Chapter 5
Vegetable Breeding Industry and Property Rights

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Abstract Plant genetics and breeding are long-term endeavor that require dedicated expertise and infrastructure plus substantial and stable funding. The development of new vegetable cultivars or breeding techniques requires time, effort and funding. Likewise, access to technology and to crop diversity remains essential for the development of vegetable cultivars. Vegetable breeding is characterised by continuous innovations and the development of new cultivars that meet the requirements of growers and consumers. The driving force behind this innovation is acquiring or increasing seed market share. However, breeding new vegetable cultivars requires high investments that can only be recouped if the breeding companies can commercialise the cultivar for a certain period. Intellectual property rights on cultivars are regarded by some in the private sector as the ultimate guardian of plant breeding entrepreneurs. They are viewed as the opportunity to control as many aspects of the invention as possible, thereby strangling the innovative capacity of the competition. As a result, a few multinationals dominate the global seed trade, while public sector plant breeding and local, small- and medium-size seed enterprises have a marginal role. Plant variety rights through patents may affect both vegetable diversity and the 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 horticulture itself. Some vegetable breeding programs were merged to reduce costs, which could lead to growers being dependent on a narrow genetic background that could contribute to biodiversity reduction and food insecurity. Access to "advanced" genetic resources is an important condition for a healthy and innovative vegetable breeding sub-sector and food security. We argued that the private sector relies on fundamental research and proof-of-concept demonstrations of feasibility from the public sector, and the public sector expects their discoveries to be expanded and implemented commercially by

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the private sector. Hence, we advocate effective and synergistic private-public partnerships for enhancing the use of vegetable diversity, accelerating its breeding and increasing genetic gains.

Keywords Biodiversity • Breeding • Food insecurity • Horticulture • Hybrids • Patenting

5.1 Introduction

Every vegetable product we see on the market has benefited from plant breeding in one way or another. The total genetic information available in a gene pool was used to breed new cultivars (Fig. 5.1). The first suggestion to exploit hybrid vigor or heterosis in vegetables was made by Hayes and 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 cultivars for the marketplace. Besides heterosis, hybrids also allow plant breeders to combine the best horticultural traits and multiple host plant resistance to pathogens and pests plus adaptation to stressful environments. Furthermore, if the parents are

Fig. 5.1 Each vegetable cultivar on the market has benefited from plant breeding

homozygous, the hybrids will be uniform, an increasingly important trait in commercial vegetable market production. The development of vegetable hybrid cultivars requires homozygous inbred parental lines, which provide a natural protection of plant breeders' rights without legal recourse and ensure a market for seed enterprises.

Since the 1970s plant breeders' rights protection has been provided by the International Union for the Protection of New Varieties of Plants (UPOV), which coordinates an international common legal regime for plant variety protection (UPOV 1994). Protection was granted for those who develop or discover cultivars that are new, distinct, uniform, and stable. Cultivars may be either sexually or asexually propagated. The UPOV coverage lasts 20 years for herbaceous species. Protective ownership was extended by UPOV in 1991 to include essentially derived cultivars. At the same time, the farmer's exemption (that permitted farmers to save seed for their own use) was restricted, but giving member states the option to allow farmers to save seed. In addition, after 1998 in Europe, and 2001 in the United States of America plant breeding companies can take advantages of patent laws to protect not only the cultivar itself but all of the plant's parts (pollen, seeds), the progeny of the cultivar, the genes or genetic sequences involved, and the method by which the cultivar was bred. The seed can be used only for research that does not include development of a commercial product (i.e., another cultivar) unless licensed by the patent holder. Patents are the ultimate protective device allowing neither a farmers' exemption nor a plant breeders' exemption (that permitted protected cultivar(s) to be used by others in further breeding to develop new cultivars).

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 cultivars being sold nowadays are proprietary products developed by private R&D. A significant consequence of this increase in R&D has been a reduction of public plant breeding programs. As a result, the cost for R&D to develop new cultivars is shifting from the publicly supported research programs to the customers of the major seed companies (Dias and Ryder 2011).

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, plant breeders, support staff, 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 plant breeding research is critical to support development of new technology and expansion of the knowledge base that supports cultivar development, competition among proprietary cultivars 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 cultivars to stay competitive. There is considerable genetic variation within the various vegetable species, which can be exploited in the development of superior proprietary cultivars. The consequences of this dynamic situation will mean relatively short-lived cultivars replaced by either the owner of the cultivar or a competitor seed company. This intense competition means constantly improved and more sophisticated cultivars for the vegetable industry. Seed companies are in the business of manipulating genes to improve cultivar's 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 cultivar will likely fail (Dias 2010a).

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 or accelerate cultivar development by saving time, providing better products, delivering genetic uniformity, or getting results that are not possible through conventional crossbreeding (Dias and Ortiz 2012a, b). There are new challenges being face by vegetable breeding. This article provides an overview of these challenges and highlights the importance of biodiversity, plant breeding and improved cultivars to modernize vegetable production and to alleviate some protective measures that can create obstacles for innovation, and risks for biodiversity and food security.

5.2 Vegetable Breeding Industry, Biodiversity and Food Security

Plant breeders play a key role in determining what we eat, since the cultivars they develop begin the dietary food chain. Vegetable breeding is the development of vegetable cultivars with new proprieties (or traits). Innovation in vegetable breeding depends on biodiversity and access to genetic resources, on specific knowledge, on the development and application of new technologies, and capital to utilise them. Access to genetic biodiversity as well as to technology is essential for the development of new vegetable cultivars. Selection is impossible without genetic variation and new cultivars cannot be bred without it, thereby making access to this variation essential for vegetable breeders.

The impact of plant breeding on vegetable production rests on the complex relationships involving growers, available cultivars, and the developers of these cultivars. 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 cultivars are available.

The least sophisticated in terms of the method of development are landraces, also known as local or farmers' cultivars. Modern vegetable cultivars are bred by crossing and selection alone and F_1 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, while public sector plant breeders or seed companies develop improved cultivars and hybrids. 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 pathogens including virus are constraints. Hence, in modern vegetable production the seed business is most efficiently conducted by a distinct industry dominated today by multinational seed corporations (Dias 2010b; Dias and Ryder 2012).

Vegetable breeding has to address and satisfy the needs of both consumers and growers. The general objectives for farmers are high yield, host plant resistance to pathogens and pests, uniformity and abiotic stress adaptation. The main attributes sought by consumers are produce quality, appearance, shelf life, taste, and nutritional value. Thus, color, appearance, taste, shape, are usually more important than productivity. The priority goal of vegetable breeding programs is then to release new cultivars combining many desirable horticultural characteristics. Consumers want more vegetable diversification in a continuous supply. Vegetables are purchased based partially on eye appeal, which means that the development of desire to consume increases market demand. Diversification also tends to increase consumption (Dias 2014).

In our view, product differentiation, including new or renewed product introductions, is a key strategy for expanding sales in vegetable markets. To exploit such an opportunity, it is important therefore to continue research in biodiversity and to disseminate information regarding the benefits of vegetables, develop new improved vegetable cultivars and processed products, evaluate the economic opportunities and the market scope of these new products, and identify marketing trends and alternatives. Furthermore, the 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 of vegetable farming (Dias 2012a). Likewise, 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 cultivars. Hence, 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 remain in place. The consequences of all these relationships may be quite profound for the farmers at each level, the seed producers, the consumers and the availability of food worldwide. It is therefore worthwhile to examine the commercial breeding industry and the future of crop biodiversity and sustainability to assess our expectations for food security.

5.3 The Commercial Breeding Industry

In the case of most vegetable crops, biodiversity and genetics are delivered in a marvelous package known as the seed. Individual growers cannot carry on the special techniques of seed production, such as seed treatment for the control of planting pathogens or the development of hybrids, as well as the incorporation of biotechnology. Vegetable seed production is often a business undertaken by a distinct industry. High tech seed industry is a key part of modern horticulture that combines plant breeding, seed production, storage, and distribution (Dias and Ryder 2011).

The private breeding sector emphasizes the development of hybrids to exploit heterosis as well as to combine multiple host plant resistance and abiotic stress adaptation. The vegetable seed business aims that growers purchase seed for each of their planting. Control of the parents prevents others to reproduce the hybrid seed. 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. Seed companies, policymakers, and researchers have neglected vegetable landraces, whose production often takes place under low-inputs, Nonetheless, these vegetable landraces still contribute significantly to household food and livelihood security, particularly for small resource-poor farmers (Weinberger and Msuya 2004). For example, in Africa 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 and Msuya 2004).

Although hybrid seed technology has a significant impact on most vegetable crops in the industrialized agriculture, the unavailability of high quality seeds remains a limiting factor to vegetable farming in the developing world. Hybrid seed production is a high-level technology and cost-intensive venture. Only a well organized seed company with scientific manpower and a well-equipped research facility can afford hybrid seed production. The public sector in the developing world often 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 cultivars to local environments, especially in the poorest countries (Rohrbach et al. 2003). Farmers themselves often produce seeds of locally preferred landraces, as the individual markets are too small and the private seed sector has little interest in producing open pollinated cultivars (Weinberger and 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 seed-borne pathogens, 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.

The global seed trade dominated by a few international corporations has effectively marginalized public plant breeding and local, small- scale seed companies. About 30 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 multinational corporations that also own other agri-business, for producing or selling pesticides and biotechnology-derived products. 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 (Dias and Ryder 2011).

There are five company's business models in the vegetable breeding: (i) those traditionally integrating cultivar development, production and marketing of seed; (ii) others undertaking plant breeding and producing seed in their home country but licensing their cultivars to companies in other countries; (iii) those developing their own capacity in applied biotechnology; (iv) some specialized in plant biotechnology only, without being active in practical plant breeding, cultivar development, and seed production; and (v) a few operating globally and having a strategic research capacity. 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. This group of companies comprises some companies originated from the agrochemical sector and that later became breeding companies via acquisitions and mergers. These last companies are combining two businesses: 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 and on properties or "traits" of the plants, and marketing of traits. 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). The companies under (v) combine a large biotechnological capacity with the production and marketing of seed while at the same time licensing technologies to other plant breeding companies. This category comprises most multinationals in the seed sector that are also active in agrochemicals or pharmacy, but also larger traditional plant breeding companies with a significant biotechnology capacity. For these companies the income from seed sales is the most important but some also generate income from licences.

Commercial vegetable breeding has brought a paradigm shift in the agricultural cropping system by developing superior and productive vegetable crop cultivars in a short period. The vegetables attracting the most breeding attention vary considerably between small enterprises and huge seed 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 the use of molecular marker 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 cultivars. The vegetable breeding strategy and targets are dependent on market trends. Successful breeders anticipate changes in the market by developing new cultivars that are ready to be released to the growers when their demand increases. It will be therefore 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 cultivars for a number of vegetables. Breeding focuses on the following most important properties: host plant resistances against pathogens and pests, increasing yield, and improving quality such as shelf life or taste, and enhancing production efficiency. Companies that are introducing a new cultivar with a new trait usually have a lead of about 4 years, after which the competitors can introduce their own new cultivars 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. Investments in R&D by the top companies in this sector are between 15 and 25 % of their turnover, which keeps track with the annual increase in very high 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. Enterprises with autonomous growth have to spend more on innovative R&D since they have to breed new cultivars and new technology themselves.

Plant breeding is a long-term and therefore costly activity. It was, at its beginnings, merely an empirical activity where plant 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, length of the generation cycle, growing conditions, and available space. This meant that the development of a new cultivar or a new hybrid took 10-24 years, depending on the species. This development period decreased to 4-11 years in the last three decades through the use of a wide range of biotechnological methods, such as *in vitro* tissue culture, *in vitro* haploidization, mutation breeding, recombinant DNA technology and DNA marker-aided breeding, among others. The application of modern technology has made plant breeding less time and space-depend and breeding processes have become much more efficient. These advances led to reducing the time by a factor 2.5 for developing a new cultivar. Even though the research and development (R&D) costs increase strongly by about 10 % annually, the return for such investments was ensured by the faster production of new cultivars.

We conclude that a breeding company tries to maintain, or preferably expand, its market share by developing good cultivars. A company can therefore only continue breeding new cultivars if a good "return on investment" is ensured. The long time needed for the development of a new cultivar entails high risks and costs. This situation requires an adequate protection against the misuse of cultivars developed by the breeder with a lot of creativity and professionalism. In Europe, Plant Breeder's Rights provide, depending on the vegetable crop, a protection of 25 or 30 years. This time is long enough because the success period of a cultivar is usually 3-7 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 cultivar via patent rights, provided that the new trait does at least meet the criteria of novelty, inventiveness and industrial applicability, and if this "invent" is not restricted to one cultivar. The exclusivity for the patent holder means that these innovative traits cannot be used in plant breeding without permission such as a licence of the patent holder.

5.4 Intellectual Property in Vegetable Breeding

To encourage innovations, compensate and reward innovators, and to protect the rights of the plant breeder the legislator has developed systems to be used to protect the "discoverer" against the risk that others without permission simply copy, imitate and commercialise own results, the new cultivar or the new finding. 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' built in hybrid seeds gave sufficient compensation to innovators, but after the enactment of intellectual property right laws related to agriculture, in most countries, private research increased and research companies rushed to gain as much intellectual property rights or patents to obtain commercial benefits. The rapid development in biotechnologies has led to "breeding by design". The knowledge ensuing from molecular biology and genomic research keeps increasing and soon access to genetic information of the complete genome of all major crops will be available. These approaches in plant breeding are anticipated to produce lot of alternative processes like "breeding by chromosomes" resulting in patentable products. Presently, big corporations are earning income by selling products and from royalty on their patents. 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 engineering system by 2030. Transgenic vegetable plants will include genes for producing 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 intellectual property policies that stimulate innovations and competition.

Plant breeders' rights 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 inter alia a process, a machine or a manufacture, but not for living organisms. It became therefore necessary to apply the criteria of the patent laws to living entities, for which they were not intended, which 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 intellectual property right laws may be confusing. For plant breeder's rights protection, as explained above, 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 cultivars. All are unequivocally obvious. Hundreds of lettuce cultivars have been bred and released over the years. These eight lettuce cultivars are not remarkable in any way. The concept, breeding methods, and characteristics claimed are all ordinary. Most plant cultivars are bred after shuffling known genes in various combinations. These 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 "multi-leaf 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 and romaine lettuce. Iceberg lettuce is normally spherical. The head leaves are closely oppressed 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 butter head 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 law.

Much of the above discussion leads to the inevitable conclusion that the patent laws are inadequate for plants and should be replaced. Intellectual property rights for plants must be framed in different terms than for inanimate objects. Many patent applications are granted broad claims on traits and processes that are essential in nature. So, in patents, the essential processes like crosses, segregations and recombinant selections that are used for developing new cultivars 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 plant breeding seems sufficient to make whole process not entirely a natural phenomenon, thus patentable.

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 host plant resistance or product quality (e.g. increase antioxidant content) create value in the process of vegetable breeding (Dias 2012b, c). For vegetable breeding enterprises, specialized in plant breeding biotechnology that have based their business model on the development and marketing of traits or marker platforms 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 a public institute facing increasing difficulties to secure funding.

Intellectual property rights have provided an essential contribution to the innovation and the success of plant breeding until now but breeder's exemption that allows them to benefit from the availability of the competitor's genetic resources and to use protected cultivars for further breeding seems crucial for the future of biodiversity and food security. Breeder's exemption plays therefore an essential role in innovation in practical plant breeding whose 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 because the economic life of a new cultivar is no more than few years and that most income can be generated during the time required to register such cultivars; i.e., 1 or 2 years. Another reason is that most vegetable cultivars are hybrids than cannot be reproduced as "true breeding lines".

We believe that a patent is however 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 cultivar with certain favorable traits, each would do further breeding only with its own protected cultivar. So there would be parallel lines of research without the enrichment to each program that comes from crossing those lines with cultivars in other programs. The owner of a patented cultivar 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 cultivar, since the cost may negate any profit from a new cultivar.

5.5 Trends in Genetic Diversity and Vegetable Breeding

About 52 % of vegetables grown in the world receive commercial breeding attention by seed companies and, of those, only 17 % are by large scale breeding programs, fostering a need for serious attention to maintenance of vegetable crop biodiversity (Dias and Ryder 2011). There has been a severe decline in the vegetable cultivar genetic base, as evidenced by the significant reduction, especially within the last 50 years, in the number and range of vegetable cultivars grown. During this period vegetable genetic diversity 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 (Dias 2010b).

Widespread adoption of simplified vegetable systems with low genetic diversity carries a variety of risks including food insecurity. In the short term, such systems risk potential crop failure. In the long term, they encourage the reduction of the broad genetic base that contributes to high yields, quality traits, or host plant resistance to pathogens and pests. This compromises the future genetic wealth of vegetables. Especially prominent among the "enemies" of genetic diversity are the commercial markets and economic social pressures promoting breeding methods leading to uniformity, encouraging extensive cultivation of preferred improved and hybrid vegetable cultivars with insufficient diversity (Fig. 5.1; Dias 2010b). In addition, globalization has stimulated the consolidation of vegetable seed companies into huge corporations and the decline of small seed enterprises 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 and 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 lead in the near future to food insecurity for poor growers and consumers (Dias 2010b). Likewise, 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). IPR for plants were intended as a defensive mechanism to prevent the loss of invented cultivars to competitors. However, with the more stringent enforcement of plant breeding rights, and particularly with the application of the utility patent law in the USA 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 situation can have serious implications for the future conservation of vegetable genetic resources and for world food security (Dias 2010a; Dias and Ryder 2011).

Some landraces and old open-pollinated cultivars 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 diversity. Hence, the continued survival of landraces and open-pollinated cultivars of vegetables depends largely on popular interest and initiative as well as preservation in genebanks. We should be alerted and concerned about the loss of genetic diversity in vegetables and about its impact on food security (Dias 2010b).

Vegetable growers have an important role in conserving and using vegetable genetic diversity. The future of world food security depends not just on stored vegetable genes, but also on the people who use and maintain crop genetic diversity on a daily basis. In the long run, the conservation of plant genetic diversity depends not only on a small number of professional plant breeders and genebanks, but also on the vast number of growers who select, improve, and use vegetable genetic diversity, 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 cultivars exclusively. Growers do not just save seed, they also act as 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 diversity 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 cultivar 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 diversity (Dias 2010b). 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 diversity achieved over centuries will be lost forever (Dias 2010b). Many horticultural benefits will be lost to worldwide growers and thus to consumers.

The exclusive adoption of hybrid cultivars 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 (Fig. 5.2). For example, a study by Daunay et al. (1997) points out that the release of F_1 hybrids (in Europe and some Asian countries such as China and Japan), which had high productivity but poor

Fig. 5.2 Commercial markets promote breeding methods leading to uniformity

phenotypic variability, 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). Hence, the eggplant cultigen pool has been considered a priority for the preservation of vegetable genetic resources since 1977. As a result, research has been carried out in Asia and Africa (Lester et al. 1990; Gousset et al. 2005), and collections built up (Bettencourt and Konopka 1990), particularly in China (Mao et al. 2008).

Fortunately, in the industrialized world new independent seed companies, offering unique collections of regionally adapted landrace vegetable cultivars, 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 genebanks. 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 genebanks are required to avoid possible conflict involving breeders' rights and gene preservation. The genetic diversity of vegetable species will be promoted by the maintenance of crop genebanks 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 cultivars and landraces by farmers (Fig. 5.3).

We argued that issues indicated above related to biodiversity, plant breeding and intellectual property rights are not confined to either the public or the private sector because addressing them will require partnerships and collaboration for success. The private sector relies on fundamental research and proof-of-concept demonstrations of feasibility from the public sector, and the public sector expects their discoveries to be expanded and implemented commercially by the private sector. Issues such as intellectual property, competition and privacy can complicate public–private interactions, but effective partnerships between the two sectors have proven to be highly synergistic (Spielman et al. 2007). With a set of unified priorities (above) and new models for cooperation and collaboration, the strengths of both sectors can be brought to bear on the significant challenges we face. Pre-competitive research in

Fig. 5.3 Local market in Africa promoting biodiversity

the public sector, jointly funded in some cases by private resources, can "lift all boats" and provide tools and resources for accelerating plant breeding improvements. Mechanisms are needed to allow the significant private investments in fundamental research, such as genome sequences and genetic maps, to be available to public researchers. Cost sharing programs, with public funds matching private investments in public research, are excellent models for encouraging direct public/private research collaborations (Yarkin and Murray 2003). A number of public sources of research funding now require matches from private industry or commodity groups, making private partnerships even more critical for public research. Creating a shared vision that supports systemic change increases the opportunities for success. These new approaches need to focus on leveraging the potential for synergy between the collaborators and set the foundation early in the arrangement to manage the risks and dangers of food security that are of greatest concern (Rausser et al. 2000).

5.6 Food Security and Prospects for Developing Countries and Poor Vegetable Farmers

Food security exists when all people, at all times have access to sufficient, safe and nutritious food to meet their dietary needs and preferences for an active and healthy life. Vegetable breeding in the developing world is reduced and focused on a very limited number of crops. 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.

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 cultivars by small and poor farmers, because these vegetables generally are much more costly to produce per hectare than traditional landrace cultivars (Key and Runsten 1999; Ali and 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 cultivars often require an intensive input regime, including large labor inputs for planting and harvest that cannot be met with family labor alone (Weinberger and Genova 2005). For small and poor farmers improved vegetable cultivars 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 cultivars 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 and 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 moneylender. For those who can get a loan, rates are often unmanageably high, with strict penalties for late repayments. Similarly, a lack of awareness, education, resources, skill training, and support prevent these farmers from using improved cultivars 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 cultivars 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.

We strongly argue that 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 15-25 % 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. Hence, credit facilities and other inputs must be also part of these vegetable production systems, so that the use of improved vegetable cultivars can help subsistence vegetable growers to overcome their poverty and food insecurity.

5.7 Conclusion

Vegetable breeding is the development of new vegetable cultivars 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 cultivars for sustainability of vegetable production. Biodiversity is the basis for vegetable breeding and for the introduction of new cultivars to improve quality and productivity. As advances in breeding are dependent upon genetic diversity, preserving and characterizing existing germplasm resources and expanding collections are essential to future crop improvement. Changing agricultural practices, including adoption of improved cultivars, can result in loss of genetic diversity that exists in native landraces.

Breeding vegetable hybrids is a key means towards the development of cultivars 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 cultivar 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 cultivars development are disappearing worldwide. It is therefore imperative that national governments and policymakers, as part of a social duty, invest in plant breeding research and development of traditional open-pollinated cultivars 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 diversity. The accomplishment of this goal may require new approaches to vegetable breeding research and development by both the public and private sector. 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 cultivars are, and will continue to be, the most effective, environmentally safe, and sustainable way to ensure global food security and healthy human nutrition.

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