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The Saga of Wheat – The successful story of wheat and human interaction

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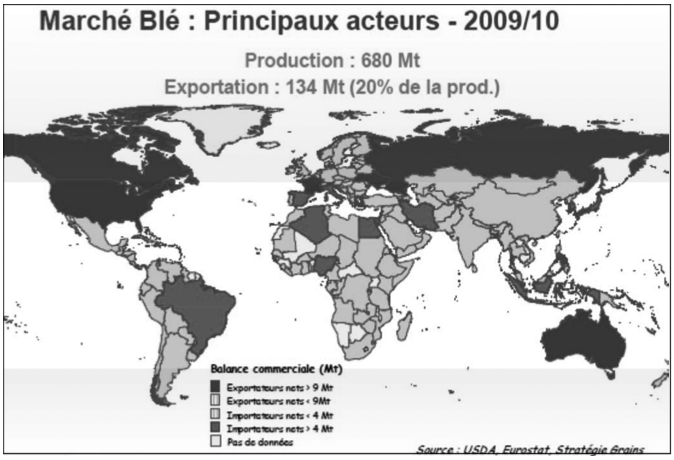
Introduction: The Status of Wheat in the world

"*Wheat is Man's bone marrow*", my grandparents used to tell me during my childhood in the Auvergne. I started to cultivate wheat with A., R. and M. Mordefroid and this chapter is dedicated to them.

Bread wheat (*Triticum aestivum* L.) is now the most important source of food in the world, particularly in temperate climate areas. It is grown on about 38% of the current arable land area from sea level up to 4,500 m in Tibet. It accounts for 17% of all crops in temperate, Mediterranean type and subtropical parts of the world, distributed evenly between 67°N in Russia and Scandinavia and 45°S in Argentina. It is a staple food for 40% of the world population, particularly in Europe, North America, in western, central and north-east Asia, Australia and New Zealand (figure 1).

Wheat has an intrinsic nutritional value, higher than those of most other cereals due to its high content of carbohydrates (about 75-80% of the grain) but also of protein (9-16%) and vitamin B, calcium, iron and other micronutrients. Furthermore, its value is also explained by the low water content of the grain, facilitating its transport, and the unique elasticity of its gluten, that enables the transformation of its flour into a wide range of products that contribute to our diet – flour, bread, biscuits, cereal bars, soup, pasta etc. giving wheat a clear competitive advantage over other cereals, including rice and maize. Wheat germ provides B vitamins playing an essential role in the defense and maintenance of the nervous system. It also provides large quantities of vitamins A, C, E, zinc, magnesium, selenium and amino acids. Wheat bran is a dietary source of fiber, potassium, phosphorus, magnesium, calcium and small quantities of niacin (table 1).



World Population :
6,790 billion

Surface of bread wheat 2010:
222 million ha

World production of bread wheat 2010:
680 million tons

World average yield 2010:
3.0 tons/ha
of which
- 5.3 tons/ha Europe 27
- 1.6 tons/ha CIS
- 3 .2 tons/ha Asia
- 1.4 tons/ha Australia
- 2.2 tons/ha Africa
- 3.1 tons/ha North America
- 3.1 tons/ha Latin Amercia

Figure 1 ■ Principal producers and exporters in the World.

Table 1 ■ Chemical Composition of wheat products per 100 g.

Wheat product	Protein (g)	Fat (g)	Carbohydrates (g)	Starch (g)	Total sugar (g)	Vitamin E (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Folate (microg)
Germ	26.7	9.2	44.7	28.7	16.0	22.0	2.01	0.72	45	?
Middlings	14.1	5.5	26.8	2.0	3.8	2.6	0.89	0.36	29.6	260
Flour	12.6	2.0	68.5	66.8	1.7	0.6	0.30	0.07	1.7	51
Wholemeal flour	12.7	2.2	63.9	61.8	2.1	1.4	?	0.09	?	57
White flour	11.5	1.4	75.3	73.9	1.4	0.3	0.10	0.03	0.7	31

(Source: FSA)

Around 60% of wheat production is now used for food (bread, biscuits, confectionery, noodles, beer) and its consumption is increasing, driven by population growth, higher incomes, renewed interest in vegetarian diets and the increasing demand from the livestock industry. Eighteen percent of wheat production is used for feed for land farming but also fishery – the USA, the EU, Australia and China are the most significant countries for the feed market.

Monogastric livestock (poultry, pigs) also consume large quantities of wheat as grain or flour. Wheat straw is used for litter on farms forming the basis of manure, used as organic fertilizer, and also serves as a poor quality forage for ruminants such as cattle. Traditionally used for malt and starch, wheat has also been used in more recent years in other industrial applications such as biofuels, biodegradable plastics, glossy paper, cosmetics and for housing insulation.

Many may think that this major cereal has always been used globally. But this is far from the truth. If wheat can be studied as a plant, its development must be narrated as a story: The story of mankind.

To study wheat from its origins in the heart of the "Fertile Crescent", and its subsequent dissemination in waves to every continent on the planet (except Antarctica) is to evoke the epic of the settlement of these different territories by mankind with whom wheat has continued to co-evolve since the Neolithic period. This chapter aims to trace the key fundamental stages of its expansion from ancient times to today.

Today, with 222 million hectares and 680 million tonnes of production in 2009-2010, an average yield of about 3 tonnes per hectare, wheat remains the most widely cultivated crop in the world. About 22% of world production is exported and 70% of exports in 2010 came from five producers (United States: 35.4 MT; EU-27: MT 21.5; Canada: 17.5 MT; Australia: 13.5 MT; Argentina: 8.5 MT) and this is responsible at times for a high variability in market prices.

In contrast with its major competitor, maize, the overwhelming majority of wheat sold by seed companies is self-pollinating, though there are some hybrid programs offering limited commercial hybrid products in Europe, China, India and South Africa. BASF has commercialized "Clearfield " wheat (Imidazolinone (IMI)-resistant mutants) since 2007 in Canada and the United States and since 2011 in Australia via AGT.

The worldwide investment in wheat breeding, 380 million USD according to CIMMYT, remains much lower than that devoted to maize which is estimated at more than 650 million USD. It is largely public funded, even if more resources have been brought in recently by the private sector, particularly in biotechnology. Current estimates predict that the first genetically modified wheat could be commercially available by 2018-2020 in America or Australia, potentially even earlier in China. By then, the enormous and complex genome of wheat – 15,961 mega-bases – will be sequenced, opening new perspectives for its improvement.

How did it come to this? What place will wheat occupy in tomorrow's world agriculture? We will unfold the milestones of wheat's history to illustrate its expansion before considering the prospects for its future development.

From the Emergence in Neolithic Times to 1400AD: domestication and the first "waves of diffusion" into Eurasia, North and North-East Africa

Since the dawn of mankind, humans obtained food from their immediate environment by gathering, hunting and fishing. It is during a period of cold and dry climate that agriculture appeared in several regions of the world around

10,000 BC. It particularly emerged in the Middle East, the center of origin of the wheat family – of which bread wheat is the most recent descendent. Between 10,000 and 2000 BC, the Neolithic revolution took place, the first city-states appeared in the Fertile Crescent, including Babylon, followed by the great ancient civilizations. All, from the shores of the Mediterranean to those of the Indian Ocean and the Sea of China, contributed to the dissemination of wheat. Between 2000 to 500 BC, an axis of East-West trade developed in Eurasia, and a second one from the Near East towards Europe, and towards North and North-East Africa. They both reinforced wheat's diffusion and production. Then from 500 AD to 1200 AD, the advent of Islam increased the rate of innovation in the heart of the ancient world, supporting cultivation and grain processing technologies. From 1200 AD to 1400 AD these exchanges increased even more within the vast Mongol Empire (figure 2 and table 2).

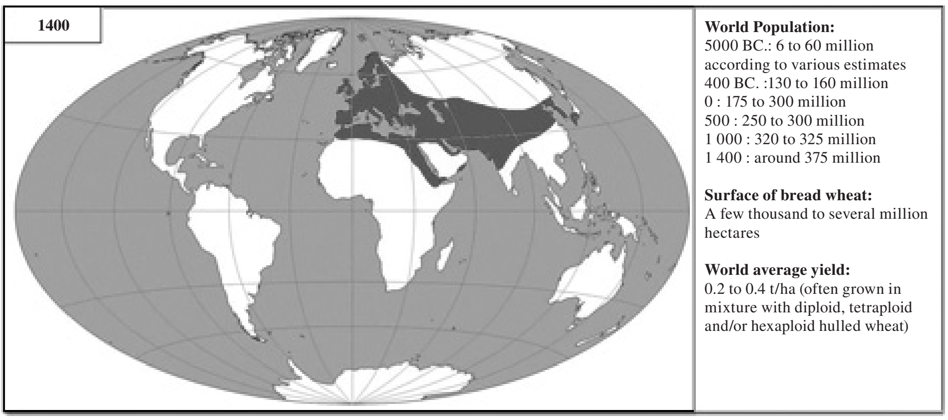


Figure 2 ■ Summary of world wheat in 1400AD.

The domestication of wheat: a complex history linked to the polyploidization: from the harvest of wild grasses to cultivation of the first diploid then tetraploid wheats

About 20,000 years ago, *Homo sapiens*, hunter-gatherer for the past 100,000 years, noticed the nutritional value, ease of storage and preservation of seeds of wild grasses that were abundant and began to collect them systematically in the region of the Syrian-Iraqi desert watered by the River Jordan, the Euphrates and the Tigris, lying between the foothills of the Anatolia mountains in the West to those of Zagros in the East, and may even include areas of Israel according to some authors.

Recently, Israeli scientists (Lev-Yadun *et al.*, 2000) suggested, based on various botanical, genetic and archaeological elements, that the crucible of our

Table 2 ■ Key dates of the period.

Humanity	
Dates	**Steps**
10,000 to 5000 BC	Neolithic revolution
5000 to 1000 BC	First states
2750 BC	Sea voyages of the Egyptian Henemu (Red Sea country of Punt)
2000 to 500 BC	Consolidation of an east-west trade axis in the Old World
600 BC	A Phoenician may have circumnavigated Africa
509 to 476 BC	Roman Republic and Roman Empire
480 BC	Exploration of the coasts of West Africa and the Gulf of Guinea by the Carthagian Hamon
340 BC	Discovery of Northern Europe by the Greek Pytheas
221 to 206 BC	Qin Dynasty (start of historical records in China)
500 to 1200 AD	Spread of Islam around the Mediterranean, Europe and India
1095 to 1291	Period of the Crusades
1180	Introduction of paper in Europe
1200 to 1400	First case of globalization by land in Eurasia by the Mongols
1245 to 1248	Travel of John of Plan Carpin from Lyon to Karakorum and back
1253-1255	William of Rubrouck travels to Karakorum and Travels of Marco Polo to China and back
1273-1283	John of Mandeville's Travels in Asia
1322-1356	
1325-1353	Travels of Ibn Battuta in Asia and Africa

Bread wheat	
Dates	**Steps**
7500 to 5500 BC	Crops of wheat and manual grinding wheels
5500 BC	First use eof the drawn plough in Mesopotamia Sourdough and leavened breads in Egypt
3000 BC	Invention of the rotary mill in the Middle East
1000 BC	First bronze and iron ploughs replacing those made of stone, row planting and field weeding in China (Zhoy Dynasty Eastern)
800 BC	Water mills in Asia Minor
500 BC	Conical grinding stones in Greece
4th and 3rd centuries BC	Invention of the breast-strap harness in China, then the collar harness (Warring States, 475-221 BC)
300 BC	Use of cythe in northern Europe
221 to 206 BC	Use of multiple row drills and of rotary winnowing machine in China (Qin Dynasty)
200BC	Separation of the Romans using slaves and animals
186 BC	Writing of the *Collegium pistorum*, a guide for Roman bakers
568 AD	Introduction of the harness in Hungary by the Avars
7th century	Spread of the use of harrows and flails in Frankish Gaul
1180	Introduction of windmills from Syria to England and France

cereal would be located in a more limited area of the Fertile Crescent, approximately located upstream of the Tigris and Euphrates, in the present territories of Syria and Turkey (figure 3). Indeed, the ancestors of seven crops pivotal to the emergence of the Neolithic – einkorn, emmer, barley, lentils, peas, vetch and chickpeas – as well as flax are only present simultaneously inside this perimeter, even if the distribution of wheat's ancestors extends beyond that area both towards the East and the West.

Furthermore, there is presently no archaeological evidence outside this central area, of domesticated forms of cereals and pulses prior to the period 7300-7000 BC, which seems to confirm this first occurrence. However, the concept of the Fertile Crescent is changing. If for decades, archaeologists and scientists believed that the domestication of wheat took place in western and north-central parts of the Fertile Crescent, a recent discovery in Cyprus, sixty kilometers off the coast of the Levant, of farming communities older, contemporary or perhaps earlier than the cereal domestication sites on the continent has expanded the origins of agriculture in the region. Excavations conducted in 2009 and 2010 further East, on the aceramic site of Chogha Golan, at the foot

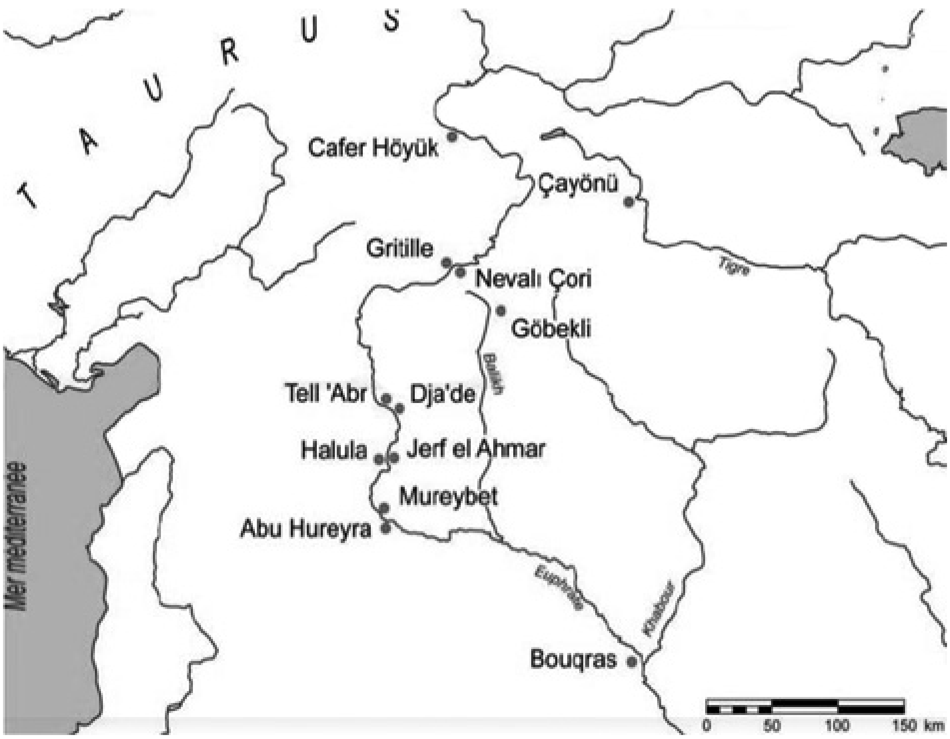


Figure 3 ■ Location map of major archaeological sites of pre-agricultural Fertile Crescent.

(Source: G. Willcox, http://perso.orange.fr/g.willcox/)

of the Zagros Mountains of Iran, revealed deposits, including plants, dating between 9700 and 7800 BC. Analysis of the plants of this pre-pottery Neolithic site revealed the presence of lentils, wild barley, wild emmer and *Aegilops taushii* in its oldest strata and cultivated emmer in its most recent layers. This shows that the origins of agriculture in the Near East include several centers rather than a single basin and the eastern Fertile Crescent played also a role in the phase of domestication. Stone mortars and pestles were also found on this site indicating that people from this period transformed the grain into bulgur or flour, which would then be cooked or roasted.

Various factors remain poorly understood during the period 12,000 BC to 10,000 BC. Several hypotheses have been proposed: climate change at the beginning of the Dryas, demographic pressure, depletion of natural resources, the Symbolic revolution, religious influence, etc. Some populations of the Natufian civilization and other neighboring cultures started to gradually extend the area of wild grasslands by sowing, to bring them closer to their preferred habitats and then to sow these seeds intentionally on cultivated land and ending up settling down in these environments. They already had stone blades for harvesting, mortars, grinding stones, and some storage structures (pottery, wells). At the same time they also domesticated animals (cattle, sheep, goats...).

Archaeological research (table 3) has shown that this development of human practices has profoundly changed certain characteristics of these wild grasses:

– while wild forms have spikes that break easily, facilitating the dispersion of spikelets and seeds onto the ground and early farmers selected, over generations, the mutant plants whose rachis does not disarticulate at maturity, thereby facilitating harvest;

– wild species have relatively long and narrow grains. The domestication of wheat has transformed the grain morphology to become shorter and rounder. The wild seeds are surrounded by envelopes (hulls and husks) protecting them from attacks from the natural environment. The first farmers, used mortar and pestle to dehusk by beating. Observing the behaviour of their harvest they gradually eliminated plants with tough glumes and retained the character “ease of threshing”. This made it then possible for the grain to be cleaned by winnowing to make it more palatable;

– seeds of wild species generally germinate only after certain environmental changes, such as change in day length or temperature, characters that were then reduced in the cultivated types;

– over many crop cycles, the first farmers were also looking for plants that grew erect and high above the weeds. Likewise “selection” took place for plants with high tillering, flowering which was relatively insensitive to day length so that they could be harvested synchronously, which is not the case for wild relatives;

– it is also possible that selection for size, seed color and resistance to shattering had been initiated at this stage, although it is not certain.

Table 3 ■ The beginnings of cereal cultivation and domestication in the Middle East.

Period	Cereal use	BC Calibration
Upper Paleolithic Kebarian	First known collection of wild barley and wheat	21,000 BC
Natufien	First known wells for permanent storage of grain	12,000-10,000 BC
Khiamian and NAPP (Neolithic pre-pottery A)	First evidences of einkorn and emmer cultivation	10,000-8700 BC
Early PPNB	First evidences for the domestication of cereals	8700-8200 BC
(Neolithic pre-pottery B)	(einkorn and emmer with segmenting ears)	
Middle PPNB	Significant increase of the cultivated areas	8200-7500 BC
Late PPNB	Appearance of einkorn and emmer with solid rachis, of tetraploid and hexaploid naked wheat	7500-5500 BC

(Source: Willcox, 2012 and Feldman, 2013)

Archaeological studies confirm that this phenomenon of domestication had not appeared before 8300 BC and shows that the gathering of wild species persisted significantly alongside the first domesticated forms for at least a millennium. Therefore a form of pre-agriculture, which was itself gradual, preceded domestication.

Between 7500 and 5500 BC, the cultivated forms of einkorn (*Triticum monococcum* ssp. *monococcum*, 2n = 2x = 14, AbAb genome), diploid species with a single grain per spikelet, and emmer (*T. turgidum* spp. *dicoccum*, 2n = 4x = 28, AuAuBB genome), tetraploid species, were the first wheat species to be gradually domesticated.

Wild emmer, *T. monococcum* ssp. *boeoticum*, includes types with a single seed per spikelet (sometimes called *T. aegilopoides*), types with two seeds per spikelets (*T. thaoudar*), and a very special type (*T.urartu*) which does not intercross with others types. The AA genome of *T. monococcum* and *T.urartu* diverged less than a million years ago.

The domesticated einkorn, a species that was replaced in the last 5000 years by tetraploid and hexaploid wheat, was derived from a form of wild einkorn with a single seed per spikelet and emerged in the Karacadag Mountains in southeastern Turkey. The cultivation of einkorn appeared in Greece, Cyprus and the Balkans around 6000 BC and was an important crop in Central Europe around 5000 BC, but its cultivation began to decline during the Bronze Age. It was largely abandoned, and is hardly grown nowadays except in mountain areas of Turkey, Iraq, Iran, Caucasus, Crimea, Romania, the territories of the former Yugoslavia, Switzerland, France, Spain and Morocco. In Spain, 120,000 ha are cultivated as fodder for mules and pigs. In France, the “petit épeautre” is grown in Provence. One archaeological domesticated einkorn with two grains per spikelet was cultivated in Syria, Turkey and Europe in the Neolithic period. Its culture disappears in Syria around 5000 BC but persisted in some parts of Europe until the Iron Age, around 1000 BC.

A naked form was identified in 1970 by the botanist M. Zhukovskii and named *T. sinskajae* and seems to be cultivated only in Daghestan. This line demonstrated that this trait is inherited from a recessive allele (soft glumes, sog, with Sog being the allele for hard glumes). The poor agronomic value of naked emmer is linked to small ears, partially sterile, brittle spikelets and soft grains, explaining why it was not widely grown.

Then, naked types of cultivated emmer, easier to thresh, appeared during the period from 7000 to 5500 BC. *Triticum parvicoccum* could be an ancestral species, now extinct, of naked tetraploid wheat, with short spikes and small grains. Traces of it were found during excavations in the Fertile Crescent and the Mediterranean Basin. Durum wheat, *Triticum turgidum* ssp. *Durum* is one of its derivatives that is still cultivated today, mainly for the production of pasta and semolina.

This early stage of diploid and tetraploid wheat cultivation in the Fertile Crescent led to the appearance of the first known forms of irrigation control. According to some archaeological sources, it seems that this inadequately controlled practice later contributed to the progressive salinization of the first cultivated land. One consequence – the search for new land – contributed indirectly to a phase of expansion, or at least to the displacement of the first crops of wheat from their center of origin in the Middle East towards Europe, Central Asia and Africa in parallel with other phenomena, including trade between ancient populations. Thus, gravity fed irrigation agriculture, from underground water, emerged in the Arabian Peninsula around 3000 BC, and probably resulted from a technology transfer from eastern Iran.

Today, cultivated emmer, *Triticum dicoccoides*, which has been grown for seven millenia in the Near East, the Middle East, Central Asia, Africa and Europe, has been largely replaced by naked wheat and is only a marginal culture (1% of the surface of the wheat area of the planet). It is mostly cultivated on a significant scale in some parts of India, Yemen and Ethiopia, where it is used in traditional dishes, and also, to a lesser extent, in Iran, the Caucasus, Eastern Turkey, the Volga Basin, Central Europe, Italy and Spain, where it is declining. It remains for durum wheat and bread wheat breeding a gene pool for various biotic and abiotic stresses tolerance, for its nutritional qualities and specific flavor, but also for the genetic diversity it brings in the creation of so-called synthetic wheats.

The emergence of bread wheat, *Triticum aestivum*, a hexaploid species in the distribution area of another wild grass related to *Aegilops taushii* (figure 4).

Since 1946, the emergence of wheat has been described, and generally accepted by the scientific community, as shown in figure 5. Like weeds, wild

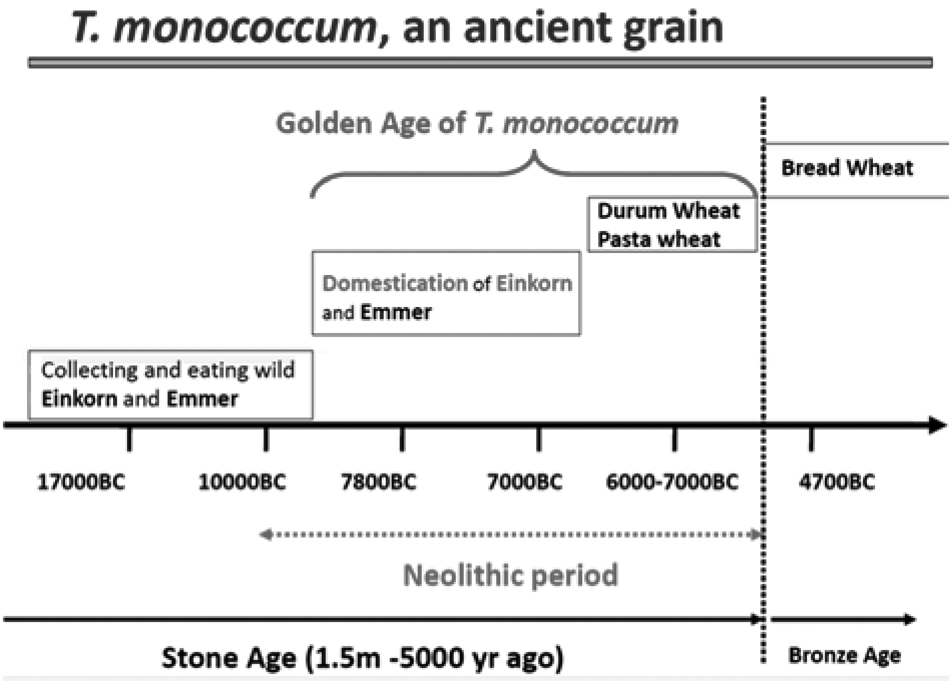


Figure 4 ■ The golden age of the first diploid then tetraploid wheats.
(Source: McMillan, 2013)

cereals colonized cultivated fields. Around 7500 BC, an ancestral spelt (*Triticum spelta*, 2n = 6x = 42, genome AuAuBBDD), an allohexaploid species, appeared through a second natural hybridization (followed by spontaneous chromosome doubling), between the cultivated tetraploid wheat (genome AuAuBB) and another wild grass, *Aegilops taushii* (genome DD). It has 21 pairs of homologous chromosomes composed of seven homoeologous groups (A1, B1, D1, A2, B2, D2, ... A7, B7, D7).

The area south and west of the Caspian Sea is considered the region where hybridization occurred because the subspecies *strangulata* of *Aegilops taushii* still grows there today and seems to be the most likely parent.

Indeed, *Aegilops taushii* spontaneously hybridizes with tetraploid wheat quite easily. The triploid hybrids often produce many non-reduced fertile gametes. However, hybridization of hexaploid wheat with *Aegilops taushii* is difficult and hybrids can only be obtained by embryo rescue. As a result, the introgression of *Aegilops taushii* in hexaploid wheat may be seen only in its distribution areas where tetraploid wheat and hexaploid wheat are grown in mixture.

A different model for the origin of wheat and spelt has recently gained more weight and questions the validity of the widely accepted theory mentioned previously (figure 6).

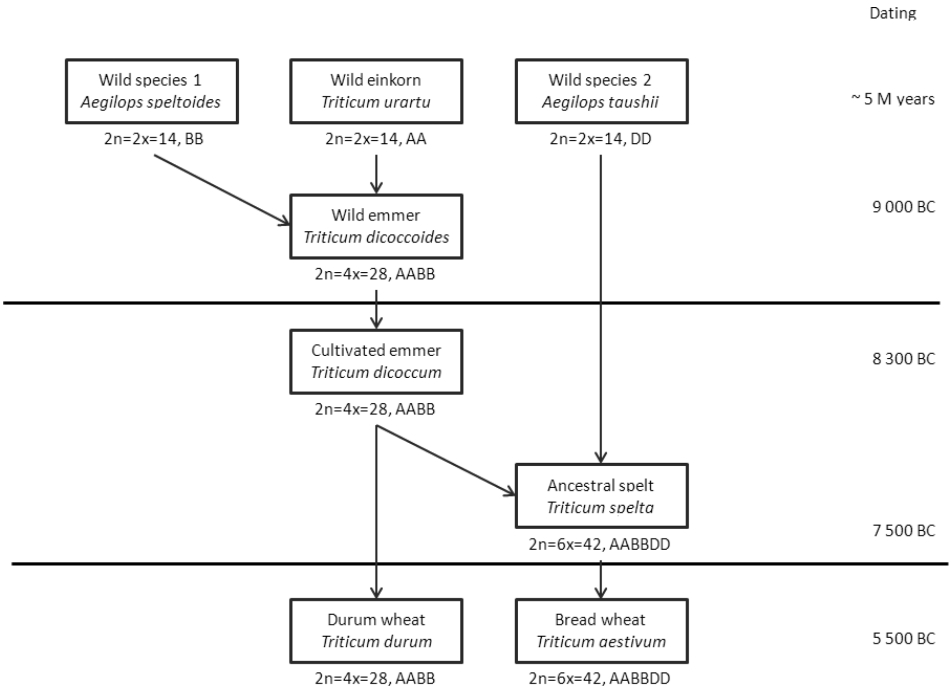


Figure 5 ■ Pattern of domestication of wheat and durum wheat from wild grasses in the Neolithic.

(Source: adapted from: http://www.newhallmill.org.uk/wht-evol.htm/)

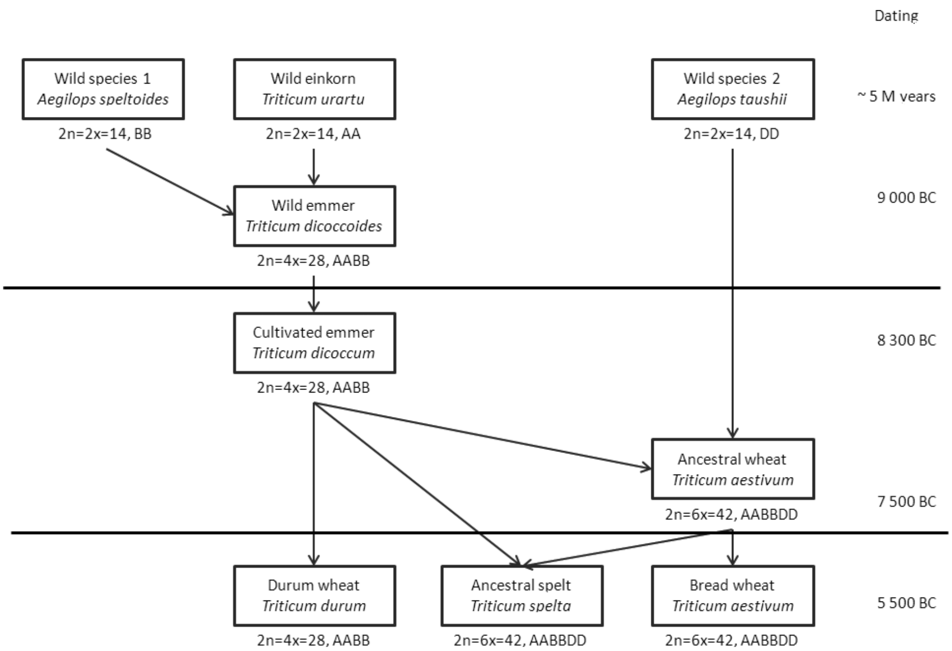


Figure 6 ■ The origin of wheat and spelt.

The use of molecular markers and synthetic hexaploid wheat lines shows that European spelt and the vast majority of Asian spelt lines analysed at a major locus responsible for the hulled/free-threshing character possessed the free threshing version on chromosome D. It follows that the tetraploid ancestor of hexaploid wheat was already free-threshing, and after hybridizing with *Ae. taushii* it would then have required little time for the emergence of fully free-threshing hexaploid wheat by a single mutation of the gene on the D genome.

Spelt also possesses the same mutation on its D genome and would therefore have originated later from the hybridization of free-threshing hexaploid wheat with emmer regaining a hulled form on the A and/or B genome. This theory is also consistent with archaeological data in Western Asia showing that free-threshing hexaploid wheat seems to precede spelt.

A few hundred years later, following various mutations and/or gene flow that remain to be determined in detail, hulless forms appeared: wheat as we know it, *Triticum aestivum*, was born!

It then only needed to be cultivated alongside the older forms of wheat. More work in the fields generated more harvests which sustained more people. But then requirements increased, including food, resulting in more work and its specialization and competition. This was conducive to the emergence of social classes and soon the need for more land which in turn accelerated an expansion and colonization process. Territorial development of wheat, and more broadly the whole family that preceded it, was already underway. Its hexaploid nature, its ability to adapt to various agro-climatic environments and to produce gluten, and therefore leavened bread, would contribute significantly to its success. This remarkable adaptation is today attributed to two major reasons. Firstly, the allopolyploidy nature of wheat has not reduced the genetic diversity of wild emmer and *Aegilops taushii* as much as previously thought (indeed more than 50% of genetic diversity of these two species are found in wheat). Secondly, the exceptional natural genetic diversity of bread wheat comes partly from *de novo* changes related to the allopolyploidy itself in particular, variations in epigenetic heritability and alterations of the expression of parental genes.

Although this Chapter is mainly devoted to "bread" wheat, it should be noted here that all the initial dispersions of hexaploid wheat started from the Middle East as a mixture of the hulled and naked, diploid, tetraploid and hexaploid wheat mentioned. During the late stages of the Neolithic period, bread wheat existed only as a minor component of these mixtures. However, it took considerable differences in the time taken for the distribution of these species to different parts of the world, influenced by subsistence requirements but also for their potential for trade and commerce, for the social prestige conferred by access to exotic things, and their integration into the native agricultural systems (table 4).

Table 4 ■ Characterization of different subspecies of common wheat.

Subspecies	Genotypes*	Phenotypes
spelta vavilovii macha	TgTgqqccSS TgTgQQccSS TgtgqqccSS	Hulled, normal seeds and ears
aestivum	tgtgQQccSS	Naked, normal seeds and ears
compactum	tgtgQQCCSS	Naked, normal seeds and compact ears
sphaerococcum	tgtgQQccss	Naked, round seeds and normal ears

* Four genes are involved: Tg (glumes coriaceous) on chromosome arm 2DL; Q (threshing easy) on 5AL; C (compact ear) on 2DL; S (Spherical) on 3 DS. The Q gene has sometimes been called "domestication gene of choice" because it also affects the adhesion of glumes that the size of straws, shortens and makes the ears and squat performance indirectly.
(Source: Feldman, 2000)

Initial dispersions to Africa and Europe

Initial Migration to Africa

From the Fertile Crescent, wheat spread to Africa through several routes by land and by sea, following the earlier arrival of goats and sheep from the same source, to the Egyptian coast of the Red Sea in the early part of the sixth millennium BC. The oldest terrestrial road reached the Fayoum depression and the Nile Valley between 4500 and 4000 BC and during the following millennium it progressed southward along the valley of the Nile to Sudan and to Libya towards the West. Thus, the remains of emmer and barley dated to 2700 BC were found in Sai and Wadi al-Khawi in Lower Nubia.

Other routes were undoubtedly by sea: some wheat also reached Libya from Greece and Crete; other routes starting in Cyprus, the southern Italian peninsula and Sicily went to the coast of Tunisia, Morocco and Algeria; another from Saudi Arabia, probably in reverse of obsidian trade, reached Ethiopia via Yemen, where chickpeas and flax accompanied the expansion of wheat.

The initial movements seem to have mainly involved barley, emmer – called "bdt" in Pharaonic times – and small amounts of naked tetraploid wheat subsp. *parvicoccum* (now extinct) – then called "swt". The flux of einkorn appears to have been absent or very limited at that time, as only traces from a later period were found in Morocco and durum wheat only became an important culture in Egypt from the Greek period around 1300 BC. Even then, wheat was a minor crop and only became important during the Roman Empire.

Although Neolithic man produced some kind of flat bread from these different wheats using flour and water, the ancient Egyptians, during the third millennium BC, appear to have been the first to produce leavened bread after fermentation of the dough in the presence of wild yeast present in the air or in the additives they employed (sugar, salt, spices, poppy seeds or sesame).

It should be noted that the wheat of the Saharan oases, studied from late nineteenth, are – with the exception of few examples of hard wheat – soft wheats with varied morphology: sometimes *speltoides*, compact, often with abnormalities. They have good ear fertility, are tolerant to high temperature and to water and soil salinity, and susceptible to yellow rust. Their origin, pre- or post-Islamic, is discussed in Chapter 21.

Double diffusion to Europe

The main stream to Europe started around 7000 BC from the Anatolia basin to Greece and then along two routes. The first, around 5200 BC, reached the northern coastal plains of the Mediterranean basin (first in Italy, Spain, south of France then Holland, Belgium and England between 4000 and 3500 BC) and the north of the Black Sea (Romania, Bulgaria, Ukraine, southwest Russia). The second went through the Balkans, through the Danube valley to the Rhine between 5000 and 4000 BC. From there, mixtures of diploid, tetraploid and hexaploid wheat diffused through central and northern Europe (Poland, Germany and Denmark around 4000 BC, Sweden around 3500 BC, southern Norway around 3000 BC, Belarus and southern Finland around 2500 BC, the Baltic countries around 1700 BC), and, in Norway, reached the Arctic Circle in the form of mixtures of emmer and wheat during the pre-Roman Iron Age (500-1 BC), about 500-1000 years after barley. Wheat involved in these dispersion currents to Europe existed as mixtures. Dominated by the emmer we still know today in the Mediterranean route and the same emmer and emmer émerroïde in the Danubian route, this suggests two periods of dispersion. Einkorn was significantly present in these mixtures until the late Neolithic period. The tetraploid and hexaploid naked wheats formed minor constituents in Central and Eastern Europe. The first forms of naked wheat included soft wheat – including compact forms accompanied by some spelt and to a lesser extent by durum wheat – that could have been adventitious. In the western Mediterranean including Spain, France and Switzerland, the first Neolithic naked wheat appears to have been tetraploid. It seems that spelt did not exist in the early Mediterranean waves. The difference of complementary cultures during the same period in these two areas is noteworthy – pea, lentil, bitter vetch and proso-millet from South-eastern Europe to Germany, and chickpea and vetch growing in the Mediterranean zone.

Dispersions to Central and Eastern Asia

Between 7000 and 5000 BC, the cultivation of wheat in the Fertile Crescent extended to Iran and the foothills of Western Afghanistan. Between 5000 and 3500 BC, two movements are evident: one to the south towards the Indian peninsula, the other north towards Central Asia through Afghanistan.

First waves to the Indian subcontinent

Dissemination of wheat to Central Asia consisted mainly of einkorn and emmer, a form of naked tetraploid wheat and a little bread wheat. Barley, chickpea and jujube also travelled along. The diffusion went through Northern Iran and reached Western Pakistan around 4500 BC, Baluchistan in the south at around 4000 BC and then the Indus plain in South-western Pakistan about 3300 BC. Further exchanges took place through the ancient seaways between the Persian Gulf, the coasts of the Arabian Peninsula and the early civilizations of India. The first traces of naked hexaploid wheat – spherical and probably resulting from a mutation – were discovered in Mehrgarh and date back to 3000 BC. For *Triticum aestivum* subsp. *sphaerococcum*, the glumes and lemmas are rounded, and the grain is nearly spherical (4-5 mm diameter). This type of wheat was still grown in Iran, Pakistan and northwestern India before the Green Revolution, and was rediscovered in 2010 and 2011 by a Japanese team in a few areas of Rajasthan and Mahārāshtra.

From the third millennium, maritime trade developed from the shores of Mesopotamia to the northeast coast of the Arabian Peninsula and the Persian Gulf as well as the north-west of India. Bread wheat, usually grown mixed with tetraploid wheat, became a significant cereal of the eastern Arabian Peninsula, the Punjab plains, as well as the plains of the Ganges and Yamuna further east in India. Bypassing the Himalayan chain from the south and from west to east, the axis of diffusion then reached Myanmar, while from the west of India a secondary multi-branched current seems to have appeared through the Himalayas to Kashmir (2800-2300 BC), Nepal (1385-780 BC) and Bhutan (2200 BC).

Dissemination of wheat to central and southern India appears to have been hindered by the forest and hills of the Satpura and Vindhaya chains. It was not until 200 BC that caravans from the south-eastern region of Chirand would carry out its diffusion across the southern areas of the subcontinent.

Diffusion to China, Mongolia, Korea and Japan

During the 5th and the 4th millennia BC, wheat and barley were cultivated in the Middle East while in North China, agriculture was based on the cultivation of proso millet and foxtail millet. These two types of agriculture seem to have met in Central Asia in south-eastern Kazakhstan, near the present city of Begash, during the third millennium.

Indeed, in the north of the area between the Kopet Dag Mountains and the Kara Kum desert, among many sedentary villages, the agro-pastoral village of Sarzam was involved in trade and mining, cultivated naked wheat and barley, hulled and naked, between 3500-2000 BC. Other sites in the foothills of Kopet Dag, like Gonur Depe and Djakurtan, also grew naked wheat with barley, various legumes and grapevine in the middle of the third millennium BC. Around 2200 BC, naked wheat diffused northward through the Dzhungar Mountains of eastern Kazakhstan, where it is found in Begash alongside proso millet brought from China in the East.

The dissemination of wheat to East Asia took several routes:

– "the Steppe Route" of small grain soft wheat leading from the shores of the Caspian Sea to the north of central Asia, southern Siberia, Mongolia to the Shandong peninsulas and reaching Korea remains to be substantiated, but seems quite plausible. Indeed, in China, the most ancient traces of wheat date from the Longshan period (2600-1800 BC) and are mainly white wheat. They are mainly found in the Shandong Peninsula where the site of Liangchenzhan is the best known. This appears as a paradox: how could a crop from the Middle East, in the West, be first significantly cultivated in eastern China, then spread westward along the Yellow River basin? The answer may lie in the flat Eurasian steppes, where semi -nomadic people could easily move from west to east and from north to south, carrying a few "exotic" seeds;

– the "Silk Road" for bread wheat (mainly white grain) originated in Afghanistan leading from Turkestan to Xinjiang and finally to the Yellow River valley. The discovery of the Xishanping site in southeastern Gansu (2700-2350 BC) and the site of Donghuishan (1700 BC) in the Hexi corridor in Gansu, suggest a direct introduction through the Xinjiang. These ancient wheats from eastern and northwestern China present morphological differences: for example, those found in Xiaohoe in Xinjiang are long while those discovered in Henan are round and short, which supports the idea of a double diffusion route.

The dates between these sites seem too close to reflect a morphological transformation of wheat under the influence of different environmental conditions. It remains to note that around 1600 BC, wheat was grown in the central plains of China and was introduced in the Korean Peninsula around 1000 BC.

A final route, concerns mainly soft red wheat, from Afghanistan to Pakistan, which crossed the Punjab plains and then split into two branches. One to the Indian subcontinent, itself branching off in two paths, one South and one to Pamir, Nepal and Tibet reaching Sichuan and Shanxi. The other branch leading through Myanmar, to Yunnan and Sichuan, and reaching the Yangtze River Basin. After an initial agricultural phase (3500-1500 BC) on the Central Tibetan Plateau based on proso millet and foxtail millet and pig farming, a richer system developed in the eastern part of the plateau around 1500-1000 BC including naked barley and wheat, peas, millets and goat and sheep herding. Thus, on the Changuo Gou site, just West of Lhasa and dating back to about 1370 BC, remains of soft wheat, naked barley, naked oats, rye, foxtail millet, peas and Tormentil root were discovered, with fishing and hunting completing the main diet.

It should be noted that wheat is a naked form, like the one found in parts of India during the same period. The recently discovered site of Haimenkou dated to between 1600 and 400 BC in northwest Yunnan revealed new wheat and millet as well as pottery and bronze objects in this region possibly suggesting a later introduction of wheat to this region by north-south migration from Gansu, through Sichuan on the eastern edge of the Tibetan Plateau.

From these main routes – the picture is probably more complex due to co-existing naval exchanges – the East Asian route of wheat disseminating intersected many times in Central China, before reaching East China, the Korean Peninsula and the Japanese archipelago.

Dissemination of wheat in North China through Xinjiang is well documented archaeologically and happened around 2700-2500 BC from the Gansu corridor to the basin of the Yellow River. Along with it there was also the more unusual barley, but apparently a complete absence of durum wheat. Before planting wheat, the Chinese had domesticated and widely cultivated proso millet, *Panicum miliaceum*, and foxtail millet, *Setaria italica*, precisely in the middle valley of the Yellow River (these species are found in Europe around 3000 BC, in northern India in 2500 BC, Yemen in 2200 BC. They are evidence for very old bilateral trading along the Silk Road and beyond). They also invented steaming and millet noodles. It is likely that the Chinese cultural habit of eating soft food stopped the expansion of durum wheat and its semolina eastward. This might also be true for chickpea and lentils, common in India, but absent in Chinese archaeological sites excavated.

Introduced in northeast China where the cultivation of proso millet and foxtail millet was already established, wheat had to adapt to dry conditions and poor cultivation practices. Wheat consumption seems to have taken off around 2000 BC. It became a major crop as early as the Shang Dynasty (16-11th centuries BC) and is known as one of the five sacred plants of ancient Chinese agriculture with millet, rice, barley and soybean.

The Chinese, Korean and Japanese agriculture and civilizations are linked. In Korea the oldest wheat remains (1000 BC) were discovered in the Munum period sites of Oun 1 and Okbang A, along with rice, barley and millet. They have compact spikes and small seeds. Korea seems to have started growing winter and spring wheat originating from China around 500 BC. In Japan, charred wheat grains dating from 200 BC were found on various sites but it is thought that wheat may have been introduced several times from China and/or Korea a few centuries earlier, during the end of the Jomon period, characteristic of the Neolithic Japanese. Compact forms of wheat that resemble Indian and Pakistani wheats are found in Korea, in south-western Japan as well as Tohoku and Hokkaido, which may trace back to ancient maritime introductions.

The studies of various genes, including *IGc1* and *Vrn*, isozyme and Glu-D1F high molecular weight glutenin subunit, suggest that there could have been three major routes of transmission of wheat to the Japanese archipelago: a passage for winter and spring wheat coming directly from Central China, a route through the Korean peninsula and finally, spring wheat probably travelling from Manchuria to the west coast of Japan. The first route has its origin in Afghanistan, leading to wheat farming in Xinjiang in northwest China, then Shaanxi Province, and from there to Zhejiang and would have reached southern Japan by sea. The second channel also originated in Afghanistan, passed through

Xinjiang, reached the plains of north-eastern China and the Korean Peninsula and then southern Japan. The last route characterized by the presence of a unique beta-amylase may come from north and north-east China and would have ended in the south-west of Japan. The presence of wheat in Hokkaido, the northernmost part of the archipelago, has only been dated archaeologically to the tenth century and could be the result of a much later independent Nordic introduction.

It is worth noting that tetraploid wheats were not significantly grown in China nor in wider East Asia. Asian soft wheats are more closely related to original wheat (monophyletic) than western wheats which were, later in the Neolithic period, introgressed with other traits from *Aegilops taushii*.

First intermingling of ancient wheats

From 500 BC to 500 AD, exchanges along the trade routes of the ancient world

The East-West exchange axis existed from 2000 BC between the Mediterranean and Chinese old agricultural worlds. From 200 BC, it was structured into four great empires: the Roman Empire (27 BC- 476 AD) – following the Roman Republic - around the Mediterranean, the Parthians in the Middle East (247 BC-224 AD), the Kushanas (30-375 AD) in northern of India and the Han empire (206 BC-220 AD) in China. They are linked by land with the Silk Road and by sea through the spice route.

All these peoples consumed more wheat and other grains than their ancestors and would exchange them, either commercially or through upheavals of their structures: military invasions, changes of dynasties, religious spreading etc. Thus, Alexander the Great (356-323 BC) made Egypt his granary to support his conquests and prompted a Mediterranean influence all the way to India, followed by a "Indianization" of south East Asia while a pre-Swahili culture appeared on the west coast of Africa. Likewise, the people of Carthage, who dominated the West of the Mediterranean until its destruction by Rome in 146 BC, traditionally consumed barley, emmer and durum wheat but only durum wheat and bread wheat after the Punic Wars, becoming a new cereal export hub for Rome – similar to Sardinia and Sicily.

Rome, with its powerful fleet controlled wheat trade – and more broadly grain – around the Mediterranean and the Middle East, Southern Europe, in Gaul and introduced its cultivation into England – by sea, but also on land with the network of its famous roads. In the best growing areas (North Africa, Campania, Etruria, Gaul, Aquitaine), naked wheats, including bread wheat but also poulard wheat replaced emmer whose use was maintained only in mountainous areas. Permanent open areas, resulting from more or less ancient clearing, or *ager* were worked mainly superficially with the ard, sometimes properly ploughed with a spade or hoe but this work was lengthy, cumbersome and limited to smaller areas. They were used on a two year rotation, a winter cereal crop – usually wheat, sometimes rye, barley, oats or meslin (mixture of the preceding species) – which provided the staple diet, alternating with a fallow year. Yields were poor: on average, 300-500 kg/ha in Gaul, although renowned for the quality of its wheat. For the transformation of grain into flour, most Roman mills used slaves or animals as energy. However, we know from texts by Vitruvius (ca 90-20 BC) that they also knew the vertical water mill. They were rarely used, but were sometimes very large like the one from Barbegal near Arles in France, in the fourth century, which had 16 wheels and was a factory. Others included those in Chemtou in north-western Tunisia and another, near the ancient Caesarea in Israel, which had horizontal wheels. The Romans, whose ancestors were fed with mostly porridge and unleavened bread, switched to bread using leaven that they made with bitter vetch flour, or millet flour kneaded in grape must, as shown by the excavations of Pompeii. At the same time, the Gauls and the Iberians were already using yeast which gave their bread more lightness. All, including the peoples of the Middle East and India, baked their bread in ovens. In the first century, Christianity, whose patristic texts often used wheat and bread as symbols, spread throughout the Greco-Roman world, while Indian merchants brought Buddhism to China and others extended it to South-east Asia by sea, also visiting Chinese ports.

Likewise, in the East, bread wheat was increasingly appreciated. In Si Wen's eulologies of the eastern Zhous (770-256 BC), wheat was called *lai mou*, the "luck seed" and considered a "gift from God". The cultivation of wheat rose significantly during the Chinese Han dynasty (206-220 BC) after various innovations: introduction of new spring wheat resources from Central Asia, common use of iron ploughshares pulled by cattle with collared harnesses, the invention of the three-row drill, seed treatments and the first use of nitrogen fertilizers (figure 7). In addition there was the widespread use of other iron tools for crop and harvest maintenance, the invention of the bucket pump and improvements of the irrigation networks and crop rotation. They also used the horizontal water mill – a technology imported from the West through Xinjiang – to produce flour, steamed bread and noodles from the 2nd century BC.

Towards the end of this dynasty, the surfaces of wheat were roughly equivalent to those of millet in North China and as early as the first century, wheat was also grown in the south of the Yangtze side by side with rice. But wheat fields, a luxury culture, were on average less productive. Bread was steamed and eaten "as is" or stuffed with vegetables or meat. The first wheat noodles, discovered by archaeology, date from that period.

Presumably, the spread of Buddhism to China in the first century, followed by trips to India by monks such as Faxian (337-ca 422), Xuanzhang (ca 600-664) or Yijong (635-713) indirectly strengthened the exchange of ideas and technology between India, China and Tibet.

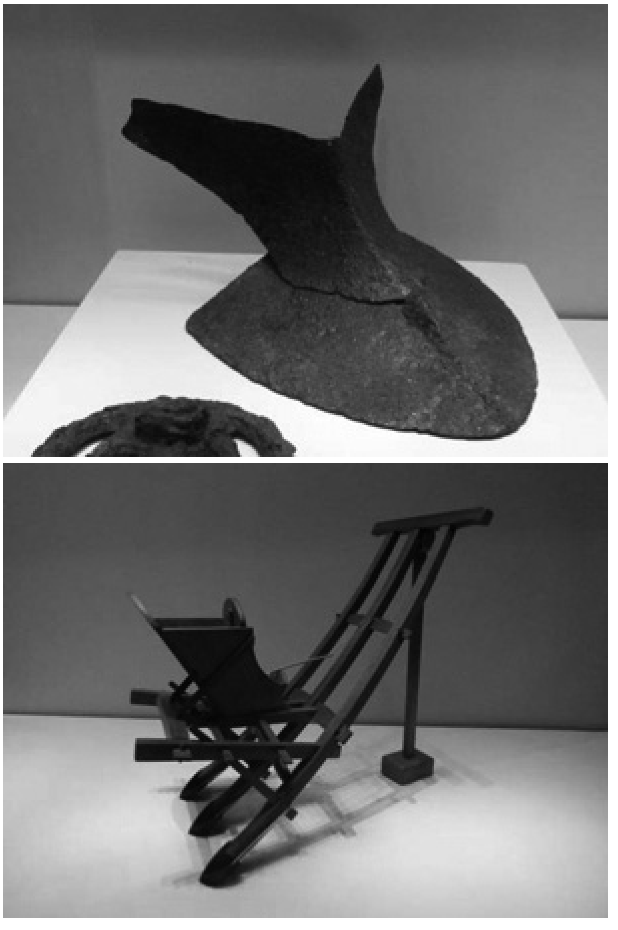


Figure 7 ■ Iron moldboard plough, important invention of the Western Han Dynasty (202 BC-8 AD) which is used to turn the soil over and reconstruction of a three-row drill from a wall painting of a Han tomb in Shanxi.

(Source: Museum of Chinese History, photo Alain Bonjean)

From 500 AD to 1200, further expansion of wheat in Western Europe and East Asia, contributions of Islam and feedback of rice to the Mediterranean and Western Europe

In Western Europe, the fall of the Roman Empire under the Merovingian (5th-8th centuries AD) resulted in a decline for cereals, even as the first urban water mills were built around 600 AD, resuming the tradition of the Gallo-Romans mills destroyed or abandoned around 450 AD.

During the following Carolingian period (8th-10th Century AD), some areas were reclaimed – Tuscany, Lazio, Auvergne, Burgundy, Parisian Basin..., freeing more areas for grazing, and therefore for more cattle and leading indirectly to a revival of the grain trade. Indeed, more cattle meant more manure available to fertilize the land and fields could be cultivated in two consecutive years with a long fallow with a regime of grazing and ploughing in the third year. Europe also discovers the shoulder collar with rigid frames in the 10th century enhancing the performance of draft animals. Thus the three-field rotation, already practiced during the late Roman period is reinvented.

In Western Europe, yields rose – at least in some years. Thus, the 1156 AD inventory of the Abbey of Cluny in Burgundy "attests of a major cereal crop with three-field rotation on large areas, a fallow rotation on small areas, and the use of heavy plough drawn by cattle for ploughing". Several yields are noted in this parchment: 2.0-2.5 to 1 in Macon and 2.7-3.3 for in Bresse (this harvest as poor as it usually is 4 to 1). In Artois the domain of Thierry Hireçon shows a productivity of 8.7 to 1 between 1319 and 1327. Not far south of Bethune, other results varied from 8-16 to 1, which was exceeded only in the nineteenth century in the same region. It is interesting to note that at this time barberry plants (Berberis vulgaris) were grown for their red fruit and pharmacological benefits unaware that it is a host for stem rust and spreads the fungus to the fields - the serious Spanish famines of 915 and 919 appear to be related to its presence.

At the same time, the number of water mills increased. In the late 10th century, there were hardly more than a hundred in England. In 1086, the Domesday Register accounts for 5,624 and this, only in the pages that were recovered. It is similar in France. In the Aube, there were 14 mills in the 11th century, 60 in the 12th and nearly 200 in the 13th. Picardie had 40 mills in 1080 and 245 in 1175. In the 12th century, boat mills were anchored under the bridges of Paris and many other cities in France, soon replaced by permanent structures attached to bridges, while tidal mills were built in France and England.

Occasionally reported from 870 in England, the windmill was then generalized in Europe during the 12th century, first on the coast of the northern countries then in the coastal areas of the Atlantic, the Baltic Sea, and the Mediterranean.

From 1000 to 1300 AD, the European population increased from 25 to 80 million, which required more bread, thus more cereals. Thereafter, particularly in northwest Europe, a clear separation developed between cropland and grassland with the use of studded horseshoes (with consequential improved hauling) as well as the transition from breast-strap harness to the collar harness (which reinforced the pulling power through the use of padded shoulder collars) and horn yokes from the 10th century. In addition the use of the harrow for better preparation of the soil, greater use of the two handed scythe, the systematic use of wheeled carts, and the construction of windmills discovered by the Crusaders in the Levant all increased production efficiency. Another development followed these innovations from the 13th century, – the transition from a two-year fallow rotation to the three-year rotation consisting of a winter cereal crop, a short fallow of 7-8 months followed by a spring cereal crop or another short-cycle culture, then a long fallow of 14-15 months. This small agricultural revolution of the second part of the Middle Ages allowed, despite significant regional differences, improved yields, on the best land, to 6 quintals per hectare for winter cereals and 4 quintals for spring cereals, producing in a good year a marketable surplus after self-consumption. Growing cereals over larger areas did not go without some famines and mass poisoning with ergot but it promoted transportation of grain from one country to another... and market speculation. The fairs increased in the 12th-13th centuries in Flanders in Champagne (Troyes, Provins, Lagny...).

English wheat was regularly sent to Holland, Flanders and France, providing a buffer to price surges. Other supplies came from eastern Prussia and the Baltic countries where land was cleared under the leadership of the Teutonic Knights, before the devastating Hundred Years War and the plagues of the 14th century. Simultaneously, a Mediterranean market, including the production areas of the Black Sea, was maintained in the South.

During the Middle Ages, virtually all cereals were used to make bread (wheat, spelt, barley, oats, millet, rye, sometimes even vetch and lentils). Bread wheat, less robust, was then often a minor crop except in a few areas, such as in the periphery of Paris as early as the 13th century.

It should also be noted that during the early Middle Ages, further North, the Vikings, took advantage of a warmer period between 800 and 1200 AD and left the coasts of Norway, the Orkney, Shetland and Faroe Islands and reached Iceland between 860 and 870, the coast of Greenland between 978 and 985, then around 1000 AD got to America, at least to Newfoundland. These people created two permanent colonies of cattle growers between 986 and 1000 AD on the southwest and southeast coasts of Greenland, which eventually disappeared between 1450 and 1480 under conditions not as yet understood.

Some authors consider that they brought wheat grains during their migrations. Some may have tried their cultivation in these new territories – at least in Iceland – but this attempt, if it occurred, was in the long-term unsuccessful because the vegetative period is too short even for spring wheat with consequential failure to adapt wheat to grow so far north (table 5).

Table 5 ■ Growth limitations for cereals in Scandinavia.

Cereal	Growing-Degree Days
Earliest local barley varieties	1170
Other local barley varieties	1300-1400
Local oat varieties	1300-1500
Spring wheat and rye	1600

(Source: Hansen, 1990)

In today's Russia, in the Selenga River Basin, near the city of Ulan-Ude, near the Baikal Lake, the Ivolginskoye site of the military colony of Xiongniu (pre-Mongolian culture 209 BC to late first century) showed wheat, barley, millet cultivation using iron ploughs of Chinese influence. In addition, the Han Shu (Annals of Han dynasty) made several references to the Xiongniu cereal culture. Later in the eighth century, the first independent Siberian state, the Khanate Kirgis, also cultivated wheat, millet, barley and hemp, also adopting the Chinese plough.

In the Far East, China was also clearing new land and making progress in cereal culture under the Tang (618-907) and Song (960-1279) dynasties by gradually diversifying the number of crops, improving seed quality, increasing the tillage tools and increasing the use of irrigation and manure, including human waste. These innovations were widely popularized by the movable type printing and distribution of many books long before Gutenberg. The center of gravity of the country's agricultural production switched from north to south between the 8th century and the early 13th century: in the 8th century, three quarters of the population lived in the low and middle basins of the Yellow and the Huai Rivers, consuming mainly millet and wheat; in the 13th century, the same proportion of the population had moved to the Yangtze basin or further south, where the richer lands and the water allowed the irrigated culture of rice, permitting a denser population and reducing transportation costs. In the north wheat yields reached 8-10 to 1 and equaled that of Roman practices, while it was on average 4 to 1 in Western Europe at the same period. The Song also promoted double cropping rice/wheat in the south by various incentive policies and, stimulated by various naval developments (compass, stern rudder), encouraged trade by sea including with the Chola dynasty in southern India and the Arab network further west.

The publication in 1304 of the *Nongshu* or Wang Zhen's Agricultural Treatise gives us a good idea of farming implements for the cultivation of wheat in the 14th century in China. For soil preparation, refining the earth and the conservation of its moisture for sowing are sought. The plough is quite different from that used then in Europe. Its metal moldboard, regularly curved, is placed directly in the extension of the share, turning the earth under the influence of its own weight and has a minimum of resistance to progress. It may be driven by a single animal while the western plough, heavier and coarser manufactured, often requires the coupling of two animals, which forces the farmer himself to spend more energy. Once the soil is tilled, weeders, harrows, twig harrows and wood or stone rollers are used to eliminate weeds, prepare the planting while retaining moisture.

Sowing is done in lines while in the West, it is done by broadcasting or when seeds are in short supply, in pockets. Row planting, which uses about one tenth of the harvest in normal years, allows the farmer to move between the rows and to control weeds either by pulling them or by using different types of hoes, or even a spade.

At harvest, the book cites the knife to harvest, the sickle and the scythe. One type of scythe so-called “armed scythe” is particularly interesting and dedicated to wheat and buckwheat. This scythe has a cradle that allows, in a single movement, to cut the stems and send them on a sled that the harvester pulls behind him.

Following these various innovations, the population of the empire increased from 60 million under the Tang to 100 million during the Song in the early 12th century. In a country where the major rivers flow from west to east, the building of the Grand Canal served to strengthen south-North exchanges, controlling the trade in grain and to feed people. It was initiated at the end of the Spring and Autumn period (722-481 BC), extended under the Sui (581-618) and further under the Yuan (1206-1368), after the invention of the pound lock in 984. In Japan, the introduction of stone mills from the continent in the 7th century allowed a first increase of the wheat area followed by a second enlargement from the 13th century, with the practice of double cropping of winter wheat or barley followed by a summer crop of rice which became widespread in the archipelago, except for Hokkaido.

From the 7th to 10th century, Islam, – born in Saudi Arabia and open to innovation – dominated militarily, intellectually and technically throughout the south of the Mediterranean and most of Spain. It also extended east to the Indus, taking for itself a large share of the former Greco-Roman influence. Culture of modern durum wheat was probably introduced or reinforced in India and Sudan during this period by pilgrims returning from Mecca. Introduction of emmer could have been renewed by Arab traders on the west coast. If rice was introduced in the Mediterranean by Alexander the Great, it was undoubtedly Arab traders, having contacts in India, who permanently established its cultivation in Spain, the Po valley, Sicily and even Hungary. Their trade network extended by sea far to the east, to China, Korea and Japan. Thus, a 9th century Arab author indicates that “*more than 150,000 Muslims live in Chinese ports*”.

In the fourteenth century, the great traveller Ibn Battuta’s accounts mentions “buns”, presumably baked in the town of Mali, probably close to the Niger. And if in 1492, with the fall of Granada, Muslims were expelled from Spain in the 15th century, the Arab-Muslim territory would nevertheless still encompass the east coast and a third of north-Africa, part of Madagascar, the Middle East, Southeast Europe through the Ottoman Empire, the territories of Central Asia as far as Samarkand, northern India, Sumatra and various islands further east. This represents a big part of the bread wheat and durum wheat surface, and contributed greatly to the mixing of populations between countries throughout this period.

From 1200 to 1400, pre-globalization by land of the Mongols

According to the historian Christian Grataloup, from 1200 to 1400, a period during which the brief Yuan Dynasty (1279-1368) joins China to the vast Mongol Empire for a time, "*the Mongols transform the road network of the Old World into an empire. Exchanges of people, goods, knowledge* […] *but also of disease* (*Black Death) surge. After the breaking up of the largest terrestrial empire in history, only the desires to re-establish these exchanges remain*".

This gigantic empire recreated direct contacts between China and the Mediterranean basin where various inventions (metallurgy, printing, naval construction...) that contributed directly or indirectly to the development of European cereals arrived by transfer of technology and ideas: new tools and agricultural methods, development of mills, development of pasta starting in Italy. Given the distances of the Mongol Empire, its masters, being of nomadic origin, established a network of relay stations between their headquarters – about 50-60,000 km or more, mobilizing more than 200,000 horses and tens of thousands of men. This military secure network enabled merchants, bankers, tradesmen, scientists, diplomats, religious people – that could sometimes be the same – to circulate, borrow and spread techniques, ideas and beliefs, for over a century, from Italy to China through Syria and Iran. There are various testimonials attesting: Jean de Plan Carpin between Rome and Karakorum between 1245 and 1247; André de Longjumeau went as ambassador to Mongolia in 1249 at the request of St. Louis; William of Rubrouck reached Karakorom from Constantinople between 1253 and 1255; Jehan de Mandeville circulating from Liege to Egypt and Persia, to India and China between 1322 and 1356. Others have also used simultaneously the maritime routes of the spice trade in their travels like Marco Polo returning from China to Venice (1271-1293), John of Montecorvino when he left for China in 1289 - to return in 1353 after 9 years of crossing Central Asia - or Ibn Battuta as part of his wanderings in India and China, but also in East Africa and the Mediterranean (1325-1354). Indeed, maritime commerce was then primarily focused between India and China "for every ship full of pepper going to Alexandria to be trans-shipped in Christian land, there are over one hundred coming to the port of Caiton (today's Hangzhou, the first port in the world at that time)" reports Marco Polo in his book *A description of the world*.

In 1368, taking advantage of insurrections, the Chinese regained control of their territory and hence started the Ming Dynasty (1368-1644). To its west the brief Tamerlane Empire (1370-1405) devastated the northern plains of India. Chinese wheat, and further east, the Korean and Japanese wheat would soon enter a long period of isolation from wheat of the Old World.

Bread wheat is still a Eurasian and a little African, and often grown in mixtures with other cereals. This situation would not last much longer.

From 1400 to 1914: second wave of wheat expansion carried by western colonialism and the beginnings of modern selection leading to the globalization of the culture of the species

(figure 8 and tables 6 and 7)

The selection pressure initiated by successive generations of farmers in these areas since the domestication of the species, continued to come from the choices made at each harvest based on the appearance of plants, ears and seeds and were the starting point for the next cycle of culture. Over the years, and human migrations, wheat spread from the Fertile Crescent into new wetter, warmer or colder environments, with a fairly wide latitude gradient. Losses through physical stresses, biotic and abiotic factors were observed, rearrangements of characters and the fixation of natural mutations were selected by farmers, mainly on easily heritable characters and these have led to the creation of many, relatively stable, country specific populations. Nevertheless, the exchanges whether they be east-west or north-south were slow. They are at the pace of man or some large domesticated animals or by sea – and then often only just along the coasts.

In the 15th century, while China and Japan withdrew and isolated themselves for a few centuries, Western Europe started to conquer new territories by sea for four main reasons:

– (a) competition between European kingdoms and lack of grain, with the occasional shortages and famines for its people (table 8);

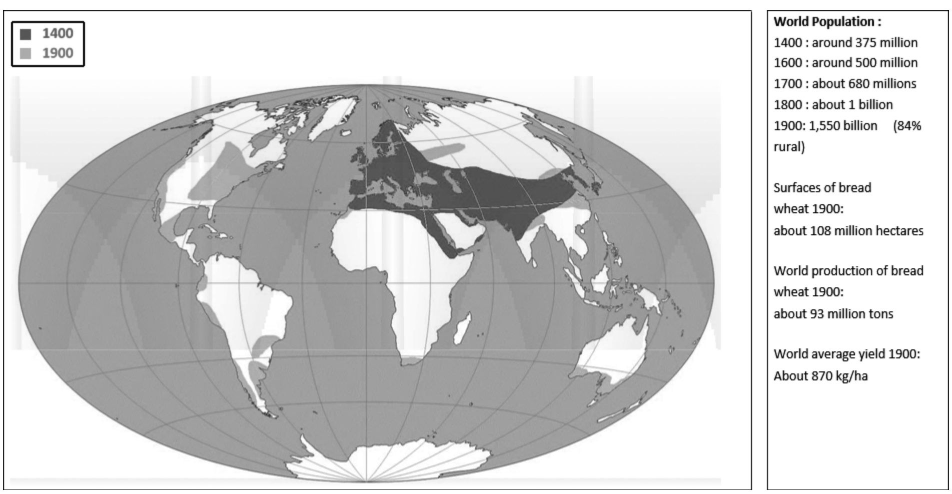


Figure 8 ■ Wheat from 1400 to 1914.

Table 6 ■ Key dates in the period – Humanity.

Dates	Steps
1400-1500	China and Europe dominate the world
1405-1433	Chinese expeditions of Adminal Zheng He in the "South Sea"
1421	First industrial patent issued in Europe to Brunelleschi in Florence
1453	Capture of Constantinople by the Ottomans
1492	Christopher Colombus "discovered" America, in fact the island of Guanahani in the Bahamas
1500-1750	Europeans invade the Americas and sail around the world, but China remains the largest economy
1602	First experiments on the use of chemical fertilizers by van Helmont
1717	First hybrids of flowering plants (Thomas Fairchild, UK, carnation)
1750-1850	Europe begins the "industrial revolution" despite losing direct ruling over the Americas
1823	Dominance, recessiveness and segretation observed in pea by Knight
1840	Birth of agricultural chemistry with Justus Liebig
	Darwin's theory of evolution
1858-59	Opening of the Suez Canal
1869	Dissemination of the European "industrial revolution" in North America and Japan, only a few old empires (China, Persia…) are not colonized, but are declining
1865	Mendel's law of heredity
1900	Rediscovery of Mendel's law by de Vries, Correns and Tschermark
1903	Invention of genetics by Bateson
1909	Definition of linkage groups by Morgan, then the concepts of crossing-over and recombination by Morgan and Cattel
1914	Opening of the Panama Canal

Table 7 ■ Key dates in the period – Bread wheat.

Dates	Steps
Around 1425	The portuguese introduce wheat to Madera
1519	The Spanish introduce wheat to Saint Domingo
1523	The Spanish introduce wheat to Mexico
1527	The Spanish introduce wheat to Argentina
1535 or 1537	The Spanish introduce wheat to Peru
1541	The Spanish introduce wheat to Chile
1547	Bread made in Peru
1556	The Portuguese introduce wheat to Brazil
1602	The English introduce wheat to Massachusetts
1605	The French introduce wheat in Quebec
1652	First crop of wheat by the Dutch in South Africa
Around 1650	The Dutch import the Chinese moldboard ploughs to Europe

Table 7 ■ Key dates in the period – Bread wheat (*continued*).

Dates	Steps
1655	The French introduce wheat in the Reunion Island
1697	First recorded importation of North American wheat to England
1701	Reinvention of the mechanical sowing machine for grain in England
1700-1720	Importing first rotary winnowing machine in Europe by the Dutch, the Swedes and the French between 1700 and 1720, then improvements by combining them with a mechanical threshing system
1760	England is a net importer of wheat
1766	Record 3.2 t/ha yield for wheat in France by Mr. Charlemagne around Bobigny in the Northeast of Paris on 8.5 ha
1767	Introduction wheat to Tahiti by the French Bougainville – with no future
1769 or 73	The Jesuits introduce wheat on the Pacifi coast of Mexico and lower California
	The English introduce wheat to Australia
1774	English corn law
1788	First wheat crop in New Zealand by Ruatara, chief of the Ngapuhi
1800	First wheat trials with monitoring of the descendence by Le Couteur Jersey
	First successful crop of wheat in Cuba
1808	Introduction of wheat to Manitoba in central Canada
1812	Introduction of wheat to Jamaica
1834	Introduction of wheat to the Bahamas
1836	Introduction of wheat to Kansas
1839	Principle of the pedigree breeding established by L. Vilmorin in sugar beet, and practiced on wheat by his son H. Vilmorin
1870	Wheat production in England tripled compared to 1700
1875	Early modern selection of wheat in Germany First wheat trials in Nex Caledonia
1881	Introduction of wheat to Dakota
1885	First steam tractor produced in the U.S. by Ford
1886	Early modern selection of wheat in Sweden
End of 19th century	Introduction of wheat to Kenya and Tanzania Beginning of modern selection of wheat in Japan
1893	Early modern selection of wheat in India
1900	Spring wheat grown in Alaska
1904	Recessive resistance to wheat stripe rust by Biffen
1905	Wheat grain color explained by Nilsson-Ehle and law of population equilibrium by Hardy-Weinberg
1908	Early modern selection of wheat in South Korea
1910	Early modern selection of wheat in Bulgaria
1911	Early modern selection of wheat in Argentina

Table 8 ■ Number of famines and food shortages that occurred in France between 1400 and 1914.

15th century	16th century	17th century	18th century	19th century	1900-1914
13	13	11	16	10	0

(Source: A. Bonjean, R. Cobland, 2000)

– (b) Ottoman control, blocking off the old terrestrial routes to India and China and increasing the risks for Mediterranean trade;

– (c) the desire to circumvent the Muslim "blockade" in the Indian Ocean;

– (d) the desire to expand the reach of Christianity – for whom wheat is an important symbol – under the leadership of Rome.

By sea, wheat from Western Europe would be introduced in successive waves in South and North America, in Africa and in Australia. This upset the previous equilibrium of genotypes mixtures by transplanting them into new environments and exposing them to new biotic and abiotic stresses, allowing a further enrichment of the genetic variability of the species. Even more so as these introductions had not always started from Europe, but from "new territories" partly through the African slave trade. At the same time, wheat and other cultivated Eurasian species were challenged – as early as the sixteenth century – by crops imported from America, including maize.

From 1700 to 1850, Europe encouraged the creation of national markets and began the industrial revolution which for wheat results in the establishment of breeding programs based on selective hybridization, the use of new cultivation and grain processing practices and the opening of global wheat trade. From 1850 to 1914, the rapid spread of the industrial revolution in North America and a little in the Southern Hemisphere and Japan, allowed Europeans to globalize the use of their genetic backgrounds for wheat. This is both the culmination of a long process and rupture, which, before 1914, generated the first regional gains of productivity that will be discussed through various examples. Only a few old kingdoms and empires (China, Korea, Persia, Thailand...), although affected, retained their ancestral varieties.

Between 1400 and 1750, the age of great discoveries diffuses wheat out of Eurasia

Ming maritime expeditions, Chinese and Japanese agricultural success, but missed synchronization of wheat

At its start, the Ming Dynasty went through a period of expansion – conquest of Vietnam, Mongolia and Manchuria – and an openness to countries of southeast Asia, India, Ceylon, the Persian Gulf, the Arabian Peninsula and even East Africa. By order of Emperor Yongle – who ruled from 1402 to 1424 – his son, Admiral Zheng He (1371-1434) lead seven major diplomatic and military expeditions with his treasure ships on the high seas between 1405 and 1433. If trade by sea between China and Africa goes back at least to the seventh century, as shown by recent excavations in South Africa, Admiral Zheng He's expeditions in the Indian Ocean are at scale not seen before in terms of the size of the vessels and number of people on board.

These voyages were not intended to colonize the territories visited but for the diplomatic prestige, to obtain a recognition of the primacy of the Middle Kingdom and tributes (unknown animals in China, spices...) from the countries visited for the Ming court in exchange for the return transport of ambassadors from other nations to the court of China and Chinese luxury goods (porcelain, silk, etc.). We know from the stories told by sailors of the time that the Chinese ships carried soybean, millet, rice and wheat and also vegetables and fruits – fresh, dried or preserved caramelized – and some meat, to feed the crew and passengers. It is therefore quite possible that Chinese wheat was introduced from China to East Africa, or even they brought Egyptian, Arab, Persian or Indian wheat to China. The fact that the main growing areas of East Africa are far inland and not on the coast, and there is no large river delta like in Asia, did not encourage a current of exchanges from China to these regions of Africa. On the other hand, some wheat may have been introduced to China but no records were kept. However, the great Emperor Yongle's Encyclopedia or Yongle Dadian says "*wheat from the ancient land of Misr*", that is to say of Egypt, "*was growing on the land of Misr, which was visited by the first Ming*" and refers to a wheat with large seeds - probably emmer - that is no longer cultivated along the Nile and replaced by fruit trees.

In 1433, China, considering itself to be the centre of the world, was under the influence of Confucian advisors anxious to strengthen agricultural production of the Chinese empire and to limit the influence of coastal cities on the economy. These great journeys were stopped, particularly as they were far from being economically viable. China missed an opportunity to spread its bread wheat and their specific uses (steamed breads, noodles) to other continents, which could have changed the eating habits of Africa, the Near and Middle East and the West.

However, the Ming Empire (1368-1644), highly centralized with a systematic control of its population, undertook various projects to boost agricultural production and increase its tax revenue from property taxes and grain products. There is little data on wheat yields from this time, but it seems that the outputs in a poor province like Shanxi were no more than 500 kg/ha around 1700, while those in wealthier provinces such as Hebei or occasionally Shandong could reach 800 kg/ha, or ratios of 1:5 or 1:8 compared to seeding rates. Note also that at the beginning of the Qing Dynasty (1644-1911), the wheat-soybean double cropping initiated during the late Ming period was extended north.

In 1543, a Portuguese ship was forced to take shelter in a Japanese port during a storm. Natives who ate wheat only as noodles or steamed buns discovered that the Portuguese ate baked bread but they were not to adopt this practice yet. Until 1615, Japan remained a relatively open and tolerant country, trading with China, Korea and some European countries. While rice cultivation had become dominant in the country, wheat areas extended from west to east and from south to north, resulting in the creation of landraces adapted to autumn sowing, at least as productive as the best Chinese varieties at that moment.

The political isolation, or *sakoku,* of the Japanese archipelago decided at the beginning of the Edo era in 1635 was to keep Japanese wheat in isolation from the rest of the world almost until the restoration of the imperial power in 1868. That same year, the first Western-style bakery, Fugetsudo, opened in Yokohama paving the way for others. In 1875, Fugetsudo became the first Japanese bakery to manufacture and sell Western-style cookies and pastries in the country. This momentum was reinforced at the beginning of the Meiji era by the invention of *anpan*, a kind of bun stuffed with red bean paste, which became a classic of Japanese food.

European maritime expeditions across the Atlantic (1415-1600), Indian Ocean and the Pacific (1497-1700) accompanied by conquests of land followed by deforestation, opening new trade routes

The 8th to the 15th century, the Venetian Republic and some other major ports like Genoa neighbours held the spice trade with the Middle East to Europe.

The rise of the Ottoman Empire, leading to the fall of Constantinople in 1453 was to give the Europeans access to the traditional spice routes and seek alternative routes of supply in Asia. Genoa, at war with Venice and cut off from its ports in the Black Sea, then turned to North Africa, from which it imported wheat, olive oil, silver and gold, but also to ports in England and Flanders, installing the passage of the communities in Portugal. This may seem trivial, but the Portuguese sailors would soon find allies in this rich community.

One of the events that triggered the Portuguese maritime expeditions, related to these Genoa enclaves, was the continued demand in grain supply. In 1415, the capture of Ceuta, which was an important wheat trading port in the Mediterranean on the northwest coast of Africa (now Morocco), opened the navigation control of the West African coast to the kingdom of Portugal, which initially drew on Genoese knowledge to exploit the African coast. Under the auspices of Prince Henry, called "the Navigator", the captains of the Portuguese galleons gradually discovered this coast going south. The island of Madeira was reached in 1419 and the Azores in 1427, where wheat soon became the main culture, Cape Bojador in 1434. The mid-fifteenth century, caravels were developed.

These first sailing boats were able to avoid coastal shipping and combined with the improvement of astronomical knowledge, could navigate the high seas. In 1445, the coasts of Senegal and the Peninsula Cape Verde were reached, in 1446 the coast of today's Sierra Leone, in the year 1460 the Gulf of Guinea, in 1471 the Southern Hemisphere is reached, and the islands of Sao Tome (where the introduction of wheat is a failure due lack of understanding of the constraints of vernalization and photoperiodism), Principe and Elmina, in 1482 the river Congo, in 1486 the coast of today's Namibia. In 1488, Bartolomeo Diaz sailed round the tip of Africa, up the East African coast to the mouth of the Great-Fish-River, demonstrating that the route to India was accessible via the Indian Ocean.

In 1492, the kingdoms of Castile and Aragon, who had just completed the re-conquest of the Iberian territory from the occupying Moors, funded the first expedition of Columbus to the West Indies: two caravels and a carrack for almost a hundred people – a little amateurish compared to the huge Chinese discovery fleet of Zheng He a few decades earlier. October 12, 1492, Columbus and his crew reached the Bahamas, then the north coast of Cuba and Haiti, before rejoining Spain on March 15, 1493.

After the discovery of the Caribbean and Latin America by Christopher Columbus, Spain and Portugal divided America between themselves in 1494 through the Treaty of Tordesillas, under the aegis of the papacy. In this agreement, it was agreed that Portugal would colonize land up to 2000 km west of the Cape Verde islands, leaving to Spain all the land beyond. Nobody knew at the time the true scale of the Americas or that South America protrudes to the east of this line, allowing Portugal to claim Brazil from 1499. No other country recognized the Treaty of Tordesillas, but with their naval supremacy, Spain and Portugal could enforce it for a century.

The Spanish first colonized the West Indies, where they hoped to find precious metals, but at the failure of their scheme, they undertook the conquest of the Americas: between 1519 and 1521, Cortez's troops took control of the Aztec Empire in Mexico; between 1524 and 1533, those of Francisco Pizarro, aided by the epidemics that his troops unintentionally spread, swept the armies of the Inca Empire in Peru.

While the Portuguese Empire founded only maritime trading posts, Spain's American Empire is characterized by putting into power leaders from their country in the conquered lands, interbreeding with local populations and the transfer of European technologies and products.

For example, wheat was introduced by the Spanish into Santo Domingo in 1519, on the east coast of Mexico in 1523 and 1529, in Argentina in 1527 and Chile in 1541, probably around the same year in Paraguay, Peru and Colombia, then on the Pacific coast of Mexico and later in Baja California in 1773. There are also references to the production of bread in Peru in 1537 and a limited export of wheat from Chile to Peru dating back to 1575. In this conquest, initially stained in blood, priests and monks accompanied the soldiers and early settlers everywhere, carrying wheat, symbol of Christianity in their meagre belongings. The latter, by proselytizing as much as by food habit, were to become the source of the American wheat growing areas, in the birthplace of maize.

In contrast to the Spaniards who imposed their regime, the Portuguese only went to their "exotic" ports to send goods back to Lisbon. They introduced wheat to Brazil in 1556 in the state of Sao Paulo. Moreover, they only spent enough time to purchase products and then return to their country to sell them. Portuguese rule lasted about 75 years, enough time for Vasco da Gama to cross the Indian Ocean to reach Calicut in India (1498) and his successors to attain Madagascar (1501), Socotra and Ceylon (1506), Mombasa, Mauritius, Muscat (1507), to defeat the Muslim fleet in 1509 off the coast of India, allowing them to take over the trade with the Indian peninsula. They then took Goa (1510), Malacca (1511) which opened the way to the Malay Peninsula, the Sunda Islands, called the "Spice Islands" (1512), the delta of the Pearl River in China (1513), Hormuz (1515) and Canton (1516) and Japan (1542). This is the same period when the first official circumnavigation was achieved for the Spanish by Magellan and Elcano (1519-1533).

The Treaty of Tordesillas collapsed as other powers – the Netherlands, England and, to a lesser extent, France – built naval fleets strong enough to defy the Hispano-Portuguese ban. In addition to taking some Spanish and Portuguese colonies, the other powers continued the colonization process by occupying land further north, such as the United States and Canada, little or not colonized by the Spanish. Thus, at the end of the sixteenth century, the Dutch took over the most valuable Portuguese colony, the Sunda Islands. They were the first to grow wheat in South Africa in 1652. By 1684 the production was well established and some was exported to India that year.

In the early seventeenth century, after various maritime explorations, several North European nations – Britain, France, Holland – began to colonize the east coast of North America with its indigenous population decimated by microbes brought by immigrants. Without these, the farming of new lands would have been much slower or even unlikely. The cities of Tadoussac, Quebec and Montreal were founded by the French in 1599, 1608 and 1642, Jamestown and Boston by the British in 1607 and 1630, New Amsterdam, future New York, by the Dutch in 1625, Charleston in 1670 by French Huguenots and Scots. The Europeans also reached Australia and New Zealand in the Southern Hemisphere in 1643-1644.

The first wheat grown in eastern Canada in 1605 is likely to have been in the French location Port Royal. A wheat plot is also recorded further west, in Quebec City in 1617. These agricultural enterprises were apparently successful since the first Canadian wheat exports to France date from 1654 and to the

West Indies in 1670. In 1721, Quebec farmers produced 7,500 tons of wheat, but the population was growing faster than production, and later, wheat had to be imported from Ontario. Wheat production in Saskatchewan seems to have begun between 1753 and 1756.

The first wheat crop in the United States was produced in 1602 on an island off the coast of Massachusetts (New England then). In 1611, it was grown in Virginia and in New Holland in 1622. However, it was only towards 1620-30 that it began to be cultivated regularly on significant acreages.

The world's food foundation was significantly altered with the massive transfer of species that resulted from the discovery of the Americas. For wheat, it opened the door to a huge potential for new growing areas that only became a reality centuries later. It also opened the door to other continents for corn, another cereal that was to become wheat's strongest competitor in the twentieth century.

Russian exploration of Siberia (1538-1660) foreshadowing a future large sowing area

The Russian colonization of Siberia began in 1538 when Ivan the Terrible gave orders to Grigory Stroganov Dmitrievich to establish himself in the "empty land" west of the Urals. The conquest of the Khanates of Kazan and Astrakhan in the sixteenth and seventeenth centuries, enabled the armies of the Russian Empire to annex the Volga basin and open a process of expansion towards the Ural mountains. The fall of the Khanate of Sibir (1582-1585) extended this potential further west.

This military conquest by successive steps opened a new area of considerable potential for wheat production, quite similar to the environment of Canadian-grown wheat. The sowing areas are between 45° and 40° north latitude and are characterized by long winters followed by short summers lasting between 90 and 110 days with annual precipitations between 300 and 450 mm with a good distribution over the year.

Pockets of cultivation areas were opened up over the years, including wheat, rye, oats, barley, millet, buckwheat, peas and other vegetables: Yeniseysk in central Siberia around 1620, Krasnoyarsk around 1630, the high basins of the Inena and the Angra around 1680, Irkutsk, further east, around 1730. The same year there was an unsuccessful attempt in the Kamchatka Peninsula as the climate was too harsh. Even after the shores of the Pacific were reached and explored by land by Ivan Moskvitin in 1639, the vast territory of Siberia would only begin to be exploited in the 1860s and particularly in the 20th century through 3 main steps:

– 1897-1914: under the tsar Nicolas II the Minister Stolypin initiated a colonization campaign leading to: the settlement of 3 million people, the doubling of the wheat acreage and a 0.5 million tonnes surplus of wheat production in 1910, due to faster mechanization than in the rest of the empire;

– 1929-1932: collectivization of farms by Stalin, leading to a decline in production despite some large mechanized farms;

– in the 1950s: Nikita Khrushchev's "virgin lands" campaign resulting in the cultivation of more than 10 million hectares of natural prairies.

From 1700 to 1914, the West takes the leadership for wheat

The early increases in wheat productivity in China, England and the Netherlands in the early eighteenth century, continued in China and Europe and increased in America, Russia and Australia in the nineteenth and early twentieth.

Until 1700, increases in area of wheat, rice and maize remained the primary response to the increased dietary needs of the human populations. It is however difficult to increase on a global level and was, at least partly, limited by fallows in order not to exhaust the soil. In China, between 1700 and 1914, with the use of fertilizers and irrigation but also the introduction of new plants from America such as corn, potato or sweet potato, Chinese agriculture continued to grow slowly but, like in Europe, with several regional famines from time to time (table 9).

During the Ming-Qing transition, the main intensification technique consisted in the transition to double annual cropping or the practice of intercropping. In northeast China where the main crops of the time were wheat and sorghum, double cropping happened through the creation and adoption of short cycle wheat varieties, with good fertility and ears maturing very soon after flowering, grown in rotation with soybean, cotton, vegetables and other cereals such as sorghum and millet. In regions further south, intensification of rice cultivation was done by inter-culture with mulberry plantations dedicated to sericulture and in the drier hilly areas, with crops of cotton in rotation with rice and soybeans or other pulses. Around 1700, another rotation became dominant in the Yangtze Delta. Culture of a single annual rice was replaced by a

Table 9 ■ Main developments in Chinese agriculture from 1650 to 1820.

Year	Population (million)	Agricultural production (million tons)	Total surface (million hectares)	Crop Surface (million hectares)	Crop yield (kg/ha)
1650	123	3,505,582	40,0	32,0	1,095
1750	260	74,100	60,0	48,0	1,544
1820	381	108,585	73,7	59,0	1,840

(Source: Madison, 2007)

short cycle spring rice, introduced from Champa (today's Vietnam), followed by a crop of winter wheat, rapeseed or soybeans or cotton. To have sufficient fertilizer for a second crop, farmers began to use oilseed cakes and cultivate alfalfa to supplement traditionally used human and animal excrements. Between 1800 and 1900, Chinese wheat productivity more than doubled, mainly through an increase of the cultivated area. In the early twentieth century, wheat yields, based on various authors, ranged from 250 to 3,500 kg/ha depending on year and production regions, with an estimated average of 400 kg/ha (table 10).

In Western Europe, where there is a reasonable amount of data, up to the eighteenth century, the land was divided into three parts. Two were cultivated annually while the third remained fallow. However, a few aristocrats in England started an agricultural revolution during the previous century. They were wealthy landowners inspired by the intensive agriculture in Flanders feeding a large population massed on small territory. Fallows were for the first time seeded with forage plants for animal feed and instead of cattle grazing on all land (open field), enclosures are created, allowing better fertilization of the soil and increased productivity for important crops like wheat, hemp and hops.

In 1701, the Englishman Jethro Tull reinvented the seed drill, soon horse drawn – though the Chinese had been using it for centuries. Developments accelerated in 1750 in the West-Midlands of England where marshes were drained and forests cleared to expand cropland (table 11). Like the Dutch, the British also began to cultivate artificial meadows (clover, sainfoin, alfalfa...), or root crops such as turnip or turnip cabbage instead of a large or small fallow to restore soil fertility. Besides the roots could feed cattle during the winter and simultaneously produce larger amounts of manure available to restore soil nutrients. This new method is a fundamental change that will double the livestock density per area unit, increase the availability for draft and manure – even before the discovery of chemical elements by Lavoisier in the 1780s that paved the way for chemical fertilization. This practice was popularized in England by Robert "Turnip" Townsend (1674-1741) and improved in Northern Europe by the introduction of potatoes, beet, canola, rapeseed, camelina, flax and hemp in the rotations.

Significant productivity gains resulted from these changes – production rose from 15 million quarters in 1700 to 17 million quarters in 1770 – but also a

Table 10 ■ Estimates of wheat production in China from 1800 to 1900.

Year	1800	1850	1900
Surface (million hectares)	8,416	14,667	20,800
Production (million tons)	6,438	13,200	23,546
Yield (kg/ha)	765	900	1132

(Source: Chinese Ministry of Agriculture)

Table 11 ■ Evolution of agricultural production in Norfolk, England, between 1250 and 1854.

Data	1250-1349	1350-1449	1584-1640	1660-1729	1836	1854
Wheat as % of cereals*	19	18	29	20	48	19
Wheat yield	14	11	14	14	21	27
% of sowing86for Cereals	87	87	87	84	49	52
Legumes	14	13	9	14	27	24
of which clover	*0*	*0*	*0*	*2*	*25*	*21*
Turnip	0	0	0	*7*	24	22
Livestock**	80	90	128	175	?	153
Draft animals 88	20	15	35	28	?	28

* As a percentage of all grains (wheat, rye, meslin, barley, oat), wheat yield estimated in hectoliters per hectare.
** Livestock units per 100 hectares of cereals.
(Source: Overton, 1996)

change in farming practices with big landowners mostly leasing their land and investing in the Industrial Revolution or in politics. The same happened in the Netherlands and Sweden. Meanwhile from 1770 to 1840, English cereal yields stagnated and the population increased rapidly during the eighteenth century, turning England from being a wheat exporter to an importer, mainly from Ireland initially (figure 9).

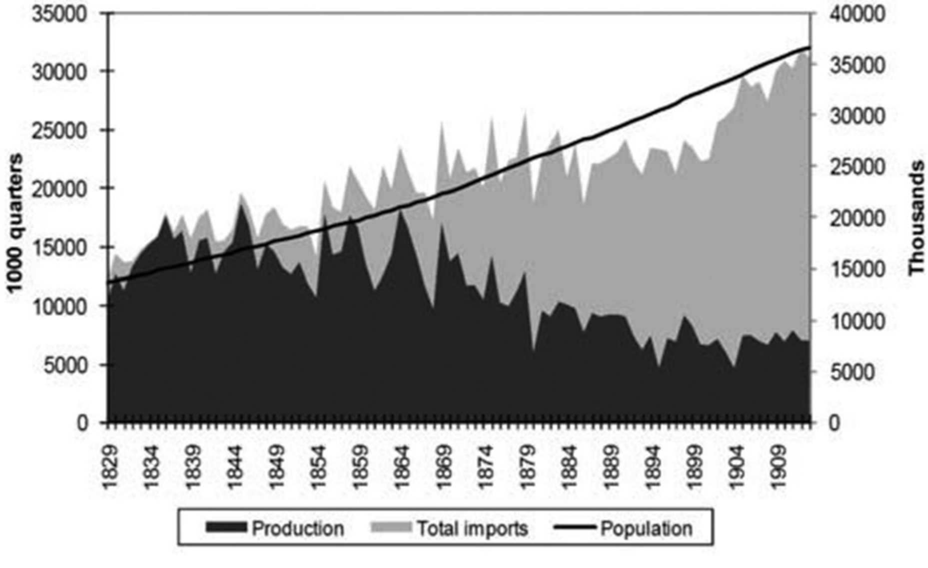


Figure 9 ■ Wheat production/imports and population in England, 1829-1913.
(Source: Mitchell and Deane, 1962, cited by Sharp 2009)

Agricultural progress was much slower in France where small landowners were numerous and resistant to innovation. The agricultural revolution began there in 1840 in the Parisian basin, forced by a drop in agricultural production, almost simultaneously with the advent of the industrial revolution. In southern regions, cabbage and corn were then integrated into the rotations.

By 1830, the discovery of guano, consisting of dried seabird droppings, on the coasts and islands of South America and South Africa, attracted great interest and became a real boost for some agricultural products of Western Europe between 1840 and 1880, before the exhaustion of these sites. However, the discovery of large deposits of nitrate in Chile offered an alternative solution before Von Liebig, Lawes and later Haber and Bosch opened the way to chemical fertilization. Nevertheless, it is estimated that in 1900 only 10 to 15% of mineral elements used by the crops came from the new mineral fertilizers in industrialized countries. In 1911, Edmond Rabaté also discovered that diluted sulphuric acid could destroy weeds. Farmers also began to drain their land at this time with brick ducts.

The transition to mechanization, linked to the rise of the "*Industrial Revolution*", and the change of values from labour to capital resulting in a massive rural exodus to cities and the colonies, also characterize the end of this period.

The mechanization of the countryside further increased productivity growth in agriculture. Indeed, from the mid-nineteenth century, the spread of railways facilitated the transport of grain to the cities, generating new financial flows. In the years 1830-40, progress took place through the use of mechanical mowers, steam threshers, steel ploughs, articulated harrows, cultivators, metal rollers and mechanical hoes, followed in the 1870s by binders, elevators and in 1890 by the first tractors and combine harvesters (table 12).

England and Holland, and to a lesser extent France and Denmark, were the initiators of modern wheat culture, but the United States with their larger farms and lower steel prices soon set up a mass production for all kinds of agricultural equipment, which deeply affected farmers' attitudes and indirectly facilitated the take-over of new land. Flat lands with limited labour – despite the additions from European emigration of the late nineteenth century and early twentieth century – contributed to the mechanization of American agriculture which became faster than Europe's. Thus, in 1910, it reached 80% of the agricultural world while only 50% in England and much less in France. The development of railways also contributed significantly to this movement.

In the United States of America, after several introductions of wheat on the East Coast from the early seventeenth century, the increase of sowing areas came about through deforestation and progressive cultivation of land in the Great Plains from east to west.

Table 12a ■ English wheat production from 1420 to 1910 in million hectares, million tons and kg/ha.

Year	1420	1500	1600	1650	1700	1750	1800	1830	1871	1900	1910
Surfaces	0.600	0.630	0.750	0.830	0.820	0.800	1.060	1.380	1.340	0.706	0.694
Production	0.408	0.424	0.536	0.790	1.004	1.088	1.550	2.346	2.734	1.412	1.457
Yield	680	673	714	952	1224	1360	1462	1700	2040	2000	2100

(Source: Broadberry et al., 2009, http://www.ukagriculture.com/crops/wheat.cfm)

Table 12b ■ French wheat production from 1870 to 1910 million hectares, million tons and kg/ha.

Year	1800	1850	1880	1900	1913
Surfaces	4.670	5.991	6.880	6.864	6.542
Production	4.203	6.600	7.550	8.860	8.690
Yield	900	1102	1097	1291	1328

(Source: World Wheat book I, 2001)

In 1718, the first wheats were located in the Mississippi Valley. In 1750, the first exports, mainly of flour, were made to England. In the early nineteenth century, Thomas Jefferson (1743-1826), third president of the United States and Virginian farmer, encouraged his fellow citizens to improve their farming practices and productivity. In 1820, wheat was grown for the first time first in the Red River Valley. In 1825, the construction of the Erie Canal made the Great Lakes (an "inland sea" almost as large as the Mediterranean) region a major new production and processing center for wheat on both sides of the US-Canadian border. It had a high population of European immigrants, particularly German. In 1839, the region that became Kansas produced its first wheat and the centre of the wheat production area shifted gradually to the West. In 1839 it was in West Virginia, in 1850 in Ohio, in 1860 in Indiana, from 1870 to 1880 in Illinois, then from 1890 to 1900 in Iowa and Nebraska in 1919.

In 1860, the rail network in the south-west of the Great Lakes was important and the tracks were used as rolling grain storage. The Civil War (1861-1865) was very beneficial for wheat. The northern states encouraged the cultivation of virgin lands in the Midwest to feed their army: 65 million hectares in 1861. With the population growth and the railway expansion it was to become 128 million hectares in 1900. Their war effort was also financed by wheat exports to Europe, mainly to England. In 1900, the United States exported 4.978 million tonnes of wheat, including the flour equivalent, mainly to Europe (table 13).

Table 13 ■ US wheat production from 1850 to 1910.

Year	1850	1860	1871-1880	1881-1890	1891-1900	1901-1910
Area (million ha)	4,003	5,738	10,934	15,009	15,672	17,543
Yield (kg/ha)	680	816	842	797	895	1050

(Source: Rutter, 1911; Selcer, 2006; http://www.davidrumsey.com/)

All this was only possible because the American Midwest farmers had created a new paradigm for wheat. Investing in mechanization in the late nineteenth century (sulky plough, mechanical drill, reaper-binder, combine, and then combine harvester), they increased productivity by reducing the farmers' labor and reducing day laborers. In the words of contemporary economist Chris Mayer: "*All of a sudden, the work of one man could produce 5,000 bushels of wheat. One miller could turn this wheat into half a ton of flour... The work of four men - a farmer in Dakota, a miller in Minneapolis and two railway men - plus a very low shipping rate could therefore provide enough flour to feed a thousand people for a year in Europe*".

In these regions, and later in similar ones in Canada, Argentina and southern Brazil, South Africa, India, Australia and New Zealand, North Africa, but also Russian, farmers were better equipped, with large areas and fewer costs than their European counterparts (table 14). They had lower production costs, but also smaller domestic markets, which resulted in overproduction of wheat that could be exported to Europe. They were also more open to innovation (table 15).

In the history of wheat cultivation, the nineteenth century stands out as the time of the great shift to modernity, with a significant increase in surfaces and to a lesser degree of yields in the years 1860-1914, which was unfortunately broken by the First World War. Thus, in Western Europe, in the words of historian JL Bernard, "*Agricultural Productivity, shaking itself from 1820, began in*

Table 14 ■ Expansion of arable land in the nineteenth century, millions of hectares.

Country	1860	1900
USA	65	128
Canada	–	8
Argentina	–	6
Australia	0,4	3
Russia	49	113

(Source: Grigg, 1987)

Table 15a ■ Australian wheat production from 1875 to 1910.

Year	1875	1880	1890	1900	1910
Surfaces (million ha)	0,576	1,327	1,307	2,294	2,667
Productions (million tons)	0,509	0,636	0,738	1,316	2,782
Yield (kg/ha)	884	479	565	574	1043

(Source: Australian gov.; USDA)

Table 15b ■ Canadian wheat production from 1870 to 1910 million.

Year	1870	1880	1890	1900	1910
Surfaces (million ha)	0,667*	0,948**	1,094	1,710	3,763
Productions (million tons)	0,455	0,880**	1,149	1,512	4,082
Yield (kg/ha)	682	928**	1042	961	1085

*: 1871 data
**: 1881 data
(Source: Craford, 1985; O'Connor, 1970;USDA)

Table 15c ■ Wheat production in the Russian Empire from 1872 to 1910.

Year	1872	1873-79	1892	1900	1910
Surfaces (million ha)	11,637	11,581	13,212	21,179	28,562
Productions (million tons)	4,298	3,160	6,369	11,512	21,111
Yield (kg/ha)	369	273	482	544	739

(Source: Smith, 1908; Crawford, 1895; USDA)

Table 15d ■ Argentine wheat production from 1870 to 1910.

Year	1870	1883	1890	1900	1910
Surfaces (million ha)	<0,050	0,244	0,949	3,272	5,839
Productions (million tons)	?	?	0,893	2,766	3,56698
Yield (kg/ha)	?	?	941	846	611

(Source: Ministerio de agricultura - Rep. Argentina; Crawford, 1895; USDA)

Table 15e ■ Indian wheat production from 1870 to 1910.

Yield	1870	1880	1890	1900	1910
Surfaces (million ha)	?	?	9,935	7,566	11,379
Productions (million tons)	?	?	6,140	5,357	9,633
Yield (kg/ha)	?	?	618	708	847

(Source: USDA)

1850 a slow and steady climb at a pace that will only take off after 1880", with the consequent increase in wheat consumption. In France for example, between 1841-1850 and 1891-1900, the annual consumption of wheat per capita rose from 176 to 245 kg.

Progressive emergence from Europe of rational selection based on controlled crosses

From the second half of the eighteenth century to the early twentieth century, the spread of European wheat and farming methods had spread in successive waves to the "*new*" territories colonized by the West, generating significant new wheat production basins in North and South America, North Africa and the territories of the Commonwealth – particularly within the Indian Empire and Australia. Meanwhile, the cultivation of wheat had risen sharply in the Russian Empire.

This expansion was initiated by the random transfer of landraces from one continent to another (figure 10), a good successful example can be illustrated by the story of the Red Fife population. David Fife and his family began to cultivate this wheat in Ontario in 1842 from seeds received from a friend living in Glasgow who himself had obtained this variety from Ukrainian imports – possibly introduced from Turkey by Mennonite farmers in the late eighteenth century. Requiring little input, this variety spread across Canada in the 1860s and remained the reference cultivar until 1900.

Figure 10 ■ Landraces having significantly contributed to the early stages of modern selection.

(Source: CIMMYT – Smale, McBride, 1996).

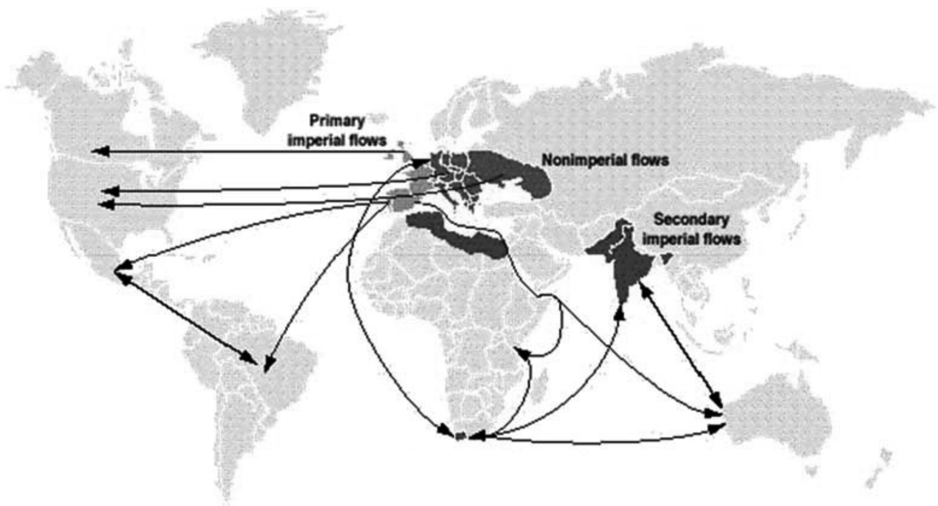


Figure 11 ■ Synthetic map of wheat germplasm exchanges of European origin and migration 1500-1900.

(Source: CIMMYT)

However, from the middle of the nineteenth century, the emergence of a scientific breeding wheat business in Northern and Western Europe, then lead to the creation of modern breeding programs that gradually extended to the various European colonies and other countries with which Europe maintained relations. This results in a sudden increase of variety exchanges between producing countries and also the advent of a new commercial culture, more global and with an industrial base (figure 11).

In the first half of the nineteenth century, inspired by economist Ricardo, some English gentlemen farmers tried to extend the principles of the Industrial Revolution to agriculture by seeking to standardize and stabilize grain production. In wheat, mainly self-pollinating, identifying plants with attractive characters and multiplying them to keep these traits from one generation to another was easy: a kind of cloning more than a selection.

In 1836, in his book *On the Varieties, Properties, and Classification of Wheat,* Le Couteur (1794-1875) highlights the practice known as "*continuous selection*" which he uses himself in Jersey. He is followed by Shirreff. Given the limited state of scientific knowledge of the inheritance of characteristics at the time, such practices were not challenged and were implemented rapidly in Northern Europe.

However, the first artificial crosses of wheat were made in England by Knight in the late eighteenth, but he gained no benefit from them. In the mid-nineteenth century, this work was taken up by Maund and Raynbird and some hybrids were presented at the Great Exhibition of London in 1851 before being grown on a large scale. Between 1850 and 1870, Shirreff at Haddington in Scotland extended this first trend of true modern selection.

Louis de Vilmorin (1816-1860) whose family was involved in the "*seed*" trade since the eighteenth century found that the English method of these precursors resulted, in sugar beet, in a marked loss of vigour in the progeny from consanguinity, that can only be retrieved by re-crossing them. While ignorant of Mendel's laws of genetics, he indirectly "*conceptualized*" the pedigree selection method from his work on sugar beet, which he described in 1856 at the Academy of Agriculture, paving the way for the genetic improvement of modern wheat and many other species. This hybridization method and its derivatives selected and recombined the parental characters, while fixing them in a few generations in an "*inbred*" variety whose progeny performed better than its parents reproducibly and identical to itself for the first time (figure 12).

Rimpau and Heine did the same in Germany, Pelowski in Poland, Mokry and Szilvay in Hungary, Pringle and Blount in the United States. Many others followed.

Other farmers specialized in the creation and delivery of these new varieties to their peers, creating breeding seed companies, first in Europe and soon in the colonies and among their allies or their business partners (table 16).

This discovery implemented in a context of improving farming techniques (row planting, mechanization, hoeing...) resulted in very significant changes

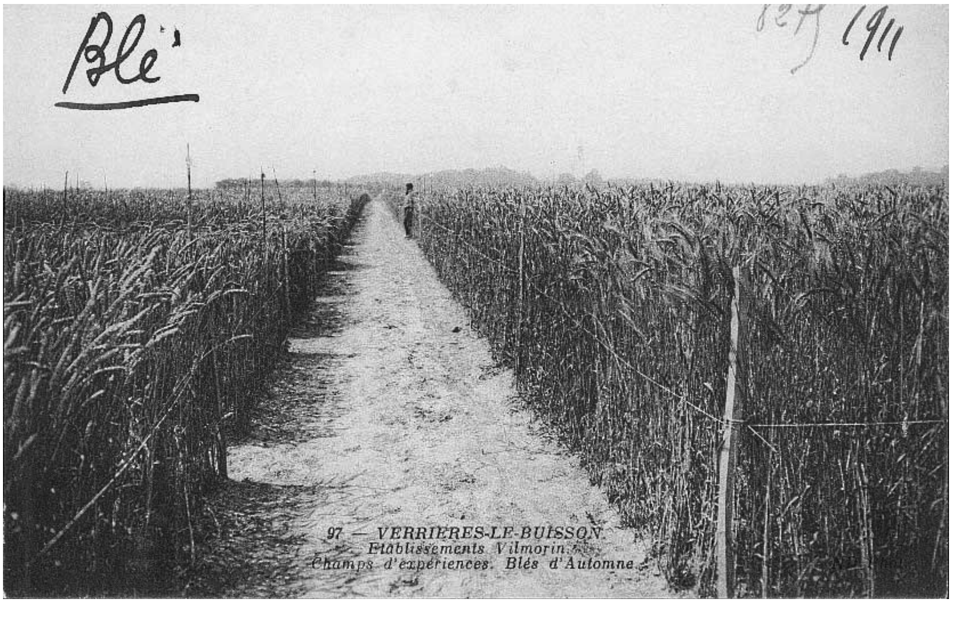


Figure 12 ■ Vilmorin nursery in 1911, note the tall wheat compared to current varieties.

(Source: A.Bonjean)

Table 16 ■ Start of the major modern selection programs based on reasoned hybridization.

Europe	Asia	Africa	North America	Mid-south America	Austria-Pacific
1790-England (Knight; first known crosses of wheat)	1893-Japan (Tokyo)	1902-South Africa (Neetling)	1877-United States Vermont (Pringle)	1912-Argentina (Backhouse)	1889-Australia (Farrer)
1856-France (L. de Vilmorin)	1904-India (Howard and Howard)	1907/8-Kenya (Delamere & Evans)	1887-Canada (Saunders)	1937-Brazil (Agronomic Insitute, Campinas)	1920-New Zealand (*Canterbury Agricultural College*)
1860-Poland (Peplowski)	1910-Korea (Suwon)		1909 PNW-US (Spillman)	1945-Mexico (Borlaug)	
1865/70-Hungary (Mokry and Szilvay)	1914-China (Reisner)			1966-Mexico (*Establishment of CIMMYT*)	
1873-UK (Sherriff)	1925-Turkey (Eskisehir)				
1875-Germany (Rimpau)	1933-Iran (*Varamin Institute*)				
1886-Holland (Broekema)					
1886-Sweden (von Neergard Gyllenkrok and Welinder					
1898-Switzerland (Martinet & Volkart)					
1900-Italy (Strampelli)					
1901-Austria (Tschermark)					
1904-Ireland (Dublin)					
1910-Russia (Rudzinski)					
1911-Bulgaria (Ivanov)					
1912-Ukraine (Sapegin and Yuryev)					
1913-Norway(Vik)					
1914-Romania (Ionescu-Sisesti)					

to the wheat plant and its culture: increased productivity by increasing the density of plants per square meter, reducing of the competition between plants, decreases in height, enhanced response to fertilizer. With selection taking into account the management of biotic stresses and baking quality, changes in the biochemical composition of the grain also occurred.

The emergence of this new business of breeding-seed production lead to the creation of national organisations to defend breeders' interests – the first was created in Sweden in 1886. Simultaneously, states set up seed testing laboratories as a protection against fraud and abuse and provide farmers with quality seeds – the first station founded in France in 1884.

In the early twentieth century, breeding gained the status of applied science following various discoveries: the description of the mechanism of meiosis by A. Weissmann in 1892, the re-discovery of Mendel's inheritance laws by de Vries in 1900, the concepts of genotype and phenotype proposed by Johannessen in 1903, the basis of quantitative genetics established by Hardy and Weinberg in 1908, the identification of the centres of origin of cultivated plants N.I. Vavilov in 1918, the discovery of chromosomes by Morgan in 1935 – paving the way working on the ploidy level to generate new genetic variability and the production of doubled haploids.

Transition towards an agro-industrial processing of wheat grain and large-scale internationalization of wheat trade (figure 13)

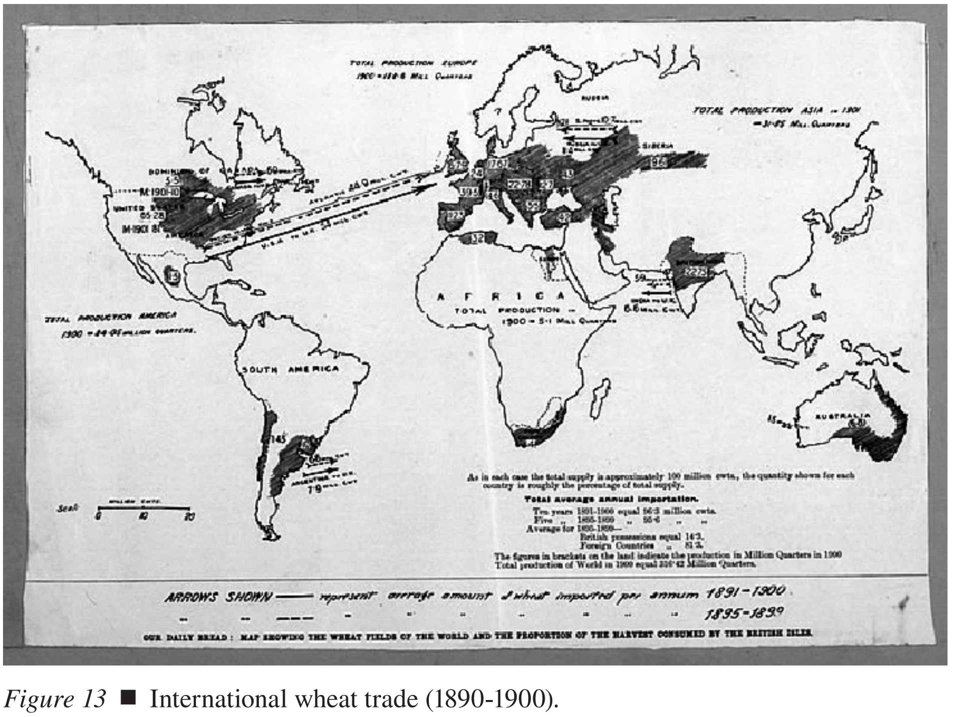


Figure 13 ■ International wheat trade (1890-1900).

Until the mid-eighteenth century, farmers regardless of their nationality produced wheat primarily for local consumption. The long-standing agricultural system consisted of a privileged minority dominating – by the control of land and sometimes water (irrigation, canals, mills...) – a society highly hierarchical with the poor, regularly hit by food shortages and famines. However the development of trade exchanges between this cereal and other plant or animal production among different areas gradually altered this organization.

From 1750 in Europe, with the emergence of mercantilism, a food market economy, based on regional specialization of agriculture, was controlled by various agro-industrial complexes (millers, brewers, etc.) which were often based in the outskirts of large port cities. Prussia and the Russian Empire were then the major producing basins exporting wheat to Western Europe. Simultaneously, a powerful agriculture emerges from colonization of the Americas, North Africa, India and Australia creating a European hegemony over these territories. Between 1870 and 1914, the steam engine offered new low-cost transportation, revolutionizing transport with rail and steamboats and allowed wheat produced in large quantities in these new territories to be brought cheaply to the European markets. The wheat trade which had, until then, remained regional or at least continental, then turned global even with the United States becoming an independent mercantilist system after the American Revolution and while most Latin American colonies gained their independence during the nineteenth century.

In 1870, the wheat price in Liverpool was 58% more expensive than in Chicago. In 1913, the price difference had dropped to 16%. This came about because the cost of transatlantic transport for wheat from New York to Liverpool fell by 1900 to a third of what it was in the 1870s. This reduction in transportation costs combined with improved grain storage on the boats, including the introduction of refrigeration in cargo compartments, opened up new agricultural areas benefiting mainly wheat, in the Canadian prairies, the plains of the US Midwest, the pampas of Argentina, the Russian steppes and the coastal plains of Australia. In the second half of the nineteenth century, wheat production in North America was to see its production cost divided by seven and its exports multiplied by four.

The industrial revolution changed the nature of production systems and concentrated industrial activities in cities and created a substantial need for workforce, generating a rural exodus leading to even greater urbanization. It also introduced factories as a production force, transforming manufacture from single units to mass production and beyond, altering the way goods are consumed.

Soon after James Watt's improvements to the steam engine, the American inventor Evans perfected his high-pressure steam engine and automated the mill. In 1834, the first steam-operated steel roller mills capable of grinding American *hard* wheat were introduced into Europe. Between 1840 and 1850, the English millers who had a significant river network and cheap coal produced more and more flour, but also standardized it, relying on increasingly efficient networks of supply and distribution. To achieve this, they needed massive investment and only a limited number of them survived. Likewise France since 1830, Germany since 1850 and the United States since 1860 reproduced this new production model often along the main rivers, in the heart of wheat production and near coal mines. By 1850, the square or long tin loaves were invented in the United States to facilitate cutting of bread slices. In 1873, two Americans Edmund La Croix and George T. Smith, of Minneapolis, patented the middlings purifier, which improved standardization and quality of flour, another major innovation for the milling industry.

Railways later became the structuring element of industrial development and trade. Successively, nations such as Italy (1870), Japan (1875), Austria-Hungary (1880), Russia (1900) and Canada (1900) established their own industrial structures. Mass consumption would prevail. By the 1880s, domestic markets were saturated and colonialism evolved as the industrialized countries adopted more imperialist policies, particularly the great British Empire, allowing them to monopolize new resources and to a lesser degree expand their markets.

This industrialization of wheat trade and processing, but also grains in general, was accompanied by an unprecedented financialization.

After the English wheat protectionist laws were abolished in 1846, the London Corn Exchange, established in 1749, remained for nearly fifty years the central structure for the emerging international wheat trade. However, in 1848, the Chicago Board of Trade was established and paved the way for future markets and in 1864 the first "paper" negotiated contracts for securing the supply of raw materials appeared. The Board of Trade became the Chicago Product Exchange in 1874, then the Chicago Mercantile Exchange 1919. The first "grain giants" were created during the same period: in Europe, Bunge was established in 1818, Louis Dreyfus in 1851, Fribourg (future Continental) in 1813, Andrew in 1877, while in the United States, Cargill was founded in 1865 and Pillsburies in 1872.

Simultaneously, the consumption of animal products in food increased in America and Western Europe and wheat gradually became used for animal feed. However, it is important to note that until the First World War there are no global statistics for wheat growing surfaces, production and yield, but only often scattered and discontinuous data for individual countries.

Table 17 ■ Production estimates for 1890.

Country	Surfaces (million ha)	Productions (million tons)*	Yield (kg/ha)
Russian Empire	13,0	6,369	490
Turkey		1,158	
Egypt		0,386	
Romania		1,390	
Austria-Hungary		3,960	
Germany		3,116	
Belgium		0,405	
France	6,8	8,661	1273
Algeria		0,541	
Spain		2,753	
Italy		2,718	
UK and Ireland		2,035	2000
USA	15,0	11,050	737
Canada	1,1	1,149	1042
Argentina	0,9	0,893	941
India	9,9	6,140	618
China	20,0	22,000	1100
Australia	1,3	0,738	565
Other countries		2,538	
World total	About 100 Mha	About 78,000 Mt	About 780kg/ha

(Source: Miklian antiquarian maps, excluding sources already quoted in this chapter)

Based on research carried out to write this chapter, the production estimates above are proposed for the year 1890 (table 17).

Between 1914 and 2015: considerable acceleration in the production of bread wheat and strengthening of globalization (figure 14 and table 18)

Throughout the nineteenth century and especially during its second half, the progressive mechanization of crops has largely favoured the extension of wheat areas. Meanwhile, despite the undeniable progress of selection in the nineteenth century, improvements of wheat productivity have been slow. Between 1900 and 1920, the early introduction of genes responsible for shortening the stems into the European genetic pool contributed for the first time significantly to produc-

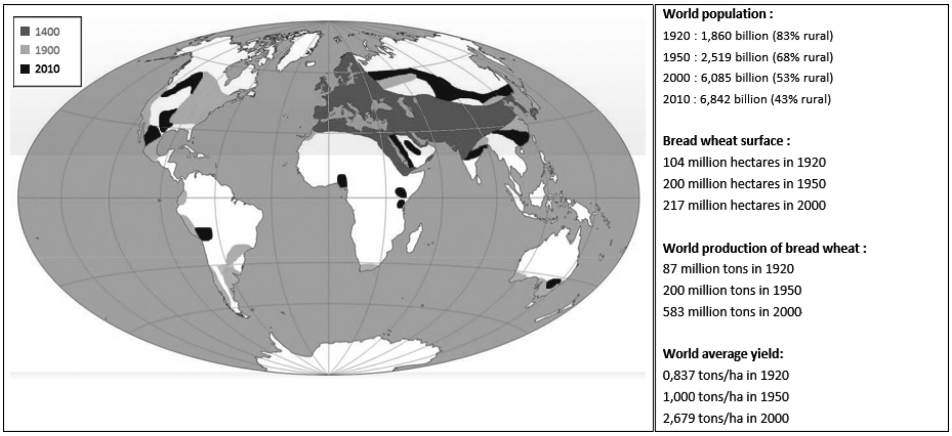


Figure 14 ■ Wheat between 1914 and 2015.

tivity. From the 1920's, wheat yields in the West soared, but relapsed during the Second World War, while the mechanization efforts continued.

Then in the second half of the twentieth century, free access to new Asian genes reducing the height of the plants, concurrent implementation of fertilizers, better seed quality, phytosanitary products, and increasing precision in mechanization came together and resulted in a considerable acceleration of production in developed countries. In the West, rationalised economics became a priority leading to an unprecedented industrialization of agriculture and globalization of the markets, while the urban population of the planet continued to grow stronger with the rural exodus to the cities. The period of 1965-1970 saw some of these productivity gains transferred significantly to some developing countries – Mexico, India and China in particular – by the "Green Revolution", while rice, maize and soybean production also progressed rapidly.

In 1992 the first genetically modified wheat was created, but despite extensive research, none is yet commercially available at the time of writing in 2015. Meanwhile, since 1998, the tonnage of corn harvested in the world has exceeded for the first time that of wheat. Hybrid rice has been developed and is grown over 20 million hectares, while a wheat hybrid system stable, safe and economically viable that could be scaled up has still not been found. Similarly now, the sequencing of the wheat genome is still in progress while those of rice and maize have been completed since 2005 and 2009. The investments devoted to conventional breeding of wheat, this old companion of the human saga, are now paradoxically a quarter of that for maize, which is however primarily used for animal feed and the production of biofuel. In terms of biotechnology investments, the proportion is even lower.

Is wheat a victim of its own success? Despite the emergence of certain concerns, it still has some enormous potential.

Table 18 ■ Highlights of the period.

Humanity	
Dates	**Steps**
1914-1918	First World War and Russian revolution leading to a change of social system in Russia
1918-1938	Europe continues its industrial revolution, despite the loss of its ruling over the Americas
1920/40	Early work on quantitative genetics (Mather, Fisher, Wright *et al.*) and study of chromosomes (Darlington)
1921	Economic crisis in the West
1939	
1939-1945	World War II
1939	Discovery of transposons by McClintock
1940	Proof of DNA as a carrier of heredity by Avery
1941	Basis of organic agriculture (organic farming) by Albert Howard
1946	"*One gene, one enzyme*" (Beadle and Tatum)
1946-1991	Zenith of the United States and the "cold war"
1953	Regulation of gene expression (Monod, Jacob and Lwoff)
1955	Gene hypothesis for resistance gene host-parasite by Flor
1965/70	DNA structure described by Watson and Crick
1962	Discovery of the genetic code (Crick, Niremberg, Matthaeri, Ochoa)
1970	Structure of genes in introns and exons (Chambon, Sharp and Tonewaga)
1976	Discovery of restriction enzymes, to cut and recombine DNA
1977/78	First SME in genetic engineering
1980/1987	Development of a first sequencing method
1982	Come-back of Asian countries among the major economies, mainly China, who regain their ranks from the eighteenth century
1983	Genentech's stock market listing and explosion of the number of SMEs in genetic engineering
1986	First transgenic animal, a mouse
1987	First transgenic plant, tobacco
1994	Published on PCR, polymerase chain reaction (Mullis)
2000	Wall Street crash and takeover of biotechnology companies by various multinational companies
	First transgenic plant (tomato) marketed in the United States by Calgene
	Sequencing the human genome and the biological database
After 2012…	Towards a "Sino-centered" economic world?

Table 18 ■ Highlights of the period (*continued*).

Bread wheat	
Dates	**Steps**
1914	Early modern selection in Georgia
Around 1920	Early modern selection of wheat in Morocco
1923	Early modern selection of wheat in Tunisia
1924	Early modern selection of wheat in Siberia
1925	Early modern selection of wheat in Turkey and Azerbaijan
1930	Beginning of modern selection of wheat in Iran, Armenia and Kazakhstan
1934	Early modern selection of wheat in Mexico
1936	Creation of ONIC in France
Around 1940	Beginning of modern selection of wheat in Sudan
1944	Creating first synthetic wheats (Kihara, Sears and McFaden)
1953	Early modern selection of wheat in Nepal
1961/66	"*Green Revolution*" based on the use of dwarfing genes in wheat (Borlaug)
1972/73	First doubled haploid wheat in France (from Buyser, Picard) and China (Ouyang, Chu)
1974	Cytogenetic identification of individual chromosomes from "Chinese Spring" (Gill *et al.*)
1974/75	First commercial hybrids of corn in the United States obtained by timopheevii cms (Dekalb and Pioneer Hi-Bred)
1980	First wheat gene cloned (MacKay *et al.*)
1985	First hybrid wheat obtained by gametocide marketed in France (Rohm and Haas)
1989	First genetic map of homoeologous wheat chromosomes, Ch 7 (Chao *et al.*)
1992	First spring wheat genetically transformed by biolistics (Vasil *et al.*)
1997	First spring wheat genetically transformed by Agrobacterium (Cheng *et al.*, Monsanto)
1998	The tonnage of corn harvested in the world exceeds that of wheat for the first time
2003	First winter wheat genetically transformed by Agrobacterium
2004	Development of the first Roundup Ready wheat
2008	First physical map of wheat chromosome, the 3B (Paux *et al.*)
2010	Draft sequence of wheat genome but only 50% of chromosome 3B is ordered and annotated

Between 1914 and 1950, disparate grain productivity

Use of East-Asian Genetic Resources and spread of a second wave of varietal innovations

In the early twentieth century, while Italy was far from being self-sufficient for wheat production, the breeder Nazareno Strampelli, called "*il mago del grano*" (the *wizard of grain)* by his contemporaries, introduced the Japanese variety Akakomugi – of Korean origin – in his selection schemes. It carries on chromosome 2D the Rht8 dwarf gene, but also close-by the Ppd-D1 gene responsible for photoperiod insensitivity and fertility improvement within the ear. In 1913, he produced a top cross of this Asian variety on the European cross Wilhelmina Tarwe X Rieti, resulting in 1920 in the variety Ardito: early flowering (15 to 20 days earlier than previous varieties), short straw (80-100 cm), lodging, cold and stem rust resistant, soon followed by a series of other varieties of the same innovative type. The same cross also produced the varieties Villa Glori, Mentana and Damiano. These varieties, obtained from intraspecific hybridization between local varieties and genetically distant or "*exotic*" material, but also interspecific crosses between wheat and other *Triticeae*, allowed Italy to distribute selected seeds and fertilizers to Italian farmers and win the "battle of the grain", an agrarian movement supported by Italian fascism in 1925. Average wheat production of 4.9 million tonnes in 1910-1913 increased to 7.0 million tonnes in 1930-33, with an increase of the average yield from 1.04 t/ha to 1.42 t/ha.

As indicated in the following table, between 1920-1940, Italy exported many varieties created by N. Strampelli to Southern and Eastern Europe, the Mediterranean basin, and even to South America and China. They were soon used by other breeders and recombined to their own material. With hindsight it is considered by some as a first "*Green Revolution*" (table 19).

Among the varieties developed two with broad adaptation should be highlighted:

– Ardito, registered in 1920 in Italy and widely cultivated in many European countries including Portugal, was introduced into Argentina where it helped locally to select Klein-33, which in 1953 became one of the parents of the famous Russian variety Bezostaya-1. This variety in 2005 contributed to the pedigrees of over 200 varieties from around the world with the Ppd-D1 and Rht8 genes. This variety was also among the leading foreign varieties introduced into China via England in the 1930s with Mentana and Villa Glori;

– San Pastore, registered in 1931, has been cultivated for over 35 years and contributed to the success of growing areas in Italy and in many Central European countries (Bulgaria, Hungary, Romania, former Czechoslovakia, former Yugoslavia).

In Portugal, a movement named "Campanha do trigo", or "Wheat Campaign", similar to the Italian "battle of the grains", occurred during the same period under Oliveira Salazar's dictatorship, particularly in the area Alentejo in the South. It was placed under the scientific responsibility of Antonio Sousa Camara who introduced varieties from N. Strampelli such Strampelli Carlotta, Ardito, Mentana, Villa Glori, and distributed them in his country, where wheat production grew from 280,000 tonnes in the years 1925-1929 to 507,000 tonnes in 1930-1934.

Table 19 ■ Quantities of the main varieties of wheat exported by Italy between 1924 and 1940-figures in quintals.

Variety	'24	'25	26	'27	'28	'29	'30	'31	'32	'33	'34	'35	'36	'37	'38	'39	'40
Ardito	367	2134	943	700	464	315	301	161	9	161	16						
Carlotta	597	1287	483	441	852	368	188	61	213	273	139	110	23	18	124		
Virgilio	48			33	121	384	229	104	856	1865	1576	2697	1408	2256	1784	3760	3748
Mentana		57	169	1194	2825	2589	3269	2334	3069	6871	7030	9564	6039	9672	6933	13259	10056
Villa Glori		15	73	92	122	297	1283	433	33	314	232	181	102	157	251	197	176
Rieti Originario			1742	1693	3026	1038	703	353	606	676	1392	1016	1690				
Rieti 11						35	54			3543	2240	1841	469	443	124	238	340
Damiano Chiesa						16	249	805	787	1977	1128	1267	934	1924	892	836	746
Edda				46	97	250	125	17	21	32					256	1286	4899
Rieti 75										606					1509	762	
Mentana Nutico										62	109						472
Roma											1664	965	1179	599	1227	1673	
Littorio											87	72	863	898	2502	9453	

(Source:http://www.retescat.com/musgra.it/museo/storia/19/tab19-1.html)

Increased mechanization and disparate recovery of productivity growth

After the Great War, the mechanization that started in America, reached Europe and its colonies where manpower was missing and where the accelerated rural exodus prompted a strong revival for the agricultural land trade. Moving from animal power to mechanical traction also increased the surface of arable land available for human nutrition by 25%, as land, previously necessary for the production of oats and hay for horses and oxen, was freed up. From the 1920s, the use of drills saved time and seeds. Later, with the introduction of petrol powered motor vehicles, the systematic use of fertilizers spread as they could be delivered more easily and directly to the farm. At harvest, a reaper-binder can do, in one day, the equivalent of the work of 10 to 12 workers.

From 1920 to 1939, European agriculture oscillated between archaism and modernity. In France the national average yield reached 1,450 kg/ha in 1935, with great differences from north to south: the northern areas produced 3,100 kg/ha, the Paris Basin 2,200 kg/ha, Limagne 1,600 kg/ha and the plains of Montpellier and Toulouse 1,000 kg/ha. At the same time, higher average yields were achieved in northern Europe: 2,400 kg/ha in the UK and 2,500 kg/ha in Holland. Spain, Italy, Greece and Central Europe did not always reach 1,000 kg/ha, while Russia stagnated at around 680 kg/ha.

Excess production of wheat existed mainly at the global level with new areas cultivated in the "new territories", cleared to become arable land, and by gains in productivity (tables 20 and 21).

More generally, a number of changes during this period affected, more or less directly, the world of wheat – these include:

– continuation of the massive rural exodus and urbanization in most major producing countries, excluding China and India, leading to a progressive standardization of dietary habits;

– increase in power of agricultural machinery;

– professionalization of the seed industry in the West;

Table 20 ■ Expansion of arable land in million hectares between 1860 and 1960.

Country	1860	1900	1930	1960
USA	65	128	166	158
Canada	–	8	23	25
Argentina	–	6	24	22
Australia	0.4	3	10	12
URSS	49	113	109	196

(Source: Grigg, 1987)

Table 21 ■ Trends in the main production areas outside Europe between the two World Wars.

Country	Major events affecting the country	Wheat trends
USA *(source: USDA)*	Rising as an industrial and economic power despite the 1929 crisis	Decrease of the cultivated area due to the progression of hybrid corn. But rise of new varieties selected regionally. First use of short varieties (Federation, Ramona, Alice / Elgin Ideed) convenient for fertilization and large mechanized operating structures. Exporting heavily through a few large private structures. 1920: 29.838 million hectares 25.91 million tons 867 kg/ha yield 1940: 21.323 million hectares 20.167 million tons 948 kg/ha
Canada *(source: Agriculture Canada)*	Member of the Commonwealth	Stagnation of production, after it had doubled between 1905-1914 and post First World War. Exporting country through the Canadian Wheat Board established in 1935. 1919-1930: 8.9 million hectares 10.0 million tons 1,112 kg/ha 1930-1941: 10.5 million hectares 9.5 million tons 910 kg/ha
Argentina (*source: Ministerio de Agricultura)*		Doubling of production. Exporting country. 1920: 5.350 million hectares 4.249 million tons 794 kg/ha 1940: 6.718 million hectares 8.15 million tons 1,213 kg/ha

Table 21 ■ Trends in the main production areas outside Europe between the two World Wars (*continued*).

Country	Major events affecting the country	Wheat trends
Australia (*source: official year book of the Commonwealth of Australia 33 -1940, p.716-717; Cairn Post from February 12th, 1941)*	Member of the Commonwealth	Mechanization of the production. "*Bulk grain*" system development, for easy grain storage and export. Exporting country through the Australian Wheat Board created in 1939. 1920: 2.599 million of hectares 1.251 million tons 481 kg/ha 1940: 5.390 million hectares 5.724 million tons 1,062 kg/ha
China (*source: Ministry of Agriculture)*	1911 Revolution and civil war The Kuomintang rises to power by in 1925 Japanese invasion of Manchuria in 1931	Slight reduction of the production surface and small gains in yield and production due to modernization. Essentially autarkic countries, albeit an occasional exporter and importer over the period. 1914-1918: 23.139 million hectares 19.785 million tons 855 kg/ha 1930: 20.285 million hectares 22.210 million tons 1,095 kg/ha
Russia *(source: World Wheat Book)*	1917 Revolution and civil war Creation of the USSR Priority to industrialization from 1928 Collectivization of the land and farmers' resistance	Countries traditionally exporting gradually becoming autarkic. Surfaces increase from 28 to 40 million hectares between 1917 and 1940. Lack of means of traction (the number of horses decreased from 4.4 million in 1928 to 2.6 in 1933) and fertilization (number of cattle falling from 8.6 to 4.4 million between 1928 and 1933) 1917-20: 28.7 million hectares 16.4 million tons 570 kg/ha 1940: 40.3 million hectares 31.8 million tons 789 kg/ha

– wheat R&D mainly financed by the private sector in the western part of continental Europe whereas similar funding is public in England, America, Australia, Russia, India and China;

– general improvement of baking quality and development of industrial bakery in the West;

– first significant industrial uses of corn, including animal feed;

– rise in the development of corn hybrids and livestock genetic improvement in North America, leading to a qualitative improvement of animal nutrition;

– development of large divisions of agro-industrial processing;

– appearance of large distribution networks;

– increased use of advertising.

In 1950, with the economic recovery that followed World War II, the average world wheat yield reached for the first time in the history of mankind the milestone of one tonne per hectare. With 200 million hectares of production area – nearly twice as much as in 1900, the world produced 200 million tonnes of wheat – more than double the figure from 1900. The international wheat trade represented around 10% of the world production.

The "backlash" from Lysenkoism

The saga of wheat suffered a great crisis between two World Wars. At the present time (2015) when Europe is trapped in a rejection of biotechnology – based on Malthusian ideology, revamped as "Green" – the Lysenko case should be remembered and reflected upon. Trophim D. Lysenko (1898-1976) was a Russian biologist close to Stalin. Embracing and expanding on the theories of Ivan V. Michurin, his philosophy crippled the productivity of Soviet agriculture between 1945 and 1965, particularly in wheat, to the point that today some historians believe that the false technological breakthrough from this "sorcerer's apprentice" is a major underlying cause of the implosion of the USSR in 1991. How did this happen to this vast country, originating from the Russian Empire which was a major wheat exporter?

At the fall of the Tsarist regime in 1917 and the creation of the USSR in 1922, the country had still, aside from a vast territory, considerable advantages in terms of wheat. In Moscow, scientists like D. L. Rudzinzki and S. I. Zhegalov were internationally recognized and performed quality work of genetic improvement at the Moscow Agricultural Academy. Several research stations like Saratov, Bezenchuk, Krasny Kut and others had initiated programmes of modern wheat breeding in the years 1910-1913 after collecting a vast stock of landraces. In Ukraine, A.O. Sapegin and V.J. Yuryev had also done so, in Odessa and Kharkov, respectively.

From the 1930s, after much fundamental work, breeding of Russian wheat had progressed significantly and contributed with its improvements to the global scientific community. The All-Russian Research Institute of Plant Industry, based in Leningrad, collected genetic resources worldwide, tested them in various states of the union pre-screened and used advanced methodological development before providing the breeders valuable material to introduce into their own breeding programmes. Its director, Nikolai I. Vavilov (1887-1943) trained in England under the geneticists W. Bateson and RH Biffin and was also in contact with the Vilmorin family in France and E. Haeckel in Germany. He began his career as a pathologist working on the plant-fungus relationships using wheat as a model. Having clarified some of the mechanisms involved, he sought out sources of resistance and discovered the value of *Triticum timophevii* tetraploid wheat in this area. Between 1920 and 1935, he organized numerous missions abroad for the collection and study of plants. This work led to the definition of his law of homologous series in variation and his theory on the centres of origin of cultivated plants, but also to the creation of the St. Petersburg germplasm collection – over 200,000 entries collected during his lifetime. For his contribution he became president of the Lenin Academy of Agricultural Sciences and the Institute of Plant Cultivation of the USSR. He was also a member of the CPSU Central Committee although he never became a member of the Communist Party.

From 1926-1927 T. Lysenko gained a certain reputation from "vernalizing" crop plants such as winter wheat or spring sown peas and gained support for this policy from Yakovlev, the Commissioner of Agriculture, following the terrible winter 1927-28 that destroyed part of sowings in Ukraine. This coincided with Stalin's launch of his five-year plan for the industrialization of the country funded mainly through agricultural exports and starving its people. Presenting himself as continuing the work of V. Michurin he became an icon of communist power and began to attack Vavilov in 1931. He argued that advances in varietal improvement proposed by the latter were too slow and suggested to replace them by large scale implementation of his own methods, highlighting their proximity to the rural community contrasting with the scientific research advocated by Vavilov, considered too elitist by Marxist dogma. Increasingly T. Lysenko and his supporters then directly attacked the very principles of genetics bringing the government to organize two conferences on agronomy and genetics between 1936 and 1939 and prevented the Seventh International Congress of Genetics to be held in Moscow in 1937.

After this troubled period, taking advantage of the context of Stalinist terror who settled on the eve of World War II, T. Lysenko assumed more and more power in the institutions of his country and systematically purged geneticists in the Soviet Union by denouncing them as agents of the West and those opposed to the ideology of the Soviets. Many leading scientists and Russian breeders of the time were exiled, imprisoned or even executed.

Increasingly, T. Lysenko then openly attacked N. Vavilov and proclaimed that there was no need to import foreign plants to develop new varieties, on the contrary, according to his own theories, local varieties were best suited for increasing production (table 22).

Table 22 ■ Average yield (in kg/ha) of winter and spring wheat in the USSR for the period 1936-1965.

Year	1936-1940	1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
Spring wheat	580	660	600	570	660	900	750
Winter wheat	940	1010	620	840	1180	1470	1540

(Source: World Wheat Book I)

By the mid-1930s, accused of wasting public money for years by establishing collections of plants from many countries, Vavilov was gradually deprived of most of its mandates. On August 6th 1940, while he was visiting western Ukraine, Vavilov was arrested, imprisoned and sentenced to death for "sabotaging Soviet agriculture on behalf of Western powers". His brother Sergey succeeded in reducing the sentence to ten years imprisonment, but Vavilov died in his cell from malnutrition and other mistreatment on January 16th, 1943.

After the second World War, T. Lysenko became the head of Soviet agronomy and biology, removing all his opponents, even though Russian agricultural production remained lower than in the rest of Europe. Somewhat challenged in the 1950s after Stalin's death, his career nevertheless continued until 1965 when he was finally sacked after the fall of his last patron, N. Khrushchev.

The USSR then reintroduced classical genetics in its scientific research after the "*eclipse of reason*" (W. Gratzer) and N.I. Vavilov was posthumously rehabilitated. From 1975, the U.S. massively exported wheat to the USSR. To protest against the invasion of Afghanistan by the USSR in 1980, President J. Carter decided to block these exports, but the Argentine regime of J. Videla sold 7.5 million tonnes of wheat to the USSR below the international price. The United States made up for the loss of the Russian market through a programme of assistance to their farmers. Discredited, J. Carter lost the election in favour of Ronald Reagan, proving that wheat may have become a political weapon.

From 1950 to 2012, unprecedented progress in world wheat production

Entering an era of abundance

While the worldwide surface for wheat production is believed to have grown by 230% between 1900 and 1950, it did not increase by more than 10% between 1950 and 2010. However, during these sixty years, world wheat production more than tripled, mainly by increased productivity. The theoretical amount of wheat available per person has grown by about 20%, despite an increase of 272% in the world population (table 23).

Table 23 ■ World wheat production 1950-2010.

Year	1950*	1960**	1970**	1980**	1990**	2000**	2010**
Surfaces (million hectares)	200	202.200	206.979	236.901	231.719	217.644	223.041
Production (million tonnes)	200	233.451	306.531	435 .867	588.801	583.075	651.607
Average Yield (kg/ha)	1000	1155	1481	1840	2541	2679	2921
World population (in billions)	2.519	3.023	3.696	4.442	5.279	6.085	6.842
Amount of wheat per capita (kg/person)	79.4	77.2	82.9	98.1	111.5	95.8	95.2

*(Sources: * CIMMYT; ** USDA)*

There are two major reasons for this phenomenal success:

– the entry of European agriculture into a period of abundance following the successive launches of the Marshall Plan in 1947 and the Common Agricultural Policy, established in 1957 and implemented in 1962;

– the "Green Revolution" taking place in some developing countries and its impact on the developed countries.

From the 1950s, supported by the Marshall Plan, Continental Europe really entered into modern agriculture. If in 1950 cattle and horses were the main driving force of the farms, there is nothing of it left in 1965, freeing up the land previously required for feeding draft animals.

In France for example, the numbers speak for themselves: 137,000 tractors in 1950, 300,000 in 1955 and one million in 1963. Mechanization swept aside the resistance to change and strengthened the rural exodus. In 1955, France had only 2.2 million farms, of which 800,000 were under 5 hectares. The increasingly powerful mechanization, systematic regrouping of the land, expansion of cereal farms, use of seeds developed from breeding programmes, adjustment of crop areas, and also the extension of weed and pest control products, contributed all to a phenomenal average wheat yield increase of 126 kg/ha/year between 1956 and 1999 – from 2.67 t/ha in 1960 to 5.20 t/ha in 1980, and 7.75 t/ha in 1998 (figure 15).

The use of herbicides, fungicides and insecticide facilitated by grants from the European Common Agricultural Policy and the relative stability of prices from the mid-1960s, has greatly contributed to higher yields in the European Union that are today the highest in the world. In 1979, 50% of the wheat areas were treated in England and 29% in Western Europe (figure 16).

Since the 1990s, this number increased to more than 95% in the United Kingdom, France, Belgium, Holland, Germany and Denmark. It is estimated

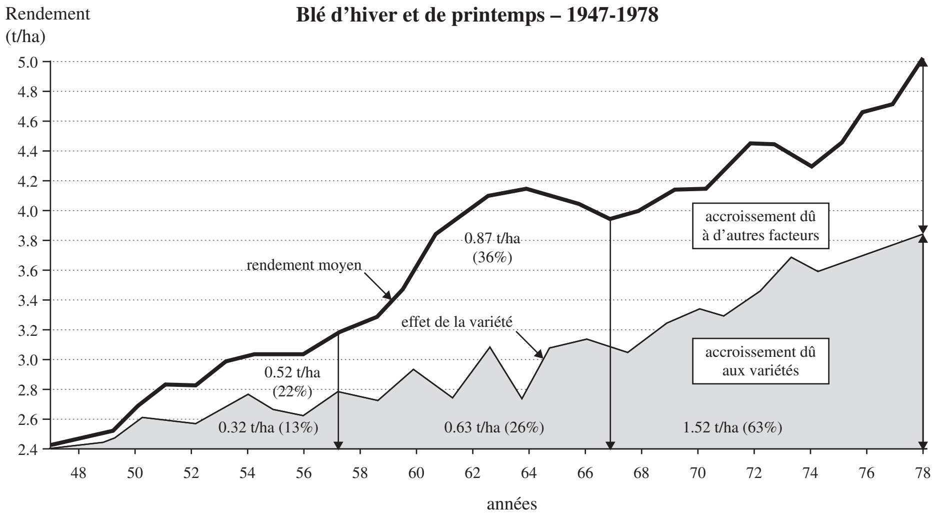


Figure 15 ■ Comparison of the influence of genetic improvements with other factors in the progression of wheat yields in France between 1947 and 1978.

(Source: Bonjean and Picard, 1990)

INDEX DES PRODUITS PHYTOSANITAIRES COMMERCIALISÉS EN FRANCE SUR CÉRÉALES (d'après Perspectives agricoles)	
1950	désherbants MCPP et 2-4-DP
1950	lutte contre les parasites et ravageurs (lindane ; anthroquinone) désherbants anti-folles-avoines sur orge (triallate)
1960	désherbants anti-vulpin et anti-dicotylédones sophistiqués
1960	lutte contre les ravageurs (diéthon, endosulfan)
1967	traitements de semences (charbons, fusarioses, etc.)
1968	désherbants anti-graminées, notamment anti-folles-avoines du blé tendre d'hiver
1970	premiers fongicides autorisés à la vente lutte contre les pucerons
1972	lutte contre les viroses de la mosaïque du blé
1975	mise en marché de pyréthrinoïdes
1977	notion de programme de désherbage et de protection fongique
1978	formulation des traitements de semences et enrobage
1980	lutte contre la mosaïque jaune de l'orge
1980	apparition de souches résistants de champignons à certains produits phytosanitaires
1980	abandon des organo-mercuriques au profits d'autres traitements de semences (aldicarbe, triazoles, etc.)
1982	souci croissant du respect de l'environnement, apparition de nouvelles molécules de protection phytosanitaires, notamment en désherbage

Figure 16 ■ Pesticides used on cereals in France between 1950 and 1982.

(Source: Bonjean and Picard, 1990)

that without these treatments, 20% of the crops would be lost in England, 26% in France and 70% in Denmark. The fungus *Septoria tritici* has established itself as the most devastating foliar pathogen. Since World War II, it should also be noted that considerable work has been done on the quality of wheat in numerous countries matching the industrialization of bakery. In France for example, where the baking strength for wheat was 80-90 in 1950, while in 2002. 60% of the harvest was between 160 and 250 and 5 to 10% of it was over 250 (figure 17).

Concurrent with this general improvement in wheat quality, there has also been an increased diversity of its uses – bread, rusks, biscuits, malt, alcohol, biofuel, starch, feed, etc. – and the success of supermarkets.

Although in deficit for wheat, Japan made, after World War II, the second major contribution to wheat breeding. In 1945/46, the USDA-ARS agronomist Samuel Cecil Salmon was part of the U.S. occupation forces. On the main island of Honshu, he collected in the Morioka Experimental Agricultural Station, in Iwate Prefecture, ten grams of sixteen lines of short and vigorous wheat that he brought back to the USDA genebank. Among them was the variety Norin 10, carrier of the recessive genes for dwarfism – Rht1 and Rht2 – and photo-insensitivity. In 1952 in Washington State, the breeder Orville Vogel crossed Norin-10 with the local variety Brevor and obtained from this cross Gaines, the variety which dominated commercial production in the Pacific North Western region in the 1960s, with yields 15-25% higher than the previous local varieties.

In 1949, O. Vogel had sent samples of Norin 10 and its descendants to his colleague Norman Borlaug, whose programme in Mexico was funded by the Rockefeller Foundation. The latter, aided by his Mexican partners, accelerated his spring wheat selection programme from a broad genetic basis by making two

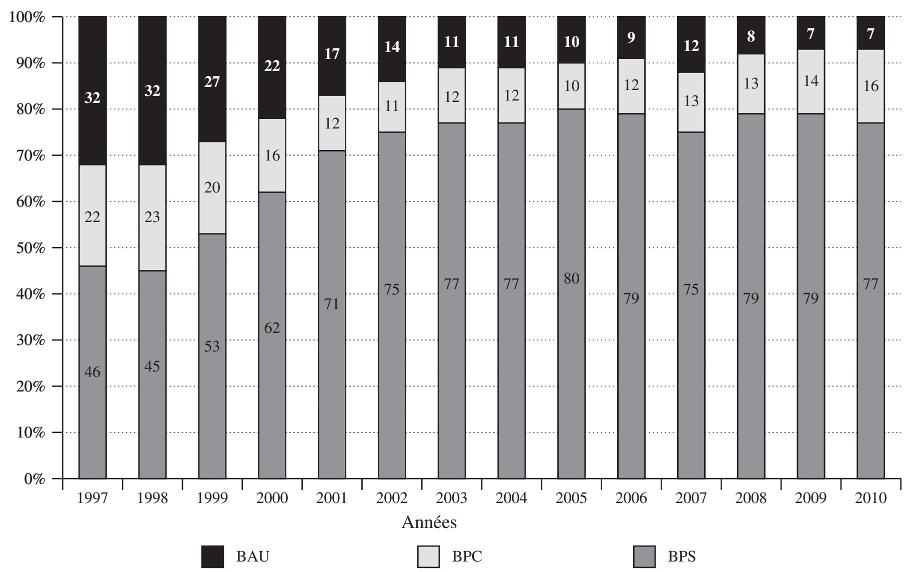


Figure 17 ■ Wheat quality improvements in France from 1997 to 2010.
(Source: Gnis, 2010)

breeding cycles per year: one in Toluca near Mexico City at 19° north latitude. at an altitude of 2640 m in a long day length area, the second 1200 km further north in Ciudad Obregon in the Yaqui valley, at 29° latitude north and 36 m altitude with shorter days. Using Norin 10 crosses from 1952, resulted in shorter varieties with a wide adaptability, disease resistant, able to withstand substantial fertilization, which increased regional productivity by 20 to 40% (figure 18).

Through his research – for which he received the Nobel Prize for Peace in 1970 – Borlaug was able to develop wheat varieties with high productivity that enabled Mexico, India, Pakistan, China and various other nations to feed their people and get them out of the immutable cycles of famines despite the obstacles placed before the introduction of new varieties – bureaucracy, opposition from local seed sellers and chiefly centuries of customs, habits and superstitions from some farmers.

In 1965-66, great interest was shown in Mexico for the semi-dwarf wheat spring developed by Borlaug and his colleagues. At the same time, India imported 200 tonnes of seed of Sonora 64 and 50 tonnes of Lerma Rojo and various cultivation suggestions. The following year it imported 13 000 tonnes (table 24).

Despite the red colour of the grain, these high yielding varieties became popular very quickly and were then converted to amber grain cultivars consistent with traditional Indian customs. Accompanied by new irrigation techniques and fertilization their growing area soon spread to other regions, further increasing overall production areas and allowing millions of people to finally escape the vicious circle of malnutrition. A similar approach was initiated almost simultaneously with CIMMYT in Pakistan and parts of China with comparable results.

The PR China has tripled its production in the past thirty years and is now 95% self-sufficient for cereals and various other crops. It became the largest producer of

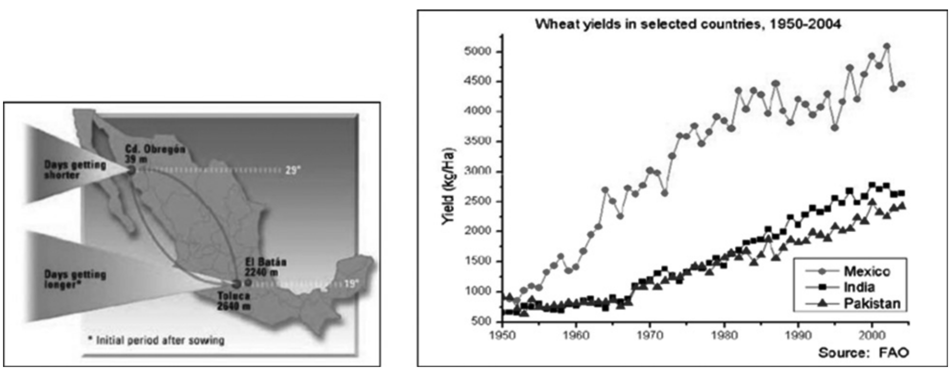


Figure 18 ■ Breeding stations created by N. Borlaug in Mexico and wheat yield gains from the green revolution in Mexico, India and Pakistan.

(Source: CIMMYT)

Table 24a ■ Wheat production in Mexico.

Year	1950-54	1960-64	1970-74	1980-84	1990-94	2000-2004
Surfaces (million ha)	0.7	0.8	0.7	0.9	1.0	0.7
Production (million tonnes)	0.6	1.6	2.3	3.7	4.0	3.0
Yield (kg/ha)	960	1,958	3,108	4,105	4,120	4,520

(Source: World Wheat Book II)

Table 24b ■ Wheat production in India.

Year	1950	1960	1970	1980	1990	2000
Surfaces (million ha)	9.8	13.4	16.6	22.2	23.5	25.7
Production (million tonnes)	6.4	10.3	20.1	31.8	49.8	69.7
Yield (kg/ha)	650	720	1,210	1,440	2,120	2,700

(Source: World Wheat Book I and II)

Table 24c ■ Wheat production in China.

Year	1950	1960	1970	1980	1990	2000
Surfaces (million ha)	9.8	13.4	16.6	22.2	23.5	25.7
Production (million tonnes)	6.4	10.3	20.1	31.8	49.8	69.7
Yield (kg/ha)	650	720	1,210	1,440	2,120	2,700

(Source: World Wheat Book I)

wheat in the world. China is now limited by availability of arable land and water and faces a major challenge to create wheat varieties more tolerant to heat and drought which is proving to be a higher priority than fighting biotic stresses.

These very substantial gains in wheat productivity are called the "Green Revolution", which were later followed by rice – developed again from Japanese germplasm (table 25).

Table 25 ■ Changes derived from the Green Revolution in Asia.

Year	Adoption of new wheat Mha/% surface	Adoption of new rice Mha/%surface	Irrigation Mha	Fertilizer Mt	Tractors M	Cereal production MT
1961	0/0%	0/0%	87	2	0.2	309
1970	14/20%	15/20%	106	10	0.5	463
1980	14/20%	55/43%	129	29	2.0	618
1990	60/70%	85/65%	158	54	3.4	818
2000	60/70%	100/74%	175	70	4.8	962

(Source: FAO, CIMMYT, IRRI)

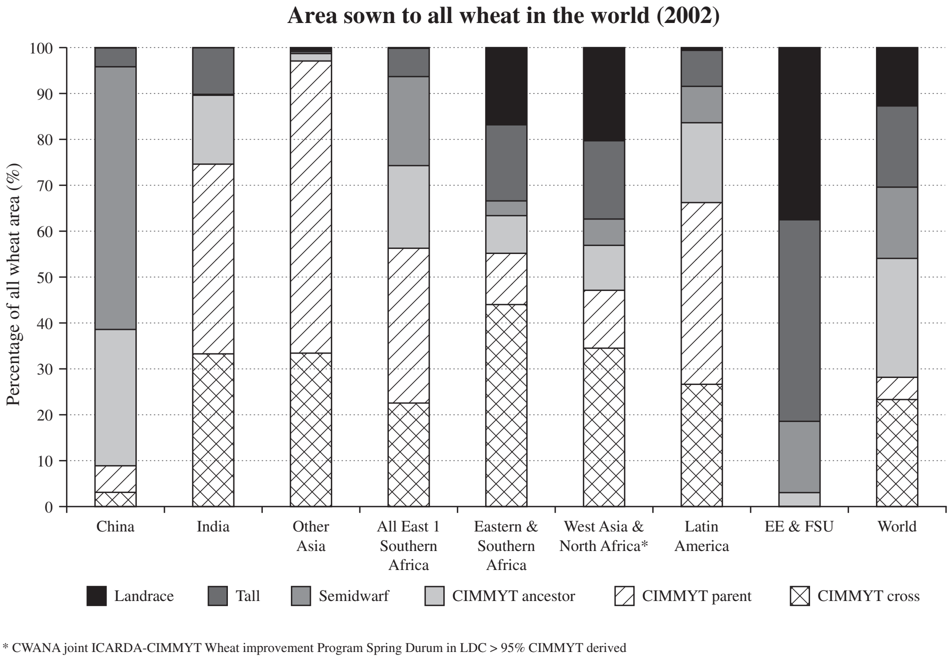


Figure 19 ■ Share by territory of CIMMYT wheat varieties and derivatives used in the world in 2002.
(Source: CIMMYT)

The introduction of CIMMYT varieties in wheat breeding programmes all around the world, lead to the global dissemination of *Rht1* and *Rht2* genes, including in Europe (figure 19).

The free flow of germplasm and knowledge attached to it was the basis for this success – a key requirement that should be remembered today, when incentives are often dominated by the prospect of short term profits.

The application of biotechnology and consequences

Based on current predictions, the world population, that reached 7 billion people in 2011, should exceed 9 billion people by 2050 mainly concentrated in increasingly large cities (megacities of 30 to 50 million inhabitants).

The requirement for wheat could then reach or exceed 900 million tonnes with water availability becoming a major limiting factor, with climate change and fossil fuel resources. The principles of conventional breeding – the breeder selection and crossing of intuited complementary parental lines and subsequent fixation of characters in certain progeny by selection – will no longer be sufficient to meet such challenges. To succeed, and this has already started, conventional wheat breeding will have to be combined with biotechnology. First to accelerate plant breeding, but also to better exploit the natural biodiversity in wheat and its relatives, and facilitating recombination. Finally, by deepening our knowledge of the complex wheat genome to the level of gene function and controlling new traits and systems.

In the early 1970's, French and Chinese scientists gave to wheat breeders a new tool for selection – doubled haploid production: *by in vitro* anther culture and colchicine treatment to double the chromosome number. With this method, varieties can be fixed more rapidly – the first commercial variety, Florin, was registered in France in 1987 by Desprez. With this method, also practiced through gynogenesis induced by pollination with bulbous barley or maize, the breeder can gain 2 to 4 years compared with a pedigree approach or its derivative methods such as bulk selection. It is widely used and could still gain efficiency if routine microspore cultures could be developed.

In 1944, the Americans E.R. Mac Fadden and E.S. Sears, and independently the Japanese H. Kihara, launched research into the creation of Nuclear genomes.

Since 1980, scientific discoveries in the field of plant biology have proliferated, particularly at the molecular level, and various technologies from image analysis to computing have resulted in a better understanding of the complex genome of wheat with its six copies of its genetic material, when most species have only two. The DNA of the 21 pairs of chromosomes contains 17 billion base pairs, representing 40 times that of rice, six times the amount of maize and five times that of humans.

So-called "synthetic wheat" has been developed by copying what had been done by nature, by recombining tetraploid wheat with *Aegilops taushii* (or related species) to generate wheat with new genetic variability. Indeed, there is an intrinsic variability in tetraploid wheat, and in *A. taushii*, since it its natural distribution spreads from Xinjiang to Shandong in China. Several teams around the world, including at CIMMYT, have followed this new approach. If the initial performances of synthetic wheat were not at first convincing commercial breeders on the lookout for immediate variety gains, the creation of varieties derived from synthetic wheat, after one or two back-crosses with local elites varieties has resulted, in the last decade, in Australia and China, in very interesting results. For example, the synthetic derived variety Chuanmai 42 gave a yield gain of about 20% in Sichuan, while also carrying a new yellow rust resistance and improved tolerance to abiotic stress. Another example of expanding the wheat gene pool is the well known 1RS-1BL rye/wheat translocation which brings to wheat a wide adaptation to new environments, despite a concomitant loss in baking quality. Others involve small alien chromosome translocations from species of tertiary wheat pool, carrying resistance to various diseases and/or new glutenins (figure 20).

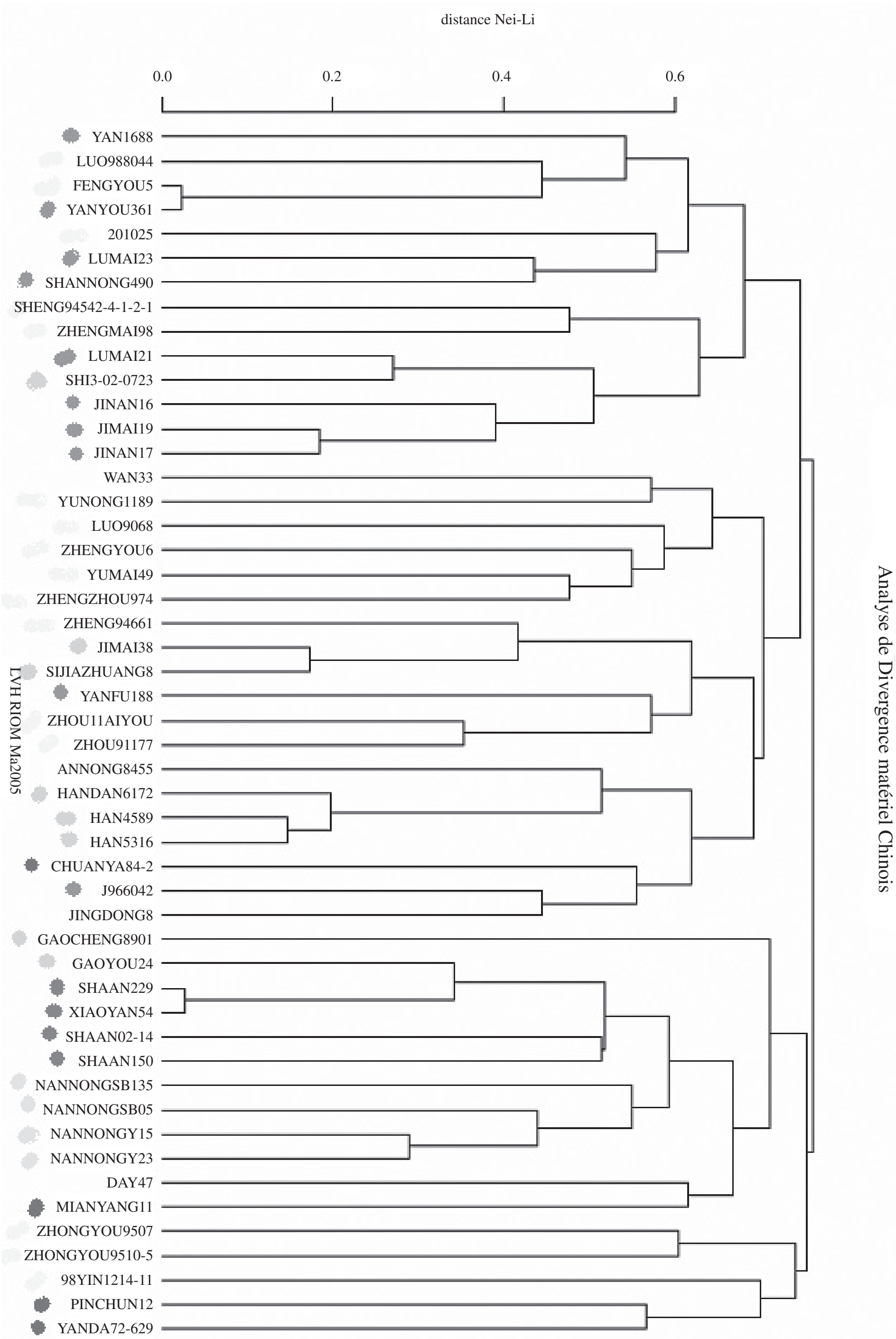


Figure 20 ■ Examples of genetic distances between Chinese wheat varieties analysed using SSR molecular markers.

(Source: Limagrain)

Molecular markers were first used in wheat to improve precision and speed in the selection process. The initial use of random markers faced the problem of the size of the wheat genome and its high number of repeated sequences. The move to informative markers and especially high throughput methods since the 2000s have mainstreamed their use in quantitative genetics and marker-assisted selection. Selection is no longer done on the sole observation of visible characters by the breeder but is now also based on genes present and their interactions, before their effect can be observed.

The genetic transformation of wheat was first achieved in the early 90s by using the particle gun, and spring wheat was later transformed using *Agrobacterium tumefaciens* in 1996 and winter wheat in 2003. Genetic engineering opened a new field of knowledge and wheat breeding. Using this technology, the effect of a gene can be turned off or amplified in the plant, or its expression can be targeted to a specific organ – like the high-amylose wheat generated by Limagrain with CSIRO – or a specific developmental stage. Genes that do not exist naturally in the species can also be used – like "*Bt*" or "*Roundup Ready*" corn. However the costs of deregulation are very large (15 to $US 100 million), their development phase very long (10 years) and they are subject to strong disagreements. In 2012, unlike corn, soybean, rapeseed, cotton and some other crops no genetically modified wheat has so far been commercialized (figure 21).

Nevertheless, genetic transformation of plants has become an essential tool in understanding how genes function and is used today on a significant scale worldwide for research applications, including in wheat.

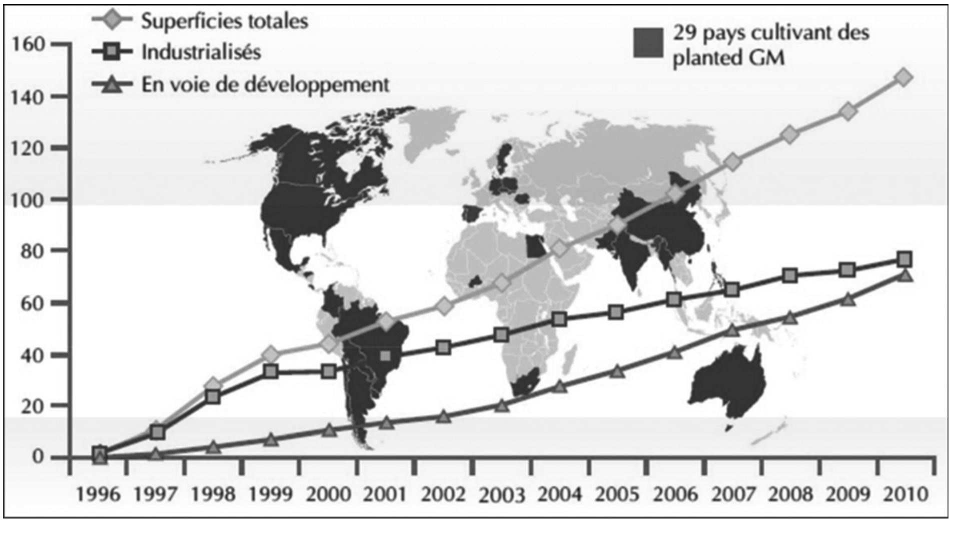


Figure 21 ■ Progression of GM crops around the world since 1996.
(Source: ISAAA).

With the advent of genomics in the 2000s, the complexity of the wheat genome (17,000 Mb, more than 90% of repeated sequences) can now be approached by ways of genotype rather than in terms of phenotype. An international consortium was established in 2004 aiming to sequence and make public the complete and orderly sequence of common wheat genome (figure 22). The results of this task will enable:

– making the link between traits and genes;

– understanding genome expression in different environments;

– using this information for precise breeding in wheat, including in genetic engineering (choice of genes, promoters, etc.).

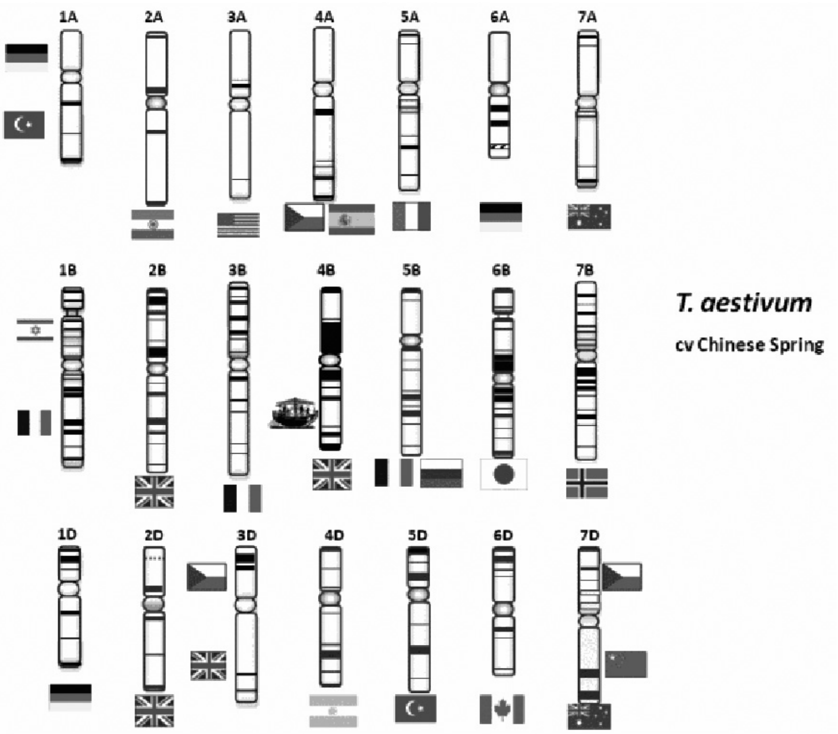


Figure 22 ■ International collaboration to sequence the 42 individual chromosomes of wheat.

(Source: IWGSC http://www.wheatgenome.org/)

New questions and rise of an opposition to technical progress

Since the beginning of time agriculture, including its cultivation, has fulfilled the demands for higher productivity from a growing population. However it must now respond to new qualitative, social and environmental pressures (figure 23).

Among the major producing basins – EU, China, India, United States of America, Russia, and also to a lesser extent Australia, Canada, Kazakhstan, Turkey, Pakistan, Argentina, Ukraine and Iran – which cover about 80% of wheat growing areas of the planet, as we have seen, yields are highly variable. The main producing countries – excluding China, India, Pakistan and Iran – are also the major exporting countries. Wheat is the regular staple diet for over a third of the population of the planet. As currently only 20% of world production of wheat is exported (only 10% of global wheat was exported in 1920), the major of wheat users are also the main producers.

The main importers are Egypt, the European Union, Brazil, Japan and Indonesia. Demand for wheat has increased rapidly with the growth of human population and income, but also the rapid growth of its use as animal feed, particularly in North America, the European Union, Australia and China. Although wheat has sometimes been challenged in terms of its value for human nutrition in recent years (like through the Atkins diet in North America or for allergies that it can sometimes cause) few substitutes have been brought forward against it because of the unique properties of wheat gluten to support a wide range of food and industrial uses, not shared with rice or maize.

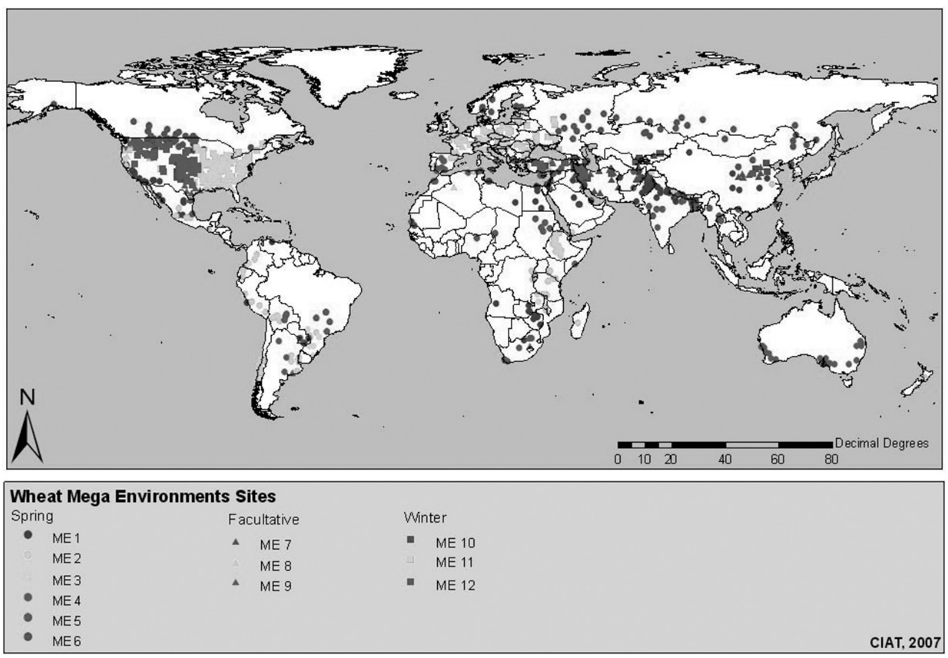


Figure 23 ■ Map of mega-environments in which wheat is cultivated today.
(Source: CIMMYT)

If wheat is the most widespread crop today on the planet in terms of surfaces and is grown on a wide variety of soils and under different climates, its distribution has not changed much since the 1970s. Its average yield per hectare has increased substantially since then, but remains behind in terms of efficiency gains compared to those of maize. rice and soybeans during this same period. Nevertheless, prices have sometimes fluctuated more than maize and rice in the last 50 years (figures 24 and 25).

From an environmental perspective, although it has contributed to the reclamation of much land for cultivation in the last century, wheat has a fairly good image and as it is largely sown in winter or early spring it makes a positive contribution towards reducing soil erosion. Compared to other crops, wheat cultivation also requires less water and pesticides (table 26).

In the short to medium term, production and consumption of wheat should remain stable because on the one hand, since 1995 the launch of corn-based biofuels limits the competition with this cereal, and the other some rice or sweet potato consumers are moving towards the use of wheat flour with the improvement of their living standards. The growth of organic farming in some areas in the West should not significantly affect the global wheat production. Many

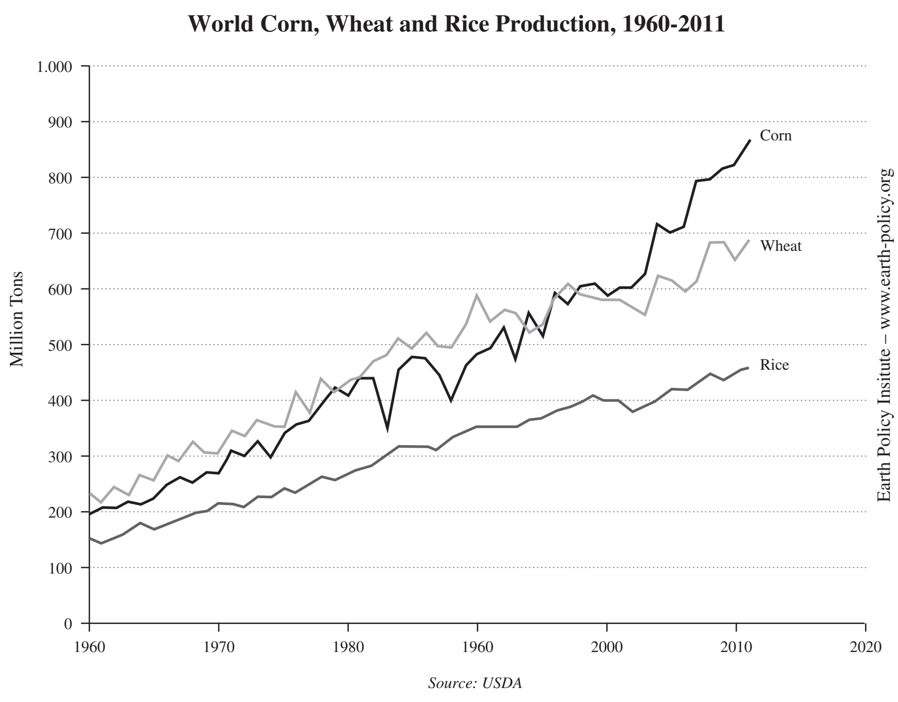


Figure 24 ■ Global production and prices for wheat, rice and maize 1960-2011.
(Source: Earth Policy Institute. OECD-FAO)

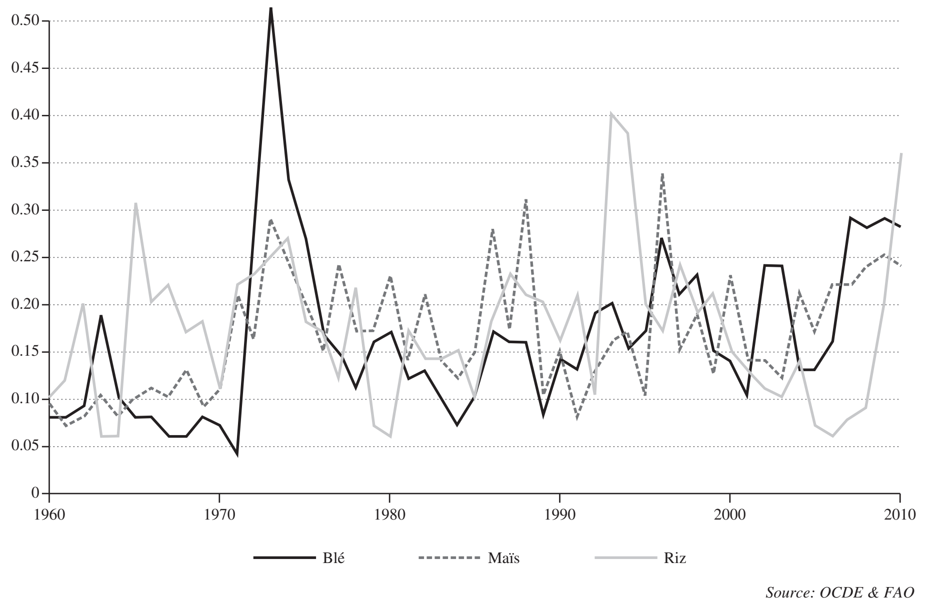


Figure 25 ■ Grain price volatility 1960-2010.

Table 26 ■ Amount of water needed for agricultural production (in litres of water per kg of product).

Productions	Litres of water /kg of product
Barley	524
Wheat	**590**
Maize (seed)	454
Upland rice	1,400
Irrigated rice	5,000
Soybean	900
Potato	590
Cotton	5,200
Egg	2,700
Milk	3,000
Cheese	5,000
Poultry	4,100
Pork	4,600
Beef	13,500

countries still face the challenge of raising their productivity to reach the global average yield.

In the longer term, some predictions of climate change due to global warming seem, in simulations, to be very favorable to some major wheat production areas in North America and Eurasia, although they would be very unfavorable to others areas like North-Africa, Mediterranean Europe, the Middle East, India and Australia.

A key issue regarding the future of wheat is the amount of research investment which the world dedicates and the distribution of the benefits of genetic progress between seed and biotechnology companies.

In 2010 it was estimated that worldwide research investment in maize was at least 650 million USD compared to 380 million USD for wheat. The impact of biotechnology on each species is difficult to measure but certainly more in favor of corn than wheat. Wheat research is often still largely financed by public funding, except in Western Europe, and will need to be strengthened to bridge the gap between these two major species which both play key roles in meeting humanity's needs. This is particularly the case in regard to maize where wheat has today – temporarily – two important technological deficiencies. Wheat is not commercialized as a hybrid and does not benefit from the advantages of hybrid vigor. Secondly it does not yet benefit from the advantages due to genetic engineering because there is so far no genetically modified wheat commercialized.

The adoption in 1961 of the UPOV Convention for the Protection of New Plant Varieties seemed to give breeders a satisfactory framework to protect and remunerate their research, addressing the world's needs for food quantity and quality and for the industry of crop production. A little later, in 1983, the plant genetic resources for food and agriculture was ratified by FAO as "*common heritage of mankind*" and should remain accessible to all, although from 1989 the free access was questioned by some developing countries considering themselves "robbed of their ancestral rights" by the developed countries with more advanced techniques. This movement came in 1992 with the adoption of the Rio Convention on Biodiversity giving individual states sovereignty over their genetic resources and specifies for the exchanges to be balanced bilateral contracts. In effect, there has been a considerable slowdown in genetic resources exchanges which had previously benefited the evolution of global productivity.

However, the development of biotechnology from the early 1990s has further complicated the situation by superimposing intellectual property rights on a gene, a sequence or a methodology to those already existing on varieties. Within a few years a single U.S. company, Monsanto, possessed over 90% of these new rights which increased tensions and fears in the agricultural world and connected industries, and had repercussions on all citizens in the world. Countries like the United States, Canada, Brazil and Argentina – to name only the most important ones – are very favorable to these new technologies, increasing substantially their agricultural productivity. Others, like China, have chosen to limit their adoption to non-food uses, like cotton. Others still, like Western Europe have largely rejected their use under the pressure of environmental groups, neo-Malthusians, despite the demands of a majority of its farmers.

Wheat or in the future hybrid wheat is very likely to be genetically modified throughout the world in the medium-long term. The European Union, although the market leader, is slipping into a situation contrary to its economic interests. It authorizes research on GMO wheat, but a large part of public opinion is against their cultivation. Yet a certain number of its major competitors, particularly the U.S., Canada and Australia aim at the commercial release of more competitive GMO wheat by 2020-25 which will significantly reduce European wheat exports. China, another top ranking wheat producer, is pursuing a biotechnology approach to develop varieties more drought tolerant to boost its grain yields after its success in hybrid rice. Similarly CIMMYT continues to breed for developing countries using all the tools at its disposal. The way producing countries will resolve the deadlock of interdependence (genetic x technology) and sometimes resistance to progress, will determine the economic future of their farmers and their agribusiness.

The other big question concerning the future of wheat is the current trend towards an increased financial control of the agricultural market. Since 1995 the United States has strongly supported maize-biofuel and there has been a convergence of food prices and energy. Fertilizer costs, the range of phytosanitary tools, irrigation, transportation of agricultural products are indeed very dependent on energy prices as shown by Momagri (http://www.momagri.org). This "think tank" brings together leaders of the agricultural world and representatives from different activities (health, development, strategy and defence) with the objective of promoting regulation of agricultural markets by creating new assessment tools (economic models and indicators) and making proposals for an international food and agricultural policy.

In developing countries there is often direct competition between food access and access to production resources, and, as in 2006-07, this can drive local agriculture into a negative spiral of productivity and dramatic price increases reinforced by speculation.

To avoid the appearance of volatile dramatic situations, a wide range of solutions are likely to be necessary to move towards a form of regional wheat markets regulation, and more generally of other field crops. These could include:

– incentive price policies for producers, tailored to the size of their farms;

– in some cases cultivation of new land;

– implementation of sustainable agriculture techniques including better water usage (called by some: "*the Second Green Revolution*");

– supportive infrastructure and logistics, and even agro-industrial processing;

– restricted support to bioenergy.

Wheat and its future role as a major cereal with rice and maize to feed an ever-growing world population

"*The destiny of nations depends on how they eat*", Anthelme Brillant-Savarin (1755-1825), Physiology of taste.

"*When there are millions starving, I think that there must be something fundamentally wrong*", Desmond Tutu (1931-), Nobel Peace Prize 1984.

Evoking the long coexistence of wheat and Man and history of agriculture in the world, this extraordinary "saga" – full of genetic breakthroughs and technology, trade, crisis and successes gives us the means to reflect on the future of wheat and, ultimately, on our own future.

Reminded recently by the food crisis of 2007-08, world hunger is more relevant than ever. Out of the world's seven billion people more than one billion still suffer from hunger today, while globally over the half of our fellow human beings now live in cities, and become increasingly older. "*The hungry are the poor, the non-consumers*" in the words of Sylvie Brunel, who was president of "Action against Hunger". Yet, paradoxically, because agriculture in the world has since 1950 been efficient, there will be 9 billion people to feed on Earth in 2050. If we do not want to rush humanity into chaos and violence, we must already meet this new demographic challenge. Yet, without advocating false solutions, we will have to provide "*access for everyone, anytime, anywhere, to healthy food, sufficient and culturally acceptable*". And primarily wheat.

Of course, our environment is no longer the same as centuries ago and continues to change: urbanization, artificial infrastructures connecting cities, deforestation and desertification of large areas, global warming from greenhouse gas emissions, new epidemics, reduction of fossil fuel... Water, free and abundant yesterday, is becoming a first vital resource, the limiting factor for agricultural production even before any access to land. Consumers in the most favored countries are also increasingly demanding. They demand perfect products, cheap, environmentally friendly and, for some, "fair trade"'.

Of course, the challenges for production and environmental protection are huge and legitimate. Production is and will always be a daily struggle. Looking at the past fifty years, although they have been particularly productive, it is clear that traditional agricultural methods will not be enough to meet the challenges of 2050. We must prepare for a new farming transformation using all the tools put at our disposal today by scientists and breeders, while using them appropriately. Similarly we must use persuasion to tackle the obstacles to innovation and those who, through stupidity or selfishness become its opponents. Above all we must be objective using science to promote production with high regard to humanity and environmental issues.

Past experience, the experiences of our own generation and those of our parents show the way forward. To remain confident for wheat and initiate steps to support the future of new generations, our own harvest.

The first issue concerns the environment directly. Theoretically, under constant climate, there is an opportunity to exploit more land since the FAO estimates that we cultivate just 40% of the theoretical surface land. By clearing a portion of the primary forests of South America, Africa and Asia, this process has begun. Nevertheless, it is not without damage to the biodiversity, soil fertility and water availability. Paradoxically, climate change observed in the twentieth century could displace some of the current production areas and give access to new territories, in particular the vast largely unpopulated expanses of Siberia and Canada, or even Patagonia, provided that development is carried out with sustainable practices. Leaving aside these theories, the intensification of cultivation for existing arable land appears to be the best route to produce more wheat with less water and fewer inputs. Starting pragmatically by increasing the productivity of the current largest production areas or the most socio-economically marginal and vulnerable areas – United States, Canada, Russia, India, Pakistan, Central Asian, Brazil, Africa...

Secondly, instead of lamenting about the changing times, it is important to increase the current progress and use, with reason, all technologies available to keep wheat, along with rice, the main cereal contributing most through its genetics to mankind's diet. For Norman Borlaug, Nobel prize winner in 1970, the issue was clear: "*If the naysayers do manage to stop agricultural biotechnology, they might actually precipitate the famines and the crisis of global biodiversity they have been predicting for nearly 40 years*". Thus transgenesis, a powerful tool to increase productivity, should be used and its research and application directed towards more favorable and acceptable targets – drought, cold, salt and toxic soils tolerance, better use of inputs – rather than the sole interest of a handful of large agrochemical companies. However, transgenics, as powerful as it is, is just another tool in the arsenal at the breeders disposal. It will be necessary to use all the opportunities available and combine them in an intelligent way and find solutions on a case by case. One example, the issue of water efficiency, can not be addressed in the same way in the plains of the French Beauce (well watered under an oceanic climate) and in the more arid areas of Shandong in China or Western Australia. It is important to be open to new discoveries: with its genome soon sequenced and a better understanding of its characteristics, new wheat varieties with more stable performances will be created, with particularly more effective root systems and photosynthesis.

The third requirement is to fight for the preservation of access to genetic resources, so that future generations can inherit the fruits of the potential held in these resources. Indeed, as shown by CIMMYT, 50% of the genetic progress achieved in wheat during the last 70 years around the world resulted from the flow of cultivars between breeders and their use in breeding to generate and then sort new progeny. While it is logical that public and private organizations investing heavily in order to isolate genes and propose improved varieties can patent their inventions to retroactively finance their research efforts, it should not lead to an obstruction of the access to biodiversity, conserved *ex situ* in gene banks or *in situ* in old varieties or related species repositories. It is urgent to define and implement a legal framework tailored specifically for biological resources with appropriate funding. Particularly as the future will involve genetically modified and hybrid wheat, many benefits could also come from the natural new genetic variability with the creation of "*synthetic*" wheat or recombinations between wheat and its related species.

A fourth approach is to invest unconditionally in the future, in science and also in training. Faced with the success of diversification of food and industrial uses of maize and soybean, today wheat lags behind. It will be necessary to diversify the uses of its grain, but also of the whole plant. There will be a need for more diversified food production and account being taken of problems related to gluten allergy occurring in some part of the population. Animal feed can be extended within traditional farming but also increasingly to aquaculture, increasing non-food or feed uses of wheat – not only of wheat grain. In universities and schools, it must become a priority to train the new generations in agronomy and agroindustry processing methods, an ancient knowledge in perpetual renewal. Without them the new contributions of biotechnology will have a limited impact.

Fifthly it is important to regulate the grain markets and ensure that an adequate financial return flows back from the processing industries and retailing to the producers. Without this support growers will inevitably leave their land rather than live without a future and respect. To meet the food requirements of their huge populations and generate decent incomes, Asia, Africa or South America will need to create agricultural policies and regionalized agroindustry as has happened in Europe and North America after WWII, before the excesses of trading speculation damage the most basic food supplies. Otherwise numbers of farmers in these countries will be condemned to extreme dependency, back to famine, rural exodus and a world prone to violence.

Wheat has a promising future, and the world's population with it , but only if various public and private players in the world go beyond their individual interests and work together, beyond their nationalities, their differences, sometimes their conflicts, to continue its improvement with better resources and coordination for the common good of Mankind.

Working through these challenges will not be easy, but there is a strong global network of breeders and related scientists as well as technological resources that can help deliver the necessary objective of relieving global hunger.

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Written in a relatively short time, this story from domestication of wheat to the present day has been a real challenge.

On one hand, it is difficult to find data and to check its validity for many parts of the world for antiquity and even the history of wheat up to the eighteenth or early nineteenth century, It was then difficult to identify trends. In addition, a large part of the historical information is largely euro-centric or Western-centric, and ignores data from other civilizations.

On the other hand, recent events are numerous and require both an aspect of selection and another of generalizations to produce a popular text, particularly for aspects related to the interactions between wheat and mankind and trade between different cultures.

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