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# Challenges and opportunities of the French apple chain

IHC 2022
INTERNATIONAL HORTICULTURAL CONGRESS
ANGERS – FRANCE
www.ihc2022.org

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Apple production in France has been marked by a centuries-old tradition and numerous successes. Its recent evolution is underpinned by the diversity of the geographical and market contexts in which it takes place. The impact of globalization now represents a permanent challenge for the actors of the apple industry, in search of economic, social, and environmental sustainability, recently reinforced by sanitary constraints and climate change. The present overview, while not exhaustive, develops the main economic aspects of the apple sector, its territorial reality, some main lines of technical progress, and outlines some ways to face the major current challenges.

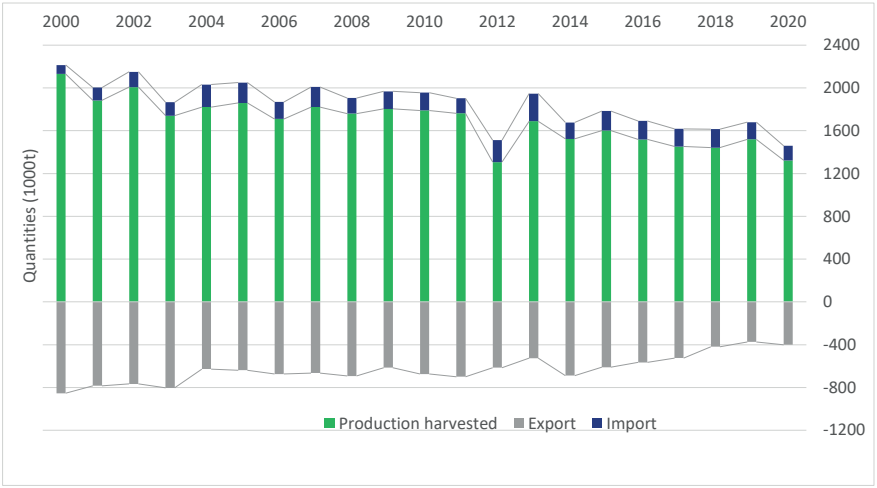


Figure 1. Apple production, imports and exports in France (fresh market). By convention, the quantities exported are indicated in negative values. Source: French Agreste statistics and customs.

## The apple industry in France: excellence in the face of international challenges

### Key figures on production and trade

Apple production for the fresh market is one of the pillars of French fruit economy, which it tries to maintain in the current context of globalization. Between the years 2000 and 2015, the area of commercial apple orchards steadily decreased from 53,000 to 36,500 ha, before it stabilized around 37,500 ha. There are about 3,500 apple farms, with an average orchard area of about 11 ha. This average masks strong disparities: more than 88% of French apple orchards are located in specialized fruit farms, about 1,100, where the average orchard size exceeds 30 ha. In contrast, there are also multi-purpose production farms with smaller orchards, and small family farms producing apples for niche markets (e.g., in the suburban context). The size of apple orchards that are certified for organic production or in conversion, approached 9,000 ha in 2020, which is nearly 25% of the total production area.

The potential of the national apple production has globally decreased, from 2 million tons (Mt) in the 2000s to 1.75 Mt in the early 2010s. It has stabilized at a threshold of 1.5-1.65 Mt since 2014, making France the 3rd largest European apple producer behind Poland and Italy. However, this production potential can be adversely affected by climate. The frequency of climate events has increased over the last decade (particularly in 2012, 2020, and 2021) (Figure 1). Affected by spring frost, the 2021 harvest is estimated at 1.36 Mt. On this basis, an average yield of about 40 t $ha^{-1}$ can be calculated, for all apple orchards combined (extensive and intensive, young and mature, conventional and organic). This is a respectable performance, and very stable since the 2000s, masking much higher yields per ha in the most specialized farms.

In terms of trade, France was the world leader in apple exports for the fresh market until 2003, with an average volume shipped close to 0.80 Mt. Outclassed by other exporting countries (China, Chile, Italy) from 2004 onwards, and more recently by Poland, France is ranked 7th largest exporter, with annual exports of 0.40-0.50 Mt (Figure 1), close to amounts shipped by New Zealand and Iran. In France, apples remain the leading exported fruit in volume and value. The main client countries are Great Britain and some European Union countries (Spain, Germany, The Netherlands) for 4/5th of the French apples shipped (Figure 2). The other destinations (1/5th: Middle East, Asia) are more irregular, or disputed by other suppliers, notably on price. The number of client countries nevertheless remains very high, at more than 100. For imports (0.15-0.20 Mt) (Figure 1), France is an open market, with 50% of its suppliers European (Italy, Belgium, Spain, Poland), and others located in the southern hemisphere (Chile, New Zealand). A significant part of apple imports counted as fresh, actually goes to processing.

In 2019, 21% of the French apple harvested production (0.38 Mt) was dedicated to processing, of which 80% was delivered to the compote industry (FranceAgriMer, 2020). For this product, France is the European leader and net exporter (about 30,000 t $year^{-1}$). Domestic consumption of compote is increasing, especially among children, with a high-end positioning and a growing share of no-sugar-added products (42% of manufacturing in 2019). Industrial processing is an important outlet for the use of sorting residues (small sizes, and damaged fruits). These fruits which are unsuitable for fresh market also contribute to the fight against food waste. For processed French apples,

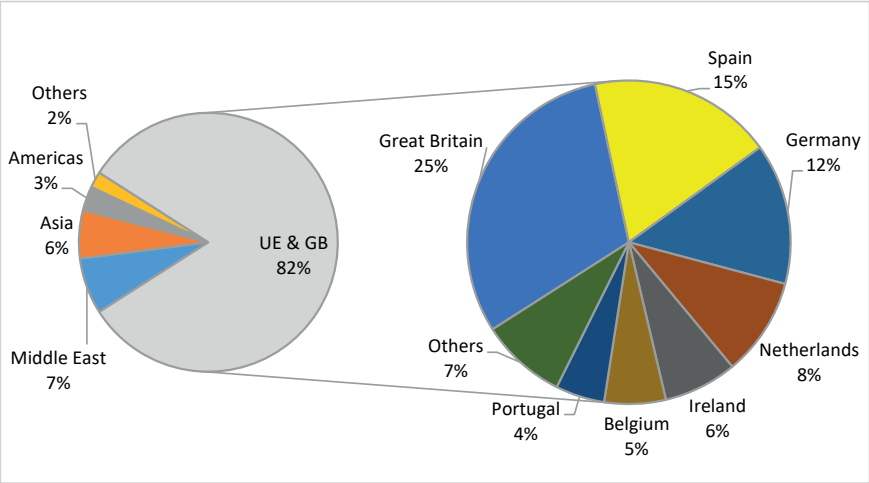


Figure 2. Destinations of apple exports from France (2020-21 season, Agreste and customs data).

industrial supplies are the subject of contracts within AFIDEM (French Interprofessional Association for Multipurpose Fruits and Vegetables). The fruit for cider, calvados, and the cider brandy sector (0.20-0.25 Mt of apples for cider or juice year$^{-1}$; 950,000 hL of cider year$^{-1}$), based on a dedicated orchard of about 9,000 ha, is not covered by this report.

## A steady consumption, with an attentive and demanding consumer

The evolution of apple consumption in France (fresh market) is based on data from Kantar Worldpanel, in particular via the indicator of the family purchases for home use. This indicator is representative of 65% of total consumption (source: Inter-professional Technical Center for Fruit and Vegetables, CTIFL), even if the share of fruit consumed outside the home is trending in increasing, except for the recent pandemic period. The analysis of the 2019 data (FranceAgriMer, 2021a) shows that apple remains the leading fruit purchased by households (16 kg year$^{-1}$), i.e., a level equivalent to 13 kg per capita. There has been a downward trend in apple volume purchased, -1.6% per year since 2011, offset in terms of sum spent (+1.5% per year) thanks to higher sales prices. Apple has a good image (taste quality, health, and convenience) and shows a penetration rate of 88% and a satisfaction rate exceeding 90%. In terms of value, apple purchases represent 15-17% of the money spent in the fresh fruit shelf. The share of pre-packed fruit in this amount has increased to almost 40% (last two campaigns), while many consumers continue to prefer bulk (markets, direct sales). As a new French regulation (since January 1, 2022) prohibits the use of plastic bags for batches of less than 1.5 kg, one can expect a higher part of presentation in cardboard or wooden sales units for lots of 4-6 fruits (Figure 3), at least for mass distribution.

French consumers can name between two and eight different varieties, while they consume an average of five (Cavard-Vibert, 2020). Their first criteria of choice in 2019 were variety, price, origin, freshness, and production method. The French supply of organic apples is becoming surplus to the needs of the domestic market (20% of families are buyers, for 10-15% of volumes). This makes some organic produce return to the conventional market.

The analysis of apple sales by distribution channel indicates that hypermarkets, supermarkets, and hard discounters represent 60% of the quantity purchased. This marks a slight decrease, while an increase in sales is noted for the drive-through formats (2%). It has been encouraged by the Covid-19 pandemic, as well as supermarkets specialized in fresh produce (4%) and organic stores (2%). Premier stores and markets, and direct sales, have a market share close to 23%.

## Collective approaches aiming at excellence and meeting societal expectations

The French apple sector is highly structured. Upstream, collective strategies, based on recognized producers' organizations, are connected within the French Apple and Pear Association (ANPP). This association brings nearly 1,400 apple producers together and represents about 70% of the surface area and tonnage for this product. It has set up a charter of good arboricultural practices, through the "Eco-friendly orchards" label (Figure 4A), recognized by the Ministry of Agriculture. It actively communicates on this approach specific to French production through various audiovisual channels and "open-orchard days". The Eco-friendly orchard label has made strong progress with French consumers both in terms of awareness (more than 50% of buyers in 2020) and confidence (77%), which is in line with societal expectations for respect of the environment. The ANPP also synthesizes the knowledge of the national and export markets to elaborate strategies of sector, develop products, and support and encourage consumption near the consumers.

About fifteen professional families of the fresh fruit and vegetable sector are grouped together within Interfel, a private law and initiative inter-professional organization recognized by the European Union. Among its actions, Interfel participates in the governance of CTIFL, particularly in its research and development orientations. Interfel also guides the actions of the Agency for Research and Information in Fruit and Vegetables (Aprifel), which gathers and disseminates knowledge on the links between fruit and vegetable consumption and health to promote their consumption. At the end of 2017, the French fresh and processed fruit and vegetables interprofessions submitted a sector plan to the public authorities. Its


Figure 3. Presentation of apples in pre-packed units at the retail stage. A) Plastic bags of 1.5-3.0 kg used for small sizes and 2nd choice (packaging discontinued for lots of less than 1.5 kg). B) Cardboard trays of 4 or 6 fruits, sometimes with an assortment of apples. These fruit shelves reflect the diversity of the French varietal offer, particularly present in the large-scale fresh produce specialists (©J.-L. Regnard).


A


B

Figure 4. A) The Eco-friendly orchards label applies to fruit from the French apple producers' quality charter. Officially approved, this label certifies that the production comes from orchards affiliated to the ANPP, committed to the production of healthy, tasty, and quality fruit, according to integrated fruit production methods that respect the environment and biodiversity, as well as the economic sustainability of the farms. The addition of the tricolor banner is a response to the French consumer's expectations of local products. B) The French high environmental value label is relative to farms strongly involved in environmental objectives. This high level of certification, not specific to fruit production, but complementary to the previous one, is awarded after external control of procedures and result indicators.

Table 1. Breakdown of apple production in France by variety (registered trademark ®, cultivar denomination and plant breeder right $_{pbr}$), for the average of the 2018-20 campaigns (in 1,000 t and %, source ANPP). For many varieties (*), mutants are available, with either a modified precocity, fewer cosmetic defects, or more intense skin color.

| Varieties | 2018-20 (1,000 t) | % |
|---|---|---|
| Golden Delicious* | 403 | 27.1 |
| Gala* | 297 | 20.0 |
| Granny Smith* | 141 | 9.5 |
| Fuji* | 59 | 3.9 |
| Braeburn* | 59 | 4.0 |
| Red Delicious* | 52 | 3.5 |
| Jonagold* | 27 | 1.8 |
| Elstar* | 16 | 1.1 |
| **Sub-total international** | **1,054** | **70.8** |
| Pink Lady® Cripps Pink$_{pbr}$* | 163 | 11.0 |
| Jazz® Scilate$_{pbr}$ | 24 | 1.6 |
| Joya® Cripps Red$_{pbr}$ | 13 | 0.9 |
| Honey Crunch® Honeycrisp$_{pbr}$ | 15 | 1.0 |
| Juliet® Coop 43$_{pbr}$ | 13 | 0.9 |
| Les Naturianes® Ariane$_{pbr}$ | 15 | 1.0 |
| Choupette® Dalinette$_{pbr}$ | 5 | 0.3 |
| Tentation® Delblush$_{pbr}$ | 6 | 0.4 |
| **Sub-total managed** | **254** | **17.1** |
| Belchard® Chantecler$_{pbr}$ | 52 | 3.5 |
| Canada | 39 | 2.6 |
| Boskoop* | 8 | 0.6 |
| Queen of the Pippin* | 11 | 0.7 |
| Goldrush® Coop 38$_{pbr}$ | 5 | 0.4 |
| Rubinette® Rafzubin$_{pbr}$ | 5 | 0.3 |
| **Sub-total terroir** | **120** | **8.0** |
| Idared | 3 | 0.2 |
| Others | 58 | 3.9 |
| **TOTAL** | **1,488** | **100.0** |

main goal is aimed at strengthening competitiveness, supporting consumption, and reinforcing the place of products and companies internationally. These interprofessions have been privileged interlocutors of the French government for the elaboration of the national strategic plan (NSP) recently submitted to the European authorities. This is a prelude to the elaboration of the future Common Agricultural Policy (CAP 2023-2027), which will be ambitious in terms of environment and climate (European Green Deal).

## Strengths and weaknesses of the French apple sector

France's place in the international apple industry is studied by a competitive intelligence published annually for the attention of the sector's actors, comparing the main apple-producing countries, on the basis of different criteria from production to consumer. The latest edition of this watch (FranceAgriMer, 2021b) shows that France was ranked 7$^{th}$ for competitiveness in 2019, thanks to certain assets: the diversity of its varietal offer, the satisfactory renewal rate of its orchards (4.3% on average), the technical skills of its producers, the dynamics of the organic sector, and a set of favorable natural factors (climate, water availability). French apple production remains handicapped by high production costs, the loss of orchard surface area (although stabilized since 2015), which limits the potential in volumes, and a contraction of exported quantities.

## A rich production potential for diverse and demanding markets

Apple production in France is characterized by great diversity. This is the result of the varied soil and climatic conditions found in the different basins, but also of the great diversity of the varieties grown, reinforced by the active breeding programs and the renewal rate of the orchards. French apple production areas are mainly located in irrigated plains, but also in hillsides or in piedmont (Figure 5), or in green belt.

According to recent official statistics of the Ministry of Agriculture, the share of French regions for a normal apple harvest (without spring frost) shows the major origins of the volumes of fruit harvested: Provence-Alpes-Côte d'Azur (23%), Occitanie (21%), New Aquit-

Figure 5. Apple orchards in Limousin. The medium elevation (350-500 m), the contrast of day/night temperatures, the soils on a crystalline base, in association with the local know-how, contribute to the reputation of the 'Pomme du Limousin' protected designation of origin (PDO; AOP in French). The PDO specifications are a refractive index of at least 12.5 °Brix, a firmness of at least 5 kg $cm^{-2}$ and an acidity of at least 3.7 g $L^{-1}$ of malic acid (©F. Besse).

aine (20%) and Pays de la Loire (17%), whereas significant volumes come from the regions Auvergne Rhône-Alpes (7%) and Centre Val de Loire (5%).

The distribution of the main apple varieties in ANPP orchards is displayed in Figure 6. It shows the importance of 'Gala' (often 25%) in the Provence, Languedoc, Tarn-et-Garonne and Loire Valley basins, a high share of 'Granny Smith' and 'Pink Lady' in Languedoc-Roussillon, and some particularities such as the dominance of 'Golden Delicious' in the Alps and Limousin, the share of 'Belchard'® Chantecler$_{pbr}$ in Charentes and Aquitaine, and the presence of regional apples in Brittany and 'Boskoop' in the north. The regional growing of diverse apples is based on the analysis of the market need (national or export), local opportunities, and characteristics of the physical environment. A wide range of varieties can thus be accessed through French fresh food retail specialists.

French orchard production can be segmented into three major groups of varieties (Table 1): international varieties, intended for both the domestic and export markets (71% of the 2018-2020 quantities, slightly down), "club" varieties, aiming for a higher value on one or two of these two markets (17% of the volumes produced, i.e., before application of the specifications, slightly up), and the so-called "terroir" varieties (8%) rather suitable for the national or even regional market. Some apple productions also benefit from official quality signs: protected geographical indications (PGIs) 'Pommes et Poires de Savoie' (since 1996) and 'Pommes des Alpes de Haute-Durance' (since 2010), and protected designation of origin (PDO) 'Pomme du Limousin' (since 2007). These terroirs have made it possible to distinguish certain favorable characteristics acquired at 350-450 m elevation ('Golden Delicious', in particular). A red label can be associated with part of this production, for 'Golden Delicious' and 'Gala', with a minimum of 13.5 °Brix, harvested at an optimal stage of ripeness.

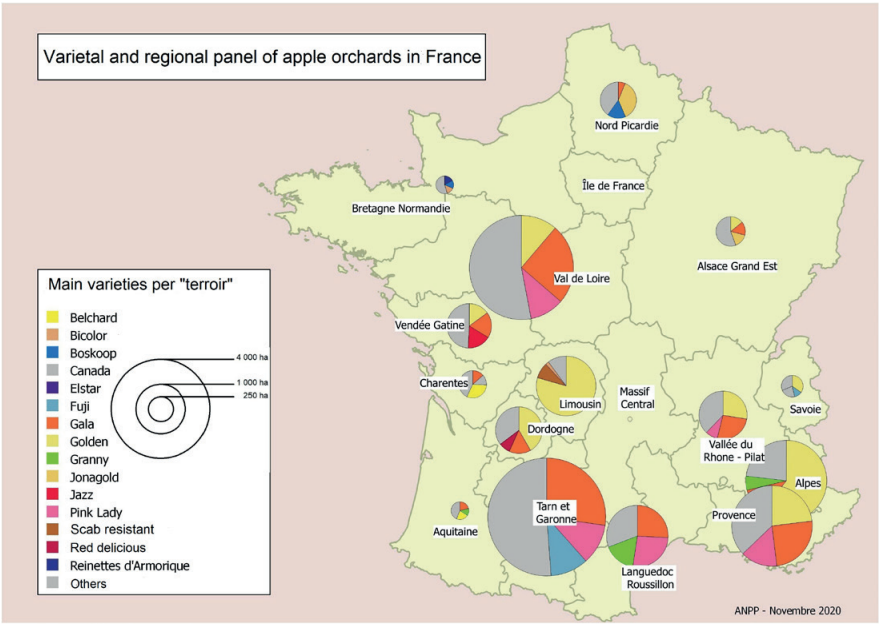


Figure 6. Varietal plantings in apple growing regions in France for orchards affiliated with ANPP. The pie chart surfaces are relative to the territorial importance, and indicate the share of the main varieties. Source: ANPP, November 2020.

Following the example of 'Pink Lady'® apples ('Cripps Pink' and its mutants), some varietal innovations are launched and managed in "clubs" (Table 1), the varieties being more or less exclusive to a few marketers, who sell the fruit under an exclusive brand name, based on the typicity of the fruit (e.g., 'Jazz'®, 'Joya'®, 'Honeycrunch'®, 'Juliet'®, and 'Les Naturianes'®Ariane). In this context, red-fleshed varieties have recently been released ('Kissabel'® or 'Red Moon'® brands), also intended for exclusive sale. By contrast, the recent scab resistant varieties bred within the INRAE/NOVADI partnership ('Story'®Inored$_{pbr}$, 'Garance'®Lespin$_{pbr}$, 'Mandy'®Inolov$_{pbr}$, 'Lory'®Inogo$_{pbr}$, and 'Galy'®Inobi$_{pbr}$, see below) are not intended for exclusive distribution, but benefit from branding strategies aimed at increasing their market value and their visibility among consumers. An increasing number of recent varieties with good hardiness, resulting from resistance or tolerance to scab, are being planted (Table 2). Some of them are suitable for production according to organic principles and are adapted for niche markets or short circuits. Given the potential for scab to overcome genetic resistance due to the *Vf(Rvi6)* gene, some treatments are still needed for these varieties, targeted at the pathogen's peak infections. Active research is being conducted (INRAE and international partners, Laurens et al., 2018) to overcome this difficulty by the breeding for a durable resistance to this pathogen.

Since the 1980s, French producers have increasingly tended to plant apple varieties with sweeter and less acidic fruit that is medium size, with very firm flesh and good storage capacity (Collective, 2021). These decisions are supposed to meet the expectations of consumers, including the youngest, in terms of gustatory pleasure, or adaptation to nomadic consumption. But they must also answer the expectations of the supply chain distribution, in terms of tolerance to handling and transport. It is necessary for the apple sector to remain attentive to the great varietal diversity now available, without becoming counterproductive in terms

## A public-private partnership in apple breeding

For more than 25 years, NOVADI and INRAE have been running a breeding program, dedicated to the selection of apple varieties that naturally offer a high level of hardiness to bio-aggressors. The main objectives of the varietal selection include a set of favorable agronomic traits: resistance or tolerance to the common races of scab, to powdery mildew and fireblight, non-attractiveness to aphids, ease of tree management, regular yield of top-quality fruit (aroma, sugar/acid balance, juiciness, fine texture) reaching high pack-out percentages thanks to an attractive presentation, and having a long shelf-life. The different stages of the breeding process are carried out jointly, with a predominant involvement of public research in the upstream steps (pre-breeding, crossing schemes, advanced phenotyping) and a strong commitment of private partners for the agronomic evaluation. In particular, the end of the selection program consists of pursuing the observations of the best hybrids in a system close to the production conditions, with experimental orchards representative of various pedoclimatic contexts. This step of assessment of varietal behavior is based at the national level on the French variety evaluation system and at the European level on an international network composed of partners who evaluate the adaptation of the pre-selections to different pedoclimatic conditions. The NOVADI company (www.novadi.fr/en/), which groups thirteen French nurserymen producing apple material for professional producers, is the exclusive world editor/manager of the varieties resulting from this program.

Table 2. Main apple varieties adapted to organic production in France. The behavior against scab is mentioned, either resistance (*Vf(Rvi6)* gene), or tolerance, as well as the control of the variety distribution (managed = club) and the main market objectives (L/S = long and/or short circuit). Registered mark®, cultivar denomination and plant breeder right $_{pbr}$.

| Maturity | Registrated mark | Denomination | Scab | Variety control | Distribution |
|---|---|---|---|---|---|
| Early | Antares® | Dalinbel$_{pbr}$ | Resistance | Brand | L/S |
| Mid-early | Cœur de Reine® | Daliclass$_{pbr}$ | Tolerance | Managed | L/S |
| Mid-early | Pixie Crunch® | Coop 33$_{pbr}$ | Resistance | Brand | L/S |
| Mid-early | Crimson Crisp® | Coop 39$_{pbr}$ | Resistance | Brand | S |
| Season | Les Naturianes® | Ariane$_{pbr}$ | Resistance | Brand | L/S |
| Season | Evelina® | Roho 3615$_{pbr}$ | Tolerance | Managed | L/S |
| Season | Opal® | UEB 32642$_{pbr}$ | Resistance | Managed | S |
| Mid-late | Candine® | Regalyou$_{pbr}$ | Resistance | Managed | L/S |
| Mid-late | Choupette® | Dalinette$_{pbr}$ | Resistance | Managed | L/S |
| Mid-late | Story® | Inored$_{pbr}$ | Resistance | Brands | L/S |
| Late | Juliet® | Coop 43$_{pbr}$ | Resistance | Managed | L/S |
| Late | Swing® | Xeleven$_{pbr}$ | Resistance | Managed | L/S |
| Late | Goldrush® | Coop 38$_{pbr}$ | Resistance | Brands | S |

of notoriety on the retail markets. It should be noted that this risk can be amplified by the various brands existing for a same apple, without forgetting the numerous labels qualifying the production methods.

## Faced with abiotic and biotic threats, an orchard design aiming at a better resilience

Increasing attention is being paid to the areas where apple orchards are planted to avoid those most prone to spring frosts, wet situations (low-lying areas, poorly drained soils), or places where soils are too light or too alkaline. The issue of adaptation to climate change is on the growers' agenda, particularly by considering the choice of irrigable situations. As an example, apple trees in the Limousin region have been grown under natural rainfall for decades, while recent orchards in this area are now installed with the support of irrigation. Beyond this example, the creation of new orchards raises the crucial question of water resources. Indeed, outside of the existing collective irrigation networks, apple growers are confronted with administrative or regulatory difficulties to create surface water reservoirs, especially in the context of individual farms. In 2021, this issue was in the French spotlight, during the meetings of the 'Varenne de l'Eau'. The public authorities are in favor of the creation of new collective water resources, made necessary by climate change or hazard control, and they support the emergence of water management territory projects (PTGEs in French). However, these projects must be implemented in compliance with wetlands legislation, which may reveal oppositions between the stakeholders (e.g., farmers vs. environmentalists).

The anticipation of mild winters unfavorable to the chilling requirement of tree (i.e., to the release of bud dormancy) has led to the evaluation of low-chilling apple varieties, notably issued from Brazilian breeding. These trials have not led to implementation to date because these very early flowering varieties are exposed to frost. The fight against spring frosts is leading more and more fruit growers to equip the orchards with means of active control, by overhead irrigation, heaters, and wind machines. To protect plantations from damage and production losses due to hail, losses for which insurance is prohibitive or even impossible, most French orchards planted since the early 2000s are protected by hail-netting (Figure 7). This type of protection, which can cost more than 12,000 euro ha$^{-1}$, not including installation labor, requires an annual deployment just after flowering and folding after harvest. Anti-scab plastic rain-roofs can be combined with these nets.

Physical protection is also used for insect control. A growing number of orchards (especially organic) in the more exposed southern areas have adopted the 'AltCarpo' netting protection system to reduce codling moth damage. Netting can be placed directly on the tree row or installed as 'mono-parcel' (Figure 8). Some nets have a double action against hail and insects.

In most orchards, moreover, the search for the natural balances encourages the fruit tree growers to strengthen or set up agro-ecological infrastructures, source of biodiversity, which are often recommended or imposed by the specifications of production. Thus, the design of orchards is attentive to plant biodiversity with the implementation of grassing of the inter-row, up to 60% of the surfaces, the annual sowing of flowering fallows (Figure 9A), and the planting of windbreaks. These vegetal structures, especially when they are multi-species, can have a melliferous (honey producing) interest and host a useful fauna (predatory or parasitic auxiliaries, pollinating insects), which facilitates biological control by conservation. With the same objectives, various specifications also

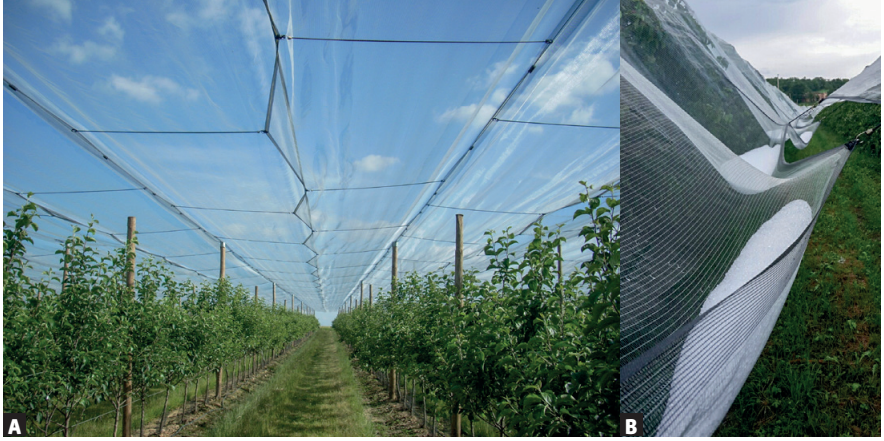

Figure 7. French apple orchards are predominantly protected by hail nets. Nets are stretched with bungee cords (A). In case of a hailstorm, the hailstones are retained by the structure (B) or fall into the inter-row, without damage to the vegetation (©Blue Whale).

Figure 8. A young organic apple orchard protected from codling moth attacks by an exclusion perimeter and cover netting ('mono-parcel' system). The mesh of the net, 5.5×2.2 mm, prevents the entry of the pest, and its egg-laying bites (©J.-L. Regnard).

recommend the installation of nesting boxes for insectivorous birds (e.g., tits) (Figure 9B), perches for birds of prey (vole predators), or even hedgehog shelters or insect hotels. These agroecological investments can be considered at the plot scale, or even at the supra-plot scale, by paying attention to interconnection corridors at the farm or landscape level.

The actions of prevention and passive control of climatic damages and biotic aggressions must be conceived from the very beginning of the orchard system, to contribute to its later efficiency aiming at a sustainable fruit production. Given their partial effects, they require complements in terms of annual direct control, as much as possible by means of biocontrol available (e.g., mating disruption or biological control).

## Innovative technical management of the orchard

### A continuous evolution driven by economic factors and supported by research and development

The technical management of apple orchards in France has undergone a constant evolution since the 1960s-70s. At that time, hedgerow systems were adopted as a standard adapted to intensification through mechanization of cultural operations (interventions made from the inter-rows, such as phytosanitary spraying) and assistance to manual operations by platforms (pruning, harvesting) (Figure 10). For economic reasons, high-density multiple row planting systems were then experimented (1970s-80s), followed by 'pedestrian' orchard concepts (1980s-90s). However, there has been no significant adoption, either because of excessive investment, or because of yield deficits at maturity. The objective of high-quality fruit production has also been more and more present, in response to markets' expectations. The first professional production charters date back to this period, especially for apples and pears. The initiatives of orchardists converged to lead to a National Charter of Integrated Fruit Production (1997), today known as Eco-friendly orchards, supported by the ANPP organization. These advances were made possible thanks to a systemic approach, consisting in synthesizing scientific and practical knowledge from research and development work in fruit production, carried out by INRAE, by CTIFL, and regional experiment stations, also fed by data from the networks of technical advisors, in close contact with orchardists.

Thus, in the mid-1990s, the work of the Mafcot group ("Maîtrise de la fructification concept et technique") co-animated by INRAE and technical advisors, disseminated innovative concepts of apple tree management based on knowledge of varietal behavior and tree physiology, stemming in part from field observations, and aimed at regulating the fruit load and increasing control of biennial bearing (Lauri et al., 2004; Lauri and Simon, 2019). Meanwhile, other experimental approaches were developed, notably by CTIFL, more focused on adapting to mechanization, including a 'fruit wall' concept based on annual mechanical pruning of tree hedges (Masseron, 2002).

Nowadays, the increasing difficulty of recruiting qualified permanent staff in fruit farms oriented towards international varieties and long circuits seems to favor a return to a very simplified management of orchards, with higher density plantings than in the 2000s, aiming at quickly reaching the performance of adult orchards (Roche, 2020), which contributes to improve the return on investment. A high yield is a divisor of expenses per kilogram of fruit produced, which makes it possible to contain production costs despite the heavy initial investments (more than 50 k€ $ha^{-1}$). In recent plantations, the row of apple tree forms a narrow geometry known as 2D, in which pruning is simplified and facilitated; the fruit hedges generate less internal light gradients, which favors fruit homogeneity and improves the harvesting rate. The alleyways, which were classically 4 m wide, tend to become narrower, with row spacings of 3.00-3.50 m. As a consequence, the planting density increases, and can reach or exceed 3,000 trees $ha^{-1}$, which in turn increases the investments. With this orchard design, the linear meterage of fruit hedges per ha is also increased, which has an impact on mechanical operation times. The objective of mechanization remains more than ever on the agenda, with for example the practice of mechanical thinning of trees as soon as they bloom (Darwin® or Eclairvale® tools, especially in organic farming). Different forms seem appropriate to establish these new apple orchards, for example the two-branch tree (Bibaum® or Ypsilon®) installed at planting (Figure 11), thanks to the pre-formation of apple trees in the nursery, or to multi-leader training (Figure 12). The adoption of

Figure 9. A) Flower strip sown around the orchard. B) Tit nesting box placed within an apple orchard (©Blue Whale).

Figure 10. A) Apple harvesting organized from the ground, with direct deposit of apples in paloxes (©Blue Whale). B) Harvesting assisted by a self-propelled platform, carrying pickers located at different heights (©J.-L. Regnard). The trellised fruit hedge system is essential to the efficient organization of harvest.

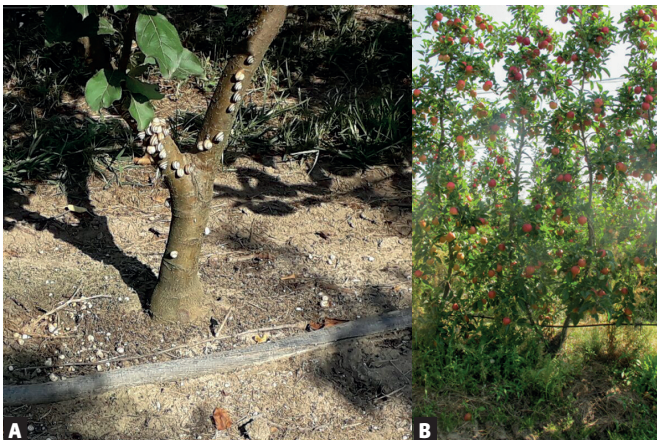

Figure 11. Two-branched apple trees. A) Detail of the branching initially obtained in the nursery (©J.-L. Regnard). B) An adult orchard in production based on this type of tree, showing the porosity of the fruit hedge (©CTIFL).

these management methods also induces a change in the range of rootstocks, the vigor of the G11 types being considered adequate, superior to that of the M9 types, which is insufficient, especially in replanting. As a result, the traditional M9 range is tending to be replaced by new rootstocks favorable to rapid fruiting, with tolerance to telluric bio-aggressors and better anchorage.

## Specifications and fruit production

In the 1980s, mass distribution influenced fruit production, with each distributor subjecting suppliers to its own specifications, before the European distributors of the Euro-Retailer Produce Working Group established a common reference framework of good agricultural practices (Eurep-Gap, 1997). Their practices aimed at safer food, based on sustainable production methods especially for fruits, and social responsibility. In 2007, this reference system evolved to become Global Gap, an essential standard for collective organizations of apple producers wishing to access the national market or especially for export. Faced with the demands of distribution, the organized fruit producers are asserting their own rules and try to have them recognized. Thus, the National Production Charter (late 1990s) evolved into the afore mentioned Eco-friendly orchards approach (2011) subsequently accredited as level 2 environmental certification, at a level compatible with the distribution benchmarks. This progress approach, oriented towards environmental, economic, and social sustainability, aims very quickly to achieve, for half of the fruit farms, the official French label of high environmental value (HVE in French) (Figure 4B). Other standards can be superimposed to the production charter to specify an additional feature; one, focused on the promotion of citizen production with strong local roots, is represented by the 'Demain la Terre' (Tomorrow's Earth, from Nouveaux Champs collective) approach while the other, 'Bee friendly'®, aiming at protecting pollinating insects, has been adopted by various producers' organizations. These procedures are subject to self-controls, internal controls and independent controls by accredited third-party organizations.

## Reduction in the use of pesticides

For pest control, the French apple orchard had already assimilated the principles of integrated fruit protection by the end of the 1970s, to overcome the impasses of a protection based exclusively on chemistry. This evolution, consistent with the objectives of fruit quality, was extended to the concept of integrated fruit production (IFP, 1990s), leading to Eco-friendly orchards today, in accordance with the expectations of distributors and markets.

Apple growers in France are subject to a very demanding regulatory context in terms of plant health, as the marketing authorizations for plant protection products are often more restrictive than those of other European countries, despite the same registration of active substances (Regulation (EC) No 1107/2009). The conditions of application of plant protection products are also highly regulated since 2006 (e.g., weather conditions, untreated areas, and residue management). Following a national consultation on a policy for the environment ('Grenelle de l'Environnement', 2007), France implemented measures to reduce the use of pesticides, through the Ecophyto I and II plans (2008 and 2014, respectively), which are the national declination of the European directive EC 2009/128. These plans have also led to the emergence of the DEPHY networks for fruit production, with a "Farm" system based on volunteer farms for agroecological transitions, supported by network engineers, and an "Expé" system consisting of the exploration of innovative R&D systems. These actions have also stimulated the provision of decision support systems and dedicated tools, which allow the triggering of chemical interventions, the development of biocontrol methods, and more broadly alternative methods of regulating bio-aggressors. The French Fruits Scientific Interest Group (GIS Fruits) published a first summary of these methods for fruit producers and technicians (Laget et al., 2015).

The strict French regulation and the control plans that accredit its application are facilitators to reach the label zero pesticide residue, but the profession deplores that technical impasses appear when the arsenal of alternative methods to control orchard pests is insufficient and/or when the authorized products are too few or withdrawn (e.g., control of the rosy apple aphid, fruit flies, or new pests such as brown marmorated stink bug). Apple production, which aims at a more natural orchard pest control, is evolving towards more resilient orchard systems. These systems make room for varieties that show resistance or tolerance of bio-aggressors and are exploiting spatial inter- and intra-specific biodiversity (market garden orchard, or multi-specific orchard).

## Precision agriculture to save resources and preserve the environment

For arboricultural practices, the time has come for the emergence of better reasoned and sized practices (e.g., adapting the volume of spray to the leaf surface deployed), which can be modulated within the framework of the plot, saving on inputs and energy, and thus bringing apple production into preci-

Figure 12. Multi-leader apple tree trial in France, established according to the Double Guyot training system (©CTIFL).

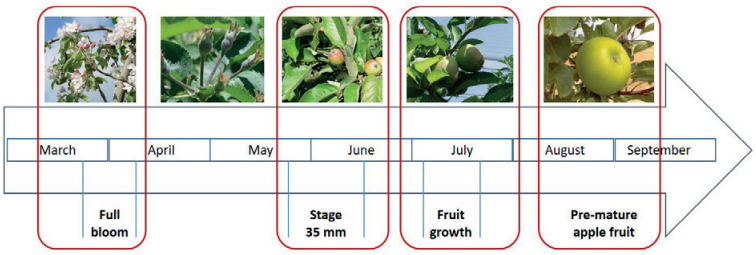


Figure 13. Annual cycle of the apple orchard showing four key periods for geo-localized image acquisition (visible or laser scanner) whose rapid interpretation is the basis for decision support for a cultural intervention and its modulation according to the maps obtained (©Blue Whale).

sion agriculture. One of the major French apple production groups (Blue Whale) has launched a project based on advances in precision imaging in the orchard to assist in decision-making. Based on four key periods for yield development (Figure 13), the current experiment consists of using mapped information at the plot level to help and/or adjust the farmer's decisions regarding thinning on blossoms or young fruit (end of March and June) as well as forecasting and preparing the harvest site (end of summer to fall).

Beyond the "orchard edge", French apple professionals wanted to assess their contribution to climate change, to minimize the negative impacts of production. Thus, as part of a framework program (Green Go) supported by ADEME (www.ademe.fr/en), various major players in the apple sector have committed to a two-year program (Peren, 2021-22) that aims to improve the environmental performance of the apple chain. This program, co-piloted by the ANPP, and concerning table apples and apple sauce, covers the orchard production, upstream, and the postharvest stages of the fruit from the fruit station to the consumer, downstream. A previous study has shown that the postharvest steps (including the movement of consumers to the shops) can account for more than 70% of greenhouse gas emissions. The environmental performance of apples is included at the production stage, with the Eco-friendly orchards charter aiming for de-carbonized production by 2024. The Peren project allows to deepen the results of a previous project on the impacts of agricultural and food products (Agribalyse), which led to the development of life cycle assessment tools (Means-InOut). The Peren project provides an inventory of the major types of orchards and postharvest chains and proposes to identify the priorities to work on, in a multi-criteria approach, to improve the environmental performance of apple. Different action levers must be evaluated at the orchard stage in terms of eco-design and carbon footprint (e.g., impact of disease-resistant varieties, fertilization management, reduction of the number of tractor and other machinery passes, and management of orchard biomass at the end of the cycle) but also at the packing station and in the supply chain. The technical and economic feasibility of the actions will be evaluated through multi-stakeholder workshops.

## A dynamic fruit sector raising questions to better meet the challenge of sustainability

The sustainability of the apple sector is based on inseparable economic, social, and environmental pillars. At the economic level, the strong organization of the profession allows the sharing of the major challenges that it faces to prepare the campaigns and to implement performance strategies. The dynamic collective animation and the work in project groups aim to answer the economic challenges and technical stakes of the sector. Among the concerns of the moment, the attention of the professionals is focused on the evolutions of the distribution, the necessary control of the production costs despite the increase of energy prices (mechanical interventions, storage, transport), the very strict French regulation on packaging and use of stickers, and the behavior of a consumer marked by a search for ethics and ecology, still remaining sensitive to the price. The producers committed to the Eco-friendly orchards demonstrate their willingness to communicate with consumers, explaining their objectives and their production methods during "open orchard" actions allowing for transparent exchanges (Figure 14). Even if this communication mode seems to answer the search for a healthy and local product, the ambition of apple production in France continues to be access to the national and export markets. Technical choices in production are made according to commercial positioning.

A dominant trend is towards an intensive and high-yielding orchard, physically protected against hazards, designed to meet the challenges of international competition and low production costs. Its optimization is based on consistency between the parameters of initial design and increasing mecha-

Figure 14. Meeting between an apple producer committed to the Eco-friendly orchard charter and the public, during recent "open orchard" days (©ANPP).

nized management, seeking to compensate for the scarcity of labor, and offering an economically viable solution to increasing hourly labor costs. In contrast, more extensive orchard models are emerging, demonstrating a search for resilience. Based on new production paradigms, some of them are tested as prototypes (e.g., agroforestry orchard, or market garden orchard), giving a large place for interspecific diversity, ensuring natural pest regulation, thus minimizing the need for phytosanitary protection. In these orchards, economic profitability depends on a parsimonious use of resources (fertilizers, water, energy) and a better value for fruits pertaining to a mode of production explicitly agro-ecological, targeted on a qualitative niche, in short circuit. Meanwhile, agri-voltaic systems for carbon-neutral apple orchards are also being tested. Equipped with pivoting panels, these systems aim at offering a shelter mitigating the effects of summer heat waves, increasing the climate resilience, whereas ensuring a sustainable production of apples and a generation of solar power.

It should be noted that the distribution is likely to reference apples issued from one or the other production model, allowing a strongly segmented offer for this fruit. The choices of the fruit growers must, in any case, be in accordance with the production methods and the commercial targets. Indeed, the different choices when creating the orchard are multi-facetted, and raise the question of varietal choice for the future. For fruit type, in addition to bicolor apples, the emergence of new high quality varieties with yellow skin (e.g., 'Rubis Gold'®, 'Opal'®) should diversify an offer mainly occupied by 'Golden' in this segment. Market niches are also possible for breakthrough innovations: red-fleshed apples or snack size apples adapted to nomadic consumption (e.g., 'Rockit'®). Tolerance to biotic stresses is a strong trend (for example durable scab resistance to scab undertaken by INRAE), interesting for both conventional and organic production, which precedes the search for varieties that will be less sensitive to climatic hazards, showing good phenotypic plasticity, in a climate context marked by uncertainty. At the genetic level, traits of tree architecture, light interception efficiency, and response to abiotic stresses are largely independent. These traits are susceptible to recombination through selection (Coupel-Ledru et al., 2022). Among the current varietal issues, the evaluation of the efficient resource use is imperative. Will it be possible to select apple varieties for water-use and/or nitrogen-use efficiencies in the future? Already, increased attention is being paid to the "services" provided by orchards, not only in terms of agricultural production and employment, but also in terms of ecosystem services and landscape (Bopp et al., 2019).

Finally, it should be emphasized that solving the numerous technical questions posed by apple production will require, more than ever, the support of multidisciplinary research and development efforts, which may fall under public/private partnerships, such as those established in France. Thus, GIS Fruits, created in 2012 and led by INRAE, brings together 22 partner institutions in the sector, including applied research (e.g., CTIFL), higher education and professional organization. GIS Fruits works on the priority themes of the fruit sector, allowing the emergence of new research questions. It stimulates collaboration and the emergence of projects between French partners, accompanies innovations and the agroecological transition. It supports the writing of syntheses on fruits (e.g., Legave, 2022, on climate change), helps to disseminate results of R&D projects, and contributes to enlighten public decisions.

Following the example of this national collaboration between partners, international scientific meetings, such as IHC2022 (www.ihc2022.org), with its various thematic symposia, will be able to facilitate the emergence of projects and international and interdisciplinary collaborations contributing to the sustainability of fruit production, and, in particular, that of the apple.

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