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Original scientific article

FROM NEOLITHIC TO LATE MODERN PERIOD: BRIEF HISTORY OF WHEAT

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History of wheat cultivation is as long as history of civilization. Adaptation of nature, animal domestication and plant cultivation, enabled transition from nomadism to sedentism 12,000 years ago, portraying the rise of *Homo sapiens* of today. First civilization, Mesopotamia aroused around 4000 B.C.E, in the riverbanks of Tiger and Euphrates, where carbon-14 dating revealed that tetraploid wild emmer (*Triticum turgidum* subsp. *dicoccoides*) was grown. Due to modest cultivation requirements and high nutritional value, wheat quickly spread from its centre of origin throughout the world. Generations of farmers have chosen seeds from plants with best architecture, adapted to local conditions for sowing, striving toward constant improvement of yields. For centuries agricultural production was based on locally adapted wheat varieties of great genetic diversity. Agriculture completely changed its course in mid-XX century as a result of Green Revolution, introduction of high-yielding cereal varieties, chemical fertilizers and pesticides, irrigation and mechanization replacing traditional techniques. The flourishing of agriculture has drastically changed the course of agricultural development and global society. Improvement of agricultural techniques by integrating scientific advancements and knowledge to assimilate environmental factors has tripled wheat yields in last 50 years. Today, wheat, maize and rice, represent staple food for humanity.
Keywords: wheat, agricultural evolution, green revolution, wheat cultivation

INTRODUCTION

Wheat, rice and maize represent staple food for humanity. Due to its adaptability to adverse climate conditions, wheat is the most widespread agricultural crop grown on over 216 million hectares, with yields of 734 million tons, and total production value of $ 123 billion

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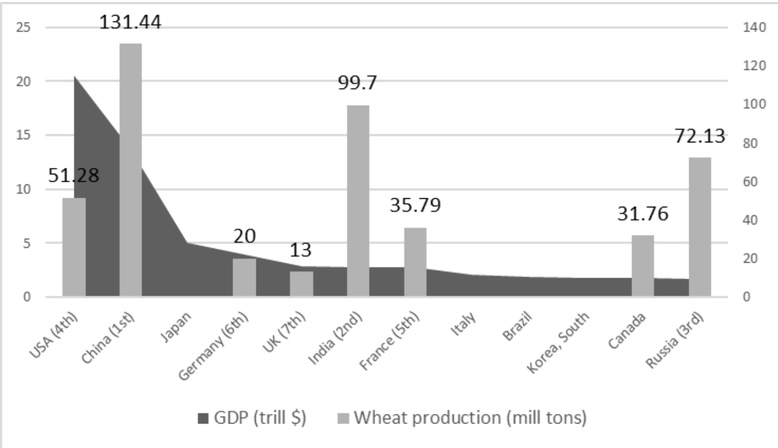
(FAOSTAT, 2018). It is grown in almost all regions in the world, most successfully produced at latitudes between 30° and 60°N and 27° and 40°S, and at altitude even above 3000 meters (CURTIS, 2002; TADESSE *et al.*, 2019). Most used for bread production, wheat grain has numerous other usages, like pasta, numerous pastry products, starch, alcohol, malt, dextrose, feed, fuel and many others (ACQUAAH, 2007; JOVOVIC *et al.*, 2017). A link can be made between wheat production and GDP of countries, and the leading wheat producing countries are the most economically powerful countries as well (Graphic 1). Top producers of wheat in 2018, belonging to the twelve countries with highest GDP: China (ranked 1st in wheat production of 131 million tons, and 2nd GDP of $13.60 trillion), India (2nd 99 million tons, 6th GDP $2.77 trillion), Russia (3rd 72 million tons, 12th GDP $1.66 trillion), United States of America (4th 51 million tons, 1st GDP $20.58 trillion) and France (5th 35 million tons, 7th GDP $2.77 trillion) (FAOSTAT, 2018; UNSD, 2020).



Graph 1. Top five wheat producing countries and GDP

Origins of Agriculture (First Agricultural Revolution)

Agriculture as known today began with processes of adaptation of environment and useful organisms to humans. Global climate change, glacier melting after the Ice Age, led to reorganization of ecosystems (FEYNMAN *et al.*, 2018). Plant and animal domestication and development of various agrotechnical practices occurred independently in a large number of locations worldwide (LARSON, 2010). Archaeological findings indicate that the beginnings of agriculture go back 12,000 years in Fertile Crescent in Middle East, credited as the Cradle of Civilization (Figure 1), where plant and animal domestication and various agrotechnical practices such as vegetation removal and tillage first arisen (FLANNERYL, 1973; LOEFFER *et al.*, 2015; FORRESTER, 2020). Middle East is centre of origin of barley, wheat, and rye (DENČIĆ *et al.*, 2001; PRŽULJ *et al.*, 2012). Lentils and broad beans, species from the *Fabaceae* family binding nitrogen from the atmosphere, were cultivated in the crop rotation, intentionally or accidentally, increasing soil fertility (LEV-YADUN *et al.*, 2000). Domestication of goats and sheep, and later cattle, occurred in this area. In central part of Americas, 8,000 years ago maize, potatoes, beans, cotton, tomato, tobacco, sunflower, llama, and turkey were domesticated (SMITH, 2005). In Asia, the first agricultural communities appear about 8,000 years ago in China with the domestication of millet, hops, mustard, soybean, rice, pigs, ducks and donkey in vicinity of agricultural fields near the Yang Ceng Jang River (DAL MARTELLO *et al.*, 2018). However, none of these crops and domesticated animals had such a profound impact on history of mankind as wheat had.

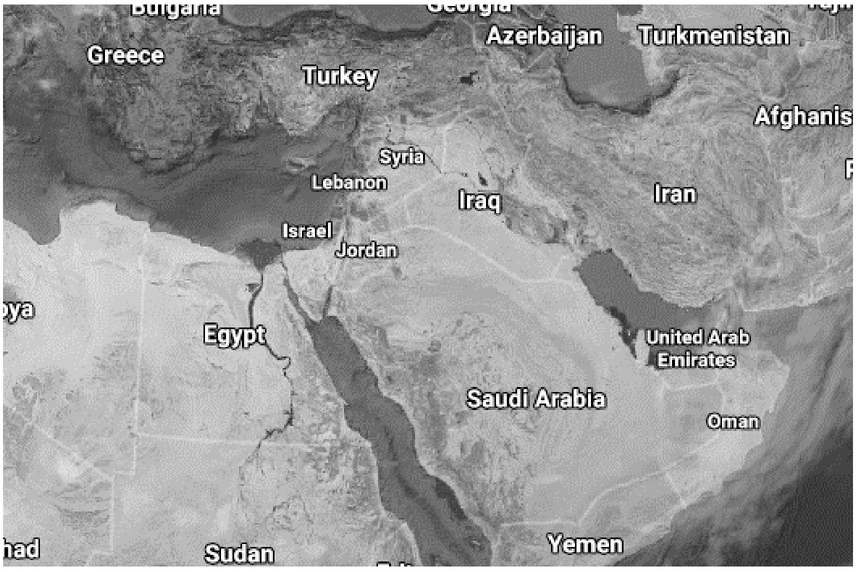


Figure 1. Fertile Crescent – Origin of Agriculture and Civilization (source: Google Maps, edited in MS Word)

Wheat domestication, 10,000 years ago, was a part of the 'Neolithic Revolution'. First cultivated form was einkorn (*Triticum monococcum*), with diploid number of chromosomes in Fertile Crescent and tetraploid emmer (*Triticum dicoccum*) in Near East (HEUN *et al.*, 1997) (Figure 1). Through the processes of natural hybridization and anthropogenic selection, wheat, with favorable characteristics - easy harvest, decreased seed dispersal and yield, new forms of wheat developed; tetraploid (AABB) wheat (*Triticum turgidum* subsp. *durum*) with four sets of chromosomes (28 chromosomes) in Near East and hexaploid (AABBDD) common wheat (*Triticum aestivum*) with 42 chromosomes in Western Asia. The origin of the A genome is *Triticum urartu*, the source of the D genome is *Triticum tauschii*, while the origin of the B genome has not been determined with certainty, and one of the assumptions is that it originates from *Aegilops speltoides* (FELDMAN, 1977; WANG *et al.*, 2013; YUKA et al., 2019). From centers of origin, wheat reached Greece 8000 BC, Balkans, Italy, France and Spain 7000 BC, UK and Scandinavia for around 5000 BP, China 3000 BC, Mexico in 1529 and to Australia in 1788

(FELDMAN, 2001). The earliest cultivated forms of wheat were selected by farmers from wild population. In centuries to follow, wheat production was focused on locally adapted varieties of great genetic diversity, produces from stored seeds past through generations.

With the process of domestication of plants and animals, biological changes under the influence of human selection increase their usefulness and become dependent to human intervention (ZEDER, 2008; MIROSAVLJEVIĆ *et al.*, 2016). In this reciprocal relationship between agricultural resources and anthropogenic inputs, as early as 2,000 years after the very beginnings of domestication, the need for movement in seek for food has decreased and social communities have become more stable (GIGNOUX *et al.*, 2011). People stationed, the first villages formed, and first communities that formed were based on kinship. However, none of the settlements formed was self-sufficient, and trade began, based on the exchange of goods as a vital component for the survival of these communities (LEV-YADUN *et al.*, 2000). Over time, agricultural societies became more complex and the need for social and political order is emerging with the introduction of religious practices, the legal system and social norms, and between 8000 and 3100 AD, first civilizations emerge (GIGNOUX *et al.*, 2011). The political organization of Mesopotamia began in the city of Sumer 5000 years ago, by merging and expanding social communities where agricultural systems were continuously evolving and becoming more sophisticated in the storage of cereals and the development of irrigation, selection of goats and sheep reared for the production of meat, milk and cheese (FLANNERYL, 1973).

In the Nile Valley 5500 years ago, the development of agriculture contributed to the growth of wealth and the development of a hierarchical system of social order. Egypt had one of the most complex societies of the ancient world. The agriculture was controlled by a state apparatus headed by a great visor. The canals along the Nile were used for irrigation, and the land was treated by a wooden plow pulled by oxen or donkeys. The sickle was used for wheat harvest (JANICK, 2002). Agriculture was the basic economy of ancient Greece and Rome, and nearly 80% of the population was involved in this activity (BARKER *et al.*, 2015). The prospectus of most Greek and Roman cities was based on agricultural production and the ability to produce a surplus that allowed part of the population to exchange their goods and engage in trade. Cereals, olives and wine were among the three most important marketed products (ZEDER, 2008). Egypt was the main source of grain supply for Romans. In Greece, state intervention was limited, with exception of grain imported from Egypt, to ensure that in times of drought, populations did not starve (BARKER *et al.*, 2015).

Agricultural development continued during the middle Ages from 600 to 1600 in Western and Northern Europe, and the Arabian Peninsula with little modification of cultivation techniques developed in ancient civilizations. The most important advances in agriculture occurred in countries north of the Alps, despite extensive migration and wars. Wetlands and forests became agricultural land due to social changes, increasing pressure of population growth and climatic factors. Land was plowed with cattle ploughs. Wheel plough began to be used in parts of Western Europe at the end of the 10^{th} century (KREMER, 1993). Medieval villages used three basic methods of cultivation and land use. Two fields were used for summer and winter sowing, while the third field was "resting" (fallow). Wheat or rye, and peas, beans, barley or lentils were sowed in winter and summer season, respectively. Every year the crops rotated and the same crop was not grown in the same field. These practices have ensured the long-term fertility of the soil. Crop fertilization was also introduced as part of cultivation practices, and mixture of clay and lime, and manure were used (BARKER *et al.*, 2015). Despite many new practices introduced, yields in the Middle Ages reach only a fifth of crop yields today (KREMER, 1993).

With the discovery of America in 1492, a new era began. New crops were introduced in production as a result of global exchange. Maize, potatoes, tomatoes, peppers and sweet potatoes are key crops that have spread from the New World to the Old, while wheat, barley, rice and beet traveled from the Old World to the New (BARKER, 2015). The movement of some species caused growth in production of different crop growth around the world and a lasting impact on many societies in the early modern period. For the first time, intensive use of fertilizers, guano imported from Peru, the use of arsenic, an artificial pesticide were introduced into production. This period, which begins with the first intensification of production, is known as the Second Agricultural Revolution (ALLEN, 1999).

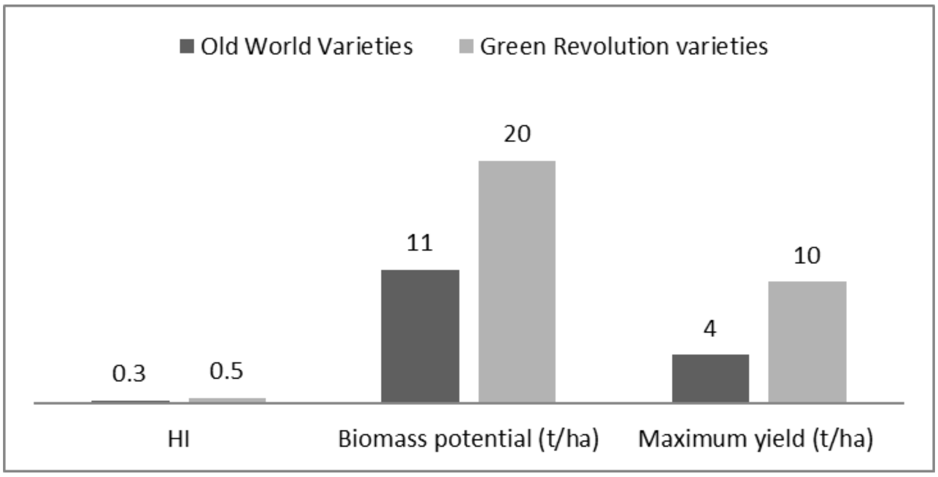
Second Agricultural Revolution

Between the 17th and 19th centuries, Britain experienced a dramatic increase in agricultural productivity, known as the British Agricultural Revolution (ALLEN, 1999). Industrial and commercial interests led to agricultural improvements in mechanization, increasing productivity (BARKER, 2015). Internal combustion engines have been used in combines and tractors, and chemical technology has found applications in synthetic fertilizers and pesticides (EVENSON *et al.*, 2003). It is estimated that wheat yields increased by half in the 19th century (OVERTON, 1996).

One of the biggest breakthroughs in agricultural development is the development of new varieties and hybrids with improved yields at the end of 19th century. Genetics, science studying principles of inheritance and variation was founded in the early 20th century, although the principles of inheritance were known much before (PINGALI, 2012; PRŽULJ et al., 2016). Application Mendelian principles of heredity were most noticeable in development of semi dwarf wheat varieties through introduction of short-straw Japanese variety Akagomughi (BELL, 1987).

Third Agricultural Revolution

The Green Revolution, or the Third Agricultural Revolution, is a continuation of the implementation of technologies and scientific knowledge that increased agricultural production around the world between 1950 and the end of 1960, which were particularly relevant to developing countries. The increase in yields is the result of the introduction of high-yielding varieties of cereals, chemical fertilizers and pesticides, irrigation and mechanization that have replaced traditional technologies (EVENSON *et al.*, 2003). The beginnings of the Green Revolution are credited to Norman Borlaug, an American scientist. His work focused on the selection of new varieties of wheat, lower, dwarf varieties resistant to lodging, seed dispersal, and a disease-resistant, broad area of adaptation, insensitive to day length with high response to inputs. By combining wheat varieties with new mechanized agricultural technologies, in Mexico where Borlaug conducted research, more wheat was produced than needed, leading Mexico to become a wheat exporter in the 1960s. Thanks to the success achieved, varieties have spread worldwide (SWAMINATHAN, 2009). Initial success in breeding new varieties attracted broad scientific society leading to development of roughly 1,000 varieties commercially used (POSNER *et al.*, 2011). Modern wheat varieties production and distribution worldwide reached their peak during 1980’s and 1990’s. This period is often cited as late Green Revolution (EVENSON *et al.*, 2003) Combination of modern varieties and intensive input use let to dramatic increase in production accompanied with minor increase in area planted. As a result, wheat yields have almost tripled in the last 50 years (KHUSH, 1999). Old varieties had a harvest index of 0.3, meaning that the grain to straw ratio was 30:70, with a total biomass production capacity of 10-12 t/ha, therefore their maximum yield potential of 4 t/ha. Green Revolution varieties, on the other hand, had a harvest index of 0.5. Their total biomass potential was 20 t/ha, so their maximum yield was 10 t/ha (KHUSH, 1999) (Graph 2).



Graph 2. Harvest Index, Biomass potential and maximum yield of old varieties before and after Green revolution

Wheat of 21st Century

Modern agricultural systems were developed with two goals: to get the highest possible yields and to achieve the highest possible economic profit (MIROSAVLJEVIĆ *et al.*, 2018). Six core practices created the spine of wheat production - intensive tillage and irrigation, monoculture, application of inorganic fertilizer and pesticides, and genetic breeding of crops - aimed at reaching these two goals. However, for almost every benefit of modern agriculture, arise problems that today's economy faces. Excessive tillage has led to soil degradation, loss of organic matter, erosion and soil compaction. Large monocultures are particularly prone to devastating pest epidemics. Uncontrolled use of fertilizers led to environmental pollution. Modern wheat varieties have greatly contributed to the loss of genetic diversity and increased dependence on synthetic inputs necessary to maintain high yield (COOPER, 2015).

Green Revolution was a key event resulting in growth of wheat production. However, it has taught scholars and decision makers' important lessons for the future (PENGALI, 2012). The degree to which technology is applied depends on socio-economic factors, so often high technology is only retained within the borders of developed countries that have the necessary financial resources. Intensive industrial development in last century led to global climate change reflected trough increase in greenhouse gas emission and temperature, periods of drought and unpredictable variation in precipitation (HOWDEN *et al.*, 2007). Climate change affects wheat production significantly, making large-scale agriculture difficult to sustain without alterations of current practices (ASSENG *et al.*, 2015; VALIZADEH *et al.*, 2014). Compared to nowadays 15% of wheat growing areas affected by drought, it is estimated that without climate change mitigation practices, area affected by drought could reach up to 60% (TRNKA *et al.*, 2019). It is therefore necessary to enable wheat to cope better with climate treats, particularly at local scale as negative weather effects are often localized (HARKNESS *et al.*, 2020). Change of wheat cultivation practices should satisfy food demands of growing human population and climate change mitigation. Crop rotation with legumes and smart N and fertilization and lime application could be beneficial to food security but the risk of eutrophication and soil acidity and marginal costs of more environmental friendly practices (SIMMONS *et al.*, 2020).

The principles of further agricultural development combine modern technology and traditional knowledge and genetic resources, including wild relatives and landraces. Agro-ecological systems of the future should be an integral part of nature to ensure food safety and security (FAO, 2018). Thus, future of wheat breeding relies heavily on scientific advances and application of genetic modification and marker assisted selection as tools for wheat improvement (PRŽULJ and PEROVIĆ, 2005; KÖNIG *et al.*, 2012). In recent years, the scientific community has increasingly focused on selection wheat varieties with higher genetic diversity, adapted to broad spectrum of environmental conditions, biological pest control and soil fertility enhancement (SADIK, 1991; RAKASCAN *et al.*, 2019). In wild wheat relatives and traditional varieties, breeders today often find resistance genes to numerous pests (TANKSLEY *et al.*, 1996). Opting toward the concept of sustainable agriculture, which sees economic development, environmental protection and social aspects as three inseparable goals should be the aim of breeding wheat for the future (EBERT, 2015; PRŽULJ *et al.*, 2020).

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OD NEOLITA DO KASNOG MODERNOG DOBA: KRATKA ISTORIJA PŠENICE

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Izvod

Istorija gajenja pšenice duga je koliko i istorija civilizacije. Adaptacija prirode, pripitomljavanje životinja i gajenje biljaka omogućili su prelazak iz nomadizma u sedentizam pre 12.000 godina, oslikavajući uspon današnjeg *Homo sapiens*-a. Prva civilizacija, Mesopotamija je nastala oko 4000. godina p.n.e. na obalama rekaTigar i Eufrat, gde datiranje ugljenika-14 ukazuje na gajenje tetraploidnog emera (*Triticumturgidum* subsp. *Dicoccoides*). Zbog skromnih zahteva pri gajenju i visoke hranljive vrednosti, pšenica se brzo proširila iz centra porekla po celom svetu. Generacije farmera birale su seme biljaka najbolje arhitekture, prilagođenih lokalnim uslovima gajenja, težeći stalnom poboljšanju prinosa. Vekovima je poljoprivredna proizvodnja bila zasnovana na lokalno prilagođenim sortama pšenice velike genetske raznolikosti. Poljoprivreda je potpuno promenila svoj tok sredinom XX veka kao rezultat Zelene revolucije, uvođenja visoko prinosnih sorti žitarica, hemijskih đubriva i pesticida, navodnjavanja i mehanizacije zamenjujući tradicionalne tehnike. Procvat poljoprivrede drastično je promenio tok razvoja poljoprivrede i globalnog društva. Poboljšanje poljoprivrednih tehnika integrisanjem naučnog napretka i znanja uz asimilaciju faktora životne sredine utrostručilo je prinose pšenice u poslednjih 50 godina. Danas pšenica, kukuruz i pirinač predstavljaju osnovnu hranu za čovečanstvo.

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