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4

French Wheat Pool

Alain P. Bonjean, Gérard Doussinault and Jayne Stragliati

Introduction

Wheat has been grown in France since Neolithic time, and several archeological documents confirm the presence of significant areas continuing from the haul period. The first organised wheat breeding programme was closely associated with the Vilmorin family going back to the 18th century. Today, wheat is the principal crop in France, with an annual production of over 35 million tonnes for several years. France, is the producer in the EEC was well as primary exporter.

In the domestic market (primary) the main marketing outlet for wheat is animal feed (farm fed, animal feed products), and secondly human consumption after conversion into flour (bread-making, cakes, biscuits, crispbread). Industrial uses are concerned mainly with the starch industry. Exports remain a fundamental component of French wheat, even though there is a tendency to decline as a result successive reforms of the European Union (EU) agricultural policy.

The large diversity of marketing outlets for our wheat continues to be a constant challenge for French breeders, who must create simultaneously different types of varieties corresponding to very different uses, at the same time keeping in mind three other objectives: improve the competitiveness of production, research the quality and respect the environment. This leads us to increasingly take into account existing interactions in terms of understanding from the creation of the variety until its transformation into products coming from the grain, even to the point of consumption, and to think in terms of chains and traceability.

Principal French agroecological characteristics

France is the contact zone between the north and the south of Europe and is a country with a generally temperate climate. It has the reputation of benefiting from a large diversity of microclimates and varied soil conditions, which result in several types of environments.

More precisely France is situated between the 40° 20' and 51°5' North latitude and between 4°47' West longitude and 8°15' East longitude. Surface area is over 551,695 km^2. No point of the territory is more than 500 km from a maritime shore. It is the only European state with coastlines bordering the Mediterranean sea, the Atlantic Ocean, the English Channel and the North Sea.

All the large European mountain ranges converge in France. In the South and South-West, the Pyrenees and the Alps make up the western extremity of the mountainous Carpathes-Caucase-Himalaya. The Massif Central, Vosges and Brittany correspond to the central European hercynain. The large plain of northern Europe spreads over the north of the country.

The average French altitude is 342 metres and nearly two thirds of the territory, which corresponds from the south-west Aquitanian basin to the west of the Massif Armorican and to the north of the Parisian basin, is under 250 metres. The rest of the country is made up of mountains of a) average height – the Massif Central in the centre of the country has an average altitude of 715 metres and a maximum altitude of 1,886 metres; the Vosges in the north-east has an average altitude of 530 metres and reach 1,425 metres; and b) the mountains of a high level – The Jura in the central-east with an average altitude of 660 metres, which reaches its highest point at 1,718 metres; the Alps in the south-east with an average altitude of 1,121 metres and the highest peak Mont-Blanc reaches 4,807 metres; and the island of Corsica in the Mediterranean with an average altitude of 570 metres and which reache 2,710 metres; the Pyrenees on the Spanish border with an average and maximum altitude of 1,088 and 3,298 metres respectively.

The most fertile French soils are the deep sedementary, soils, made up from the accumulation of residues of old soils by the action of water or wind. They are either the periglacial loes or the alluvial soils of the valleys and of coastal plains. They cover the north, the north east and the north west of the country, the Auvergne, the valleys of the Loire and the Garonne, the lower Rhone valley and the coastal plains of the Mediterranean and the Atlantic. These territories actually make up the 'cradle' of French wheat production (Boulaine, 1991). It is necessary to point out that the water-ways present everywhere in France are modest by the size of their basins and their outlets if one compares them to large rivers like the Amazon or the Yellow river. Four Rivers – Seine, Rhone, Garonne and the Loire – represent 70% of the total water discharge. Despite the limited dimension of these fluvial basins, France is more or less well served with rainfall compared to other countries.

The French climate varies with altitude: on average the temperature drops by 1°C when the altitude increases by 200 metres. The precipitation varies according to the western exposure, which brings the principal precipitation, thus the eastern regions are a lot drier; the French territory receives on average 450 thousand m^3 of water in the form of rain and sometimes snow, an average approximately of 800 mm of rain per year. There exists another climate gradient, which goes from the channel to the Mediterranean: in the north-west the climate is cool and regularily rainy; in the south-east it is of Mediterranean type, with the rain concentrated and dry summers. However, for the average of the hexagone, the autumn is the wettest season, followed by the summer and then the spring.

France benefits from moderate temperatures, which decrease from south to north. The yearly averages are more than 15°C in the south and are a little below 10°C in the north. Only the higher altitude regions have average temperatures lower than 0°C in January. Greater variations can sometimes exist, exceptionally: down to –30°C in Alsace in the north-east and up to 43°C at Toulouse in the south-west.

This results in four main types of climate: "oceanic climate" in the western half of the country, "continental climate" in a large part of the north-east, "mediterranean climate" on the south-east coast and the mountain climate (figure 1).

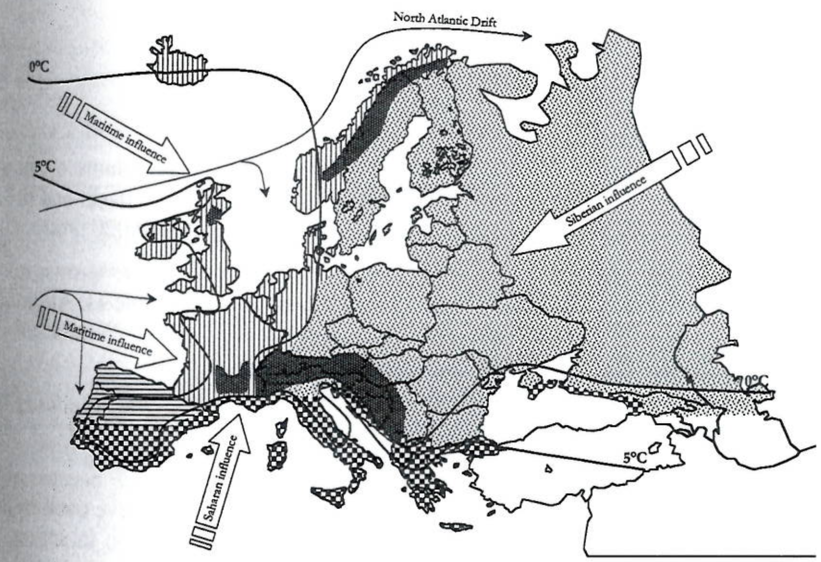

Figure 1 ■ Different climates of France.

→ Maritime current; January Isotherm; Oceanic climate; Continental climate; Mediterranean climate; Mountain climate

These variations, in keeping with the size of the country, explain the importance of French agriculture and the dominant position of wheat as a crop; in fact, wheat can adapt itself to grow everywhere except in areas of high altitude. More generally, French agriculture (735,000 farming units in 1995, cultivating an average of 38.5 hectares, with 1,043,000 farm workers) occupies the first place of the EEC s effectives with 10%, even if it only corresponds to 3.8% of the national Gross National Product. More than 55% of farmers cultivate wheat with a large variation in area within the type of farming structure (figure 2).

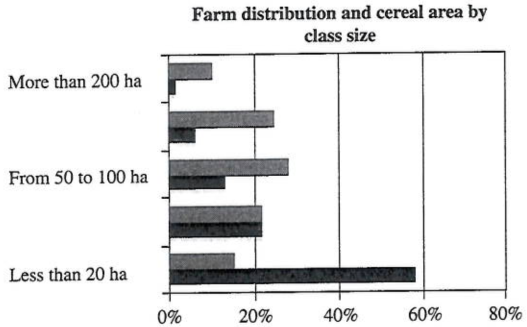

Figure 2 ■ Size of the main cropping farms in France.

■ Area of farms ■ Number of farms

Areas, production, performance and uses of wheat in France

Wheat production is concentrated farm in several large areas: plains of the north and north-west, Parisian basin, Champagne, Berry, the Loire basin and its rivers, the Garonne basin (figure 3). Wheat is grown on around 410,000 units.

After reaching 7 million ha between 1890 and 1895, wheat was grown in France on more than 6 million ha up until the First World War (table 1). At this time France still imported wheat from North America, Russia, Poland but became provisionally self sufficient from 1938.

After the Second World War, the first objective given for the wheat industry was to become self sufficient and to feed the population.

With its agriculture rebuilt after the Second World War, France became a wheat exporter in 1950. Since then national production and yields have continually increased despite a change in the sown area (a drastic reduction in spring wheat, abandoned cropping in marginal zones, competition on the good soils from maize and oil protein crops). In 1998, with a record harvest of nearly 40 million t, French exports exceeded 15 million t of which 8.8% was to other EU countries and 6.8% to third world countries.

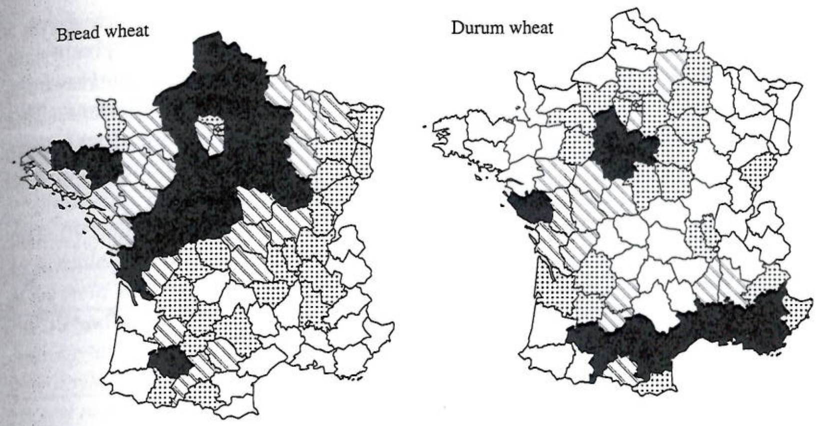

Figure 3 ■ Distribution of wheat areas in France (harvest average 1995 and 1996).

Area in bread wheat: Less than 5,000 ha; From 5,000 to 30,000 ha; From 30,000 to 80,000 ha; More than 80,000 ha

Area in durum wheat: No area; Less than 500 ha; From 500 to 5,000 ha; More than 5,000 ha

Table 1 ■ Evolution of the areas, yield and the total production of wheat in France since 1800.

Year	Areas (hectares)	Yield (q/ha)	Production (1,000 t)
1800	4,670	9.00	4,203
1850	5,991	11.10	6,600
1880	6,880	11.00	7,550
1900	6,864	12.90	8,860
1913	6,542	13.30	8,690
1935	5,363	14.50	7,760
1950	4,319	17.80*	7,700
1960	4,312	26.70	11,513
1970	3,554	35.00	12,439
1980	4,466	52.00	23,223
1990	4,789	65.90	31,559
1998	4,922	77.60	38,319
1999	4,816	73.00	35,317

* 17.80 q/ha takes into account winter and spring wheat and 20.00 q/ha is only winter wheat in 1950.

Origin: Ministry of agriculture and fisheries; Onic; Sigma ITCF.

The analysis of average wheat yields in France over two centuries shows a very slow progression between the years 1800 (9 q/ha) and 1950 (20 q/ha in winter wheat). General progress during this period was only 0.1 q/ha/year. However, between 1950 and 1999 the increase in yield rose to 1.3 q/ha/year (figure 4). This growth follows a linear tendency and, despite the hazards due to the climate there is no signs of a change in this trend.

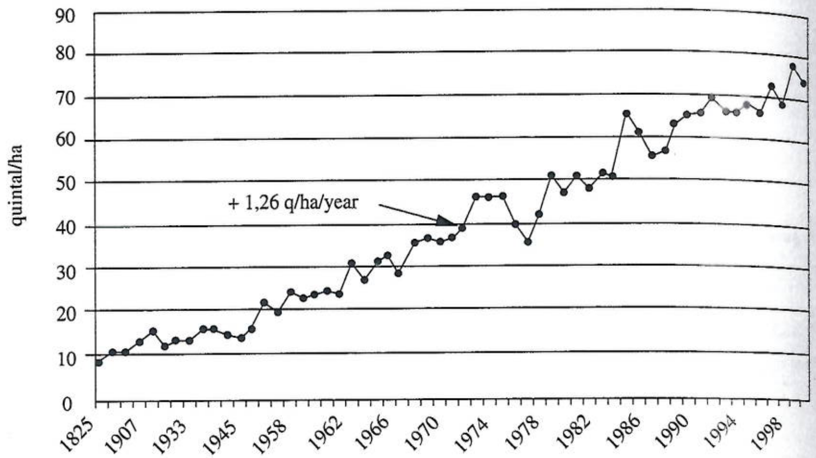

Figure 4 ■ Yield of wheat in France from 1825 to 1999.

When comparing, the varieties listed between 1950 to the present day, and taking into account the appropriate technical input, it is possible to estimate the genetic progress and dissociate it from the progress obtained from cultural techniques. The genetic progress has been estimated at 0.5 q/ha/year since 1950 with 0.8 q/ha/year attributed to improvement from technical inputs.

On further analysis the most important factors, include the ability of recent varieties to form grain from the vegetative dry matter produced, represented by an increase in the number of grains produced per unit area. Breeding has also allowed us to move in a favourable direction the relationship between the number of grains per unit area and thousand grain weight. Another part of the progress is due to the adaptation of modern varieties to intensive growing conditions. One of the deciding factors was shortening of the straw by the use of dwarfing genes, *e.g.*the variety Courtot, added to the National List in 1974. This reduction in height allowed growers to increase the level of nitrogen application, to increase the harvest index (grain/total dry matter produced) are well as improving the consistency of yields by limiting the risk of lodging. Another key factor was the development of certified seed, producing better quality than that of farm saved seed. Lastly, the increase in the average yield meant a retreat from the least favourable zones, a move away from spring wheat to more profitable winter wheat and the adaption of varieties and growing techniques to zones of limited potential.

Remark: *under our latitudes, taking into account the interception of the light energy from a wheat crop during the year and the efficiency of the transformation of this energy, the photosynthesis of a wheat plant in C3, allows a theoretical production of 220 q of dry matter/ha, in the order of 110 q/ha of dry grain, according to Austin (1980). An increase of this potential could be made by prolonging the plant cycle (early sowing and retarding the senescence period) and by improving photosynthesis. In addition an increase of grain yield could be made by improving the harvest index which today already reaches 50% under favourable conditions. However, in the immediate future, the increase in average grain yield should continue in France according to the observed trend over the last 50 years by adaptation to constraints that limit potential and by changing growing techniques. In the future, increase, it is possible that we shall observe a slow down in the increase of yield which, by consequence, could give renewed interest in hybrid wheat. Today for heterosis yield is more or less the same as that of the genetic progress observed for conventional lines during the time needed to produce hybrids and their inscription on the list. So if the genetic progress of conventional lines slow down, the heterosis yield of hybrids will become superior.*

In agronomic terms the large majority of wheat, if not all of it, is sown in the autumn; sowing in the spring has become exceptional and reserved to areas which are at risk of being destroyed by frost and without possibility of sowing alternative wheat.

In the rotations, wheat can sown be after 'clean up' crops (sugar beet, potatoes, maize) or after protein/oil crops (rape, sunflower, peas, soya). The wheat seed is almost all treated with fungicidal seed dressings. The growing conditions are more intensive in the north than in the south (table 2).

The reduction of production costs is a constant objective for producers. In addition consumers expect the production techniques to assure a healthy and tasty quality of product and respect the environment. In recent years this has resulted in more accurate nitrogen and sulphur fertilisation of the plants, less nitrogen loss, an optimisation of the application of trace-elements and irrigation, and, going even further, crop protection strategies in controlling the application of phytosanitary products and a better knowledge of storage conditions for the quality of the finished product. Incorporating effective traceability of production is now the first objective in the French wheat sector. So as to control the quality of wheat all along the chain to satisfy the market and consumer demands.

In terms of type, the French wheats since 1990 are red grained winter wheat, more mid-hard than mid-soft (it was actually the converse 10 years before) and, very rarely, white grained wheat. According to their profile, we can distinguish five main classes of wheat (table 3) since the establishment of a new classification in 1999.

On the world market, French bread making wheats are well placed in comparison with Canadian and US wheat of the soft-red type, and even French biscuit wheat is better placed than the latter (figure 5).

Table 2 ■ Variations of growing practises and their economic impact according to the French regions.

Areas	North and East	Intermediate	South
Soil type	Lime or clay	Chalky-clay	Various
Common preceding crop	Sugar beet, potatoes, rape, peas	Rape, sunflower, maize, peas	Sunflower, soya, maize, sorghum
Sowing date	Beginning of October to the end of November	October	November
Sowing rate (grains/m^2)	250-350	300-350	300-350
Nitrogen rate (units)	200-220	180-200	150-200
Principle annual parasites in normal conditions	North; yellow rust, *Fusarium*, East and Champagne; *Septoria*, mildew, aphids	Brown rust, yellow rust, *Septoria*	Brown rust
Parasites depending on annual conditions (could be severe)	Eyespot, take all, *Fusarium*	Mildew, *Fusarium*, viruses	*Fusarium*, viruses
Number of straw shortener treatments	1-2	0-1	0
Number of fungicide treatments	2-3	1-2	1
Number of herbicide treatments	2	2	2
Number of insecticide treatments	1-2	1-2	0-2
Irrigation	Not generally	Often	None
Operational costs (FF/ha)	2,000-2,700	1,000-1,700	900-1,300
Harvest date	25 July to 15 August	10 to 20 July	1 to 10 July
Principle type of wheat	Late to mid-late	Mid-early to early	Early quality
Popular varieties	Shango, Ritmo, Apache, Tremie, Isengrain	Soissons, Isengrain, Apache, Aztec	Soissons, Aztec, Cezanne, very high quality wheats
Price for the farmer (FF/q)	65-70	65-75	70-75
Average yield (q/ha)	70-100	65-75	55-70
Cross margin, with EU Premium (in FF/ha)	2,500-5,000	3,000-4,500	3,300-3,700

Table 3 ■ Experimental classification for French wheat quality.

Classes	Protein content (%)	Baking strength (W)	Hagberg seconds	Specific weight (kg/ha)
E (extra)	> or = to 12%	> or = to 250	> or = to 220	> or = to 76
1	12.5 to 11.5%	from 250 to 160	> or = to 220	> or = to 76
2	11.5 to 10.5%	According to contract specification	> or = to 180	> or = to 76
3a	< 10.5%	Non specified	Non specified	> or = to 74
3b	< 10.5%	Non specified	Non specified	< to 74

Source: Onic 1999.

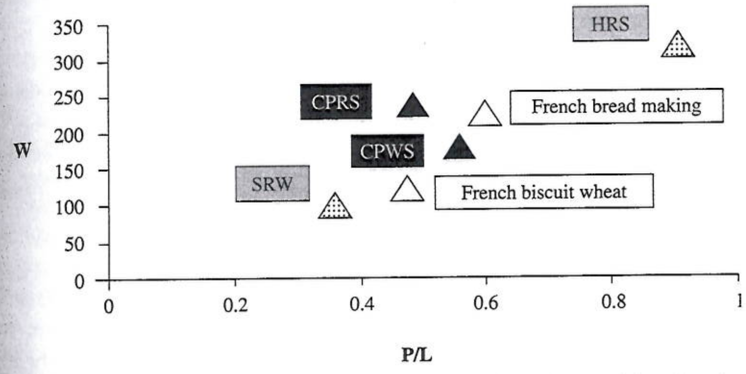

Figure 5 ■ Comparison of French wheat baking strength on the world market (average 1995-1996).

▲ Canada
△ United States
△ France

Source: ITCF.

For a long time the principal marketing outlet for French wheat was bread making, but this is no longer the case (figure 6).

Historically the French have been very large bread consumers: 800 grammes per day per person in 1700, 550 in 1800, 500 at the beginning of the 20th century, 300 in 1960, 170 in 1980, 130 in 1998. Today the use of wheat by the miller in France does not represent any more than a 10% of the total volume of the national outlet of wheat.

In parallel, other uses have developed - in first place animal feed, but also industrial marketing outlets like starch production or bioethanol.

France, which up until 1924 was just able to be self sufficient in its needs, has become a regular wheat exporter since the 1950s, principally of good baking

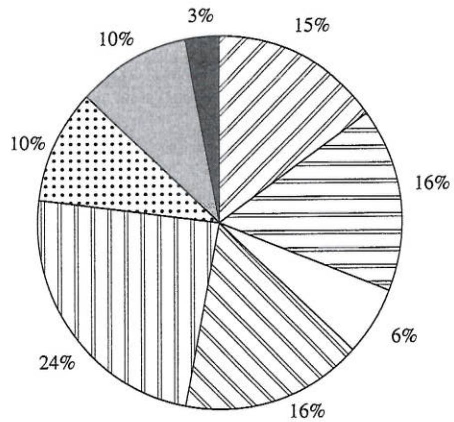

Figure 6 ■ Utilisation of French wheat, 1997/98.

Over yeared stocks campaign
FAB
Flour export
Grain export Third World
Grain export EEC
Other millers
Bread-making
Other

Total utilisation: 32 million t, total export: 15 million t.

Source: ONIC.

quality grain. In 1998, with a record harvest of nearly 40 million t, French exports were over 15 million t, of which 8.8 million t were to other European countries and 6.8 million t to Third World countries. Despite this, France continues to import small quantities of wheat regularly, principally 'extra strong' types: 23,000 t were imported in 1998.

In terms of flour, the French miller exports in the order of 1.5 million t to more than 90 different destinations world wide, principally the Yemen (23% of exports), Libya (13%), Algeria (12%) the UE (9%) Mauritania (4%) Sudan (4%) and Angola (4%). Despite this the value of exports French millers has been in decline since 1991.

Historic development of wheat in France

Origin and crop progression of wheat

Two large human migrations, dating from the Neolithic period, and from the east of the Mediterranean basin, arrived in central and western Europe. One of

hese migrations originated from the Balkans and the Danube basin, the other olonised little by little the coast line of central and western Mediterranean. From ,000 BC the west of Europe, including the territory which corresponds today to rance, opened up little by little to pottery and animal production. Agriculture robably reached this zone shortly afterwards. Thomas (1988) pointed out that in he south of France in 5,000 BC, the presence of engrain *(T. monococcum)* and of midonnier *(T. dicoccum)* were confirmed along with a type of wheat *(T. aes-ivo-compactum)*, although this crop didn't dominate the other cereals. He also howed the presence of amidonnier in Alsace during the same period and crop-ing of wheat and barley in the Parisian basin, Bourgogne and Franche-Comté wards 4,000 BC.

This initial pool of French wheat was reinforced by the introduction of Greek heat, as various Greek settlers established trading posts in the south of France round 1,000 BC. The new genetic base which resulted, and which Julius Caesar escribes in account of the Gaul war, was then enriched by wheat populations nd poulard wheat *(T. turgidum)* from the Romans people (2nd century BC to th century AD) which contributed to marginalise the growing of amidonnier. Guillaumin (1948) points out that the Gauls developped the concept of plough-ing. Boulaine (1992) cites in the Gaul period a figure of 16 q/ha of wheat as a igh yield limit in soils having good organic matter content. Eydoux (1958) escribes, from archeological data of the 3rd century, a Gaul-Roman hydraulic ill at Barbegal, near Arles at which the production of 2.5 t of flour per day had een estimated, which representing treatment of very important quantites of rain. André (1981) outlines at the same time, how Gauls and Iberes used the east from beer, to give their bread a lightness missing in Italian bread.

After the decline of the Roman empire, the agriculture of the Merovingian ynasty (5th-8th century AD) suffered a decline associated with the loss of a part f the knowledge of the Roman agronomists. Under the influence of the Francs, he Frisons and the Saxons, the principal cereals in northern France at that times ere oats, as is cited by Gregoire de Tours (538-594) in his *De gloria confes-orum.* Wheat was confined to the more southern latitudes. During the Merovin-ian period (5th-10th centuries), agriculture discovered the plough harness and einvented the three year crop rotation practised by the Romans. This period was lso signifiant as it marked the reclaiming of new areas for cereal cropping Auvergne, Parisian basin, etc.) and also by the general use of the turning plough hare under the influence of various monastery orders (Bonjean and Picard, 990). Later, Thomas (1988) cites the inventory of the Abbeys of Cluny in Bour-ogne of 1156, which confirms the dominance of cereal cropping with a three ear rotation on large domains, two yearly on the small ones, and the use of a eavy plough pulled by oxen for ploughing. This text indicates some yields of heat of in the ratio of 2-2.5 to 1 of seed in Macon and of 2.7-3.3 to 1 in Bresse or a year judged as bad, and 4 to 1 in a normal year. Towards 1250, the Benedic-ine knight W. de Henley indicated in his book "Farming Information", which onsisted of the first agronomy course in high-French, that the yield ratio xpected from Froment was 5 to 1.

Thomas also cites figures for the domain of Thierry d'Hirecon in Artois, between 1319 and 1327 where the wheat average yield was 8.7 for 1 of seed; to the south of Bethune other yield figures in the same period range from 8 for 1 and 16 for 1. These ratios were not reached again or even overtaken before the 19th century in France.

In the Middle-ages, the growth of the agricultural population very quickly reduced soil fertility, and with winter climatic conditions often being very cold followed by dry summers, the stagnation of the country folk weakened wheat production as well as other cereals. Poverty often appeared along with plagues, wars, including the hundred years war, pest epidemics, etc. Even 13th century, farmers were conscious of the importance that natural products like animal manure can give to wheat, insufficient number of animal being reared and the modest quantities available were not enough to compensate for the poor soils. As a result, a continual erosion of the soil fertility occurred, resulting in excessive set aside and unadapted fields (for cropping). Up until the 19th century the history of France is punctuated with plagues and famines (table 4) which don't disappear until after 1880.

Table 4 ■ Principle national famines from the 9th to 20th century.

Centuries	Number of famines
9th and 10th	36
11th and 12th	53
13th	10
14th	10
15th	13
16th	13
17th	11
18th	16
19th	10
20th	0

Sources: Cepede et Bernard, 1991; Fossier, 1982.

From the beginning of the 16th century, the merchant bankers of European cities such as Venice, Anvers and Genes took advantage of the riches plundered from the Americas to finance new land reclamation projects in France and in the west and south of Europe as well as sanitary and draining work. The Beauce, the Brie, the north of France and the highlands of Auvergne then specialised in wheat cropping or "fromentals" with yields of 12 to 15 q/ha, significantly higher than the rest of France, where rye at the time was cultivated more than wheat (yields of 3 for 1 were being obtained at the same time on the plain of Ambert). The "Théâtre d'Agriculture et mesnage des champs" d'Olivier de Serres (1539-1619) showed that the "Rousset" an epeautre with red awns, was one of the most widespread wheats in France in the 16th century. A number of other authors point out the importance of méteil (mixtures) during this period which corresponds to the cropping of a mixture of several cereals: wheat and rye in Auvergne, barley and oats under the name "manipole" in Limousin, wheat, epeautre and rye in Artois, etc.

In 1602 the Dutchman van Helmont carried out the first experiments in France with chemical fertilisers but only for research. Later, the use of soil liming in the Fertois produced on increase in wheat yields a third, and Boulaine and Feller (1989) reported a record wheat production of 32 q/ha on 8.5 hectares in 1766 at Bobigny near Paris, by a leading farmer called Charlemagne. In the 18th century, despite it's localized existence, the epeutre diminished little by little in favour of wheat because it's milling was more expensive, but the meteil kept it's place because the bread cost less than that of the froment. Even if a few agronomists tried to improve the country folk's habits by pilot demonstrations, the resistance to change (table 5) was still important, as stated in a complaints book of 1789: *"All these new creations only work around chemicals. We were in accordance with nature and we were fine. They want to denature us by changing our soil and our climate"*. This is not without certain threads of present day thought about the use of biotechnology in agriculture. The well known chemist Lavoisier, who was also farmer Général de Roy, gave an estimate at the end of the 18th century to his governer, of a French average wheat yield of 8.77 q/ha.

It was only with the disappearance of the feudal constraints and the emergence of different sciences in agriculture that the French peasant started to develop modern wheat cropping (table 6). Two elements are fundamental to this evolution. Firstly fallows were replaced by root crops (turnips, swedes, sugar beet), by leguminous plants (clover, dicots), forage grasses (rye-grass, dactyle) and by

Table 5 ■ The comparison of crop distribution north of Paris between 1548 and 1740.

Period	1548-99	1600-49	1650-74	1675-99	1700-24	1725-40
Sample ha	547	1,450	1,602	2,132	1,821	1,297
Number of cases	7	16	9	8	7	16
Wheat (%)	35.0	34.7	37.9	36.3	37.4	33.8
Other cereals (%)	33.4	31.2	30.1	30.8	29.4	32.9
Fallow (%)	31.5	31.9	31.7	32.5	32.5	29.3
Artificial meadows (%)	0	0	0.3	0.4	0.7	4.0
Total	100	100	100	100	100	100

Source: Chevet, 1999.

Table 6 ■ The evolution of crops on ploughable land in France between 1789 and 1859, (million ha).

Crops	1789	1859
Fallow	10,000	5,000
Wheat	4,000	6,000
Oats	2,500	3,000
Rye and other grain	7,000	6,000
Artificial meadows	1,000	3,000
Roots	100	2,000
Other crops	400	2,000

Source: Chevet, 1999.

American plants (potatoes, maize, etc.) which reduced the dominance of cereals and allowed an increase in numbers of large animals on the farming units secondly, the rediscovery, by Saussure and Liebig, of the nature of mineralisation in crop nutrition, putting to the forefront the importance of nitrogen, phosphorus and potassium, which resultefied in a fertiliser industry based on the NPK.

From 1820, soil preparation was greatly improved by the use of the Dombsle plough, which took nearly 50 years to achieve national acceptance. The appearance, towards 1850, of the first drills was part of an evolutionary trend as scythes replaced sickler, in turn scyther were replaced by 'traction' animals and these latterly were replaced by steam machines for threshing. By the end of the 19th century there had been a real revolution in wheat production.

From 1880, as described earlier, the work of Vilmorin also offered the farmer more productive wheat varieties; this put an end to the meteil practice. Also, according to the statement of J.L.Bernard (1991): *the agricultural productivity which will take off from 1820, will slow down after 1850 and remain at a slow and regular rhythm and which will evolve only from 1950 and this will include wheat as well.*

Principal stages of modern breeding of French wheat

From a genetic point of view, from the origin of the wheat crop until the end of the 19th century, it is the landraces (segregating bulks) that were cultivated in France. These were made up of genotypes, for a large part heterozygous, having in common a certain number of characters of adaptation to the environment; for example the populations from eastern France like Rouge d'Alsace, Mouton possess a good resistance to cold. They were genetically heterogeous, often differing slightly from one farm to an other. This resulted in slow evolution over the centuries from the effect of natural selection due to the environment and mass selection done by man selecting the best filled grains.

After 1850, a new wheat group started to spread in France: this was the wheat d'Aquitaine, which was derived from loads of wheat from the Ukrainian port of Odessa, arriving in Marseille. The most well known population of this group was the wheat Noé, from the name of the Marquis of Noé, who distributed it from the south-west towards the Beauce and the Brie. Some varieties close to the pure line were extracted from this population: Rouge de Bordeaux, Japhet, Gros Bleu, etc. These wheats were characterised by a large window of adaptation, good precocity, a medium resistance to lodging and susceptibility to yellow rust. They also had quite a good baking value.

At the same time wheat of English origin such as Chiddam d'automne, Squarehead, were cultivated in the north of France. These were late, productive, quite resistant to lodging and of medium quality.

Selection in the "population de pays" for the most improved genotypes was only effective in the short term. In the middle of the 19th century, inspired by the

English predecessors such as Knight, Le Couteur and Sheriff, Louis de Vilmorin (1816-1860) started to carry out the isolation and autofecundation of plants before their hybridisation, inventing in this way pure lines by genetic selection. He announced in 1856 at the Academy of Agriculture the principals of this method, as applied to sugar beet, in his paper on the creation of a variety of sugar beet. He analysed heritability in plants and applied this simultaneouly to wheat, even before the formal laws of genetics were discovered by Mendel in 1865. This concept of genetic selection allowed, well before the application of Mendel's laws, the more efficient creation of wheat varieties and other species. In fact, Mendel's laws were only rediscovered after the work of Correns, Tschermark and de Vries in 1900 and used in a scientific manner in plant breeding only after the formulation of the concept of the pure line by Johansen in 1903.

Also from 1883, de Vilmorin his son Henry (1843-1899) distributed seed from the first modern French wheat Dattel, obtained in his nurseries in 1874, following a cross made between Chiddam d'automne à epi rouge with Prince Albert. Some other crosses between the wheat d'Aquitaine and English wheat were made between 1890 and 1910 and gave a series of Vilmorin varieties like Bordier (Noé × Prince Albert), Bon Fermier (Gros Bleu × Blé Seigle), Hatif Inversable (Gros Bleu × Chiddam d'Automne) which were the basis of French wheat in the 20th century. From 1918, the wheat de pays only occupied half of the sown area, while the wheat d'Aquitaine stayed at 20% and the Vilmorin wheats reached 30%. This percentage of Vilmorin wheat continued to increase up until the Second World War with famous varieties such as Vilmorin 23, Vilmorin 27 (figure 7) and Vilmorin 29 which were also commercialised in a number of foreign countries, European or even further afield (including Argentina, Chile, Russia, Morocco). The dominance of the Vilmorin wheats would be maintained until the beginning of 1950s.

Originating in the Parisian basin, the Vilmorin dynasty was the founder of the French school of wheat breeding which developed at the end of the 19th century and at the beginning of the 20th, principally in the small plain of Pevel, a region in the north of France situated between Bersée, Cappelle, Pont-à-Marcq and Orchies (Bonjean and Picard, 1990). A number of French breeders are from this region, including Bataille, Belloy, Blondeau, Cambier, Desprez, Lafite, Laurent, Legland, Lepeuple, Moment-Hennette, Pucel and Ringot, whereas the others such as Benoist, Bormans, Dromigny, Hammel or Tourneur were, at the same time, like Vilmorin, natives of the Parisian basin or, like Mandoul and Tezier originated from the south of France.

At this time, Professor Schribaux showed the limits in the long term of the strategy practised by Vilmorin and competitors. Developed essentially the need to increase productivity, their breeding used the same parents (Follows, Jonard, 1951) in a repetative manner. This underlined that since 1940 French wheat has in common a number of characters: colourless ear without awns, semi-lax to oval glumes, earliness, resistance to diseases, lodging and the cold. From the point of view of the botanist Flaksenberger, this forms a homogenous group to the extent

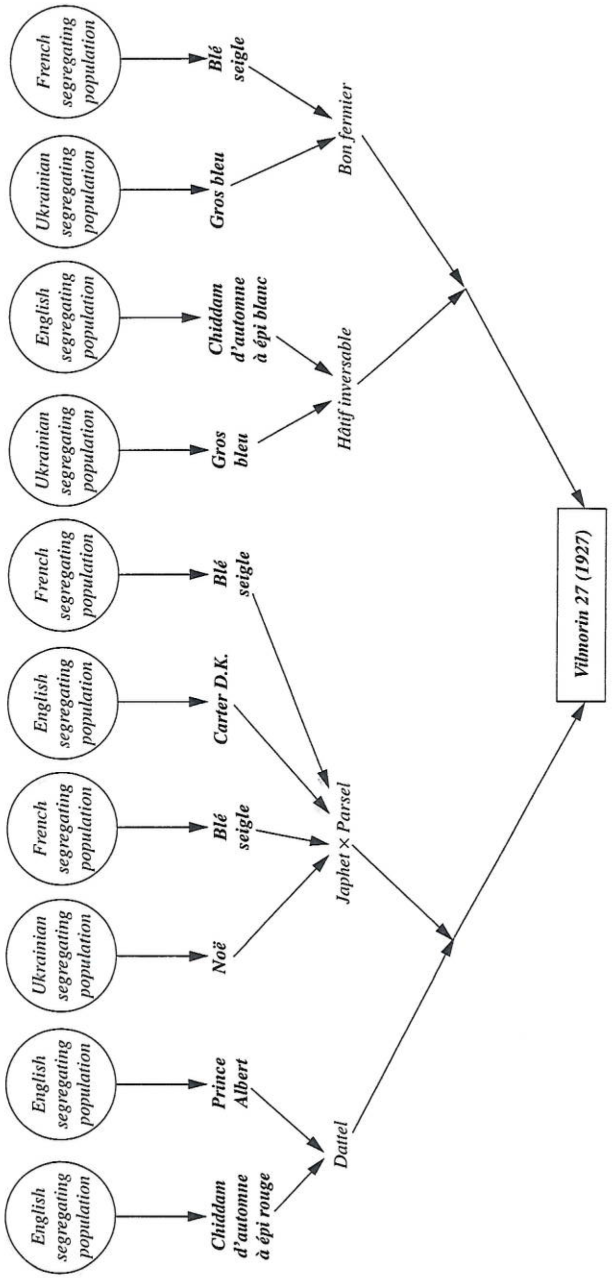

Figure 7 ■ Pedigree of the variety Vilmorin 27 (1927).
Segregating population or selection in one of these populations.

that he classes them in a special sub-species, *Triticum vulgare gallicum.* Following the efforts described previously, Shribaux and then Crépin put more emphasis on increasing the stability of yield and to discover parents with a resistance to constraints in the environment (cold, shrivelling, diseases, etc.). They introduced very widely in their crosses parents from central and southern Europe, from America and even Japan such as Oro, Ardito, Thatcher, Martin, Akagomughi.

In the same state of mind, Jacques de Vilmorin (1823-1933), who put into practice their ideas, also became conscious of the need to improve at the same time baking quality. In collaboration with Chopin, an *apparatus l'alvéographe de Chopin* was developed. It measured the tenacity and elasticity of doughs and the prediction of value for young wheat generations. Various Canadian parents and wheat from eastern Europe such as, Red Fife and Széckacz were then introduced into the crossing programme to increase the quality of French wheat at the time.

It is without doubt thanks to the introduction of this exotic genetic material that the gain in productivity, adaptation to the environment and quality the French wheat was accomplished during the period of 1945-1960. This period was marked by two famous varieties Cappelle and Etoile de Choisy the pedigrees of both which are quite different. Listed in 1946 (figure 8) Cappelle was the result of the exploitation of the synergy between the d'Aquitaine and the English wheats. Etoile de Choisy listed in 1950 (figure 9), which was especially developed in the south of France, was the result of varieties of French origin and wheat from Professeur Shribaux, it's earliness coming from the Italian variety Ardito.

The two varieties subsequently, played a major role in the pedigrees of French wheat between 1965 and 1975. They gave birth, more or less directly, to varieties which dominated the period until the 80's, such as Champlein, Capitole, Hardi, Top, Talent Arminda, Fidel and Camp-Rémy. Talent distinguishes itself by its short height, due to a dwarfing gene *Rht8*, inherited from the Italian variety Fortunato. However, the first real semi-dwarf French variety was Courtot (figure 10) listed in 1974, which carries *Rht1* and *Rht2* coming from the cultivars from the extreme Orient. It was used extensively in crosses to obtain the wheats of today, which possesses nearly all its genes.

One of the other varieties greatly used at this time was Maris Huntsman, listed in 1973. This was a derivation of Cappelle and English parents and also from *Triticum timopheevii* which donated its disease resistance, especially mildew. This type of cross led to another well known variety, Thésée, listed in 1983 (figure 11).

Since this date the origin of the parents used in France has become more diverse and complex from CIMMYT, the US, Chile, Russia, China, etc. – even if the use of this exotic genetic variability selected in conditions very different from ours (day length, temperature, etc.) requires a few precautions.

Finally, associated species, wild or cultivated, constituted another important reservoir of usable genes for breeders. Their introduction needed the creation of interspecific hybrids and the study of their descendants at a cytogenetic level to

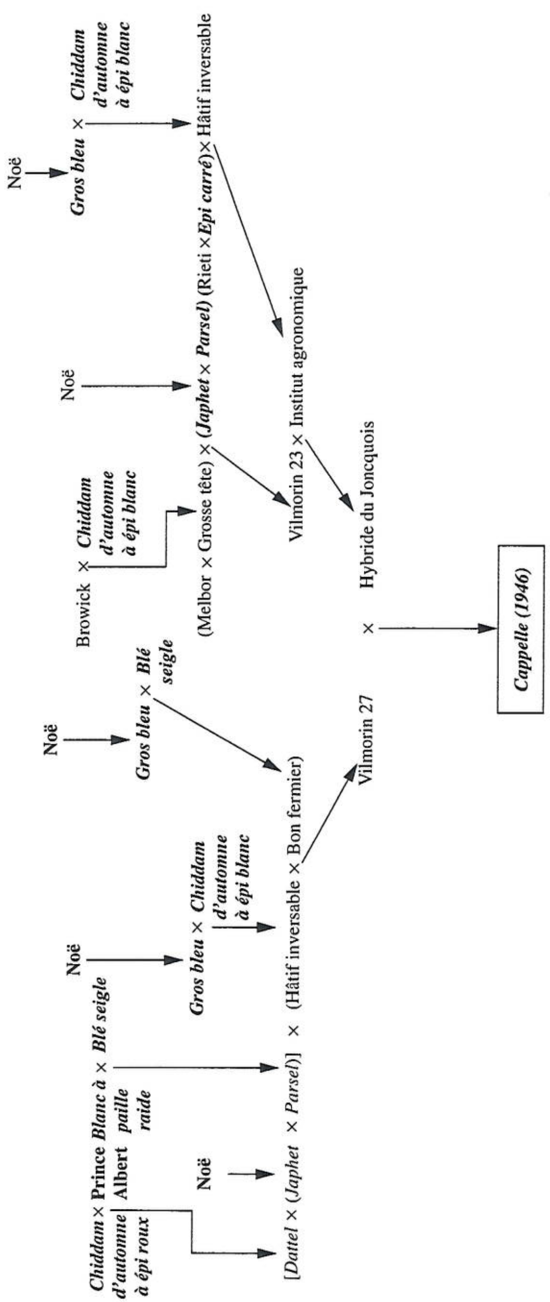

Figure 8 ■ Pedigree of the variety Cappelle (1964).
Segregating population or selection in one of these populations.

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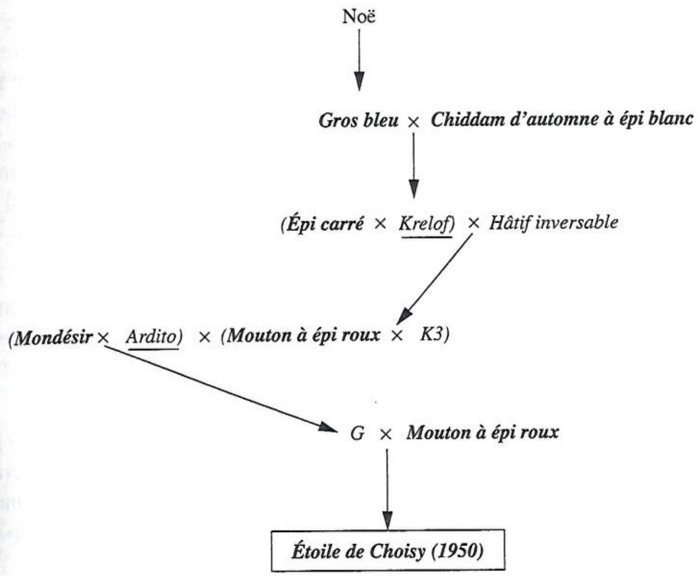

Figure 9 ■ Pedigree of the variety Etoile de Choisy (1950).
Segregating population or selection in one of these populations.
Exotic genetic sources.

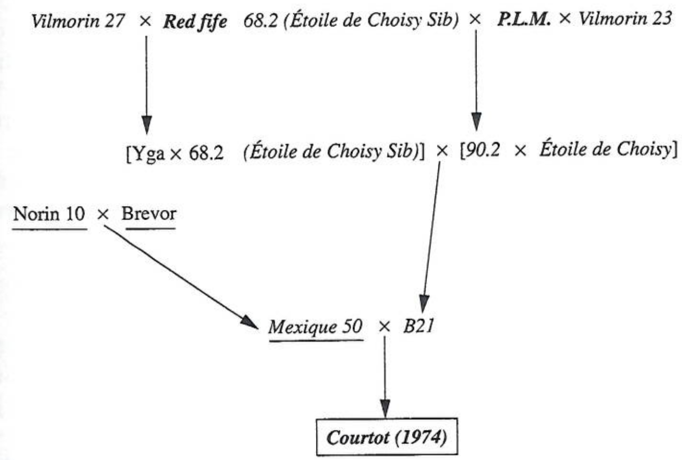

Figure 10 ■ Pedigree of the variety Courtot (1974).
Segregating population or selection in one of these populations.
Exotic genetic sources.

create wheat at with 42 chromosomes, in which the genetic information transferred is reduced into interesting characteristics. The easiest transfers are those which come from species posessing at least a homogeneous genome with that of wheat. This is why *Triticum dicoccoides* has been used to improve resistance to yellow rust and to mildew. The transfer from polyploid species of *Aegilops* is carried out in the same way. The most well known example concerns the transfer of the resistance gene for eyespot *Pch*1, coming from *A. ventricosa* and transferred onto the chromosome 7D of wheat, accompanied by a fragment of the chromosome from *Aegilops*.

It is also how the varieties Roazon (1974) and Renan (1989) were created by Inra from the amphiploid V. P containing the chromosomes of *A. ventricosa* and of *Triticum persicum*, backcrossed three times to the variety Marne to return to the chromosome constitution of the wheat genitor VPM (figure 12).

The first cycle of breeding was carried out from a cross with the variety Moisson and resulted in the creation of Roazon. A second cycle allowed the creation of the variety Renan (figure 13) with wide general resistance to diseases and very good baking quality. It is a model wheat, very well adapted to reduced input systems.

Over the last 10 years, a number varieties listed on the French catalogue carry the *Pch* 1 gene, presenting a good level of resistance to eyespot. Despite this, the frequency of introduction of this gene in to French varieties is not very high, without doubt because of the difficulty of selection for the resistance of this disease. This is disapointing given that there is a well defined marker using an isoenzymatic system, endopeptidase, but it may also be a reflection of unfavourable agronomie effects from the introduction of the fragment of chromosome coming from *A. ventricosa*. However, the introduction of the gene linkage *Yr 17*, *Lr 37*, *Sr 38* for resistance to rusts has been very frequent. A marker, RAPD, closely associated with this cluster, has been developed by F. Devryver, and this was converted in 1998 by O. Robert into SCAR, which was more specific. Around 50% of French varieties listed between 1997 and 1999 possess this group of genes. This situation is not without it's disavantages as the resistant gene to yellow rust *Yr 17* was largely overcome in France in 1998. Happily since then, varieties like Apache (figure 14) which possess another source of resistance were put at the disposition of French farmers.

One must remember that a transfer from species having homogeneous genomes can be carried out by the substitution of a whole chromosome or the chromosome arm. Several varieties listed on the French catalogue possess the substitution 1B/1R of rye or the translocation 1BL/1RS, the short arm of chromosome 1B being replaced by its homologue the short arm of chromosome 1R. To facilitate the recombination between chromosome homologues breeders have used the *ph* gene which increases pairing between chromosome homologues.

The diversity of wheat cultivated in France since the end of the 20th century has increased compared to that of varieties in the years 1950 to 1980. Still today,

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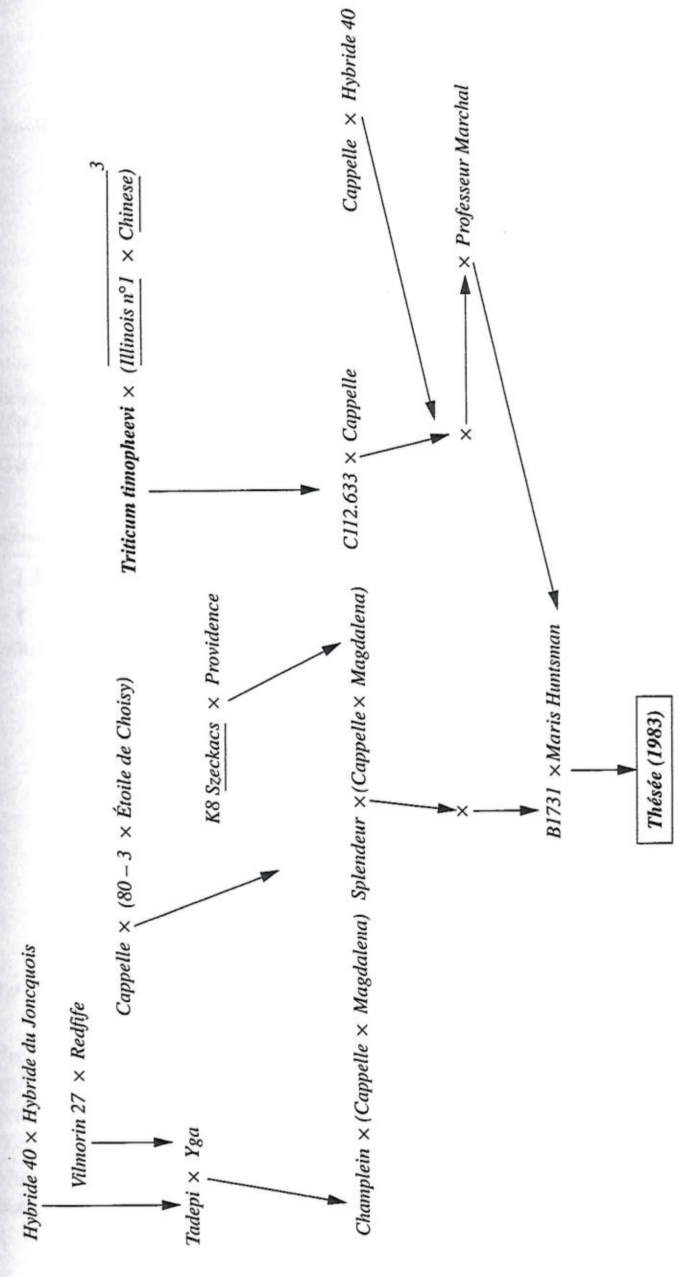

Figure 11 ■ Pedigree of the variety Thésée (1983).
Species related to wheat.
Exotic genetic sources.

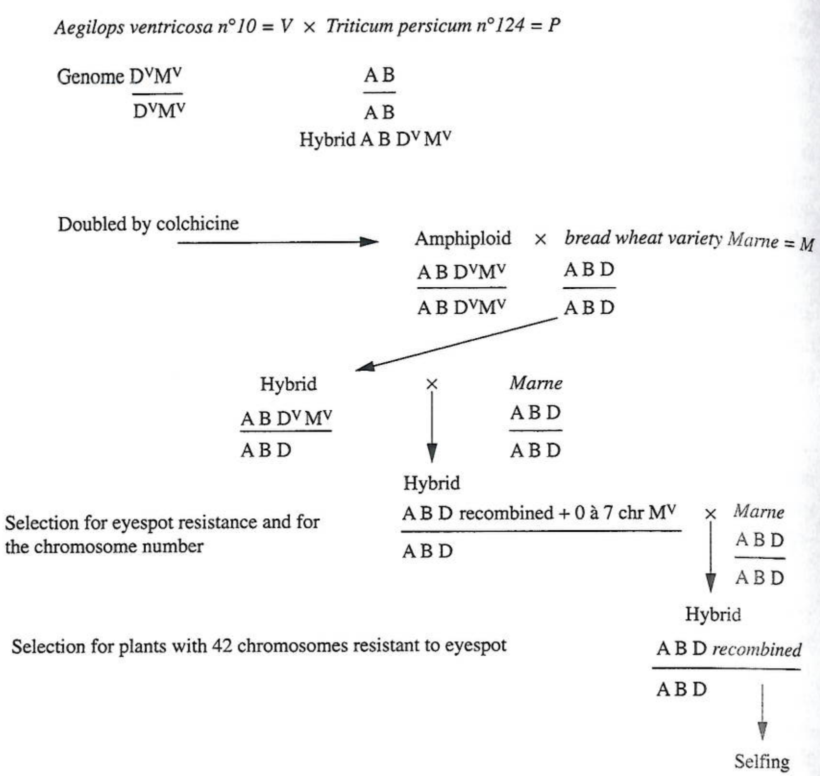

Figure 12 ■ Pedigree of genitor VPM.

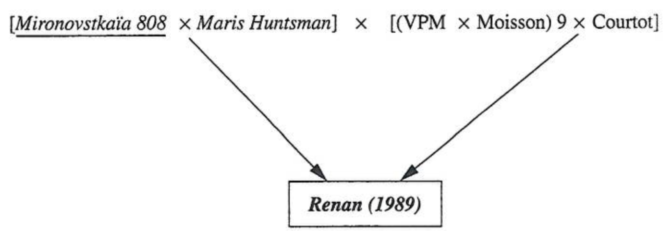

Figure 13 ■ Pedigree of the variety Renan (1989).
Exotic genetic sources.

number of French breeders of wheat is quite large, even if the first 10 multiply 90% of the area (table 7). This situation guarantees a certain varietal diversity to the farmer and the consumer.

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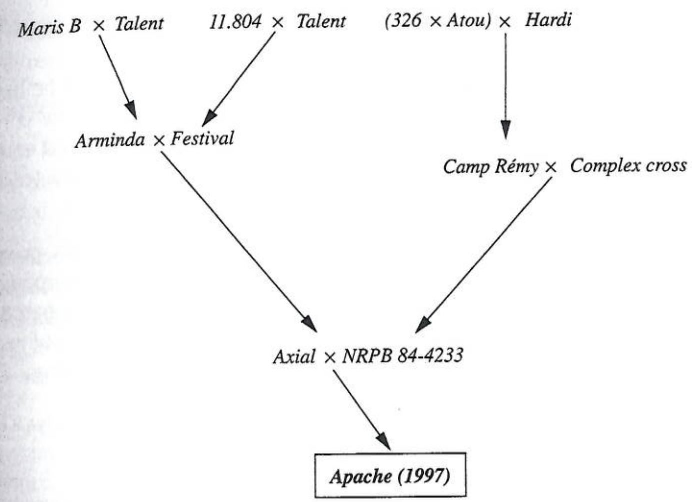

Figure 14 ■ Pedigree of the variety Apache (1997).

Table 7 ■ Ten main breeders of wheat in France in 1998/99.

Breeding companies	Principal varieties
Benoist	Oracle, Sideral, Récital
Deprez	Isengrain, Soissons
Hybritech	Cockpit, Domino, Mercury
Hybrinova	Hyno-Precia
Nickerson-Limagrain	Aztec, Apache, Claire
P.B.I. Monsanto	Charger, Shango, Vivant
Procosem	Ritmo, Versailles
Serasem-Sigma	Altria, Tremie
Unisigma	Baltimor, Sponsor, Record, Rapor
Verneuil	Cézanne, Texel

The art of French wheat research in the year 2000

The wheat research carried out in France is principally done by the private sector and Inra (Institut National de la Recherche Agronomique), which takes advantage of collaboration with various other organisations such as ITCF (Institut Technique des Céréales et des Fourrages), universities, CNRS (Centre National de la Recherche Scientifique) and Unigrains. All the varieties coming from French research are listed on an official catalogue according to the procedures described below.

Catalogue inscription

In order to be commercialised in France, all new wheat varieties must be listed on a catalogue of one of the European countries and have satisfied the corresponding technical tests. Nevertheless, up until now only varieties listed on the French catalogue have had large market shares (Doussinault and Bastergue, 1992).

The variety candidates may be originate from breeding establishments, private or public. They follow a two year study cycle, run by the GEVES (Groupement d'Etudes des Variétés et des Semences) and must show their value compared to existing varieties to satisfy the users in the chain – farming multipliers of seed, farming producers, co-operatives, industrial users and seed distributors. The examination consists of two types of test:

– a test of appreciation of the distinction, homogeneity and stability (D.U.S.)
– a test for the agronomic and technological value (V.A.T.)

The D.U.S test is carried out over two years in two nurseries, one situated in the Parisian basin and the other on the west coast of France. The pedoclimatic characteristics of the two nurseries allow the morphological and physiological differences of the genotypes to be expressed. The verification of the D.H.S. takes into account about 40 precise observations of morpho-physiological characters in conformity with UPOV (Union pour la Protection des Obtentions Végétales) guidelines and by a few biochemical tests. At present molecular markers are not taken into account. Multiple comparisons are carried out on the data collected annually with that of existing French and foreign varieties, which make up the reference collection. These studies result in an official description of the variety, a real identity card indispensible to certify the seed and protect the breeder.

With regard to V.A.T., the candidate variety must prove that it offers genetic progress compared to the most cultivated varieties which are used as the controls. This genetic progress is measured from a national trial network consisting of some 20 sites each year. The geographical distribution of the trials is organised in such a manner that it represents the main areas of production. The technical protocols are defined by the cereal department of the CTPS (Comité Technique Permanent de la Section) created in 1942, which has a directional role in the breeding. The protocol used consists of two repetitions fungicide treated and two untreated. It also allows an assessement varieties for resistance that to disease. The trial operators are divided into three groups:

– public research, Inra-Geves (20%);
– agricultureal development via the ITCF (20%);
– breeding companies – breeders (60%).

These agronomic trials are followed by the regional agents of the Geves to confirm their agronomical value as well as their statistical value.

The technological value is evaluated according to the varieties' end use market (French bread-making, industrial uses, etc.) in comparison to known and stable

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varieties. The higher the technological quality of the variety the lower the yield level required for inscription.

Complementary explanations:

For listing on the catalogue, the classification of wheat varieties according to their technological aptitudes is done by comparison to known controls which serve at the same time as references for the agronomic value (figure 15).

For example, to characterise a variety destined for French bread-making in the north zone, comparisons are made for the season of 1999/2000 with the varieties Soissons, Isengrain, Charger, which are recommended by French millers. These are also amongst the four controls for agronomic value, these being based on the four varieties most cultivated in that zone.

Dough rheology characteristics are measured by the Chopin alveograph at a constant hydration, and a French baking test is carried out from a grain sample mixture, made up from regional samples.

The experts in this branch compare the results of each variety to those of the controls and propose a class Ble Panification Superior (BPS) if the variety studied is comparable to the controls reputed as being satisfactory, Ble Panification Courant (BPC) if the results of the candidate variety are inferior by a maximum of 10% compared to the BPS. The candidate varieties with biscuit potential are compared to the variety Crousty by indirect tests: grain hardness, dough rheology, extrusion test and, eventually, a biscuit test. The experts propose a class in accordance with the results. This system of classification is open and other classes or specialities can be added in the future if they correspond to the markets (starchy wheat, wheat for poultry feeding, etc.). This technology class resulting at the inscription is not definitive, it is designated after one harvest. Analyses carried out afterwards by industry and by the ITCF can modify the initial class given. However, a good co-ordination is in existence between the official organism, which is the CTPS, and the industrial users.

The factors for yield stability are evaluted by studying the behaviour of the candidate variety compared to the climatic risks (cold, lodging, etc.) and to pests and diseases. Bonuses and penalties are attributed in comparison with the control varieties.

All the results and observations obtained during the different trials are presented to the commission of experts, who make the propositions to the cereal section of the CTPS who make the decision. The commission is made up with all parties having equal influence – this is what makes the French system original – with different professional branchs of the seed business producers, industrial users and representatives from public and ministry establishments. A research of a consensus is always obtained as well as in the commissions as for the cereal section (the ultimate concertation group who recommend the inscription propositions to the Ministry of Agriculture and Fisheries). This is the only way to officialise the inscriptions to the French catalogue, via the official journal.

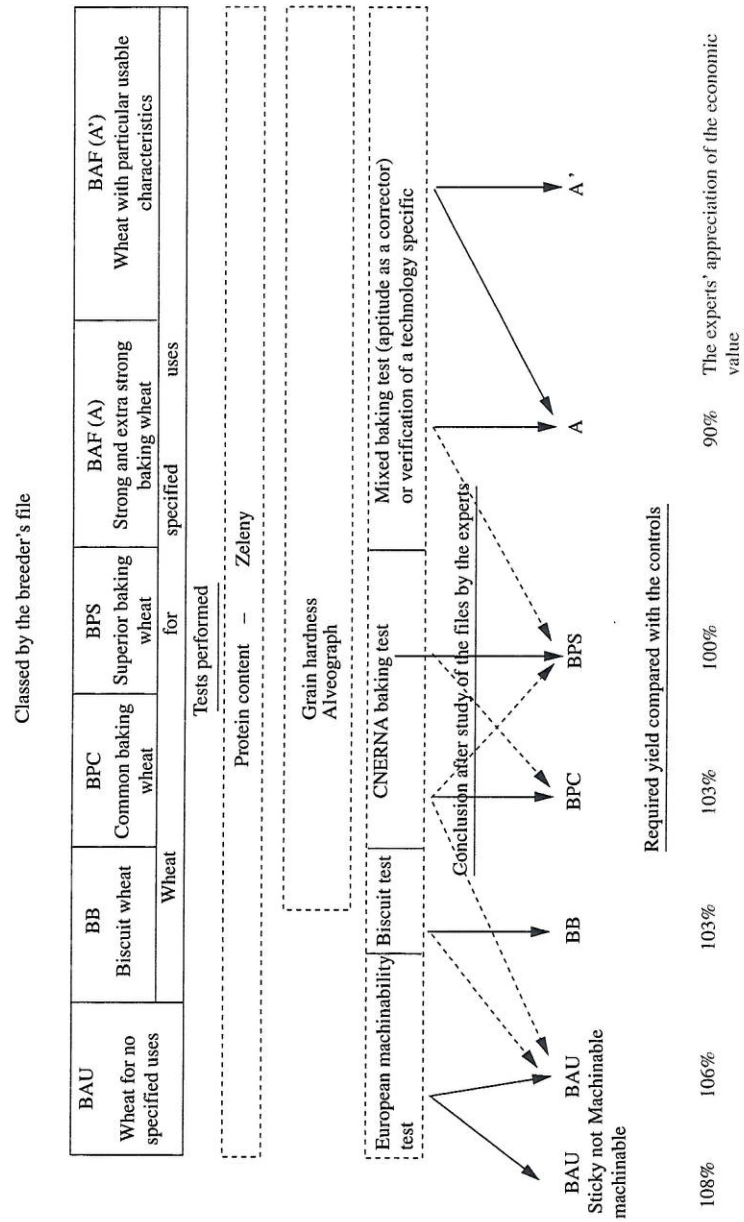

Figure 15 ■ Classes and inscription criteria of French wheat in the CTPS 1999 according to their utilisation.

Out of about 100 varieties proposed annually (table 8) only around 20 are listed: for example, 21 winter wheats were listed on the national catalogue in 1998 for and 16 in 1999.

Table 8 ■ Number of varieties of wheat tested by the CTPS during the period 1992-99.

Years	1992	1993	1994	1995	1996	1997	1998	1999
Winter	71	66	65	70	78	91	82	85
Spring	1	0	1	1	0	0	4	2

At the beginning of 1999, the French farmer had available for sowing, by means of the national catalogue, 177 varieties of conventional winter wheat, 16 winter hybrid wheat and six spring wheat varieties from the 'A' list[1]; 76 winter wheat varieties from the 'B' list[2] and one spring wheat, for production in France but destined for export.

Principal breeding objectives for conventional lines

Still, today, the hybridisation between 2,3, or 4 parents, followed by natural self pollination is the breeding practice most generally used in variety creation. The "genealogical breeding system" remains the most significant breeding system because, out of 64 lines kept in trial for inscription on the 1999 catalogue, 57 were from genealogical breeding and two from single seed descent. The five remaining lines were fixed by haploidisation, via anther culture (the first variety listed on the French catalogue from a double haploid was Florin in 1985).

Up until the 1980s, productivity was intensive. This is a situation where the farmer tries to limit the environmental constraints by correcting by various inputs (fertilisers, fungicides, irrigation, etc.) and using technical protocols to maximise yield (early sowing, optimal sowing rates, etc.). The improvement of the technical "savoir faire" of the farmer was also a key factor in yield progress. The ITCF also played an important role in this area.

In parallel, the baking value of varieties for French bread-making has greatly improved allowing adaptation to the sophisticated procedures used by the agro-industries (use of frozen dough, faster mixing dough time, etc.).

Progressively other objectives are added. Today breeders are seeking genotypes which are adapted to the present environment, that are tolerant to a reduction in inputs (fertilisers, in particular nitrogen, water, fungicides). The level of productivity and quality must remain acceptable to the income of the producer and the end user. These objectives make breeding even more demanding and

1. 'A' list: varieties able to be cultivated and sold in France.
2. 'B' list: varieties cultivated in France.

require a better understanding of the complex characteristics of genetic traits, such as, for example, the aptitude to optimise nitrogen use or the parameters of the technological value of flour.

In fact, different varietal types will be developed to respond to different situations in which the preservation of the environment and the quality of the products offered to the consumer will be more and more the primary objectives.

Variety breeding for adaptation to the French environment

Factors concerning stability of yield was been one of the main pre-occupations of French breeders for a long time:

– vernalisation and cold resistance: most French wheats are true winter wheats, as it is a basic pre-occupation in variety creation that the genetic solution is the only possibility for a farmers to avoid the extremes of the winter climate;

– earliness: this character has its importance in all the southern areas, or in the north of France where there exists the risk of grain shrivelling at the end of the cycle, or where an early harvest has a positive effect on the harvest quality;

– height and tolerance to lodging: spectacular up until the 1980s, breeding for straw shortening reached an optimum level with respect to lodging risk; in areas of a high productivity potential, the use of chemical straw shorteners reinforce this genetic gain;

– resistance to ear sprouting: the risk of ear sprouting is relatively weak in France compared to that existing in the United Kingdom and in Ireland. However, taking into account its potential impact in technological terms, breeders screen this character by various other ways (artificial tests, markers, etc.).

Breeding for resistance to pests

A large number of crop pests are found in France.

Amongst these are:

– *Gaeumannomyces graminis*, agent for take-all. This parasite is present in nearly all soils in France and attacks the roots. It causes damage in rotations where cereals are grown frequently, and notably where the practice is wheat sown after wheat. No present variety gives a significant level of resistance, however high tillering varieties with a strong rooting system are less affected.

– *Pseudocercosporella herpotrichoides,* othermise known as eyespot. This fungus attacks stems and destroys the canal ducts promoting the appearance of white heads before maturity as well as lodging. The most important damage is found in wheat grown on heavy ground and after mild and wet winters. A good lend of resistance to eye spot was introduced from *Aegilops ventricosa* (Doussinault *et al.*, 1983) when creating the line V.P.M.

The gene introduced, called *Pch 1*, protects the wheat principally up until stem elongation. Another source of partial resistance, at a lesser level and which is expressed at the adult stage, was made evident from French wheats such as Cappelle Desprez. Today, only a small number of French varieties contain *Pch 1*, associated with the resistance derived from Cappelle.

– *Erysiphe graminis fsp tritici*, the fungus responsible for mildew. This is a parasite which is made up of a number of physiological races. Mildew can be seen every year, but the importance of the attack can vary considerably from one year to the next. It is favoured by dry springs. The specific resistance genes found most frequently in the French varieties are *Pm2, Pm 4b, Pm5, Pm6, Pm8, Tal et ar* and finally several varieties possessing *Pm3a*. The resistances have been overcome by the French mildew populations, except that carrying *Pm3a* (Pope de Vallavieille *et al.*, 1999). However, the average level of resistance of French wheat at the adult stage is quite high: that is to say as well as the specific resistance genes, which continue to diversify, there exist unidentified genes which are expressed at the adult stage and which present a good level of adult resistance.

– *Puccinia striiformis, P. recondita, P. graminis*, rust agents. Yellow rust is the first disease to be found at the beginning of the season. It only produces a severe attack about one year in five. The French varieties possess specific gene resistance, in particular *Yr 17* coming from *Aegilops ventricosa* (Robert *et al.*, 1999). Since 1998, new races overcoming *Yr 17* can be widely found in France. However, about half the varieties also possess genes which are expressed at the adult stage and thus avoid a severe epidemic. The systematic use of a complete fungicide programme allows the control of these pathogens in France.

Brown rust occurs later than yellow rust, at flowering, and regularly particularly in the south of France. The French varieties are carriers of specific resistance genes, in particular *Lr 37* coming also from *Aegilops ventricosa* and genetically associated with *Yr 17* (Robert *et al.*, 1999). At the moment this resistance is still effective and, as for yellow rust, French varieties carry genes expressed at the adult stage.

Stem black rust (*P. graminis*) appears infrequently in France and only gives a little damage.

– *Septoria tritici* has become the predominant foliar disease in the last few years. The level of resistance of French varieties is for the moment, only average; the identified genes are not always efficient in French conditions, necessitating the use of fungicides.

– *Stagonospora nodorum* is another form of *septoria* which develops more at the end of the vegetative cycle and appears less frequently. For this necrotrophic parasite, the level of variety resistance remains quite weak.

– *Group Fusarium roseum*, and *Microdochium nivale*, agents of several types of *Fusarium* (the first produce toxins, the second does not). Depending on the pathogens and the environmental conditions attacks are made on seed stock remains, roots, leaves and ears.

– *Helminthosporium tritici repentis*, wheat helminthosporium, often confused with the symptoms of *S. nodorum*, is a disease which is increasing in the east and the north of France. It seems favoured by minimal soil preparation techniques and not ploughing.

– SBWMV, WYMV, the soil borne wheat mosaic virus and the wheat yellow mosaic virus, are present in France, especially in the Parisian Basin. They were observed for the first time in 1980 on wheat grown in the east of the Parisian Basin. They are transmitted by the fungus *Polymixa graminis*, which also attacks barley. Amongst the French varieties, around 80% are resistant to WYMV and 30% are tolerant to the two viruses. The variety Tremie is very tolerant to the two mosaics and widely grown in the infected areas.

– BYDV, another virus transmitted in the autumn by aphids, is particularily serious in situations of early drilling and mild autumns. For the moment no variety is resistant and the only treatment possible is insecticide spraying periodically after shoot emergence or by seed dressing.

– *Heterodera avenae* is the most severe nematode of wheat in France. It provokes cysts on the roots and is favoured by intense cereal rotations. The damage is localised and rarely serious. Resistant genotypes exist but are not listed on the official variety catalogue.

To decrease fungicide use, breeders seek resistant combinations which can be used by farmers allowing them to reduce by least one treatment and guarantee the durability of the resistance genes for the life of the variety. This comes back to combining in the same genotype resistances to different parasites, against which, treatments may be applied at the same time. Breeders also aim to develop varieties with a gene or gens which will create a selection pressure on the pathogen populations or the pests resulting in new populations capable of overcoming the resistant genes used.

In terms of the evolution of disease resistance, the varieties grown in France show a net improvement during the course of the last years for resistance to rusts and to mildew, but on the contrary a slower level of improvement for resistance to other principal parasites which are eyespot, *Fusarium* and the *Septoria*. For example, the cluster of genes resistant to the rusts *Yr 17, Lr 37,* and *Sr 38* introduced by INRA into wheat from interspecific crosses using *Aegilops ventricosa* is present in seven varieties out of 21 listed in 1998 (Doussinault, 1999). However, the resistance gene to eyespot, *Pch 1*, coming from the same pool of parents, is present in only two varieties in 1998. If the selection for the rusts is easier than that of eyespot, then the use of a biochemical marker, endopeptidase Epd1b (McMillin *et al.*, 1986) for the gene *Pch 1*, should allow in the near future an efficient screen for this character.

Moreover, the general criteria of disease resistance is estimated by the difference of yield between the plots fungicide treated and untreated in a trial network for inscription on the catalogue. Certain varieties such as Renan and Rumba present a net superiority in this domaine, allowing for a decrease of variable costs.

Nitrogen use and efficiency

In France the yield objective expected by farmers is very high, 80 to 100 q/ha. To achieve this objective, it is necessary to supply the plant with the nitrogen

necessary: in wheat, the average requirement has been established as 3 units of nitrogen for one quintal of grain (Coic, 1985), even if there exists differences in varietal groups (ITCF, 1999). The level of nitrogen is actually high-up to 250 units/ha – taking into account the residue from previous crops – a practice which has been made possible by breeding varieties resistant to lodging and are shorter strawed by making extensive use of dwarfing genes *Rht 1* and *Rht 2*. The general use of straw shorteners has contributed a great deal to the increase in the amount of nitrogen applied, in turn causing the pollution of waterways and the ground water by loss of nitrogen during the autumn. That is why today one of the objectives of the researcher is to detect genotypes that are more efficient in the absorption of nitrogen and less susceptible to nitrogen deficiencies possible in the field (Le Gouis et Pluchard, 1996, Doussinault, 1998).

There exists a variability among genotypes for several factors:

– the absoption efficiency of nitrogen accumulated in the foliar parts compared to the amount of nitrogen available, (consisting of the remains in the soil after winter and the amount of nitrogen contributed by the fertilizer);

– the efficiency of utilisation which corresponds to the grain yield compared with the nitrogen absorbed;

– the harvest index of nitrogen, which is the relation between the nitrogen in the grain compared with the nitrogen contained in the foliar parts.

At a low level of nitrogen, it is the absorption efficiency which contributes the most to grain yield. The correlation is weaker than the efficiency of utilisation, which has the disavantage in that it tends to favour genotypes having grain content relatively poor in proteins. The harvest index of nitrogen increases with yield but also with the level of protein. It reflects a function of the plant orientated to a good migration of glucidic and proteinic reserves in the grain.

In order to characterise the genotypes trials need to be carried out in a multilocal network over several years, including the situation where nitrogen is the only limiting factor in the soil. The nitrogen requirments can be 10-15% inferior at 3 kg/q for certain genotypes (Gate, 1998).

Water use and efficiency

The technical protocols leading to levels of yield of 100 q/ha or more need irrigation especially in the regions with light soil and/or soils with water deficiency, as in the south eastern part of France, Auvergne and the south of the Paris basin. As water resources are limited, breeding needs to be orientated towards better water use efficiency. The resistance to water stress by some genotypes often has a cost in terms of yield, that is to say that the yield which can be reached under favourable conditions is lower than that of classic varieties. For example, the reduction of the stoma conductance allows the plant to reduce its water loss but limits at the same time its assimulation of CO_2 and, therefore, photosynthesis. Breeding, therefore, will look at the tolerance to water stress taking into account the most simple physiological criteria (adjustment of osmotic capacity, carbon isotopic discrimination, plant architecture, factors contributing to the allocation of resources, assimilate transfer, regulation of growth phenomena). It is about identifing the morphological and physiological characteristics which allow the variety to tolerate better the water constraints without affecting the yield which this variety could reach under optimal conditions. The capacity of osmotic adjustment (which allows the tissue to remain rigid thanks to an accumulation of osmolytes) is one of the criteria which satisfies the two objectives quite well (Teulat, 1997).

Breeding for quality

Breeding for quality has not ceased to progress over the last 30 years. The average baking strength of French wheat, measured by the W of the Chopin alveograph, is today near to 210, when it was around 60 in 1910, 75 in 1925, 90 in 1955 and 140 towards 1960 (Branlard, 1999). There has also been, not totaly disconnected with this finding, a simultaneous increase in hardness. The best ameliorant wheats today have baking strengths of more than 350.

Present day common French wheats frequently have protein levels between 10 and 12%, which corresponds to national bread-making and biscuit requirements. However, with the demand from importing countries, the development of frozen dough and other technical advances, there has been an increased commitment by breeders to develop wheats capable of synthetising more proteins, and notably to identify within the genome the genes implicated with better nitrogen efficiency and transfer of amino-acids in the grain. There also exists in France continuing work (Branlard *et al.*, 1994; Metakovsky et Branlard, 1998; Branlard *et al.*, 1999) concerning the diversity of protein quality, taking into account sub-units of high molecular glutenins, the omega-gliadins as well as the sub-units of low molecular glutenins (table 9), for which molecular markers have been found or are still to be researched.

As it has been pointed out, the hardness of the French wheat increased during the 20th century: 30-33 on average in 1925, 40-45 in 1960, 55-60 in 1999.This evolution is not independent of the use of the alveograph (Branlard *et al.*, 1997) as a means of evaluation for the utilisation value of the wheat at inscription. It appears to be connected with the puroindolin genes though for the moment their role is not clear. While awaiting a better understanding of the hardness effect, the selection of wheat lines is determined by the method of spectrometry using near infrared: this should result in a range of hard to soft wheat, offering a large spectrum of use for agro-industry.

Certain French breeders are also presently developing programmes in the starch area, looking to create wheat rich in amylose or amylopectin, coming from work sequencing principal enzymes implicated in the synthesis of these components. Programmes exist also on the polysaccharides not amylased – arabinoxylanes, arabinogalactans, etc., on the proteins involved with the transfer of lipids, the carotenoides and the micronutrients enlarging the diversity of research in the quality area (table 10).

Table 9 ■ Principle glutenin sub-units and gliadins existing in recent French wheat varieties.

Name	Gli-A1	Gli-B1	Gli-D1	Gli-A2	Gli-B2	Gli-D2
Apollo	O	L	B	H	L	G
Arminda	F	F	B	R	R	N
Aubaine	F	F	J	T	C	N
Cappelle	O	F	B	G	G	G
Capitole	O	F	B	P	G	H
Courtot	K	B	B	T	C	A
E. de Choisy	O	M	B	P	AE	A
Hardi	O	F	B	P	O	A
Maris Huntsman	F	G	B	L	L	A
Pernel	C	F	A	G	G	VH
Prinqual	F	C	A	C	C	H
Renan	F	B	G	K	M	E
Sideral	O	F	B	R	B	N
Soissons	K	B	B	T	O	Q
Talent	F	F	B	L	O	H
Tremie	B	B	B	L	L	G
Name	**Glu-A1**	**Glu-B1**	**Glu-D1**	**Glu-A3**	**Glu-B3**	**Glu-D3**
Apollo	0	6 + 8	2 + 12	D	J	C
Arminda	0	7	2 + 12	A	G	C
Aubaine	2*	7 + 8	5 + 10	E/F	G	C
Cappelle	0	7	2 + 12	D	G	C
Capitole	0	7 + 9	2 + 12	D	G	C
Courtot	2*	7 + 8	2 + 12	A	C	C
E. de Choisy	0	7 + 8	2 + 12	D	I	C
Hardi	2*	7	2 + 12	D	G	C
Maris Huntsman	0	6 + 8	2 + 12	A	F	C
Pernel	1	7	5 + 10	A	G	C
Prinqual	2*	17 + 18	2 + 12	E/F	G	A
Renan	2*	7 + 8	5 + 10	A	C	B
Sideral	0	7 + 9	2 + 12	D	G	C
Soissons	2*	7 + 8	5 + 10	A	B	C
Talent	0	7 + 9	4 + 12	A	G	C
Tremie	0	6 + 8	3 + 12	E/F	C	C

Source: G. Branlard, 1999.

Lastly, different programmes are presently in place to analyse the effect of the environment on the characters to select and on the stability of quality. This should allow the identification particular experimental conditions for the evaluation of the genetic variability and identify the components of expression for these characters. Afterwards, their genetic control can be studied, which should simplify their use in breeding systems which, in a relatively short time, can take advantage of molecular marking.

Table 10 ■ Varieties recommended ordeing evaluated by French millers in 1999.

Types of wheat	Recommended varieties	Varieties under observation
Bread making quality – proteins 12-12.5% – W > 200 – P/L < 0.7 – baking score > 225	Aligre Aztec (south zone) Baroudeur Camp Rémy Malacca Paindor Récital Shango Soissons Victo (south zone)	Cézanne Hyno-valea Meunier Orpic Taldor
Strong wheat – Proteins > 14% – W > 350	Florence Aurore Galibier Lona Manital Qualital Tamaro	Exquisit Panifor
Biscuit quality – proteins < 11% – W < 150 – P/L between 0.3 and 0.5 – soft	Albinoni Ami Crousty	Ornicar

Sources: ANMF, Semence et Progress.

Another aspect to underline in the terms of quality is the importance of the export market. Wheat production in France has surpassed 35 million t of which half is exported. Taking into consideration the abundance of the product, the importance of the consistency between the loads of grain offered and the demand is becoming more and more important. The French cereal branch decided to, under the direction of ONIC (Office National Interprofessional of Cereals), to install a classification system based on the geographical and genetic origin of the loads, and also a measure of the indicators, such as specific weight, moiture content and protein content. This follows the examples set by the experienced exporters such as Australia, the US and Canada, which allows, not only, to supply to the buyers loads of confirmed quality but should also consist of an extra element that of varietal choice. Considering the level of a French production, if France is unable to supply wheat at 14-15% protein like some other countries, then it should allow it to offer to its clients the quality of wheat required for bread-making and other special uses (tables 5 and 9)

Hybrid wheat variety development

After a commercial check in the 1980s due to the difficulty of the seed production and insufficient heterosis compared to the continued important genetic progress with conventional lines, hybrid wheat in France occupied for the season 1999/2000 around 130,000 ha a little less than 3% of the total area of wheat. For the moment it is the chemical form of hybridisation which is used, if in the long term a genetic system would be more efficient.

The yield gain from the best hybrids can reach 10% compared to the best parent. However, when the hybrid arrives on the market its parents already date to some 6-8 years earlier and as the genetic progress of the lines are on average 1% per year, this erodes a large part of the heterosis value for the farmer.

Today, 16 hybrids are listed on the French catalogue and 12 hybrids were proposed for listing in autumn 1999. Moreover, seven lines are listed on a list of hybrid parents created for hybrid production. The other parents used are varieties already listed on the French catalogue or the European equivalent. This is to say that the creation of lines specifically bred to make hybrids is only in its infancy and today the heterosis is exploited between lines not created uniquely for this purpose.

However, it is possible to build completely original genetic combinations which, in particular, combine the alleles of resistance genes on the same locus. It is equally possible to quickly combine several types of resistance to the same parasite and the resistance to several parasites. That is why hybrids may offer a better regularity of yield than pure lines.

Hybrid varieties of high quality could be developed for the agro-food industries as well as for traditional markets.

Developement of breeding tools

A large part of this subject has already been developed by colleagues, authors of other chapters of this book. However we present here a succinct point of view of French geneticists and wheat breeders.

Genetic resources

The INRA looks after, by means of a common network with various national breeders and the office of genetic resources (BGR), a collection containing a primary gene pool (around 8,000 genotypes of old French varieties and exotic varieties, recently cultivated varieties and varieties from the breeding programmes), a secondary gene pool comprising of the *Tritici* which can be crossed with wheat (around 1,000 genotypes of diploid and tetraploid wheat, various *Aegilops*) and a third gene pool, comprising of the *Tritici* which when crossed with wheat, give sterile or lethal hybrids. This collection contains the genetic stocks aneuploids, (monosomics, ditelisomics, nullisomics, etc.) useful for genetic analysis of the wheat genome.

Projects establishing core collections and an enthusiastic organisation of genetic resources exist at present in France. The objective is to understand better the variability and hierarchy between the sources of diversity.

In vitro *culture*

France has participated for over 70 years (Picard, de Buyser, 1973) in the production of double haploids, perfectly homogenous, coming from anthers. The first variety resulting from this method, Florin, was listed by the breeder Desprez in 1987. The results are frequently dependent on the genotypes used and various studies carried out in France, often in collaboration with Chinese scientists (Bernard, 1993; Lemaire unpublished) and the use of gynogenesy by interspecific crossing with maize, have allowed in the last years a net improvement in performance of these techniques. Various breeders – Limagrain/Nickerson-Verneuil, Desprez, and also a servicing company, Agrogène, situated in the Paris basin – are at the forefront in this area.

Molecular markers

France has been involved since 1992 in the development of molecular markers for the wheat genome primarity RLFPs, through the partnership of GIS Grenoble, INRA, the University de Paris-Sud and the majority of the French establishments, and wheat breeders. However, the RFLP markers were found to be little used because of their difficulty of utilisation and the low level of polymorphism found. French scientists turned towards the development of markers and microsatellites, which were better adapted and genome specific, as well as developing new forms of markers.

It is by these means that the few reference cards were obtained allowing the cartography of the potential markers, and the French teams are members of the International Triticeae Mapping Initiative (ITMI).

At the application level, various markers related to interesting characters have been identified and are more and more utilised in breeding, even if their discovery is not always published. Amongst the results with in the public domain, a few are used by French breeders, such as markers linked to the resistance to brown rust, introduced from *Aegilops ventricosa* (Bonhomme, 1994), the marker of the gene Ha/ha for hardness (Sourdille, 1996), etc.

Genomic, genetic transformation and bio-computer science

The development of research and understanding of the cereal genomes requires at the same time the acquisition of new tools and the definition of agronomic objectives where technologies rely on genetic resources. The first part corresponds to putting into action the genetic tools, often developed on model species most often rice in the case of wheat, the second on the genetic studies, including the relation genome-environment, which calls for genomic tools. The French research on the genome, which takes into account the applications concerning wheat, are found in the partnership Genoplant, established between the French state, its public research (CIRAD, CRNS, Inra, IRD) and various private companies who are Biogemma (Limagrain, Pau-Euralis, Unigrains, Sofiprotéol, Bioplante (Desprez, Serasem) and Rhone-Poulenc).

The evolution of wheat research will not only be for validating certain genomic results, but also for determining the mechanisms of gene function. It is an operation which remains technically difficult and necessitates significant investments which only a few large companies such as Limagrain or Inra have undertaken in our country.

There does not exist for the moment commercial crops of transgenic wheat in France.

However, bio-computing appears more and more an indispensable complement to validating all the aforementioned research, bearing in mind the large amounts of information needed to be treated and processed which are necessary to farther our understanding of wheat.

Prospective

In trying to sum up, if one considers the long list of research and breeding programmes actually underway in France on wheat, the considerable financial amounts which are not only allocated by the public sector but also by private establishments and also the important marketing outlet perspectives in the average and long term – notably in the proximity of our borders – this allows us to consider that France will continue to have a major role amongst the European cereal producers.

The strong world demand for cereals, the stronger segmentation of markets at the processor level, the worldwide and free exchange of germplasm, the protection of natural resources and the risk from the shortage of water should in France, as elsewhere, guide the breeders of wheat towards the winning strategies of tomorrow. For all these reasons the French wheat industry is supportive of a politicy of intellectual property, which protects the rights of the breeding company, preserves the breeder's exemption which is the guarentee of the continuation of the exchange of genetic resources and favourises the re-investment of their research.

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