybrids and the incorporation of biotechnology, cannot be efficiently carried by individual growers. By these reasons in modern vegetable production the seed business is usually conducted as a distinct industry. High tech seed industry is a key part of modern horticulture that combines, seed production, genetic improvement, seed production, storage, and distribution.

Private breeding companies are placing more and more emphasis on the development of hybrids to exploit heterosis, and to combine multiple disease and stress resistance, but also for economic purposes to ensure growers must purchase seed for each planting. Control of the parents prevents other seed companies from reproducing the hybrid.

Farmers pay all the breeding work and seed marketing costs when purchasing improved or hybrid vegetable seed. International seed companies are mainly interested in the breeding and production of vegetable seeds with a high commercial value. Traditional vegetable landraces have largely been neglected by seed companies, policymakers, and researchers. But while their production often takes place under low-input conditions, they contribute substantially to household food and livelihood security, particularly for small resource-poor farmers (Weinberger & Msuya, 2004). For example, in Africa traditional landraces constitute an important source of micronutrients, contributing between 30% and 50% of iron and vitamin A consumed, respectively, in poor households (Gockowski et al., 2003; Weinberger & Msuya, 2004).

Breeding companies strived more and more to bring hybrid seeds onto the market. Worldwide the share of hybrid seed is increasing at a fast pace of 8 to 10% annually in most of the vegetables. More than two-thirds of the 5000 non-hybrid vegetable varieties available in 1984 seed catalogs from North America were dropped during last 25 years. A hybrid is produced by crossing two carefully selected parent lines to produce seed combining the best characteristics of each. Hybrids often exhibit higher productivity and vigor than open pollinated varieties due to heterosis. The superior characters of hybrid plants, unlike that of open pollinated varieties, cannot be maintained by farmers by saving their seeds for growing in the next growing season since the uniformity, vigor and overall performance of the hybrid is lost during seed multiplication. Therefore farmers are obliged to buy seeds from the seed companies every growing season if they want to compete in the marketplace. Many growers have been skceptical about the cost of hybrid seeds but found that they gave excellent returns. The main reasons which influenced the growers' decision to adopt improved or hybrid vegetable seeds are the ability of the product to meet the market demand, for high productivity, uniformity, resistance or tolerance to diseases or pests, better response to costly inputs, high quality, and storability. Hybrid vegetable varieties are used increasingly in large-scale intensive production because they provide increased marketable product for commercial growers and thus add to commercial incentives for the seed companies.

Open-pollinated varieties are derived by repeated selection of superior plants from within the same line and are genetically uniform for appearance traits. In naturally self-pollinated plants such as tomato, lettuce, and legumes, inbreeding leads to homozygosity. It has generally been found that self-pollinating vegetables such as tomato, after they have become stabilized, do not substantially change their genetic constitution. Thus it is easy to maintain the purity of self-pollinated vegetable crops by removing occasional variants. In the case of cross-pollinated plants such as cucurbits, cole crops, sweet corn, beet, and spinach, uniformity can be achieved by rigorous selection and confining natural crossing within the selected population. Isolation distances of at least 1,500 m between different varieties of the same species are recommended for all cross-pollinated crops that are to be harvested for seed.

Hybrid vegetable technology has made significant impact on most vegetable crops in developed countries, but a major limitation to vegetable production in many developing countries is the unavailability of high quality seeds. Hybrid seed production is a high level technology and cost intensive venture. Only well organized seed companies with good scientific manpower and well-equipped research facilities can afford hybrid seed production. The public sector in developing countries frequently does not have sufficient capacity to supply adequate quantities of good quality vegetable seed to poor growers and at present, there are few private sector seed companies adapting varieties to local environments, especially in the poorer countries (Rohrbach et al., 2003). Farmers themselves often produce seeds of locally preferred or traditional landraces, as the individual markets are too small and private companies have little interest in producing open pollinated varieties (Weinberger & Msuya, 2004). Without proper seed production, processing technology, quality assurance, and management supervision, locally produced seeds are often contaminated by seed transmitted viruses and other disease organisms, and are genetically diverse. Lack of proper storage facilities and an effective monitoring mechanism often leads to low or uncertain seed viability and vigor. Moreover, low capital resources and poor market information discourage the development of seed-related agribusinesses. Seed quality and treatment are keys to product quality, and there is a need for upgrading quality control laboratories to meet international standards.

By those reasons in modern vegetable production the seed business is usually conducted as a distinct industry. The global seed trade is now dominated by international corporations whose vast economic power has effectively marginalized the roles of public sector plant breeding and local, small scale seed companies. Thirty years ago there were thousands of seed companies in the world, most of which were small and family owned. Today, the top six global seed companies control almost 50% of the commercial seed trade. Some of these companies belong to worldwide corporations that also have other business areas besides seed like pesticides and biotechnology. A large number of acquisitions of small and big seed companies happened between 1996 and 2008 and these companies have increased their turnover both in conventional and in organic vegetable production.

The analysis of the companies involved in vegetable breeding reveals mainly five business models: i) vegetable breeding companies traditionally integrating variety development, production and marketing of seed; ii) vegetable breeding companies that breed and produce seed in their home country but licence their varieties to companies in other countries; iii) vegetable breeding companies that have meanwhile developed their own capacity in applied biotechnology; iv) vegetable breeding companies specialized in plant breeding biotechnology only, without being active in practical breeding, variety development, and seed production; and v) globally operating companies that have a strategic research capacity between fundamental and applied. Some of these companies belong to worldwide corporations that are also involved with pesticides and biotechnology. In the traditional vegetable breeding companies (i and ii) their income is primarily the selling of seeds. Although even these traditional companies are now also increasingly using biotechnology in their breeding programmes. In the companies that have still developed their own capacities in applied biotechnology (iii) their income remains by selling seed and not by generating income via licences on patents. Although this group of companies also comprises some companies originated from the agrochemical sector and that later became breeding companies via acquisitions and mergers. These last companies are combining two business: selling seeds and acquiring market positions via licences on their patents. Biotechnology companies (iv) are focusing on income from contract research for seed companies and on licence income from their biotechnological findings based on patent rights. This in particular concerns patents on molecular breeding techniques, marker platforms (e.g. Keygene) and on properties of the plants ("traits"), marketing of traits (e.g. BASF-CropLife). The value of such patents will in the end have to be paid at the level of the market for the seeds and planting materials by the end users (farmers and growers). Globally operating companies (v) combine a large biotechnological capacity with the production and marketing of seed while at the same time licensing technologies to other breeding companies. This category comprises most multinationals in the seed sector that are also active in agrochemicals and/or pharmacy, but also larger traditional breeding companies with a significant biotechnology capacity (e.g. Rijk Zwaan). For these companies the income from seed sales is the most important but some also generate income from licences.

A greater desire for year-round availability of vegetables has had a significant impact on seed companies, requiring full year-round production and consequently a global presence. Unlike for instance agrochemicals "where one size fits all", seed varieties need to be adapted and differentiated to suit the agronomic needs of the respective region where the vegetable is grown. Active international trade and overseas vegetable seed production by contract is common in many countries. Each multinational company vies to provide better vegetable seeds to compete with domestic seed producers. In China, whose seed market is estimated to be valued at more than US$1.4 billion, the increased recognition of new and high-yielding hybrid varieties has encouraged the local development of a large number of vegetable seed producers and distributors. Four types of vegetable seed producers were established: public seed companies, research institutes, foreign seed companies, and local seed companies. Private seed companies have been expanding rapidly in recent years and there are now thousands of small firms. Some companies have started to breed their own varieties and establish marketing networks. They play a strong role in the Chinese vegetable seed industry. About 60 foreign seed companies have opened branch companies or stations in China. Most of them not only sell their vegetable seeds but also have established breeding stations. In other southeastern Asian countries such as India, Indonesia, Vietnam and Malaysia, the percentage of hybrid vegetable varieties is lower than in China, and so a large expansion of seed companies has not yet occurred. While there has been rapid growth in the seed markets of developing countries due to a shift away from farm saved seed, the seed markets in developed countries, particularly those of Europe and Japan are stagnant. In Europe and the United States, the seed industry has been concentrated and is largely in the hands of large corporations and many small firms are closing.

Commercial vegetable breeding has brought a paradigm shift in the agricultural cropping system by developing superior and productive vegetable crop varieties in a short span of time. The vegetables attracting the most breeding attention vary considerably between small and huge seed companies/corporations. Small seed companies have a tendency to specialize in a few vegetable crops. In large international companies the breeding activity is more diverse, but is concentrated on the more economically important crops. In these companies, the application of modern biotechnologies such as molecular marker technology has become an integral component of many commercial vegetable breeding programs (Dias, 1989). The access to modern tools of plant breeding such as genomic information to develop markers for important traits and genetic resources are the key drivers of successful modern vegetable plant breeding. In an era of continuous change, vegetable plant breeding is contributing towards fulfilling requirements of producers and consumers as well as in assessing climate or growing conditions, through continuous innovations to develop new and better varieties. Vegetable breeding strategy and targets are dependent on market trends. Successful breeders anticipate changes in the market by developing new varieties that are ready to be released to the growers when their demand increases. Therefore it will be interesting to see how breeding companies react to changes in vegetable consumption and to evaluate the potential influence that the vegetable market and growing systems may have on breeding targets and priorities.

The commercial vegetable breeding sector produces a continuous flow of innovative new varieties for a number of vegetables. Breeding focuses on the following most important properties: resistances against pests and diseases, increasing yields, quality improvement (such as shelf life, taste), and increasing production efficiency. Companies that are introducing a new variety with a new trait usually have a lead of about four years, after which the competitors can introduce their own new varieties with the same trait. In such cases they make use of the "breeder´s exemption". This is how this "open innovation" system leads to a wide availability of such an innovation. Investiments in R&D by the top companies in this sector are very high, between 15 to 25% of their turnover, and this level keeps track with the annual increase in turnover. Most of the top companies show an annual growth of 5-7% with net profits exceeding 10%. Such growth can be realised in two different ways: by mergers and acquisitions or by autonomous growth. Companies with autonomous growth have to spend more on innovative R&D since they have to creat new varieties and new technology themselves.

Plant breeding is a long-term and therefore costly activity. Until the 1980s breeding was merely an empirical activity where breeders, on the basis of much knowledge and experience about traits of the reproductive material made crosses and select the most suitable plants. This process was strongly affected by growing season, lenght of the generation cycle, growing conditions, and available space. This meant that the developement of a new variety (e.g. a new hybrid) took 10-24 years, depending on the species. This developement period decreased to 4-11 years over the last 30 years by application of a wide range of biotechnological methods, such as *in vitro* tissue culture, *in vitro* haploidization, mutation breeding, DNA technologies, molecular breeding, etc. The application of modern technology has made plant breeding less time and space-depend and breeding processes have become much more efficient. This resulted in a reduction of the developement period of a new variety by a factor 2.5. Even though the R&D costs increase strongly (by about 10% annually) the return of such investiments in ensured by the faster production of new varieties.

A breeding company tries to maintain, or preferably expand, its market share by developing good varieties. A company can only continue the developement of new varieties if a good "return on investment" is ensured. The long time needed for the development of a new variety entails high risks and costs. This requires an adequate protection against the misuse of varieties developed by the breeder with a lot of creativity and professionalism. In Europe, Plant Breeder´s Rights (see 5.2) provide, depending on the vegetable crop, a protection of 25 or 30 years; this is long enough because the success period of a variety is usually 3 to 7 years. Seed companies can recover their investments by increasing the price of innovative seeds. This is possible in view of the usually fairly low price elasticity of vegetable seeds caused by the seed price being only marginal in comparison to the total production costs of a plant, by seeds being essential as basic material for production, and by innovations giving the seed a worthwhile added value. Currently, its also possible to protect a new trait in a variety via patent rights (see 5.3), provide that the new trait does at least meet the criteria of novelty, inventiviness and industrial applicability, and if the inventation is not restricted to one variety. The exclusivity for the patent holder means that these innovative traits cannot be used in breeding without permission (licence) of the patent holder.

4.6 Techniques of vegetable breeding

4.6.1 Introduction

From the 1980's onwards, major changes took place in plant breeding research as result of the application of modern biotechnologies. Commercial breeding had until then been based on traditional/classical breeding methods and plant biotechnology was limited to rapid *in vitro* multiplication of propagation material, the production of *in vitro* haploid plants for the rapid development of homozigous lines, etc. Since that time molecular technologies are now part of the plant breeder's tool box. The knowledge of molecular genetic is developing at high speed. Before long we will have access to genetic information of the complete genome of all major crops including some vegetables. Application of these techniques is called "molecular breeding", which uses enormous amounts of genetic data (bioinformatics), and which enables the combination of genetic information with information on gene expression (transcriptomics and proteomics), physiological data (metabolomics) and phenotypic data. The main breakthrough techniques are briefly described below.

One of the largest leaps forward in molecular breeding was the development of marker technologies (e.g. AFLP DNA fingerprint technology) to visualize the genetic make-up of plants. Breeders can use DNA images based on these technologies to analyse the germplasm of their vegetable crops. Marker assisted selection (MAS) has become an integral component of many commercial vegetable breeding programs (Dias, 1989). The aim of molecular breeding is to supplement conventional methods with faster and more efficient breeding through MAS and/or marker-assisted backcrossing (MAB). Molecular markers that are closely linked to the trait of interest may be identified and applied in gene pyramiding, facilitating introgression of desirable traits into varieties, early selection, etc. For more complex traits conferred by polygenes, quantitative trait loci (QTL) analysis is carried out. The decision to implement molecular markers as a selection tool is based on the fact that the cost of molecular marker analyses has steadily decreased due to the development of new, less expensive marker technologies, and by the implementation of automation for marker detection. Thus, for phenotypes that are simply inherited, screening with markers is often less expensive, and may be more precise, than screening for the phenotype in the field. QTL analysis is more complex and therefore may be more expensive. Markers bring additional value when they can be used to accelerate the development of new improved vegetable varieties. This may occur when phenotypes can be assessed only in specific seasons (since markers can be done anytime), or by improving the efficiency of selecting a recurrent parent for backcrossing or for selecting multi-locus genotypes. For example, in southern India, molecular-based tools were used to identify strains of the tomato leaf curl virus (ToLCV) and to select genes of resistance from wild tomatoes germplasm that were then bred into cultivated lines. ToLCV-resistant lines were developed that produce twice the yield of the most popular varieties in the region after only a few years (Hanson et al., 2000). Tomato resistant varieties to geminivirus were also developed with the help of the molecular markers. SCAR and CAPS markers linked to the beta gene in tomato have been developed for MAS (Zhang & Stommel, 2001). MAS for higher provitamin A carotenoids content is under way in muskmelons. Recently developed markers for watermelon lycopene β-cyclase allows selection differentiating lutein yellow carotenoid plants from lycopene red fruited plants early in development (Bang et al., 2007).

In vitro haploidization techniques like anther and microspore culture and *in vitro* gynogenesis, are also used in many breeding seed companies to accelerate the production of homozygous inbred parental lines and new hybrid vegetable varieties. For example successful *in vitro* microspore culture of broccoli and an improvement in the existing cole protocols, to make this technique available for the purpose of routine breeding, was described by Dias (2001, 2003) in 10 different broccoli genotypes. This protocol is now used by several seed companies worldwide to produce doubled haploid lines for pure inbred progenitors to obtain and ensure uniformity in generated hybrid varieties. Developmental cycles of commercial hybrid varieties range between 5 and 12 years. Besides breeding lines necessary for creating hybrid seed need to be refined for specific markets.

Another important tool for improving vegetable varieties is through genetically modified (GM) technology. Dias & Ortiz (2012) made recently a review of the status of transgenic vegetables to improve vegetable production. These authors analised the advances and potentials in transgenic research on tomato, eggplant, potato, cucurbits, brassicas, lettuce, alliums, sweet corn, cowpea, cassava, sweet potato, and carrots. Highlighted was host plant resistance to pathogens and pests, tolerance to herbicide, quality (both fresh and processed), and vaccine delivery in transgenic vegetables. They suggested, by their review, that the most promising traits seem to be host plant resistances to insects and pathogens, especially for vegetables such as tomato, eggplant, potato, summer squah and sweet corn. Traits such as disease and pest resistance or product quality creat value in the vegetable chain for farmers, traders and consumers.

Many vegetable crops have been genetically modified to include resistance to insects, plant pathogens (including viruses) and herbicides, and for improved features such as slow ripening, higher nutritional status, seedless fruit, and increased sweetness (Dias & Ortiz, 2012). Transgenic crops enable breeders to bring favorable genes, often previously inaccessible, into already elite varieties, improving their value considerably and offer unique opportunities for controlling insects and pathogens. The first commercially grown genetically modified crop was Flavr Savr™ tomato by Calgene in 1994, where the tomato fruit was made more resistant to rotting by adding an antisense gene that interferes with the production of the enzyme polygalacturonase (Kramer & Redenbaugh, 1994). This tomato was deemed to have a long shelf-life. However, it proved later to have a very short "market shelf-life" since the variety was considered inferior by growers, and was rapidly withdrawn from the market. An important lesson was learned by plant genetic engineers: the importance of cooperation with breeders. New vegetable varieties must be tested for performance in all markets before sales.

Two successful commercial examples of GM vegetables are GM squash and sweet corn varieties. In the United States squash yield losses due to viruses often range from 20% to 80% in summer squash (*Cucurbita pepo*) with a reported US$2.6 million economic loss in the state of Georgia in 1997 (Gianessi et al., 2002). Three of the most important viruses affecting squash production are *zucchini yellow mosaic virus* (ZYMV), *watermelon mosaic virus* (WMV), and *cucumber mosaic virus* (CMV) (Zitter et al., 1996). No summer squash variety with satisfactory resistance to CMV, ZYMV, and WMV has yet been developed by conventional breeding (Gaba et al., 2004). Control of squash viruses has focused on cultural practices, including delayed transplanting relative to aphid flights, use of reflective film mulch to repel aphids, and application of stylet oil to reduce virus transmission, in combination with insecticides to reduce aphid vector populations (Perring et al., 1999). In the state of Georgia, it is estimated that ten applications of stylet oils and insecticides are made routinely to control aphids and, hence, limit virus incidence and transmission (Gianessi et al., 2002). Two lines of squash expressing the CP gene of ZYMV, WMV, and CMV were deregulated and commercialized in 1996 (Medley, 1994). Subsequently, many squash types and varieties have been developed, using crosses and backcrosses with the two initially deregulated lines. This material is highly resistant to infection by one, two or all three of the target viruses. (Ochoa et al., 1995; Tricoli et al., 1995; Fuchs et al., 1998; Schultheis & Walters, 1998). The adoption of virus resistant squash varieties has steadily increased in the United States since 1996. In 2005, the adoption rate was estimated at 12% (approximately 3,100 ha) across the country with the highest rates in New Jersey (25%), Florida (22%), Georgia (20%), South Carolina (20%) and Tennessee (20%) (Shankula, 2006). Virus-resistant transgenic squash has allowed growers to achieve yields comparable to those obtained in the absence of viruses with a net benefit of US$22 million in 2005 (Shankula, 2006). Engineered resistance was the only practical approach to development of varieties with multiple sources of resistance to CMV, ZYMV, and WMV. US vegetable grower benefited drom having GM squash varieties resistant to those virus in markets where GM squash is allowed.

Sweet corn, expressing Cry1Ab endotoxin, was introduced commercially in the United States in 1998 into an industry that is highly sensitive to damage to corn ears from lepidopteran pests (Lynch et al., 1999). Research showed that this endotoxin was very effective against the European corn borer (*Ostrinia nubilalis*) in the state of New York, providing 100% clean ears when no other lepidopteran species were present and in excess of 97% when the two noctuids, corn earworm *(Helicoverpa zea)* and fall armyworm *(Spodoptera frugiperda)*, were also present (Musser and Shelton, 2003). Studies in other states in the USA have shown that *Bt*-sweet corn provided consistently excellent control of the lepidopteran pest complex and the potential for 70 to 90% reductions in insecticide requirement (Lynch et al., 1999; Burkness et al., 2001; Hassell & Shepard, 2002; Musser & Shelton, 2003; Speese et al., 2005; Rose & Dively, 2007). Although it was estimated that of the 262,196 ha of sweet corn (fresh and processing) grown in the United States less than 5% was *Bt*-sweet corn in 2006 (NASS, 2007), because processors have avoided growing *Bt*-sweet corn due to concerns about export markets. Since then it has been therefore grown only as a fresh market vegetable crop. By using appropriately timed insecticide applications with *Bt*-sweet corn varieties, fresh market sweet corn growers in South and North Carolina have been able to extend their production later into the season when populations of *H. zea* and *S. frugiperda* are generally too high to control satisfactorily with insecticide applications alone (Hassell & Shepard, 2002). Even when two insecticide sprays are required on *Bt*-sweet corn (e.g., for late season control of *H. zea*), an economic assessment in Virginia found a gain of US$ 1,777 ha^{-1} for fresh-market sweet corn vs. non-*Bt*-sweet corn sprayed up to six times with pyrethroid insecticides (Speese et al., 2005). *Bt*-sweet corn has also proven to be soft on the major predators of *O. nubilalis*, including the lady beetles *Coleomegilla maculata* and *Harmonia axyridis*, the hemipteran *Orius insidiosus* (Musser & Shelton, 2003; Hoheisel & Fleischer, 2007), and a complex of epigeal coleopterans (Leslie et al., 2007). Overall, *Bt*-sweet corn was much better at preserving these predators while controlling *O. nubilalis* than were the commonly used insecticides lambda-cyhalothrin, indoxacarb and spinosad. *Bt*-sweet corn can replace the traditional method of controlling *Lepidoptera* with broad-spectrum insecticides. It may however allow secondary pests to arise. Results from these studies led to the development of a decision guide for sweet corn growers that uses information on biological control and can advise them on the economic return of using various options, including *Bt*-sweet corn (Musser et al., 2006). These results demonstrate also that some of the new *Bt*-sweet corn hybrids allow a truly integrated biological and chemical pest control program in sweet corn, making future advances in conservation, augmentation and classical biological control more feasible. The use of *Bt*-sweet corn has proven to be very effective against the targeted lepidopteran key pests and plantings of *Bt*-sweet corn continue to rise in the United States, with new *Bt*-fresh-market hybrids being released each year.

The introduction of a GM plant on the market requires a safety analysis, both in terms of consumer health and ecological effects. According to a recent COGEM publication the total costs associated with the market introduction of one transgenic plant with one transgenic event is between 6 and 10 million euro. Biotechnology products will be successful if clear advantages and safety are demonstrated to consumers. However, countries vary in their market standards of acceptance of GM products.

Pest and virus-resistant transgenic plants are particularly valuable if no genetic sources of resistance have been identified or if host resistance is difficult to transfer due to genetic incompatibility or links to undesired traits. In such cases, engineered resistance may be the only viable option to develop pest and virus-resistant varieties. However, vegetables are considered minor crops and traditionally have had fewer resources channeled to them compared to field crops. While it is becoming less expensive to create GM crops for pest management, developing a marketable product and a regulatory package remains costly. Development and regulatory costs can be more readily recouped if the product is grown on an extensive area, as would be done with field crops, but which is not generally the case for individual vegetable crops. For example, the large agricultural biotechnology companies have for the most part abandoned the development of GM vegetable crops because of the high costs associated with product development and deregulation. For vegetables, there are many varieties of the same crop and the expected life of a particular variety can be quite limited. Introducing a GM trait into a breeding program can be complicated and cost prohibitive, especially in crops where backcrossing is difficult or impossible (e.g. potatoes). In most countries, deregulation of a GM trait is event specific. For many vegetable crops, it is not possible to develop a single GM event that can be converted into many different varieties of a single or closely related group of vegetable species via conventional breeding. For example, *Brassica* contains about 40 closely related commercialized crops, including cabbage, cauliflower, broccoli, Brussels sprouts, turnip, Chinese cabbage, pak-choy, various mustards, swede, vegetable rapes, etc. (Kays & Dias, 1995, 1996). No single parent exists that can be used to backcross the transgene into the many different types of *Brassica* botanical varieties. Individual events would have to be developed for many of the crop types and deregulation of more than one event for a single protein is problematic for most business models. For the few transgenic vegetable crops that are being developed, novel or unconventional strategies have been employed to bring the crops to market based generally on private and public partnerships, in which the private sector would focus on selling hybrids to higher end producers while the public sector would focus on low resource growers. Consumers concerns on GM vegetables, in particular in Europe and Japan, is also important. Globally it is widely accepted that the introduction of GM varieties of vegetables is some way off, but it remains a future possibility mainly in developing countries where more than 80% of the world's 6.8 billion population lives, the majority of the vegetables are produced and pest problems are most acute.

5. Intelectual property in vegetable breeding

5.1 Introduction

As stated the development of a new vegetable variety, or a new breeding technique, requires much time, effort and money. Making new vegetable varieties requires high investments that can only be recouped if the breeding companies can comercialise the variety for a certain period of time. To encourage innovations, compensate and reward innovators, and to protect the rights of the breeder the legislator has developd systems to be used by the breeder and/or discoverer to protect himself against the risk that others can without permission simply copy, imitate and commercialise his result, the new variety or the new finding.

The first half of the 20th century saw the development of a specific type of property right for the breeding sector: "plant breeder´s right". The advent of modern biotechnology in plant breeding in the 1980s brought along another form of intellectual property right (IPR): "patent right´s". The plant breeder's right under plant variety protection laws protects breeder's innovation and authorizes him to exclude others from commercializing his newly developed variety without his permission. On the other hand, "breeder's exemption" ensures that the other breeders in the field can use the protected variety to develop new varieties by making use of the commercially accepted properties of the protected variety.

The technological intervention in plant breeding brought about rapid development in crop improvement and the availability of genomic, proteomic and metabolomics information, in turn, enhanced strategic interests in patent rights in plant breeding. The overall system of intellectual property rights (IPR) applicable to a broader range of protections made plant breeding and the commercial seed sector more efficient and effective. The values created by patents or by other IP protection laws have resulted in the consolidation of the plant breeding industry. Both IPR systems are described in this chapter.

5.2 Plant breeder's rights

Plant breeder´s rights (PBR) represent the oldest form of protection available to plant breeder´s. PBR is a protection system specifically designed for the breeding of new plant varieties. After the approval of "Plant Patent Act" in 1930 in United States, that permitted the patenting of asexually propagated plants, seed companies compaigned for international protection for sexually derived varieties as well. Their efforts culminated in 1961 with the establishement of the "International Union for the Protection of New Varieties of Plants" (UPOV) which purpose was the legal protection of plant varieties through defined plant breeder's rights. UPOV was first enacted for countries of the European Union, and the original law was the result of a revision of the "Netherlands Seeds and Planting Materials Act" that was introduced in the Netherlands in 1941 for the protection of plant breeder's rights. This original law was revised in 1972, 1978 and 1991 (UPOV, 1994). A drastic revision was made in 1991 where protective ownership was extended to include "essentialy derived varieties", which was defined as a variety that is more than 85 per cent similar to the originally protected variety. This implies that breeder’s rights on a new, distinguishable variety that strongly resemble the parent variety as a result of the application of particular method of plant breeding or biotechnology (such as repeated backcrossing, genetic transformation or mutation) may be dependent on the rights over the parent variety. At the same time, the “farmer’s exemption” was restricted, giving member states the option to allow farmer’s to save seed. The spirit of the original attempts of UPOV to protect plant breeder’s rights was that the granting of a certificate of protection should not inhibit the flow of information and products through continued research by the entire plant breeding community. Unfortunately, those collective revisions detract from that spirit. Membership was expanded, first to other developed countries and later to 16 developing countries. By 2004, a total of 54 countries subscribed to UPOV.

PBR protection available to breeders allows them to protect their new plant varieties and restrict others from using these varieties without the permission of title holder. PBRs only provide protection to the variety and offer no protection for the method necessary to obtain the variety. This means that PBR is only meant to protect the product in the market. The varieties in order to qualify for protection must fulfil the conditions of distinctness, uniformity, and stability (DUS), and novelty. Distinctness: the variety is deemed to be distinct if it is clearly distinguishable from any other variety of which the existence at the time of submission of the application is a matter of common knowledge. A variety can be distinguishable from an existing variety by a difference in morphological (e.g. flower colour) or physiological (e.g. salt tolerance) properties. Uniformity (Homogeniety): the variety is deemed to be homogeneous if it is, having regard to the variation that may be expected from the particular features of its own reproduction, sufficiently homogeneous as regards its relevant characteristic. Stability: the variety is deemed to be stable if in its essential characteristics it remains true to its description after repeated reproduction or propagation. Novelty: the variety is deemed to be new if propagating or harvested material has not been sold or otherwise disposed of, for the purpose of exploiting the variety. The novelty concept in PBRs does not refer to a certain variety not having existed before but to a variety not having been sold before. This plant breeder´s rights approach of the novelty concept made, many define this condition as the condition of commercial novelty. PBRs grant the holder the authority to forbid others to reproduce, handle, offer for sale, sell, import and export or store material of the protected variety. PBR does not extend to private actions, experimental actions (“research exemptions”), or actions for breeding activities (“breeder’s exemption”). In breeder´s exemption, the breeder can neither act against third parties that use the protected variety as basic material for the development of new breeding products. In other words, the breeder cannot act against actions carried out in order to breed other varieties. This restriction holds a fundamental confirmation of the exploitation thereof. This means that PBR do not protect or restrict genetic material for further use and that existing, already successful varieties can be used as basis for new varieties. This results in the genetic potencial of the varieties showing an increasing line year after year. PBR do thus not prevent buiding on existing varieties already protected under plant breeder´s rights. “Research exemption” is provided to other researchers to use the variety for experimental purposes, which means that the breeder cannot act against third parties that use he protected variety for experimental purposes. “Farmer’s privilege” is another exemption where the farmer who has lawfully acquired the protected variety can keep a small amount of seed from his own harvest to be re-sown without asking the breeder for permision.

5.3 Patent rights

Patent rights offer a second protection system that has for some years been available to the plant breeder. From the end of the 1980's with the biotechnological intervention becoming widely prevalent, patent protection for plant related inventions were awarded in many countries, mostly from the developed world. In the United States patent systems became important for the breeding sector following subsequent court decisions: i) Diamond vs Chakrabarty in 1980, which involved the first patent on a man-made microorganism; ii) in 1985, plants were considered patentable following the ruling in *Ex* parte Hibberd; and iii) in J.E.M. AG Supply, Inc. v. Pioneer HiBred International, Inc. (Stoll, 2001), where the US Supreme Court allow the use of the general patent law to grant true patents for plants, plant materials and methodologies. In Europe patent rights alow patents on plant properties, plants *per se* and numerous molecular plant techniques since 1998, the year in which the European Union Biotechnology Directive was enated (EU, 1998). In United States the purpose of the utility patent law was extended to plants in 2001. These facts mean that new varieties resulting from modern molecular breeding are legally protected under patent laws offering wider protection. Unlike PBRs where only plant variety is protected, patents are granted for inventions in general, not just for plants. However, in many countries, the patents for plants are not granted. Where patent rights are granted, they include plant genes and to some extent the plants or plant varieties. Though there is no specific rule of patentability of plant genes or the gene sequence, it is necessary that they meet the requirement of patentability i.e. novelty, inventiveness and commercial utility. As per the EU Biotechnology Directive (Article 5), the commercial use of gene sequence must be stated in the patent application. Initially, there plant patents were not available in the European Union. Due to the fact that some biotechnological inventions were not protectable using existing protection like PBR, a new biotechnology directive was implemented in 1998 in all member states of European Union. Although, plant varieties *per se* are not patentable, the additional provision introduced in the EU Biotechnology Directive allowed invention concerning plants to be patentable if the technical feasibility of the invention is not confined to a particular plant variety. Inspite of this restriction, there are a number of cases where patented genes are inserted into the plant material which leads to indirect patent protection of the plant variety. The patented genetic material can then only be used further after obtaining the permission of the patent holder. The plant covered by a patent, for instance cannot be used as a crossing parent in breeding without permission.

In patent laws, only pure scientific research comes under exemption whereas research aimed at the development of a new commercial product is not exempted. In United States, the exemptions under patent laws are strongly restricted as a result of a court ruling in the case of *Maley* v. *Duke University* (Ludwig & Chumney, 2003). This led to further complex situation where GM plants cannot be used for scientific research, a restriction that many researchers are critical about (Waltz, 2009). This lack of a research exemption in the United States has created the unusual situation where a university invention, if licensed exclusively, may be unavailable for ongoing research even in the very laboratory where the invention itself was made. To address this situation, many universities in their exclusive license agreements now reserve rights for the use of inventions within their own institution or, even more broadly, within all academic or nonprofit research institutions. Now, the question that arises is that since plants are self-reproducing, up to which generation does one grant patent protection?

It must also be clear that the patent system does not allow for any reproduction of seeds by farmers. The only exception is the "farmer's privilege" that has been explicity introduced in the European Biotechnology Directive. This experience may be an interesting example for developing countries.

5.4 Plant breeder's rights *versus* patent rights

In the pre-protection era, most of the innovators were compensated in terms of their professional growth. In private breeding, the 'first mover advantage' and 'trade secrets' inbuilt in hybrids gave sufficient compensation to innovators, but after the enactment of IPR laws related to agriculture, in most countries, private research increased and research companies rushed to gain as much IPR protection or patents as possible to gain commercial benefits. The rapid development in technologies, particularly, molecular biology has led to "breeding by design". The knowledge of molecular genetics is making rapid advances and soon access to genetic information of the complete genome of all major crops shall be gained. These approaches in plant breeding are anticipated to produce lot of alternative processes like "breeding by chromosomes" resulting in patentable products. Presently, big corporation companies not only earn money by selling products but also from royalty on their patents. A scenario study by the OECD (2009) predicts widespread use of the technologies based on high-throughput sequencing, proteomics, metabolomics and phenotyping, new types of genetic markers and new genetic modification system by 2030. In GM vegetable plants the genes will be inserted in plants for production of pharmaceuticals and other valuable products. Whether these technologies will become commercial successes depends upon costs related to research, market introduction and regulations, public acceptance and balanced intelectual property policies that stimulate innovations and competition.

The descriptions of both forms of intellectual property protection reveal fundamental differences between plant breeder´s rights and patent rights as regards the subject of protection (PBR is granted for one, physically existing, variety; a patent is granted for products or processes as formulated in the claims), the condition for protection, content of the right, and the exemptions. It particularly applies to the exemptions that when both systems apply at the same time (as in case of a plant variety coming under the patent on a property or method) only those exemptions apply that are applicable in both systems. All other exemptions, such as the breeder´s exemption, are subsidiary to the right of the other system (the patent). This means that when a variety protected under PBR is part of a patent claim, the variety may under PBR be used for further breeding whereas this may not under patent rights.

The coexistence of patent rights and plant breeder´s rights is recognise in the European Biotechnology Directive (EU, 1998). The legal instrument provided in the Directive to enable coexistence between patent rights and plant breeder´s is the compulsory licence. Art. 12(1) aproaches the problems from the position of the breeder and stipulates that when a breeder can neither obtain nor exploit a PBR without infringing a patent of an earlier date, he may request a compulsory licence for non-exclusive exploitation of the inventation protected by such a patent. Art. 12(2) then deals with the problems in a similar way from the point of view of the patent holder and stipulates that when the holder of a patent on a biotechnological invention cannot exploit such an invention without infringing on a PBR of an earlier date, the patent holder may request a compulsory licence for non-exclusive exploitation of this plant variety that is protected under PBR. Art. 12(3) lists the conditions that must be met by breeder and patent older to obtain a compulsory licence. Breeder and patent older must demonstrate that they have unsuccessfully approached the patent older or PBR holder, respectively, to obtain a contractual licence and that the plant variety or the invention represent a "significant technical progress or significant economic interest" in relation to the invention for which a patent is requested or for the protected plant variety.

The PBR have a few weaknesses but they were written specifically for plants, and thereby implicitly recognize the differences between plants and inanimate objects. This is a saving grace. Much more egregious is the application to plants of the patent laws, which do not recognize these differences and therefore creates serious problems. The patent laws were written and amended over the years to protect a process, a machine, a manufacture, etc., but not for living things. Therefore, it became necessary to apply the criteria of the patent laws to living entities, for which they were not intended. This has had some interesting consequences. Consider the bases for granting a patent. Under the patent law, an invention must be novel, non-obvious, and useful. The use of the term novel in IPR laws may be confusing. For plant breeder's rights protection, as explained before, it means new in a commercially available sense. Under patent law, it means: "of a remarkably new and different kind". As stated by Ryder (2005), this criterion is badly abused in plant patents. For example in 12 lettuce patents involving lettuce found in an internet search, eight are for new varieties. All are unequivocally obvious. Hundreds of lettuce varieties have been developed and released over the years; these eight are not remarkable in any way. The concept, breeding methods, and characteristics claimed are all ordinary. Most plant varieties are developed by shuffling known genes in various combinations; the genes code for obvious, known traits. The other four patents were for characteristics or procedures. One was for aphid resistance transferred by traditional breeding crosses from a related wild species. The resistance was closely linked with a deleterious character; they were separated through crossing-over, and the recombinants were identified by molecular methods. The overall process was clever but obvious: breeders often find it necessary to break undesirable linkages. The second patent was for a trait called "multileaf characteristic" and refers to lettuce plants subject to fasciation, a flattening of the stem due to a wide meristematic apex. The trait was selected to occur very early in the life of the plant and resulted in the production of many leaves within a relatively narrow size range. This trait would be advantageous in producing cut leaves for packaging. This innovation may be considered non-obvious. The third trait is an elongated iceberg type lettuce produced by crossing iceberg lettuce x romaine lettuce. Iceberg lettuce is normally spherical. The head leaves are closely appressed and cup-shaped and are therefore hard to separate. Romaine lettuce has elongated leaves that remain separated. The claimed trait specifies iceberg type leaves (characteristic texture and taste) in an elongated head where the leaves also separate easily. This combination of traits is non-obvious. The fourth patent is for a chemical treatment that inhibits head formation of iceberg or butterhead lettuce, so that the leaves remain upright and open. Interior leaves are exposed to light and therefore are green instead of white. This presumably increases the content of certain nutrients, for example, beta-carotene, of these leaves. This may qualify as a non-obvious invention, although the idea of producing all green head leaves has been proposed before. The last criterion for protection is utility. The meaning of this is straightforward: the invention is marketable and therefore has potential economical use. This criterion is particularly important to the inventor, because the driving purpose of the invention is to sell it and make money. The difficulties noted above stem from a failure to properly apply two of the three basic requirements that qualify an invention as patentable under the patent law. Much of the above discussion leads to the inevitable conclusion that the patent laws are inadequate for plants and should be replaced. IPR protection for plants must be framed in different terms than for inanimate objects. Many patent applications are granted broad claims on traits and processes which are essential in nature. So, in patents, the essential processes like crosses, segregations and recombinant selections which are used for developing new varieties should be excluded. However the term "essentially biological" processes are not well defined. In the European Biotechnology Directive, these are defined as entirely natural phenomenon of crossing and selection. A technology step in breeding seems sufficient to make whole process not entirely a natural phenomenon, thus patentable.

Patent for plant varieties is considered the ultimate protector of breeder's rights, affording the opportunity to control as many aspects of the invention as possible, thereby strangling the innovative capacity of the competition. The patent is a means to slow the flow of progress of plant breeding research, except within the company holding the patent. While obviously benefiting that company, it is a big step backwards for the plant breeding community and by extension, for agriculture itself. Theoretically, if each seed company could obtain a patent on a new variety with certain favorable traits, each would do further breeding only with its own protected variety. So there would be parallel lines of research without the enrichment to each program that comes from crossing those lines with varieties in other programs. The owner of a patented variety can share it by licensing its use in breeding to other companies. The cost of the license, in outright payment or in royalty fees, may be quite steep. This would certainly limit the interest in using that variety, since the cost may negate any profit from a new variety.

Patents allow elevation of the profit motive far above the good-of-society and biodiversity requirements. There are two major products of plant biotechnology: traits and methods. Traits such as a disease resistance or product quality (e.g. increase antioxidant content) create value in the process of vegetable breeding. For vegetable breeding companies, specialized in plant breeding biotechnology that have based their business model on the development and marketing of traits or marker platforms (*cf.* 4.5) the protection through patents is essential. For them patent system is the only way to create freedom to operate for further innovation. Patents are also necessary to enter into public-private partnerships, to maintain freedom to operate for scientists, assist in the downstream utilisation of public inventions, and to obtain cash benefits for the institute facing increasing difficulties to secure public financing.

It is recognized that these IPR have provided an essential contribution to the innovation and the success of plant breeding until now but breeder's exemption which allows them to benefit from the availability of the competitor's genetic resources and to use protected varieties for further breeding seems crucial for the future of biodiversity and food security. Breeder's exemption plays an essential role in innovation in practical plant breeding which motivation is to find creative solutions for problems in vegetable farming and in the value chain that can capture a market segment. It should also be noted that nowadays no breeder's rights are requested for many vegetable crops in view of the fact that the economic life of a new variety is no more than few years and that most income can be generated during the time required to register such varieties (1-2 years). Another reason is that most vegetable varieties are hybrids than cannot be reproduced.

6. Trends in biodiversity and vegetable breeding

As referred above, about one half (52%) of the total number of vegetables cultivated in the world receive commercial breeding attention by seed companies and, of those, only 17% are in large scale breeding programs, fostering a need for serious attention to maintenance of vegetable crop biodiversity. There has been a severe decline in the vegetable variety genetic base, as evidenced by the significant reduction, especially within the last 50 years, in the number and range of vegetable varieties grown. During this period vegetable genetic biodiversity has been eroding all over the world and vegetable genetic resources are disappearing, on a global scale, at an unprecedented rate of 1.5–2% per annum. Widespread adoption of simplified vegetable systems with low genetic biodiversity carries a variety of risks including food insecurity. In the short term, such systems risk potential crop failure. In the longer term, they encourage the reduction of the broad genetic base that contributes to high yields, quality traits, disease and pest resistance, etc. This compromises the future genetic health of vegetables. Especially prominent among the "enemies" of genetic biodiversity are the commercial markets and economic social pressures that have practiced breeding methods that promote uniformity, encouraging extensive cultivation of preferred improved and hybrid vegetable varieties with insufficient biodiversity. In addition, globalization has stimulated the consolidation of vegetable seed companies into huge corporations and the decline of small seed companies that serve local and regional markets. In consequence some vegetable breeding programs have been merged or eliminated to reduce costs. Thus fewer and fewer companies/corporations are making critical decisions about the vegetable research agenda, and the future of vegetables worldwide. Inevitably, two things will happen. There will be fewer vegetable breeders in the future and growers will be dependent on a narrower genetic background that could contribute in the near future to food insecurity for poor growers and consumers. Also, with the advent of genetic engineering, these huge seed corporations are also assuming ownership of a vast array of living organisms and biological processes. Of equal concern are expanded uses of legal mechanisms, such as patents and plant breeder's rights that are removing vegetable plant germplasm from general public use (Ryder, 2005). Intellectual property rights for plants were intended as a defensive mechanism to prevent the loss of invented varieties to competitors. However, with the more stringent enforcement of plant breeding rights, and particularly with the application of the utility patent law in the United States to protect all forms of an innovation, this has become an offensive weapon to stifle competition and inhibit the flow of germplasm and information. This can have serious implications for the future conservation of vegetable genetic resources and for world food security.

Some landraces and old open-pollinated varieties of vegetables have existed for long periods outside the commercial and professional plant breeding circles because they have been kept alive within communities by succeeding generations of seed savers. Unfortunately, there are fewer and fewer active seed savers among the millions of vegetable growers, due to the demand of commercial markets and the professionalization of the sector. This is an additional threat to genetic biodiversity. So continued survival of landraces and open-pollinated varieties of vegetables depends largely on popular interest and initiative as well as preservation in gene banks. We should be alerted and concerned about the loss of biodiversity in vegetables and about this impact on food security.

Vegetable growers have an important role in conserving and using vegetable biodiversity. The future of world food security depends not just on stored vegetable genes, but also on the people who use and maintain crop genetic biodiversity on a daily basis. In the long run, the conservation of plant genetic biodiversity depends not only on a small number of institutional plant breeders and seed banks, but also on the vast number of growers who select, improve, and use vegetable biodiversity, especially in marginal farming environments. That is why we should be also alerted and particularly alarmed by the current trend to use improved and hybrid vegetable varieties exclusively. Growers do not just save seeds, they are plant breeders who are constantly adapting their vegetable crops to specific farming conditions and needs. For many generations, vegetable growers have been selecting seeds and adapting their plants for local use. This genetic biodiversity is the key to maintaining and improving the world's food security and nutrition. No plant breeder or genetic engineer starts from scratch when developing a new variety of tomato, pepper, cabbage or lettuce. They build on the accumulated success of generations of growers, who have selected and improved vegetable seeds for thousands of years. If poor small-scale growers in marginal areas stop saving seeds, we will lose genetic biodiversity. Growers will lose the means to select and adapt vegetable crops to their unique farming conditions, which are characterized by low external inputs. Hybrid seed technology is designed to prevent growers from saving seed from their harvest, thus forcing them to return to the commercial seed market every year. Hybrid vegetable seeds alone, and used globally, can be a dead-end to biodiversity. If growers abandon completely their traditional vegetable landraces in the process of adopting only hybrids, crop genetic biodiversity achieved over centuries will be lost forever. Many agronomic benefits will be lost to worldwide growers and thus to consumers.

The exclusive adoption of hybrid varieties in marginal areas may restrict the vegetable producing capacity of growers. It will also destroy biodiversity, and it may contribute in the long-term to food insecurity. For example, a study by Daunay et al. (1997) points out that the release of F_1 hybrids (in Europe and some Asian countries like China and Japan) displaying higher productivity, but with poor phenotypic variability, has contributed to the losses of eggplant landraces, thus inevitably leading to genetic erosion of *S. melongena.* Moreover, some African cultivated eggplants have been lost following social, economic, and political changes (Lester et al., 1990). Therefore, the cultivated eggplant has been considered a priority vegetable species for the preservation of genetic resources since 1977. Several studies have been carried out in Asia and Africa (Lester et al., 1990; Gousset et al., 2005), and collections built up (Bettencourt & Konopka, 1990), particularly in China (Mao et al., 2008).

Fortunately, in some developed countries new independent seed companies, offering unique collections of regionally adapted landrace vegetable varieties, have recently emerged. Furthermore vegetable hobbyist groups, mainly from organic horticulture, are thriving and maintaining old vegetable landraces, in organizations known as "Seed Savers." In this way traditional landraces are being restored to native growers and urban and peri-urban growers. Some of these traditional landraces display combinations of traits that make them especially responsive to local or regional conditions, or are well-suited to particular growing methods, such as those used in organic horticulture or low-external-input systems, or are tolerant to local pests and diseases or other stresses and constraints. Organic growers who seek to grow "full-cycle" or seed-to-seed, are also working to ensure the continued availability of organically grown seeds. There are also considerable ongoing efforts by national governments and international organizations to preserve plant vegetable germplasm in gene banks. This is a valuable but static approach, as further evolutionary changes and improvements will not occur until the seeds are planted, and selection takes place. It is also an activity that relies heavily on continued political stability and support, including sustained governmental funding. Active and positive connections between the private breeding sector and large-scale gene banks are required to avoid possible conflict involving breeders' rights and gene preservation.

The biodiversity of vegetable crop species will be promoted by the maintenance of crop gene banks by governmental and non-governmental organizations, the continued use of diverse sources by plant breeders, especially in the public sector, and by the use of local varieties and landraces by farmers.

7. Prospects for developing countries and poor vegetable farmers

Breeding of vegetables in developing countries is reduced and focused on a very limited number of crops. It is strongly dependent on public investments in the centres of the Consultative Group on International Agricultural Research (CGIAR). One interesting exception it is the recent partnership for new vegetable varieties between Rijk Zwaan international breeding company and Tanzania Government which aim is jointly to develop new vegetable varieties with hight quality standards for the African farmers and consumers. This program will be strongly supported by technology, facilities and know-how of Rijk Zwaan in colaboration with local Tanzania partners. The general lack of private investment in developing countries can be explained by the dominance of the public sector on the one hand and the low purchasing power of the majority of the farmers. Besides in some of these developing countries the market is too small to generate the interest of the international breeding companies for specific programmes. Those CGIAR centres, e.g. AVRDC, provide varieties or half-bred materials to national public institutes, universities and to the private seed sector particularly in Asia.

A major concern in developing countries is that under UPOV, farmers are not allowed to exchange seed of protected varieties, and that only for specific crops farmers may be allowed to reuse their own seed. This is opposed to traditional seed handling practices by farmers in these countries, and exchange is an important tool to maintain biodiversity and in preventing seed shortages among poor farmers. During the Green Revolution, the local exchange of seed was stimulated in order to increase access to better varieties. The level of implementation of breeder's rights (UPOV) legislation differs widely within developing countries. Most Latin American countries responded by joining UPOV under its 1978 or 1991 Acts. Most Asian countries developed systems that are closed to UPOV (but didn't join) or combine breeder's rights with aspects of politically important farmer's rights because these are considered insuficiently protected by UPOV. In Africa, few countries are members of UPOV (South Africa, Kenya – and Tanzania has applied). Developing countries are sometimes asked to become a member of UPOV in exchange for trade agreements and sometimes they are asked to introduce patent rights for plants and even plant varieties. This puts developing country policy makers, who are aware of the importance of local seed exchange among farmers for basic vegetable crops in a difficult position. UPOV recognises an exemption for private and non-commercial use, but this is interpreted by many as to be valid only for farmers who consumed all of their crop within the family. Since almost all farmers take some surplus vegetables to the local market, this strict interpretation does not help much and is not likely to lead to UPOV membership least developed countries.

The legal systems of most of these developing countries is relatively new and not mature enough to tackle the growing patent complexities and they expect a rational approach and freedom to operate in using biodiversity.

Nearly half of the world's vegetable farmers are poor and cannot afford to buy hybrid seed every growing season. What are the prospects for these growers since they produce 15-20% of the world's vegetables and they directly feed almost one billion people in Asia, Latin America, and Africa?. Capital and risk factors are the key constraints that limit the adoption of improved vegetable varieties by small and poor farmers, because these vegetables generally are much more costly to produce per hectare than traditional landrace varieties (Key & Runsten, 1999; Ali & Hau, 2001; Ali, 2002), and most farmers require credit to finance their production. While landraces are usually cultivated using a level of input intensity appropriate to the financial resources available within a household, improved vegetable varieties often require an intensive input regime, including large labor inputs for planting and harvest that cannot be met with family labor alone (Weinberger & Genova, 2005). For small and poor farmers improved vegetable varieties also tend to be riskier than landraces, since the higher costs associated with seeds and production impose a greater income risk. Small farmers may have lower production costs with landraces, because they achieve adequate yields with fewer inputs. In addition, the profits from improved varieties or hybrids tend to vary because yields are often higher but prices fluctuate. From another perspective variable prices and yields increase the variability in market supply (Key & Runsten, 1999).

The lack of capital available to small and poor farmers denies them the opportunity to invest in vegetable production inputs. Without collateral help these farmers are usually unable to secure a loan from a bank or money lender. For those who can get a loan, rates are often unmanageably high, with strict penalties for late repayments. Similarly, a lack of education, resources, skill training, and support prevent these farmers from using improved varieties and then to generate a stable income from their production. In addition, governments usually do not regulate the price of vegetable crops or even provide market information, unlike for field crops. Improving market information systems for vegetable crops and facilitating farmers' access to credit are then essential components of a strategy to enable poor farmers to grow improved vegetable varieties and to overcome the insecurity of their food supplies. The problem of food insecurity in this situation, like that of poverty, is thus frequently traceable to macroeconomic conditions and market failures due to actions of exploitative intermediaries, including landowners, moneylenders, and traders. A major obstacle to success in vegetable production is the shortage of affordable credit. In some cases vegetable farmers must pay high interest rates of 15 to 25 % per 100 days. Desperate for cash, subsistence farmers are forced to sell their crops immediately after the harvest to middlemen or their creditors at unfavorable prices. As pointed by HKI (2010) low cost quality seeds are essential for these farmers. Credit facilities and other inputs must be also part of these vegetable production systems, so that the use of improved vegetable varieties can help subsistence vegetable growers to overcome their poverty and food insecurity.

The benefits from the use of improved varieties are shown by a project supported by the United States Agency for International Development (USAID) and conducted by AVRDC from 1991–2000 at Bangladesh, in two districts (Jessore and Savar), with the aim of overcoming constraints in vegetable production (Weinberger & Genova, 2005). The two districts were selected because they have large vegetable production areas. In Savar three-quarters of all agricultural land is in vegetable production, while in Jessore, the share is 50%. Technological interventions included germplasm evaluation and variety development for many vegetables, off-season production technologies, and grafting technologies for tomato and watermelon to control soil-borne diseases. Between 1996 and 2000, after variety development and the introduction of some new facilities, rural infrastructures and extension services, vegetable production grew at an average annual rate of 5.4%. In a survey conducted with 300 growers, the adoption of improved varieties (42%) and hybrid seed (30%) were the most responsible for this increase in vegetable production of all the technologies used. Among 27 vegetable crops propagated by seed there were 5 (19%) where the only change in vegetable production was the adoption of improved varieties or hybrid variety seeds; in 14 (52%) there was the additional adoption of simple cultural practices like row sowing and fertilization. Tomato grafting and other more sophisticated practices were not implemented. Of the hybrid varieties used, 92% were of cross-pollinated species in which hybrids are important for uniformity. Vegetatively propagated vegetables were not included in the activities. Eager to increase their production, the majority of the growers (91%), regardless of farmer type, invested in some new vegetable technology over the last five years of the project. The average proportion of growers who adopted an improved technology was 43%, and the average adoption rate among all technologies was 31%. Improved or hybrid vegetable varieties were 72% responsible for the increase of vegetable production, since it was easier and cheaper for the growers to buy improved variety seeds than to adopt other technologies. This fact per se highlights the importance of improved varieties and the need to invest in varietal improvement research, since it requires fewer behavioral changes compared to adopting new crop management practices. In terms of farmer's receptiveness to these improved technologies, small-scale farmers, particularly small landowners, tend to be late adopters due to skepticism about the cost of improved and hybrid seeds and capital and risk constraints compared with larger-scale farmers with large cultivated areas (Collins, 1995).

Increased vegetable production has also resulted in important employment benefits for the community such as: new employment opportunities, substitution of family labor by hired labor, and increased wages. Local support industries have also benefited from the expansion of vegetable cultivation both on the input and output side. A higher degree of input commercialization was observed for vegetables as compared to cereals and included all inputs such as seed, inorganic fertilizers, pesticides, farm manure, plastic, mesh netting and bamboo poles. In general, a higher share of vegetable output was sold on markets as compared to the production of cereals. Vegetable growers were highly integrated into markets, selling a large share of their products and retaining a small portion for home consumption. This was true for both small-scale and large-scale farmers. Since supermarkets continue to play a minor role in Bangladesh, most of the vegetable produce was sold either in the local markets or to wholesalers.

In general, the survey project found that vegetable production has contributed to widespread welfare improvement and poverty alleviation in Bangladesh. While nearly all communities agreed that they were benefiting from increased vegetable production (either in terms of enhanced consumption, enhanced investment, saving opportunities, or increased welfare), the grower level data also showed that larger-scale farmers have been able to capitalize more. On average, 90.3% of households experienced an improvement in their lives over the past five years, but large-scale growers reported greater increases in well-being as compared to smaller-scale farmers. The study has also shown that more impact can still be expected, particularly if agro-technology industries develop further. However, the availability of cheap, high quality vegetable seed may be restricted and a major impediment to progress.

Similar projects were implemented by AVRDC in other Asia-Pacific countries and in Africa and the results were similar showing that farmers receive more income from vegetables per hectare than grain crops, and that efficient vegetable production using cheap improved seeds contributes to poverty reduction and less food insecurity. These projects show that improved vegetable varieties could benefit poor farmers and landless laborers by increasing both production and employment. It could benefit the rural and urban poor through growth in the rural and urban non-farm economies and by making food available that is high in nutrients.

8. Concluding remarks

Vegetable breeding is the development of new vegetable varieties with new proprieties. In this era of changes, vegetables will play a major role in well-balanced diets and in the current global battle against malnutrition. There will be continuous need of biodiversity and new and performing varieties for sustainability of vegetable production. Biodiversity is the basis for vegetable breeding and for the introduction of new varieties and hybrids to improve quality and productivity.

Creation of vegetable hybrids is a key means towards the development of varieties for modern vegetable production. Hybrid seed production is high technology and a cost intensive venture. Only well organized seed companies with good scientific manpower and well equipped research facilities can afford seed production. Due to globalization, most vegetable breeding research and variety development in the world is presently conducted and funded in the private sector, mainly by huge multinational seed companies. Few companies are controlling a large part of the world market. Public vegetable breeders and public sector variety development are disappearing worldwide. This means in general that there will be fewer decision-making centers for vegetable breeding and variety development. This has also resulted in the focus on relatively few major vegetables produced worldwide, to the detriment of all other cultivated vegetables. It is imperative that national governments and policymakers, as part of a social duty, invest in breeding research and variety development of traditional open-pollinated varieties and in the minor and so-called "forgotten" vegetables. Smaller seed companies, which are usually specialized in few vegetable crops, must be supported, possibly through autonomous affiliation with the larger companies. More investments in this area will mean less expensive seed for growers to choose from, and increased preservation of vegetable biodiversity. The accomplishment of this goal may require new approaches to vegetable breeding research and development by both the public and private sector.

Domestic and international vegetable markets are changing rapidly, and a variety of factors such as supermarkets and improvements in transportation and refrigeration have largely contributed to this development. Trade liberalization has impacted on the increasing importance of exports, which are increasing for high value vegetable crops. Increasing urbanization, with increasing incomes mainly of growing middle classes in most parts of the world, requires large quantities of vegetables. These may be produced locally or at great distances from where they are consumed, with effects on vegetable post-harvest processing and value-added activities. The standards for participation in high value vegetable markets have increased, both in developed and developing countries and supply chains are increasingly complex, undergoing rapid changes, and often based on strong vertical integration. The participation of small-scale growers in dynamic vegetable markets for higher value vegetables is a major challenge. Participation requires, particularly in developing countries, a set of institutional changes, training, and credit facilities to allow them to compete in increasingly competitive global markets that demand safe, uniform and high-quality produce. Credit facilities and other inputs must be part of subsistence vegetable production systems, so that the use of improved vegetable varieties can help subsistence vegetable farmers to overcome their poverty and food insecurity.

Since the introduction of modern biotechnology in the 1980's many new (in particular molecular) technologies have been devepoded that are important for plant breeding, which enables, e.g., speeding up of the breeding process and the discovery of genetic information. These technological breakthoughs have led to major changes in plant breeding and the development of molecular breeding. Molecular tools will be useful for selecting resistance genes, and increasing quality, nutritional value, and yields. These traits plus food safety will be important aspects of future breeding efforts. Overall, there is great genetic and phenotypic diversity for types and amounts of micronutrients in the various vegetables. Consequently there is a good potential for increasing micronutrient content and thus enrich the diet of the average consumer. More research is needed with the goals of providing benefit to poor and malnourished populations.

Biotechnology provides the ability to produce a broad array of insect-resistant and pathogen-resistant varieties that also express a variety of other value-added traits such as nutritional and post-harvest traits. As the number of value-added, GM traits increases, the number of potential combinations of traits that could be stacked within individual varieties increases geometrically, as to the cost associated with maintaining inventories of geographically adapted varieties expressing different combinations of traits. Consequently, we can expect that commercially available, GM vegetable varieties of the future will express multiple, unrelated, transgenic traits, and farmers in many cases likely will not have the option of planting varieties expressing only single traits. The availability of transgenic vegetable crops does not however ensure that they will be adopted by growers. The benefits of their adoption must exceed their costs for a large proportion of vegetable growers from one season to the next to be widely adopted.

The objective of plant breeding is to produce better varieties for farmers and growers. Investor's interests usually are not the breeder's first priority. Development of new technologies and its use in plant breeding have led to escalation of costs for the breeding companies. Further, protection and regulatory costs add to the high risk investments for the smaller breeding companies. The increased complexity of markets and the higher demands force modern plant breeding to reduce the time for new varieties development, thus, further escalating the cost. The short span of life of a variety in the environment is resulting in shorter earn back period. This double impact is bound to put more pressure on investors to recover their investment through protection of intellectual property, and consequently royalties.

Protection of intellectual property in plant breeding is not the primary driver to develop new, innovative varieties but it is an adequte tool to protect the new varieties in the market against illegal reproduction and sales. Plant breeder's rights as well as patent rights play a major role in supporting plant breeding and innovation. Despite the large differences between both systems, plant breeder's rights and patent rights may have two fundamental, identical objectives: i) on one hand, both rights systems ensure that the developer/inventor is recognised for his creation/invention by granting an exclusive right. For the proprietor this serves in practice a business-economic purpose that may provide; ii) on the other hand, plant breeder's rights as well as patent rights include an important socio-economic objective, by disclosing information on the patentable invention and by making a plant variety under

PBR available for further breeding ("breeder's exemption") . This offers possibilities to built on such inventions and may stimulate further innovation by others, including competitors, which serves the public objective of economic development, food security and preservation of biodiversity. As regards patent rights, however a clear distinction needs to be made between patents on technologies for plant breeding and patents on genetic properties of plants. Granting patent rights for genetic traits is conflicting with plant breeder's rights, the breeder's exemption in particular. The access to genetic variation/biodiversity is so crucial to further innovation in breeding that a form of breeder's exemption within patent rights is required. Amendement of regulations is necessary to increase room for innovation in vegetable breeding. This can be reached by restricting the scope of patents in plant breeding, and more specifically by reinstating the exemption of patents on varieties or by introducing full breeder's exemption in patent rights.

Until recently vegetable breeding research and development that targets small-scale and poor vegetable growers has largely been undertaken by public sector institutions and national agricultural research institutes. Public plant breeding remains a key component of vegetable research systems worldwide, especially in developing countries. However the increasing presence of private sector breeding and a decrease in national and international support makes it difficult for the public sector to continue operating in the traditional manner. Declining funding for public vegetable breeding coupled with the rapid increase of vegetable production and consumption and an urbanizing population, has created a difficult situation. More public sector vegetable breeders are needed worldwide to select and to produce non-hybrid varieties of the minor and "forgotten" vegetables. Breeding of vegetables and other minor crops must continue as a viable endeavor. This will benefit small-scale growers, and will safeguard biodiversity and food security in developing countries. A good example is China where there are four types of vegetable breeders and seed producers: public seed companies, research institutes, foreign seed companies, and local seed companies.

While the maintenance of vigorous public sector breeding programs in areas where private companies are not interested in providing low cost varieties is highly desirable, an additional approach to maximize vegetable and horticultural research input would be the development of global programs with public–private partnerships. The public sector may support portions of vegetable and horticultural R&D that are not attractive to the private sector, and feed improved breeding lines and systems to the private sector for exploitation in regions where the private sector is active, and nurture private sector development in regions where it is lacking. Many in the public and private sectors support such a complementary approach to overcome poverty and malnutrition in developing countries.

In summary, we must ensure that society will continue to benefit from biodiversity and from the vital contribution that plant breeding offers, using both conventional and biotechnological tools, because improved and hybrid vegetable varieties are, and will continue to be, the most effective, environmentally safe, and sustainable way to ensure global food security in the future.

9. References

Ali, M. (2002). The vegetable sector in Indochina: a synthesis. The vegetable sector in Indochina countries: farm and household perspectives on poverty alleviation. AVRDC-ARC. Bangkok.

Ali, M. & Hau, V.T.B. (2001). Vegetables in Bangladesh. Technical Bull. 25. AVRDC, Shanhua, Tainan.

Andre, C.M.; Ghislain, M.; Berlin, P.; Oufir, M.; Herrera, M.R.; Hoffman, L.; Hausman, J.F.; Larondelle, Y. & Evers, D. (2007). Andean potato cultivars (*Solanum tuberosum* L.) as a source of antioxidant and mineral micronutrients. J. Agr. Food Chem. 55:366–378.

Bang, H.J.; Kim, S.G.; Leskovar, D. & King, S. (2007). Development of a codominant CAPS marker for allelic selection between canary yellow and red watermelon based on SNP in lycopene beta-cyclase (LCYB) gene. Mol. Breed. 20:63-72.

Bettencourt, E. & Konopka, J. (1990). Vegetables. pp. 204–220. In: Directory of germplasm collection. IBPGR, Rome.

Biacs, P.A.; Daood, H.G.; Huszka, T.T. & Biacs, P.K. (1993). Carotenoids and carotenoide esters from new cross-cultivars of paprika. J. Agr. Food Chem. 41:1864–1867.

Brown, C.R.; Culley, D.; Yang, C.P.; Durst, R. & Wrolstad, R. (2005).Variation of anthocyanin and carotenoid contents and associated antioxidant values in potato breeding lines. J. Am. Soc. Hort. Sci. 130:174–180.

Burkness, E.C.; Hutchison, W.D.; Bolin, P.C.; Bartels, D.W.; Warnock, D.F. & Davis, D.W. (2001). Field efficacy of sweet corn hybrids expressing a *Bacillus thuringiensis* toxin for management of *Ostrinia nubilalis* (Lepidoptera: Crambidae) and *Helicoverpa zea* (Lepidoptera: Noctuidae). J. Econ. Entom. 94:197-203.

Collins, J. (1995). Farm size and non traditional exports: Determinants of participation in world markets. World Development 23:1103-1114.

Daunay, M.C.; Lester, R.N. & Ano, G. (1997). Les Aubergines. In: *L'amélioration des Plantes Tropicales. Repéres.* Charrier A., Jacquot M., Hamon S. & Nicolas D. (eds.) pp. 83–107 CIRAD-ORSTOM, Paris.

Dias, J.S. (1989). The use of molecular markers in selection of vegetables. SECH, Actas Hort. 3:175-181.

Dias, J.S. (2001). Effect of incubation temperature regimes and culture medium on broccoli microspore culture embryogenesis. Euphytica 119:1-6.

Dias, J.S. (2003). Protocol for broccoli microspore culture. In: *Doubled haploid production in crop plants. A manual*. Maluszynski, M., Kasha K.J., Forster B.P. & Szarejko I. (eds.). pp. 195-204. Kluwer Academic Publishers, Dordrecht.

Dias, J.S. (2010). Impact of improved vegetable cultivars in overcoming food insecurity. Euphytica 176:125-136.

Dias, J.S. (2011). World importance, marketing and trading of vegetables. ICH 2010, Lisbon. Acta Horticulturae (in press).

Dias, J.S. & Ortiz, R. (2012). Transgenic vegetable crops: progress, potentials and prospects. Plant Breeding Reviews 35:151-246.35:151-246.

Dinham, B. (2003). Growing vegetables in developing countries for local urban populations and export markets: Problems confronting small-scale producers. Pest Manag. Sci. 59: 575–582.

EU (1998). Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions. PBL no. 213. EU Brussels. pp.13.

FAO (2009). FAOSTAT data. Available from http://www.fao.org.

Fuchs, M.; Tricoli, D.M.; McMaster, J.R.; Carney, K.J.; Schesser, M.; McFerson, J.R. & Gonsalves D. (1998). Comparative virus resistance and fruit yield of transgenic squash with single and multiple coat protein genes. Plant Disease 82:1350–1356.

Gaba, V.; Zelcer, A. & Gal-On, A. (2004). Cucurbit biotechnology - the importance of virus resistance. In vitro Cell. & Develop. Biol. - Plant 40:346–358.

Gabelman, W.H. & Peters, S. (1979). Genetical and plant breeding possibilities for improving the quality of vegetables. Acta Hort. 93:243–270.

Gayon, J. & Zallen, D.T. (1998). The role of the Vilmorin Company in the promotion and diffusion of the experimental science of heredity in France, 1840–1920. J. History Biol. 31:241–262.

Gianessi, L.P.; Silvers, C.S.; Sankula, S. & Carpenter, J.E. 2002. Virus resistant squash. In: *Plant Biotechnology: Current and Potential Impact for Improving Pest Management in U.S. Agriculture. An Analysis of 40 Case Studies*. National Center for Food and Agricultural Policy, Washington, DC, USA.

Gockowski, J.; Mbazo'o, J.; Mbah, G. & Moulende, T. (2003). African traditional leafy vegetables and the urban and peri-urban poor. Food Policy 28:221–235.

Gousset, C.; Collonnier, C., Mulya, K.; Mariska, I.; Rotino, G.L.; Besse, P.; Servaes, A. & Sihachakr, D. (2005). *Solanum torvum*, as a useful source of resistance against bacterial and fungal diseases for improvement of eggplant (*S. melongena* L.). Plant Science 168:319–327.

Graham, R.D.; Welch, R.M.; Saunders, D.A.; Ortiz-Monasterio, I.; Bouis, H.E.; Bonierbale, M.; Haan, S.; Burgos, G.; Thiele, G.; Dominguez, M.R.L.; Meisner, C.A.; Beebe, S.E.; Potts, M.J.; Kadian, M.; Hobbs, P.R.; Grupta, R.K. & Twomlow, S. (2007). Nutritious subsistence food systems. Adv. Agron. 92:1–74.

Grube, R.C.; Radwanski, E.R. & Jahn, M. (2000). Comparative genetics of disease resistance within the *Solanaceae*. Genetics 155:873–887.

Hanson, P.M.; Bernacchi, D.; Green, S.K.; Tanksley, S.D.; Muniyappa, V. & Padmaja, A. (2000). Mapping a wild tomato introgression associated with tomato leaf curl virus resistance in a cultivated tomato line. J. Am. Soc. Hort. Sci. 125:15–20.

Hanson, P.M.;Yu, Y.R.; Lin, S.; Tsou, S.C.S.; Lee, T.C.; Wu, J.; Jin, S.; Gniffke, P. & Ledesma, D. (2004). Variation for antioxidant activity and antioxidants in subset of AVRDC—the World Vegetable Center *Capsicum* core Collection. Plant Gen. Res.: Characterization and Utilization 2:153.

Hassel, R. & Shepard, B.M. (2002). Insect population on *Bacillus thuringiensis* transgenic sweet corn. J. Entom. Sci. 37:285-292.

Hayes, H.K. & Jones, D.F. (1916). First generation crosses in cucumber. Republic Conf. Agr. Exp. Stat. 5:319-322.

Henson, S. & Loader, R. (2001). Barriers to agricultural exports from developing countries: The role of sanitary and phytosanitary requirements. World Devel. 29:85–102.

Henson, S.; Masakure, O. & Boselie, D. (2005). Private food safety and quality standards for fresh produce exporters: The case of Hortico Agrisystems, Zimbabwe. Food Policy 30:371–384.

HKI (Helen Keller International) (2010). Homestead food production model contributes to improved household food security, nutrition and female empowerment-experience from scaling-up programs in Asia (Bangladesh, Cambodia, Nepal and Philipines). Nutr Bull 8:1-8.

Hoheisel, G.A. & Fleischer, S.J. (2007). Coccinelids, aphids, and pollen in diversified vegetable fields with transgenic and isoline cultivars. J. Insect Sci. 7:64.

Hotz, C. & McClafferty, B. (2007). From harvest to health: Challenges for developing biofortified staple foods and determining their impact on micronutrient status. Food Nutr. Bul. 28:S271–S279.

Kader, A. (2003). A perspective on postharvest horticulture (1978–2003). HortScience 38:1004–1008.

Kays, S.J. & Dias, J.S. (1995). Common names of commercially cultivated vegetables of the world in 15 languages. Economic Botany 49:115-152.

Kays, S.J. & Dias, J.S. (1996). *Cultivated Vegetables of the World. Latin Binomial, Common Names in 15 Languages, Edible Part, and Method of Preparation*. Exon Press, Athens, Georgia.

Keatinge, J.D.H.; Waliyar, F.; Jammadass, R.H.; Moustafa, A.; Andrade, M.; Drechsel, P.; Hughes, J.d'A.; Kardivel, P. & Luther, K. (2010). Re-learning old lessons for the future of food: By bread alone no longer − diversifying diets with fruit and vegetables. Crop Sci. 60:S51-S62.

Kerr, E.A. (1969). Do tomato cultivars deteriorate after they are introduced? Reports of the Horticultural Research Institute of Ontario, Vineland Station, Ontario, Canada. pp. 75–80.

Key, N. & Runsten, D. (1999). Contract farming, small-holders, and rural development in Latin America: The organization of agroprocessing firms and the scale of outgrower production. World Devel. 27:381–401.

Kramer, M.G. & Redenbaugh, K. (1994). Commercialization of a tomato with an antisense polygalacturonase gene: the FLAVR SAVR™ tomato story. Euphytica 79:293–297.

Lacerrot, H. (1996). Breeding strategies for disease resistance in tomato with emphasis to the tropics: Current status and research challenges. 1st Intl. Symp. on Tropical Tomato Disease. Recife, Brazil. pp. 126–132.

Leslie, T.W., Hoheisel, G.A.; Biddinger, D.J.; Rohr, J.R. & Fleisher, S.J. (2007). Transgenes sustain epigeal insect biodiversity in diversified vegetable farm systems. Env. Entom. 36:234-244.

Lester, R.N.; Jaeger, P.M.L.; Spierings, B.H.B.; Bleijendaal, H.P.O. & Hooloway, H.L.O. (1990). African eggplant: a review of collecting in West Africa. Plant Gen. Resources Newsl. 81–82:17–26.

Lincoln, R.E. & Porter, J.W. (1950). Inheritance of beta-carotene in tomatoes. Genetics 35:206–211.

Lincoln, R.E.; Zscheile, F.P.; Porter, J.W.; Kohler, G.W. & Caldwell, R.M. (1943). Provitamin A and vitamin C in the genus *Lycopersicon*. Bot. Gaz. 105:113–115.

Lynch, R.; Wiseman, B.; Sumner, H.; Plaisted, D. & Warnick, D. (1999). Management of corn earworm and fall armyworm (Lepidoptera: Noctuidae) injury on a sweet corn hybrid expressing a cryIA (b) gene. J. Econ. Entom. 92:1217-1222.

Ludwig, S.P. & Chumney, J.C. (2003). No room for experiment: the federal circuit's narrow construction of the experimental use defence. Nature Biotechnology 21:453.

Mao,W.; Yi, J. & Sihachakr, D. (2008). Development of core subset for the collection of Chinese cultivated eggplant using morphological-basal passport data. Plant Gen. Res. 6:33–40.

Medley, T.L. (1994). Availability of determination of non-regulated status for virus resistant squash. Federal Register 59:64187–64189.

Monsanto (2009). Supplemental toolkit for investors. Updated June 2009. Monsanto.

Musser, F.R. & Shelton, A.M. (2003). Bt sweet corn and selective insecticides: their impacts on sweet corn pests and predators. J. Econ. Entom. 96:71-80.

Musser, F.R.; Nyrop, J.P. & Shelton, A.M. (2006). Integrated biological and chemical controls in decision-making: European corn borer control in sweet corn as an example. J. Econ. Entom. 99:1538-1549.

NASS (2007). Vegetables: 2006 annual summary. National Agricultural Statistics Service, Washington DC.

OECD (2009). The Bioeconomy to 2030. Designing a policy agenda. OECD, Paris.

Ochoa, J.P.A.; Dainello, F.; Pike, L.M. & Drews, D. (1995). Field performance comparison of two transgenic summer squash hybrids to their parental hybrid lineage. HortScience 30:492–493.

Perring, T.M.; Gruenhagen, N.M. & Farrar, C.A. (1999). Management of plant viral diseases through chemical control of insect vectors. An. Rev. Entom. 44:457–481.

Pfeiffer, W. & McClafferty, B. (2007). HarvestPlus: breeding crops for better nutrition. Crop Sci. 57:S88-S105.

Premanchandra, B.R. (1986). Genetic regulation of carotene biosynthesis in selected tomato strains: Aspects of beta-carotene biosynthesis and B gene specificity. Intl. J. Vitam. Nutr. Res. 56:35–43.

Regmi, A. & Gehlar, M. (2001). Consumer preferences and concerns shape global food trade. Food Rev.: Global Food Trade 24:2–8.

Reyes, L.F.; MillerJr, J.C. & Zevallos, L.C. (2005). Antioxidant capacity, anthocyanins and total phenolics in purple and red-fleshed potato (*Solanum tuberosum* L.) genotypes. Am. J. Pot. Res. 82:271–277.

Rohrbach, D.D.; Minde, I.J. & Howard, J. (2003). Looking beyond national boundaries: Regional harmonization of seed policies, laws and regulations. Food Policy, 28: 317–333.

Rose, R. & Dively, G.P. (2007). Effects of insecticide-treated and lepidopteran-active *Bt* transgenic sweet corn on the abundance and diversity of arthropods. Env. Entom. 36:1254-1268.

Ryder, E.J. (2005). Intellectual property rights for plants. The case for a new law. Chronica Horticulturae 45(2):5-11.

Schultheis, J.R. & Walters, S.A. (1998). Yield and virus resistance of summer squash cultivars and breeding lines in North Carolina. HortScience 8:31–39.

Shankula, S. (2006). Quantification of the Impacts on US Agriculture of Biotechnology-Derived Crops Planted in 2005. Available from http://www.ncfap.org/

Shepherd, A. (2005). The implications of supermarket development for horticultural farmers and traditional marketing systems in Asia. FAO, Rome.

Simon, P.W.; Pollak, L.M.; Clevidence, B.A.; Holden, J.M. & Haytowitz, D.B. (2009). Plant breeding for human nutritional quality. Plant Breed. Rev. 31:325–392.

Speese, I.J.; Kuhar, T.P.; Bratsch, A.D.; Nault, B.A.; Barlow, V.M.; Cordero, R.J. & Shen, Z. (2005). Efficacy and economics of fresh-market Bt transgenic sweet corn in Virginia. Crop Protection 24:57-64.

Stommel, J.R. & Haynes, K.G. (1994). Inheritance of beta carotene content in the wild tomato species *Lycopersicon cheesmanii*. J. Hered. 85:401–404.

Stoll, R.L. (2001). J.M.E. Ag Supply v. Pioneer Hi-Bred international, Inc. – a commentary. UPOV Gazette 92.

Sudhakar, P.; Singh, J.; Upadhyay, A.K. & Ram, D. (2002). Genetic variability for antioxidants and yield components in pumpkin (*Cucurbita moschata* Duch. Ex Poir.). Veg. Sci. 29:123–126.

Tomes, M.L.; Quackenbush, F.W.; Nelson Jr., O.E. & North, B. (1953). The inheritance of carotenoid pigment systems in the tomato. Genetics 38:117–127.

Tricoli, D.M.; Carney, K.J.; Russell, P.F.; McMaster, J.R.; Groff, D.W.; Hadden, K.C.; Himmel, P.T.; Hubbard, J.P.; Boeshore, M.L. & Quemada, H.D. (1995). Field evaluation of transgenic squash containing single or multiple virus coat protein gene constructs for resistance to cucumber mosaic virus, watermelon mosaic virus 2, and zucchini yellow mosaic virus. BioTechnology 13:1458–1465.

UPOV (1994). International Convention for the Protection of New Varieties of Plants of 2 December 1961, as revised at Geneva on 10 November 1972, 23 October 1978, and March 1991. Publication 221, UPOV, Geneva.

Zeder, M.A.; Emschwiller, E.; Smith, B.D. & Bradley, D.G. (2006). Documenting domestication; the intersection of genetics and archeology. Trends in Genetics 22:139-155.

Zhang, Y.P. & Stommel, J.R. (2001). Development of SCAR and CAPS markers linked to beta gene in tomato. Crop Sci. 41:1602-1608.

Zitter, T.A.; Hopkins, D.L. & Thomas, C.E. (1996). *Compendium of Cucurbit Diseases*. APS Press, St. Paul, MN, USA.

Waltz, E. (2009). Under wraps. Nature Biotechnology 27:880-882.

Weinberger, K. & Genova, C. (2005). Vegetable production in Bangladesh: Commercialization and rural livelihoods. Technical Bull. 33. AVRDC, Shanhua, Tainan.

Weinberger, K. & Msuya, J. (2004). Indigenous vegetables in Tanzania: Significance and prospects. Technical Bull. 31. AVRDC, Shanhua, Tainan.