Horticultural highlights

We are all in this together: reimagining international societies • Ecuador demonstrates a sustainable way forward for small farmer producers • Genetic data improve management and use of apple genebank collections • Tackling postharvest losses in mango among resource-poor farmers in Kenya • Vegetable seed sector in France
Vegetable seed sector in France

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Introduction
Vegetable production in France (Box 1) has developed since the 19th century from traditional “vegetable belts” along the fertile river plains near urban centers, such as the valleys of Seine and Loire, Rhône and Var rivers (Figure 1a). Intensive production developed from the beginning of the 20th century in areas with favorable soil and climate, in particular in French Flanders (St Omer, for cauliflower and winter vegetables), upper Seine valley (asparagus and “green” vegetables), central France (Orléans and Sologne, for asparagus, strawberry, cucumber), Brittany (St Malo basin for cauliflower, potato), western France (Nantes basin for carrot, corn salad, leek, lily of the valley), and southeastern France (Provence and Hyères region, for Mediterranean vegetables).

From 1950 onwards, several areas became specialized: Normandy (carrot, turnip, leek and winter vegetables), Brittany around Roscoff and Plougastel (cauliflower, onion and shallot, potato, strawberry, tomato), Limagne plain (garlic, shallot), southwestern France (tomato from Marmande, beans and strawberry from Villeneuve-sur-Lot, melon), Camargue (melon, tomato), and around Perpignan (chicory, lettuce, tomato). More recently, highly mechanized open field crops have developed: melon in the Charentes, carrot in the sandy soils of the Landes, onion in the Beauce plain. Production under glass or plastic cover, which ensures early production, progressed from 1960 onwards because it secures also the visual quality of the product. The use of plastic and cellulose-fiber protecting materials contributed to the intensification. The original notion of “primeurs” has been altered because internationalized production carried by lorries now supplies Europe all year round.

The production of vegetables for food processing is progressing with varieties adapted to highly mechanized technical routes (bean, broccoli, celery, gherkin, onion, pea, spinach, sweet corn, tomato), produced in northern and southwestern France, Brittany, Saône and Rhône valleys. Seed quality (germination vigor, grading coating and priming) and variety adaptation (hybrid vigor in particular) have enabled precision sowing in the field to become widespread.

Box 1. Economic data on vegetable production in France
French vegetable production (7,500 ha under cover, 210,000 ha in the open field) amounts to 6 million tons (Mt), 30% of which are industrially processed (Oberti et al., 2020). The huge matching seed market for growers is supplied by French and many foreign companies (particularly Dutch, American, Japanese, Italian companies), as well as multinationals.

More than 1 billion tons of vegetables are produced per year in the world, 72% of which are produced in Asia (China alone produces 400 Mt). France ranks third as vegetable producer in the European Union (EU) and exports 1 Mt (Lor, 2015). Importations of tomato (500,000 t), carrot, squash, melon, onion, and salad mostly originate from Spain, Italy and Morocco, for a total of 1.9 Mt. Annual consumption (mostly carrot, tomato, lettuce, melon, bean and brassicas) is about 126 kg per capita, over 50% of which are supplied by supermarkets. It is a lower consumption than in Turkey (first consumer in Europe), Italy and Spain (the two first consumers in the EU).

The share of family gardened production fell significantly from 1980 onwards, but has risen up in recent years: 16.5 million gardeners produce vegetables in France. This represents a substantial amateur seed market.

Figure 1. Geographic distribution of vegetable and seed production in France: a) Historical vegetable production areas. Rivers (blue), towns (green) (* place of IHC2022) cited in text; b) Total seed production of small seed vegetables, 9,675 ha in 2019; c) Total seed production of pulses, 12,205 ha in 2019 (Source: GNIS).
Until the end of the 19th century, vegetable growers traditionally cultivated and sometimes improved their local varieties. From then, selections and new varieties were increasingly released by private seed companies. As early as 1950, breeders and seed producers jointly invested in genetic improvement and seed technology to make available high-performance varieties coupled with high-quality seed produced in selected regions. Supported by public research, technical institutes, extension services, networks of agro-technicians and high-quality agricultural education, the vegetable seed sector achieved a high level of organization and technical performance that serves as a model throughout the world since 1980. Since 2000, there is a public concern for setting up environment-friendly production practices and for producing healthy food. The vegetable seed sector participates in the development of agro-ecological and organic agriculture in France, Europe, and elsewhere. The strength of the French vegetable seed sector is based on several assets, among which public regulations, public and private research and development, which serve as a model throughout the world since 1980. Since 2000, there is a public concern for setting up environment-friendly production practices and for producing healthy food.

### History of vegetable breeding and vegetable seed companies

France is known throughout the world for its seed companies. The de Vilmorin family began seed selection at the end of the 19th century. It created in France, in a significant way, a dynamic seed production and breeding activity, which took off at the end of the 19th century. From the 1960s, the companies Clause, Tézier, Caillard, Société de Production Graines (SPG), later Gautier Semences, and many others developed into a vast network of 400 vegetable seed companies (breeders, producers, and seed brokers) spreading from the Loire valley (Boret, Brivain, Camus, Cesbron, Curis, Fautrat, France Graines, Gildaye, Godineau, Griffaton, Guillard, Hodebourg, Moreau, Tourmelin), Paris basin and the north (Blondeau, Cayeux, Lecouf-Maillet, Mollard-Sanrival, Peltier, Séminor, Simon Louis), the east (Denaiffe, Fabre, Lafitte, Voltz), to the Rhône valley (Bourget Sanvoisin, Blain, Ducrettet, Genest, Gérend, Gondian, Mirabel, Ribot & Faure, Rivoire-Laveine) and the southwest (Catros Gérard). There are still 80 vegetable seed production and marketing companies in France in 2020.

### Conservative breeding of heirloom varieties

During the 20th century, these establishments, in contact with vegetable growers, collected, maintained, improved, and produced several hundreds of varieties and local populations, formerly created by the vegetable growers. These are the old varieties and populations from the public domain, the specific heritage of French vegetable growers, maintained by conservative selection, still available to the sector (Box 2).

### Creative selection

Until 1960, Vilmorin and Clause were the pillars of vegetable breeding thanks to their research sections dedicated to variety creation and production techniques. Vilmorin breeders created improved varieties, including the first F₁ hybrid tomato variety in France, ‘Fournaise’ (1956). From 1955 onwards, the National Institute for Agricultural Research (INRA¹), in partnership with private seed companies, also became involved in research and creative breeding. As early as 1970, these actors created modern varieties, hybrids, or varieties, that met the technical criteria required by large-scale producers and marketers. The vegetable distribution sector requires homogeneous products that

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¹INRA became INRAE the 1st of January 2020 (https://www.inrae.fr/en/about-us)
are easy to pack and transport, and that are adapted to mass production, whether mechanized or automated. Breeders took these objectives into account and added an essential agronomic component: resistance to bio-aggressors. Indeed, the intensification of vegetable production favors the incidence of many diseases and parasitic attacks that generate heavy damage in the field and post-harvest. In order to reduce the phytosanitary burden, breeders introduced resistance genes into new varieties by cross-breeding. InRA and IRAT (which later became part of CirAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement) also worked on vegetables adapted to tropical zones, either in research stations located in the French West Indies (adaptation of tomato to humid and hot climates, resistance of tomato to begomoviruses, resistance of tomato and eggplant to bacterial wilt), in New Caledonia, and in La Réunion island (improvement of “lontan” vegetables, resistance of solanaceous crops to bio-aggressors), or in partnership with public institutions in Africa (work on ‘Galmi’ onion in the 1960s in the Niger valley).

A true international industrial force

Vilmorin integrated the Limagrain seed cooperative group in 1975, and was joined later on by other vegetable seed companies such as Harris Moran, Clause and Tézier, all of them forming the group Vilmorin & Cie. With the acquisition of Ferry Morse, Nickerson, Kyowa, Hazera, Henderson and Mikado, the group became, in 2019, the world leader in vegetable seeds. Other French vegetable seed companies, such as Gautier Semences, ASL (melon), Hoquet (chicory), Darbonne and Marionnet (strawberry and asparagus), are becoming European leaders. Other forms of economic organizations also develop vegetable breeding activity such as agricultural cooperatives (Top Semences, Unisem, Sicail and GE Al drômois for garlic and shallot), grower groups (Organisation Bretonne de Sélection (OBS) for shallot and Brassicaceae), and family businesses (Technisem for tropical markets, Agrosemens for organic seeds). In 2020, about 30 French companies are breeding and/or marketing new varieties of vegetables. This high concentration of seed companies is due to the internationalization of markets and the high cost of research. Many foreign companies set up their research stations in France to select, produce and sell vegetable seeds in France or for world markets. Syngenta, Bayer-Monsanto, BASF-Nunhems, Rijk Zwaan, Enza Zaden, Bejo, Sakata, Takii, are present in the lower Rhône and the Loire valleys, and in the southwest. Their vegetable breeding research centers located around Avignon and Angers are part of the European seed centers, together with Den Haag-Enkhuizen in the Netherlands, Latina in Italy, Valencia and Almeria in Spain. During the last fifty years, seed production in France has been concentrated in a few geographical areas such as Loire, Rhône, and Garonne valleys, and Beauce plain. Seed crops under tunnel are developing in France (e.g., lettuce, and carrot, cauliflower, cucurbit and solanaceous hybrids) to guarantee a high level of sanitary quality together with parental lines security. Seed production also moved far abroad (Australia, Americas, North and East Africa, India, China) for cost efficiency reasons.

After a period characterized by “captive” seed markets such as North Africa for historical reasons, seed markets became increasingly international from 1980 onwards and mobilized the French breeding teams. This trend began with the development of vegetable production basins in the Canary Islands, Morocco, Italy and Spain. The seed market extended progressively to other large scale production areas such as Eastern Europe, Turkey, Middle East, and further on to the USA, South America, India, South-East Asia, and China. This global change contributed to a genetic mixing between the cultivated types of most crop species. It accompanies the diversification of vegetables and contributes to a rapid renewal of research themes. This market widening is reflected in increased profits of the French seed industry, which competes with the USA, the Netherlands and Japan: in 2019, France was the first European seed producer and the second European seed exporter (see section on Vegetable seed production in France).

The dynamism of public-private research & breeding

In 2020, more than 20,000 varieties of about 40 vegetable species are registered in the European catalogue and satisfy the EU market, out of which more than 2,500 varieties are registered in France (200 new varieties per year). Since the 1950s, French breeding has been characterized by a strong partnership between public and private research, which has led to considerable progress in terms of yield regularity, visual uniformity and appearance, adaptation to packaging, physiological adaptation to a diversity of cropping systems and environmental conditions, and resistance to bio-aggressors. In 2016, the French seed sector invested €116 million in research, i.e. 25% of its turnover (GNIS, 2016). Very early on, public research accompanied the development of the vegetable seed sector, with the creation, in 1965, of the Association of the Creators of Floral and Vegetable Varieties (ACVPF), chaired by INRA. This association provided training for breeders, and until 1978 instilled a dynamic of cooperation between its members for the evaluation and use of genetic materials created by INRA. Then, public research became increasingly financed by short term contracts and compartmentalized programmes, accessible via competitive calls for tenders. Outstanding public researchers have succeeded each other in managing the genetics and vegetable breeding programmes at INRA Avignon, Rennes, and Versailles. The seed companies have grouped together within the National Federation of Vegetable Grains and Seeds (FNGPS), which became the French Seed Union (UFS), with a plant breeding section, and at the European level in the European Seed Association (ESA). The French Breeders Association (ASF since 1962), and the European Association for Research on Plant Breeding (Eucarpia since 1956) ensure the continuous training and network meetings of breeders (www.selectionneurs.asso.fr and www.eucarpia.org, respectively).

The preservation of genetic resources

Facing the growing importance of varietal selection, and genetic erosion of crop heirloom diversity, the French public authorities set up in 1995 a national system for a mutualized management of genetic resources, in the form of networks for species of economic interest. Partners are institutional organizations (INRA, GEVES, agro-engineering schools, CirAD for tropical and subtropical species), seed companies, seed banks and other national, regional or local organizations acting in the field of genetic resources conservation. Coordination is ensured as follows:

- Fruit Solanaceae and melon: INRAE Avignon,
- Artichoke and cardoons, chicory, onion, lettuce: GEVES Angers and Cavaillon,
- Brassicaceae and carrots: Agrocampus Ouest Rennes and Angers,
- Grain legumes: INRA Dijon,
- Strawberry: CIREF Bergerac.

These networks operate under the aegis of the national coordination structure for plant genetic resources (www.geves.fr/plant-genetic-resources/national-coordination/national-coordination-structure/). They maintain, describe and evaluate more than 15,000 ancient or foreign varieties, genotypes of particular interest, together with wild forms and relatives. Their objectives are to secure and maintain the genetic integrity of the collections over the long term, to mutualize regeneration, conservation, description and evaluation efforts, and to space out regeneration cycles. Other priorities include the visibility of the collections and their valorization, through an increased use in research.
and breeding programs. A challenging question concerns the conservation of the genetic diversity and progress created over the last decades as F₂ structures. A source of genes for breeders, these collections are outstanding materials for deciphering the molecular structure of genetic diversity, as done in particular for tomato, pepper and carrot.

European collaboration for genetic resources is facilitated via the long term input of the European Cooperative Programme for Plant Genetic Resources (www.ecpgr.cgiar.org), as well as via EU time limited projects devoted to genetic resources management and conservation (Daunay et al., 2013).

Research at the cutting edge of plant biotechnology

Since 1950, methods and tools have undergone major developments, first in cell biology and in vitro culture micropropagation, somatic embryogenesis, haploidiplodization via androgenesis or gynogenics, rescue of embryos from interspecific crosses, protoplast fusion (Daunay et al., 2007). Some major works carried out in France are worth mentioning:

- Control of the propagation of garlic and shallot by meristem culture (INRA Avignon and Ploudaniel), in vitro propagation of asparagus (INRA Versailles) and artichoke (INRA Avignon), which led in particular to the vegetative propagation of commercial material such as certified Onion yellow dwarf virus (OYDV) free plants of garlic and shallot, and hybrid structures of leek and asparagus,
- Control of somatic embryogenesis in carrot (seed companies),
- Haploidiplodization in Solanaceae and cucurbit (INRA Avignon), in Brassica (INRA Versailles) and umbelliferous plants (seed companies),
- Rescue of embryos resulting from interspecific crosses in Solanaceae and Cucurbita spp. (INRA Avignon),
- Fusion of protoplasts in Brassica (University of Orsay, INRA Versailles and seed companies) and chicory (University of Lille and seed companies).

French research has been at the forefront in developing these techniques for the improvement of many vegetable species. One of the major contributions of biotechnology is probably the deadlock break of intergeneric and interspecific hybridization (Box 3):

The burst of molecular techniques in the 1990s and their continuous evolution has revolutionized genetics, although the extent of their use in breeding schemes varies from one crop to another, and concerns mostly high cost return crops. Mapping and marking of genes and QTLs associated with traits of agronomic interest have allowed the development since the 2000s of marker-assisted selection (MAS) for disease resistance, male sterility, and pollen compatibility. Functional characterization of target loci involved in fruit quality, stress resistance and durability of resistance, access to allelic diversity thanks to sequencing, and genome wide techniques widen the way to an increasingly technical breeding.

French breeding success due to genetic improvement

Several publications review French vegetable breeding since 1955: Pitrat (2002), Pitrat and Foury (2003), Doré and Varoquaux (2006), Brand and Audergon (2013), Pitrat and Audergon (2015). We provide some examples of genetic advances and new released varieties originating from INRA and partners.

Conservative and sanitary selection of commercial material

Conservative breeding maintains genetic material as conform to itself and free of seed and plant transmitted bio-aggressors. It is successfully applied to the maintenance of open pollinated varieties and commercial or hybrid parental lines. Sibling crosses or in vitro culture are used for the maintenance of low vigor lines of allogamous species (e.g., asparagus, artichoke, onion, leek).

For most sexually propagated species, sanitary selection (choice of seed mother plants) and methods of prophylaxis during propagation (under insect-proof tunnel) are used to avoid seed-borne pests. As early as the 1960s, the production of healthy seeds was established on:

Protected seed production of hybrid cabbage in Anjou (Photo ©E. Laurent).

Box 3. Hybridization of genera and species

In Cichorium intybus (chicory and bitter leaf chicory) and C. endivia (plain and curled leaf chicory), cross-breeding between species has been carried out on a few genotypes to create plain and curled leaf with tuberous roots suitable for production in growing chambers.

In zucchini, Cucurbita pepo, partial resistances to Zucchini yellow mosaic virus (ZYMV, genus Potyvirus), Watermelon mosaic virus (WMV, genus Potyvirus), Cucumber mosaic virus (CMV, genus Cucumovirus) and powdery mildew have been introduced from Cucurbita moschata, C. okeechobeensis or C. ecuadorensis.

In lettuce, Lactuca sativa, wild species were used to introduce:

- the L. virosa Nr gene of resistance to the black aphid (Nasonovia ribis nigrī) by using L. serriola as a bridge species,
- Bremia resistance genes from L. saligna and L. virosa.

In tomato and pepper, wild species are commonly used to introduce disease resistance traits.

In Brassica spp. for which the resource of cross-compatible species is large, innovative crosses are being made (e.g., multi-jet broccoli, cabbage). Interspecific crosses allow also the introduction of tolerance to cabbage hernia (Plasmodiophora brassicae).
• bean for the bacteria *Pseudomonas savastanoi* pv. *phaseolicola* and *Xanthomonas axonopodis* pv. *phaseoli*,
• lettuce for *Lettuce mosaic virus* (LMV, genus *Potyvirus*),
• spinach and corn salad for late blight (*Peronospora* spp.),
• tomato for *Tobacco mosaic virus* (TMV, genus *Tobamovirus*), *Pepino mosaic virus* (PepMV, genus *Potexvirus*), and *Clavibacter michiganense* subsp. *michiganensis*.

In 2015, 260 bio-aggressors were regulated worldwide, including 60 in the EU, to guarantee healthy seed trade, in accordance with the recommendations of the ISPM38 standard of the International Plant Protection Convention on international movements of seeds.

Vegetatively propagated species (garlic, shallot, artichoke, asparagus, strawberry) are subject to sanitary selection, with or without meristem culture. Mother and commercial plants are certified under the control of the Official Control and Certification Service (SOC). France is one of the major players in the world for marketing certified healthy plants of:

• garlic and shallot free from *Onion yellow dwarf virus* (OYDV, genus *Potyvirus*), *Leek yellow stripe virus* (LSV, genus *Potyvirus*), nematodes and *Sclerotinia* (performed by INRA Avignon and Landerneau) (Messiaen et al., 1999),
• strawberry free from nematodes, *Phytophthora cactorum* and *Verticillium dahliae* (performed by Centre Technique Interprofessionnel des Fruits et Légumes, CTIFL).

**Diversification**

 Breeders continuously improve the genetic material to make it match as closely as possible the requirements of producers and marketers, in a diversified context of “terroirs”, growing conditions (from open field green belts to off-ground crops, mechanized crops for food processing industries), and marketing techniques.

Diversification of the harvested products concerns mainly Solanaceae (tomato, pepper, eggplant), cucurbits (melon, zucchini, cucumber) and lettuce, species for which the selection effort has been the most important in France since 1985 (in terms of number of new registered varieties).

• Tomato for the French and European market. The plant has been adapted to the various agro-climatic environments of protected crops (aptitude for fruit setting, root vigor, homeoastasis). The fruit has been diversified in terms of color, shape, firmness, homogeneity, even if the French market is still globally dependent on two ideotypes (sizes 150 and 200 g, firm, smooth, red fruit, without green collar).

• Melons of Charentais, Spanish, Italian netted, “Galicia”, American, Korean or Japanese types. Sugar content, firmness, proportion of flesh, homogeneity of fruit presentation have been improved by genetic crosses between these types.

• Quadrangular peppers. The plant has been adapted to the various agro-climatic environments of sheltered cultivation (ability to set fruit, root vigor, homeoastasis), thickness of the pericarp has been increased and fruit color has been intensified. The Mediterranean market is now interested in the horn type.

• Lettuce varieties. The plant has been adapted to various agro-climatic environments, in particular resistance to bolting and short day head formation, and new types have been proposed (e.g., semi heading, anthocyanin, oak leaf). Diversification also significantly created new ideotypes for plain and curled leaf chicory varieties, improved ‘Nantes half-long red’, ‘Touchon’, “Bureau”, ‘d’Amsterdam’). From 1980 onwards, the improvement of sowing techniques (switch from scattered to precision sowing), ensuring a better expression of the potentialities of each plant, made it possible to enhance the homogeneity provided by the F₁ hybrids. The use of three-way hybrids facilitated seed production by increasing seed productivity of the female parent. The genetic structure of hybrids allows the cumulation of many traits of interest, including resistance genes to various pathogens (*Alternaria dauci*, powdery mildew, cercosporiosis), resistance to bursting, root strength, resis-

Creating material adapted to intensive production: hybrids for allogamous species

The objective was to create uniform and vigorous varieties, adapted to mechanized production, capable of resisting climatic hazards and bio-aggressors, and productive. Breeding programs have targeted cross-pollinated vegetable species such as *Brassica* (Box 4), carrot, onion, radish, leek, turnip, fennel and beetroot.

In carrot, the improved varieties derived from traditional populations achieved remarkable yields until around 1975 (e.g., selections of improved ‘Nantes half-long red’, ‘Touchon’, ‘Bureau’, ‘d’Amsterdam’). From 1980 onwards, the improvement of sowing techniques (switch from scattered to precision sowing), ensuring a better expression of the potentialities of each plant, made it possible to enhance the homogeneity provided by the F₁ hybrids. The use of three-way hybrids facilitated seed production by increasing seed productivity of the female parent. The genetic structure of hybrids allows the cumulation of many traits of interest, including resistance genes to various pathogens (*Alternaria dauci*, powdery mildew, cercosporiosis), resistance to bursting, root strength, resis-

• Uniformity in hybrid carrots in Sologne, France. A. Carrots nearly ready for harvest (Photo ©Vilmorin), B. Processing factory (Photo ©HMClause).
tance of foliage to mechanical harvesting, earliness and hardiness, high early yield and reduction of waste rate. Root quality was also improved: smooth and shiny epidermis, fine pivot, uniform color between xylem and phloem, absence of green collar. More recently, di-haploid lines are being used in hybrid parental combinations to increase the level of homogeneity of such varieties. Seed technology (e.g., grading, vigor, ability to emerge at high summer temperatures) has accompanied the success of this varietal renewal, which is spreading worldwide. French and Dutch companies are still the leaders in these hybrid carrot global markets (Brand and Audergon, 2013).

Breeding for quality traits
Organoleptic and nutritional quality, dear to French gastronomy, is a lock that has been persistently ignored by breeders. For a long time, agronomists, producers and marketers have minimized the importance of this criterion by putting forward the concept of societal demand, which prioritized vegetables easy to transport and preserve, quick to process. Such criteria are far away from fruit organoleptic and cooking qualities. Let us quote some counter-examples where breeding has been convincing, by using empirical selection methods:

• for a quality product: example of French bean
Breeding achievements on reduction of beans parchment and string is exemplary. The development of a quality bean industry, inherited from the French "filet" bean harvested by hand just before the string develops, led French breeders as early as 1975 to improve the "mangetout" bean for the fineness and straightness of the pod, and to adapt the architecture of the plant and its flowering to mechanical harvesting (crossing between crop groups including wild progenitors). Thus improved, a new bean type was born: the "wireless net" bean ("filet sans fil"). This new type currently concerns more than 50% of the beans sown in France for industry, and it is also appreciated by gardeners. However, there is a limitation to this improvement, because in the absence of string, growers, gardeners and consumers have a wrong perception of pod age. Too old fresh pods are frequently marketed, stringless and straight but containing nearly mature grains that are detrimental to pods palatability.

• for taste: examples of strawberry, melon and tomato
Strawberry varieties combining the taste of wild strawberries and agronomic criteria of industrial strawberries have been created (INRA, CIRÉF - Interregional center for research and experimentation on strawberry, Darbonne and Marionnet breeding companies). Such varieties derive from the proof of concept named 'Garriguette' (INRA, 1972) and ‘Mara des Bois' (Marionnet, 1992), and combine outstanding flavor and aromas together with yield, fruit firmness and preservation. For melon, breeding programmes for taste have been set up (e.g., sugar content), based on the use of genitors identified for their taste quality. In cucumber, lettuce, chicory endive and eggplant, breeding programs have focused on reducing bitterness. For tomato, INRA and French breeders worked from 1956 to 1985 to improve the traditional French tomato types (‘Saint Pierre' and ‘Marmande'). INRA focused on improving the fruit (red color homogeneity, elimination of spots, regularity of locules number, sugar/acid balance, resistance to cracking, slight firmness) and the plant for its plasticity of adaptation to various environments. They had a large success (from 'Montfavet H.63.5' to ‘Ferline', and varieties released by the private sector). After the "long shelf life" period (see below section "Improving long storage ability"), a fundamental research program on fruit quality was developed in the 2000s by Dr. M. Causse at INRA. Measurement methodologies, genetics of quality traits, and material suitable for MAS were released (Navez et al., 2016).

Recently, the vegetable industry focused on improving the content of components favorable to human health, such as: enrichment of glucosinolates in cabbage broccoli, provitamin A, vitamin C, flavonoids and carotenoids in pepper, provitamin A, vitamin C, β-carotene and lycopene in tomato and carrot, and selection for antioxidant properties of melons used in cosmetics.

Breeding for adaptation to glasshouse production
Adapting crops to greenhouses, heated or not, and more generally to unfavorable conditions (short days, low light intensity, low temperatures, high humidity) has mobi-
lized breeders since the 1970s. Some French achievements deserve to be mentioned:

- Breeding of lettuce able to form heads in short days and low light succeeded as early as the 1960s (initial Dutch work exploited by Dutch and French seed companies). It generated European production of lettuce under glasshouses and tunnels during winter. An equivalent work was carried out on radish (INRA Avignon and seed companies).
- Breeding of solanaceous crops for “cold temperature, short days, low light intensity” conditions and for disease resistance. From 1956 to 1970, breeders at INRA Avignon, relayed by those in the private sector, improved the fruting capacity of tomato genotypes under cold conditions (pollen with better germination), in the field as well as in greenhouse, with aerated vegetation limiting foliage parasites. This work led to the creation of hybrids of the ‘Montfavet 63-5’ type (INRA, released in 1963, listed in 1973), then from 1975 onwards, of many hybrids from seed companies (e.g., ‘Lucy’, 1973, ‘Carmello’, 1979) that were successful in Europe, the Mediterranean area and the Middle East. An equivalent work was carried out on pepper (e.g., ‘Lamuyo’, 1973, ‘Sonar’, 1980) and eggplant (e.g., F. Bonica, 1973). These new genotypes contributed to the explosion of industrial greenhouse production in Spain, Italy and Morocco, from 1975 to 1985, with also the high contribution of Dutch, Italian and Spanish seed companies. Partial parthenocarpy was also used in tomato and eggplant. These programs were updated regularly to respond to the evolution of these markets, up to now. Hundreds of varieties were bred for these markets, with regards to firmness and later for organoleptic quality.

Intensification of glasshouse cultivation has induced serious soil microbiological imbalances, which breeders have addressed with varieties and rootstocks resistant to soil-borne pests and pathogens, particularly in tomato (e.g., *Fusarium oxysporum f. sp. lycopersici* (FOL), *F. oxysporum f. sp. radicis-lycopersici* (FORL), nematodes, *Pyrenochaeta lycopersici*, *Verticillium dahliae*), pepper (e.g., nematodes, *Phytophthora capsici*) and melon (*Fusarium oxysporum f. sp. melonis*). Since the 2000s, in a context of drastic reduction of chemical soil disinfection, breeding programmes mobilize genetic resources to meet this challenge. Rootstocks are selected, either within the crop species, from interspecific crosses, or from wild species. Targeted traits are root system vigor, resistance to pests and pathogens, suitability for long-lasting cultivation with low heat requirements (Torres and Brand, 2015).

Since 2018, investigation into root vigor and architecture of solanaceous crops and melon genetic resources, has been undertaken (INRA Avignon and seed companies).

**Controlling sexuality and its genetic determinants**

In melon, monoecy was introduced in Charentais type from the variety ‘Cantaloup d’Alger’, at the beginning of the 1980s (work at Tézier company). Proof of concept was released as a smooth, non-netted, early, monocious ‘Charentais’ type. Monoecy allows the economy of castration in the manufacture of commercial hybrids. Further, monocious genotypes develop female flowers on the main stem, thus improving production earliness and reducing manual pruning cost. Gradually, the defects associated with monoecy (e.g., vitrescence, elongated fruit shape tendency) were reduced. Monoecy then extended to all types of melon in the world. Such drastic changes of genetic structures and reproduction mode also occurred with nearly uniform seed propagated hybrids,

- for artichoke (INRA Avignon, Nunhems) replacing the traditional vegetative clones,
- for asparagus (INRA Versailles, Vilmorin, Darbonne, Marionnet) replacing OP populations.

**Strategic turns**

Breeding has taken several strategic turns over the past 70 years. We illustrate three of them: uniformity of varieties, resistance to bio-aggressors and improvement of vegetable postharvest.

**Uniformity of varieties**

The last 50 years were marked by a strong increase in variety uniformity, based on the spread of pure lines, exploited for themselves or as hybrid parents, and of clones for vegetatively propagated species. Hybrid structures have been created and became almost generalized for species with suitable floral biology and seed yield (Daunay, 2009). For some species, the control of male sterility has enabled industrial production of hybrid seeds. First used in solanaceous crops and cucurbits, male sterility was abandoned because of its cost and slight expression instability depending on agro-climatic conditions. Quite the contrary, hybrid seeds production with a male sterile component became widespread in *Brassicaceae* (INRA Versailles, INRA Rennes, seed companies), and *Umbelliferae* (INRA Avignon, seed companies).

**Resistance to bio-aggressors**

Vegetable production is affected worldwide by 10 to 50% of losses because of bio-aggressor damages. As early as the late 1950s, breeding began to create genetic material resistant to major bio-aggressors. Breeding
for genetic resistance to fungi, viruses, bacteria, and insects nowadays with some 150 host/pathogen combinations (about 40 crop species), i.e. 240 research programmes in France to date. A national network managed by GEVES is responsible for the maintenance and distribution of crop reference and control materials as well as of pathogenic strain reference collections (MATREF network). French and European research teams have had great successes in introducing resistances in their commercial varieties. Although the risks of circumvention of monogenic resistances by pathogens are well documented (e.g., lettuce/Bremia lactucae, pepper/Tomato spotted wild virus (TSWV), pea/Ascochyta and Fusarium oxysporum f. sp. pisi), they are still widely used and many of them have not been circumvented (e.g., the bean Are gene of resistance to Colletotrichum, the tomato Tm2 gene of resistance to any strain of TMV virus and the pepper L1, L2, L3, L4 alleles (L locus) of resistance to TMV race 0 and Pepper mild mottle virus (PMMoV), all used for over 60 years). Combining polygenic resistance mechanisms to monogenic ones, and/or to other protecting strategies remains a major challenge that mobilizes breeding teams. Research tracks are diversifying:

- **Gene pyramiding.** In pepper for example, the major gene pv2 of resistance to potyviruses, which decreases the virus population in the plant, is associated to a particular QTL which decreases the probability of appearance of viral mutants and thus delays the circumvention phenomenon,
- **Identification of natural defense stimulators (NDS).**
- **Resistance management, such as alternating resistance genes in time and space,** in order to limit host selection pressure on the pathogen.

French research is currently focusing on partial genetic resistance, whether or not associated with production techniques. Polygenic partial resistances are supposed to be more “sustainable” than monogenic resistances. Their use is relevant in the background of agroecology (Torres et al., 2018), where crop rotations, clay-humus complex, biological life of the soil, surrounding environment and production basin are considered all together.

**Improving long storage ability**

For tomato, since 1980, the specialization of production areas far from the French and North European consumer markets (e.g., Sicily, Spain, Canary Islands, Morocco) has led marketers to favor products with a long shelf life and resistance to transportation. For tomato in particular, fruit firmness was introduced from the early 1980s in INRA and seed company breeding programs, leading to the creation of French varieties derived from ‘Ferline’ F1 (1986), and of hybrids for Mediterranean markets (‘Cristina’, 1990, then ‘Elana’). Later on, the introgression of the rin gene in heterozygous state was generalized, among other reasons because of the world success of ‘Daniela’ (1989), and its numerous diversifications. The rin gene reduces ethylene production, carotenoid biosynthesis, fruit softening and aroma development. As a consequence, fruits are too firm, insufficiently colored (in autumn French glasshouse conditions) and lack of taste. Hence, rin has been replaced from 2005 onwards by polygenic constructions that allow external and inter-carpellar walls thickening and offer acceptable taste quality. These improved genetic types supplied the markets, first in the two caliber sizes sought after by supermarkets, then in new varieties resulting from diversification (Italian tomato, cherry, bunch, elongated, green, yellow, black types). However, from 2010 onwards, the soft so-called “authentic” old types (heirloom varieties) reappeared, such as ‘Marmande’, ‘Ox heart’, ‘Pineapple’, ‘Crimson Black’, ‘Rose of Bern’, mostly produced for local markets.

For melon, the Charentais type is characterized by a climacteric crisis leading to aromatic fruits of short term conservation. By successive crosses with Spanish types, French breeders managed to create Charentais type melons deprived of climacteric crisis. Hybridized with other f1 melons from the United States (Eastern and Western types) and Japan, they created a new ideotype bearing sweet fruit with netted skin and a fruit shelf life of 5-6 days considered suitable for the market.

**French model of professional organization for the vegetable seed sector**

**Structuring and regulation**

For vegetables, the French professional organization set up very early close collaboration between public institutions and private seed companies, as a strategy of synergy between actors of the sector, in order to support research, innovation, industrialization and internationalization. As early as 1950, in order to organize the market and monitor the rights of variety users (farmers, industrialists and consumers), studies on marketed varieties were conducted, within the framework of the Permanent Technical Committee for Plant Breeding (CTPS) of Ministry of Agriculture, i) at INRA, ii) at the Ecole Nationale Supérieure d’Horticulture (currently AgroCampus Ouest, Angers) in collaboration with seed companies. These studies led to the creation of the first official national catalogue of vegetable and strawberry varieties (1960). From 1960 onwards, registration of varieties and seed lots quality control was structured within the CTPS, which is responsible for advising the Ministry of Agriculture on the regulations concerning their marketing. Variety registration was first delegated to INRA then to GEVES (1970). The “seed lot quality” section was delegated to the Official Control Service (SOC) whose management is entrusted to the National Interprofessional Seeds Group (GNIS). These bodies report to the CTPS, which gives its final advice and proposal to the Office in charge of varieties and seeds within the Ministry of Agriculture. This latter takes the official decision for registering a variety.

European consultation and harmonization are being built within the Standing Committee on Seeds of the European Union, ensuring a free market for seeds and varieties in European territory. Other studies are also conducted at the National Seed Testing Station (SNEs, https://www.geves.fr/about-us/national-seed-testing-station/) to characterize the quality of commercial seed lots. As a consequence, the seeds and varieties market is cleaned up and offers a quality guarantee to its actors.

In order to protect the rights of breeders of new plant varieties, the legislator introduced a Plant Variety Protection Act, in 1970 in France, which gives the breeder a reliable and time-limited right. This system is managed in France by the national plant variety office (Instance Nationale des Obtentions Végétales, INOV). An equivalent European right is granted by the Community Plant Variety Office (CPVO), which confers the right in the EU territory. The world Union for the protection of new varieties of plants (UPOV, established in 1961), harmonizes the technical and legal aspects in the form of inter-
national recommendations. France is very active in these bodies. The Director of INRA at that time was one of the active creators of the Plant Variety Right established by the Paris Convention in 1961.

The organization of national seed production and marketing is carried out by GNIS, which provides a forum for dialogue, exchange and decision-making between the professional actor groups concerned with seeds and seedlings, from the breeding of varieties to the use of seeds and seedlings. GNIS also provides a contractual framework for relations between seed companies and seed multiplication farmers. Its technical service, the SOC, is in charge of the quality control of seeds and seedlings by the French State (Box 5). GNIS also plays a role in promoting the vegetable sector in France and abroad.

The National Federation of Seed Multiplier Farmers (FNAMS) is the national structure that runs economic and technical aspects of seed production by farmers, and represents them at the economic and trade union level. FNAMS acts as a technical institute for seeds, the actions of which are financed by the inter-profession.

Since 1960, the French vegetable seed sector has evolved through a strategy of concordation with the French and European public authorities, both to promote contract research and to regulate the markets and guarantee a high quality level of varieties and seeds. The CTPS facilitated the matching between economic demands and interests of the actors, and relayed the syntheses and conclusions to the State’s decision-making authorities. Since 1990, the French and Western European model has spread to Eastern Europe, the EU, the Mediterranean and African countries. It has strongly contributed to French and Dutch leadership in the world. One question is whether this model is capable or not of adapting to the rapid all-scale changes induced by the global challenges. These include the agro-ecological transition, the adaptation of the regulation of varieties, seeds, and plant variety protection to the specificities of developing countries, as well as the necessity to guarantee food, nutrition and health security to human populations. The French vegetable sector has taken up these questions.

Research and education
State and professional bodies have structured plant breeding research and teaching at national level. As seen above, INRA has heavily invested in the vegetable sector by creating research units in plants genetics and breeding (stations in Versailles, Rennes, Avignon, Guadeloupe) and biotechnology (fruit and seed biology in Bordeaux). Other institutions have contributed to specific efforts on tropical vegetables (CIRAD), strawberry (CTIFL), chicory (CTIFL, Lille University), carrot, cabbage and cauliflower, crosne (Stachys affinis), sea crambe, tuberous celery (AgroCampus Ouest Angers and Rennes).

Agricultural education specific to vegetable breeding and grain crops has been organized to train:
- growers and technicians (BTS level in France, BSc in the Anglo-Saxon system): i) for vegetable production (e.g., agricultural high schools of St-Germain-en-Laye, Sainte-Livrade, Abil), and ii) breeding and seed production (e.g., agricultural high schools of Valence, Castelnaudary, Lille-Genech, Nermont, Pouillé),
- executives (BSc+1, MSc, PhD) in agro-engineering schools and universities (e.g., Paris, Rennes, Montpellier, Toulouse, Clermont-Ferrand, Beauvais, Angers, Lyon).

For example, AgroCampus Ouest Angers and the University of Angers deliver a Master’s degree in plant biology for seed and seedlings, supported by the Research Institute of Horticulture and Seeds (IRHS).

Vegetable seed production in France
The French vegetable seed industry is characterized by its know-how and the great involvement of its members. The various agro-climatic conditions available in France are suitable for producing seeds of many species. This production is carried out mainly in the open field, but also in insect-proof tunnels for pollination control. GNIS terminology for qualifying vegetable seeds distinguishes vegetable species that are harvested fresh and gathered under the generic epithet of “small seed vegetables” from pulses that are harvested as dry grains (garden pea, bean, lentil, chickpea, faba bean, etc.). Small seed vegetables include species belonging to the families Apiaceae (carrot, parsley, coriander, etc.), Chenopodiaceae (garden beet, spinach, Swiss chard, etc.), Brassicaceae (cabbage, radish, rocket, etc.), Cucurbitaceae (gourd, squash, melon, etc.), Valerianaceae (corn salad), Asteraceae (lettuce, chicory, etc.) and Solanaceae (tomato, eggplant, pepper).

France is the first producer and second exporter in Europe
With nearly 22,000 ha of multiplication in 2019, including 9,700 ha of small seed vegetables and 12,200 ha of pulses, France is the leading producer of vegetable seeds in the EU. Thanks to its recognized know-how in terms of quality, France is also the second largest exporter in Europe and has a positive trade balance of more than €260 million, in a highly competitive international environment. World trade in vegetable seeds was €3.6 billion in 2015. Europe, North America, and the growing Asian markets are the most profitable.

Seed production relies on a network of 2,500 farmer-multipliers and 96 seed companies that ensure rigorous monitoring, traceability and controls at every production stage. Nearly 1,500 nurseries throughout the territory also produce vegetable seedlings for growers and gardeners. Every year, more than 2,000 million seedlings are marketed, 90% of which are for the professional market. For certified crop plants, forty companies are specialized in the production of garlic, shallot and strawberry.

Box 5. Vegetable variety and seed lot quality control
The official quality of a vegetable variety is assessed in France by two complementary systems. The variety is subject to mandatory standardized tests at European and world (UPOV) levels to verify its identity, uniformity and stability (D.H.S. test). Its identity card is drawn up with its main characteristics, including its genetic resistance to diseases. At the end of these tests carried out by GEVES, and on the proposal of the CTPS, the variety is registered in the Official Catalogue of Varieties and the Community Catalogue, which gives it a marketing authorization in the EU territory.

Its quality of yield and adaptation to the agro-climatic and economic market context in France are tested in a non-obligatory manner by technical institutes. CTIFL, Union Nationale Interprofessionnelle des Légumes de Transformation (National Interprofessional Union of Vegetables for Processing, UNILET), regional stations as well as producer groups. The quality of seed lots produced in France is controlled by the SOC in approved laboratories, on the basis of quality criteria such as species purity, germination and vigor, with harmonized tests at EU and OECD levels. GEVES-SNES coordinates these laboratories, especially for securing the application of the recommendations of the International Seed Testing Association (ISTA), in order to guarantee the exportations and importations out of the EU. Once a year SOC reports to the CTPS for its activity.
Import Potagères fines Garden vegetables 9533 9762 10274 10748 11145 9814 10045 9673
Légumes secs Pulses 7365 7491 8291 9792 10891 12427 13656 12208

The export value of vegetable and flower seeds between 2012 and 2019. Source: GNIS.

Figure 2. Evolution of acreage (in ha) of vegetable seed production in France between 2012 and 2019. Source: FNAMS.

Figure 3. Evolution of the French net commercial balance (in kEuros) in vegetable and flower seeds between 2012 and 2019. Source: GNIS.

Box 6. Organic agriculture (OA) vegetable seeds to boost the development of OA

With changes in food consumption habits, and the growing concern of consumers for signs of product quality, the production of “organic” vegetables is strongly increasing in France, as indicated by the surface areas doubling over the last six years. Responding to this fast-growing market represents a challenge for the seed sector. The production of OA seeds is complex because it must meet a double requirement: the respect of the rules and standards applied to seeds, together with the respect of the OA specifications. Although the multiplication of OA vegetable seeds still concerns limited surfaces, it is constantly increasing. The production represented 740 ha in 2019 (333 ha in 2014) and mainly concerned lentil, chickpea, onion, radish, beetroot and carrot. With multiplications also carried out abroad, the range of OA vegetable seeds is growing strongly in 2019, more than 1,250 varieties were sold by 35 seed companies. The seed sector aims at continuing this development and supporting farmer-multipliers in these more complex productions for further technical and economic success.

plants and asparagus claws. This activity represented 1,400 ha of multiplication in 2019. Vegetable seed multiplication is spread throughout France in multiplication zones (Figure 1b,c) Each zone has specific soil and climatic conditions and “terroirs” favorable to 73 species: garden pea (4,300 ha), chickpea (4,050 ha), onion (1,990 ha) and carrot (1,530 ha) take up the largest areas. The total area devoted to vegetable seed production has increased steadily since 2012 (Figure 2), except a brief decrease in 2019, explained by 2017-2018 exceptional harvests. Seed companies continue to rely heavily on the economic development of vegetable seeds. They invest 25% of their turnover in research and development, in order to create the varieties of tomorrow adapted to market and environmental challenges.

The export value of vegetable and flower seeds, although stagnating in 2018/2019 compared to the previous seasons, jumped by 48% from €313 million to €462 million between the 2011/2012 and 2018/2019 seasons. During the same period, imports increased by 49% from €134 million to €200 million. The trade balance for vegetable seeds remains largely in surplus with a positive balance of €262 million, 92% of which is related to small seed vegetables (Figure 3).

Important technical work that contributes to the excellence of the sector

The results of the vegetable seed sector can be explained by important assets:

• a solid organization of the sector, which allows the production of quality seeds, favorable “terroirs” and climatic conditions,
• a structured network of farmer-multipliers with recognized technical know-how and specific equipment,
• a climate of trust between players in the sector regarding the confidentiality of multiplied varieties,
• rigorous monitoring of production by seed companies,
• close collaboration between farmer-multipliers and beekeepers, to ensure pollination of seed-bearing crops,
• sanitary control of production, with crops grown under insect-proof tunnels to avoid viral diseases, or in protected areas at high altitude. The sanitary control of the seeds produced implements numerous tests to guarantee the absence of 112 fungi, 71 viruses and viroids, 27 insects and 5 nematodes mainly on Brassica, beans, pepper and tomato.

Additionally, the production of vegetable seeds follows strict rules with controls at all stages, from multiplication to marketing, in order to provide quality seeds that meet the requirements of vegetable growers, nurseries and gardeners.

Each year, the GNIS vegetables and flowers section defines a program of technical activities meant to improve the production and quality of seeds multiplied throughout the territory, in terms of sanitary quality and specific purity (absence of seeds of other species). This program, implemented by FNAMS, aims at maintaining the competitiveness of the French industry.

In recent years, this program has focused on alternative methods for weeding and controlling diseases and pests: mechanical tools, robotics, biocontrol products, and integrated biological protection. This shifted orientation was accentuated in 2019 with part of the pro-
gram devoted to the control of vegetable seed production for organic agriculture (OA), from the time the crop is planted (Box 6). Results are regularly communicated to seed companies and to farmer-multiplicators through technical meetings, technical circulars, brochures, a bimonthly magazine and the websites of GNIS and FNAMS (www.fnams.fr/produire/production-de-semences/potageres/).

**Computerized management of crop location to ensure seed varietal quality**

Among the qualities expected, the seed lot must correspond exactly to the chosen variety (conformity and purity). Varietal purity is directly related to pollination, which requires minimum isolation distances between propagation plots to avoid the arrival of undesirable pollen on the seed carrier field. Isolation distances take into account the floral biology of each species: autogamy (self-pollination) vs. allogamy (cross-pollination), entomophily (pollination by insects) vs. anemophily (wind pollination). Distances range from 100 m (for pea) to 5,000 m (for certain types of carrot). In order to facilitate the management of isolations, the sector has acquired a computerized mapping tool. It allows the remote declaration of crops before they are planted, with the precise location of the plots on an IGN (National Geographic Institute) map. These locations, which can be consulted by stakeholders in the sector via an internet interface, are validated, after verification of the isolation distances between plots, during regional meetings attended by representatives of companies and farmer-multiplicators. After validation, the plots can be planted. This tool, which is appreciated by the sector, currently concerns 23 species, representing more than 3,000 plots mapped on the territory and a dozen regional meetings per year to validate the locations.

**Varieties and seeds more respectful of human health and of environment**

Since 1980, seed companies have been marketing old varieties or varieties derived from them, which are of interest to gardeners and growers targeting direct distribution: consumers are rediscovering tastes and textures from a wider genetic diversity. A national brainstorming is ongoing since 2000, and action strategies have been initiated to lead to vegetable and grain production practices that are more respectful of human health and environment, particularly with regard to nutritional quality and biodiversity preservation. At the same time, the criterion of uniformity becomes less of a priority, and thanks to the short food circuits that are progressing at the same time (particularly for vegetables), the notion of conservation and resistance to transport hazards is becoming less important. Economic and agronomic models are also reviewed, particularly with regard to selection methods (participatory selection, farm-saved seed production) and their efficiency. Contextual questioning is taken into account: for example, would a too strong varietal uniformity limit adaptability? What is the cost/benefit ratio of hybrids compared to populations? Is the cost of biotechnology in research consistent with its agronomic and social utility? Participatory breeding programs, inserted in European networks, take up such questioning, such as the Brassica programme at INRA Rennes (Chable et al., 2020).

Some seed companies have taken the turn, by adopting these stakes. They contribute to the development of seed production systems that respect the OA specifications, and/or they deliver a greater genetic diversity on the seed market. This is the case of Sati-va and Zollinger in Switzerland, KulturSaat and Bingenheimer Saatgut in Germany, and Agrosemens, Germinance, Graines Del Pays, le Blau Germe, Essem Bio as well as some twenty seed craftsmen in the French regions. The Farmers’ Seed Network (Réseau Semenc-es Paysannes) coordinates actions in this direction. Industrial seed companies are also developing OA seed production to target a market that in 2019 corresponded to 8% of French sales (5% in 2015). The released varieties are phenotypically diversified, and depending on market segments, they are:

- modern varieties, hybrids or not, intended for intensive OA,
- old known or “forgotten” varieties, including those from other continents (e.g., Seed Savers in the USA),
- varieties specifically created for the OA context (e.g., Sativa, KulturSaat), such as populations (Box 6).

In short, agricultural concepts and production systems are evolving, thanks to the growing consideration of agro-ecological and sanitary principles. Meanwhile, new actors (e.g., towns, regions) are taking up food-related issues in territories such as localized food systems, food sovereignty and security, nutrition and health that need to be taken into consideration in both seed systems and breeding strategies. A number of priorities can be defined that address such agricultural and food global challenges:

- Maintain farmer’s and researcher’s access to genetic variability and biodiversity in a globally recognized system of exchange with equitable benefit sharing,
- Strengthen the eco-systemic sustainability of vegetable production, including the development of crops where varieties and food systems are reasoned in an integrated manner,
- Encourage production systems that promote innovation both upstream and downstream and reward genetic progress according to new selection criteria including sustainability.

**Conclusion**

Since the 1960s, the context of vegetable species selection has undergone profound changes: vegetable production became more specialized and technologically advanced; it became deseasonalized and was developed on new territories in France (metropolitan and overseas) as well as in the Mediterranean region. Crop intensification has led to a strong development of sanitary constraints. In response to these background changes, specific organization and research on varieties, seed technology and production systems have evolved. Scale changes occurred: breeding teams have acquired expensive biotechnological tools, which necessary profitability has led breeding companies i) to strengthen their collaboration with public research, ii) to grow up through purchase of, or fusion with competitors, and iii) to internationalize their commercial activities.

By means of its efficient public research and of a strong national organization of the vegetable sector, the French State has created the conditions that led to the development of a dynamic and conquering French seed industry. The area of influence of the economic players of the vegetable sector has extended worldwide. Asia, which has the largest vegetable cultivation area in the world, and Africa, whose domestic market has not yet been fully explored, are the next key partners in research and training as well as for industrial and commercial developments. This potential partnership will be brainstormed at the XXXI International Horticultural Congress in Angers, France (www.ihc2022.org), by addressing the major challenges of food crop quality, nutritional security and health to worldwide representatives of the vegetables sector. So far, breeding has only partly met these challenges in a context of production intensification that has reached its limits. Socio-cultural considerations now need to be linked to environmental challenges (climate change and biodiversity loss) for developing rapidly agro-ecological production systems and “alternative” seeds and varieties adapted to resilient and sustainable food systems.

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References


New books, websites

The books listed below are non-ISHS-publications. For ISHS publications covering these or other subjects, visit the ISHS website www.ishs.org or the Acta Horticulturae website www.actahort.org


Acquiring information and scientific knowledge is one of human’s characteristics. This is achieved through personal communications and library resources. In this book, the distinguished editors, along with 46 eminent authors, provide readers with the latest information about why moringa is considered a “Miracle Tree”. It provides readers with information about why moringa trees have great potential in combating extreme poverty and hunger. Detailed botanical information is given in chapters 2 and 3. The authors then provide information on the economic aspects of moringa. Then information on the climate, soil, and cultivation are discussed along with high density (HD) planting cropping systems, and several methods and practices involved in harvesting, post-harvest technology, and processing of moringa. Chapter 9 provides a comprehensive overview of the insect and mite pests and pollinators and their management. Diseases of moringa and their management are next. Genetic resources, diversity, and moringa crop improvement with an insight into nutritional quality and health benefits of moringa follow. The medicinal potential and health benefits encompassing traditional and modern medicine are described followed by the potential of moringa for livestock production. The agricultural and industrial potentialities of moringa, the account of moringa leaf extract as a natural bio-stimulant, and the benefits of moringa as an active ingredient for the cosmetics industry are summarized. The readers are provided with detailed information on farmer participatory and community livelihood projects in different parts of Africa. Finally, the book provides a comprehensive review of the potential of moringa with regard to climate change, sustainable livelihoods, and food security. This book provides a global perspective of moringa around the world and gives a future outlook on the challenges ahead.

Reviewed by Mahmoud A. Sharafeldin, Chair ISHS Working Group Moringa


