TRITICALE REVIEW: NAVIGATING PAST ACHIEVEMENTS, CURRENT REALITIES AND FUTURE HORIZONS IN AGRICULTURAL INNOVATION

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Abstract. The purpose of this paper is to understand the evolution and sustainability of triticale from the perspective of time: past, present and future. This review paper is based on analyzing the specialized literature using a set of keywords, a search that conducted to scientific databases, such as Web of Science, Google Scholar and Scopus. The findings reveal that triticale is more and more cultivated and present in the agriculture topics. Due to its plasticity to adapt at adverse environmental conditions this culture is suitable for growing under poor conditions compared to wheat and other cereal crops. Most of the farmers started to see the advantages of this culture and triticale started to be more visible by being cultivated and also studied. Triticale is the first man-made cereal crop species that combines the positive attributes of wheat and rye.

Keywords: triticale technology, production, triticale uses, triticale advantages.

INTRODUCTION

Historically, triticale combines the best attributes of wheat and rye: wheat's functional characteristics for food production and rye's adaptability, incorporating the functionality and high yield of wheat and the durability of rye, has mostly been used as animal food (Nakurte et al., 2012). Therefore, in the literature, we can find research data on the growing conditions of triticale and on its uses for animal feeding, but less is known about the use of triticale in the human diet. Some investigations indicate that triticale has potential for use in bread production (Martinek et al., 2008). However, because most of the varieties available are not suitable for leavened bread making on their own, due to the production of a weak and sticky gluten, they can only be successfully used for producing a range of unleavened products such as cakes, cookies, biscuits, waffles, noodles, pastas and breakfast cereals (Skovmand et al., 1984; Pena, 2004).

According to the specialized literature, triticale is not a fully completed plant, but in spite of this the attributes of today`s triticale provides the crop with enough competitive advantages for it to be cultivated around the world.

MATERIALS AND METHODS

This review paper is based on analyzing the specialized literature using a set of keywords, a search that conducted to scientific databases, such as Web of Science, Google Scholar and Scopus. On the basis of this platforms and using a set of keywords like: triticale, triticale history, triticale uses, cultivation, triticale advantages, triticale diseases this review article has been composed. For the analysis of the use of triticale and other data and curiosities about this cereal, a number of 32 references were studied from national and international specialised literature.

RESULTS AND DISCUSSIONS

Triticale production and main characteristics

Triticale, originally called *Triticosecale rimpaui, later renamed* (X *Triticosecale Wittmack*), is the first man-made cereal grain crop species, an amphiploid hybrid between the seed-bearing parent wheat (*Triticum turgidum* spp. *durum* or *Triticum aestivum*) and the pollen parent rye (*Secale cereale*).

The first deliberate hybrid between wheat and rye was reported by A.S. Wilson in Scotland in 1875. However, the first fertile hybrid between wheat and rye was produced by the German breeder W. Rimpau in 1888. The hybridization can also produce hexaploid (AABBRR; 2n = 42) or octoploid (AABBDDRR; 2n = 56) genotypes. At the beginning, especially octoploid genotypes of triticale seemed to have sterile flowers, frequency high aneuploidy, low grain yield, low weight, pre-harvest sprouting and lack of adaptation to different pour environments (Camerlengo and Kiszonas, 2023).

Considering this, in the second half of the 20th century specific breeding programs appeared and produced triticale cultivars with enriched characteristics. According to this, in the 1996s, CYMMIT breeders identified a spontaneously cross between triticale and a semi-dwarf common wheat variety, which represented a step forward about grain yield and wider adaptability.

As a result, the harvested area significantly increased from 1980s, in 2020 the world production of triticale was 15,361,341 tons from 3,812,724 ha harvested, slightly higher than that reported in wheat (FAOSTAT data).

Meanwhile, as actual data from FAO show, in Table 1 are the first 20 countries which are relevant considering production of triticale in the 2022 year.

Table 1.

Top 20 countries production of triticale, 2022

Country	*Tons*	*Country*	*Tons*
Poland	5,440,270	Lithuania	204,560
Germany	1,929,700	Romania	192,410
France	1,613,730	Hungary	186,480
Belarus	1,192,879.87	Sweden	162,500
Spain	634,890	Brazil	127,737
China, mainland	386,071.11	Australia	117,200
Türkiye	320,000	Serbia	96,897
Russian Federation	306,874.99	Chile	81,067.66
Austria	292,870	Italy	64,910
Czechia	207,620	Canada	60,504

Source: https://www.fao.org/faostat/en/#rankings/countries_by_commodity

Triticale cultivation

Sustainable production and consumption are two essential conditions for sustainable development (Bengtsson et al., 2018; Prati, 2022). In addition, this paper aims to determine the evolution of triticale during time and also its uses, diseases and importance in this continue world evolution. Accordingly, a comprehensive literature review was carried out with the aid of a predefined set of keywords and publications by other authors from scientific literature were consulted. The focus of the present review article can also be to provide an overview on end-use quality characteristics of triticale.

According to the scientists' vision, triticale should have had the best traits of both parents, the bread-baking quality of wheat grains and excellent adaptability of rye to different agro-ecological and soil conditions, as well as increased tolerance to pests and pathogens. A new type of grains should have been cultivated with less investment in production technology and would have been suitable for growing in developing countries with the aim of providing larger amounts of basic food for the population (Glamočlija et al., 2018). However, modest knowledge in the field of genetics did not provide an answer to solve the problem that arises by crossing different species and as a consequence has a sterile F1 generation, said Laibach, 1925 in "The importance of triticale in animal nutrition" by Glamočlija et al., 2018. Nevertheless, the expectations of the global public and forecasts were that the newly created grain, thanks to its high fertility potential, would significantly increase food production, both in underdeveloped and developed countries. The Swedish geneticist Arne Müntzing (Müntzing, 1979) wrote that it should be expected that the synthetic species of triticale will join the old grains as food for a significantly larger number of human population and their domestic animals.

The First World War interrupted the work on triticale selection in Europe, but it was continued on the American continent. Using the most modern genetic methods, the first problem of poor fertility of the new hybrid was solved. The second step was to increase the quality of grain for human consumption and domestic animal consumption. Work on triticale selection in Europe was continued between the two World Wars. Since the beginning of work in CIMMYT, more than 200 varieties of triticale have been created and can be used in different ways (Glamočlija et al., 2017).

Nutritional quality of triticale

The nutritional quality of triticale in some respects surpasses with that of wheat or is similar to, but triticale's higher lysine content, better protein digestibility and better mineral balance makes it especially suitable for being used in animal feed and less in human food. The majority of the triticale produced around the world is used for animal feed. Triticale has higher protein content than wheat, together with a more favourable amino acid balance, factors which are advantageous for the swine and poultry industries. It is also used as ruminant forage or feed - in the form of silage or hay (Arendt et al., 2013).

On the other hand, triticale flour shows inferior technological quality compared to wheat, therefore it is less frequently used for food production, if not mixed with wheat flour that confers high quality for bread-making. Technological properties of triticale flour and dough remain of a poor end-use quality with a lower utilization in food processing compared to wheat and rye (fig 1). However, the high nutritional value of triticale grain may be a strength to a wider diffusion in food industry through the production of healthy foods (Camerlengo and Kiszonas, 2023). This can also be better observed in the Figure 1. The health benefits of consuming nutrients from triticale maybe will lead to increase consumer acceptance towards triticale.

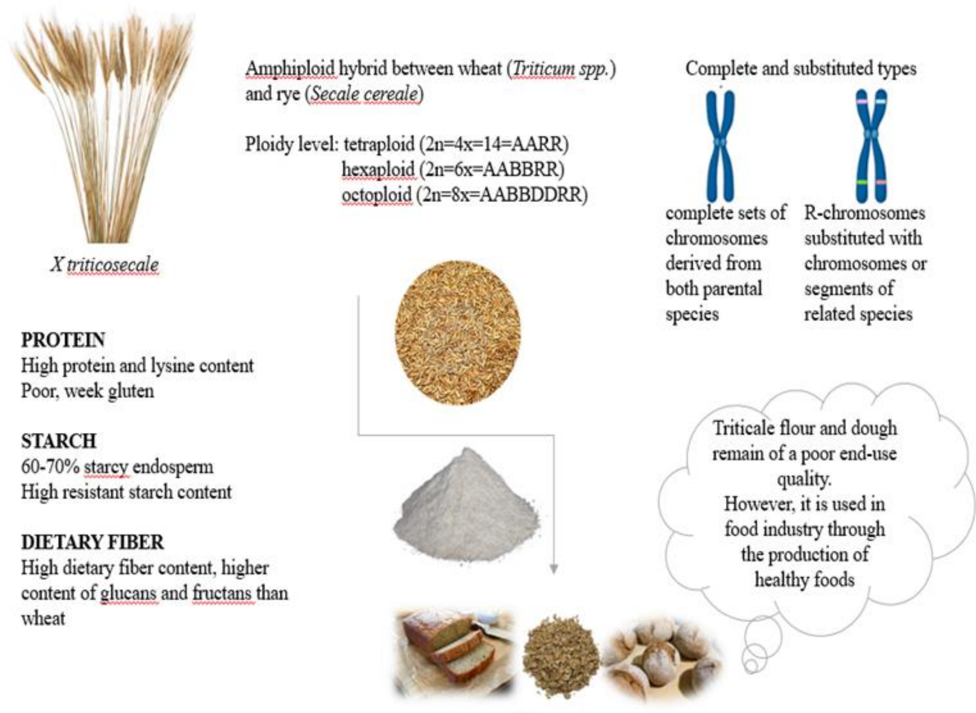

Fig 1. Triticale composition and uses
Source: own developing inspired by Camerlengo and Kiszonas, 2023

Triticale plays a unique role in producing dietary bread (fig. 1) for patients with metabolic diseases, which explains why global demand for triticale production has risen in recent years (FAOSTAT 2018). In general, triticale grain helps to control diabetes (Havensone et al., 2017), improves digestion, boosts circulation, increases cell production, and boosts bone growth. In the same area, in Table 2 some functions of the most common components of triticale grain are detailed and explained. Despite all these triticale grains are cultivated and consumed much less than other grain crops, which may be explained by the lack of more detailed information on their nutritional value (Kamanova et al., 2023).

Table 2.
Selected components of triticale grain and their functions

Component	Feature	References
Carbohydrates	Amylopectin and amylose affect gelatinisation, retrogradation, water absorption and paste viscosity	Cornejo-Ramírez et al., 2015
Phenolic compounds	Antimicrobial activity Antimutagenic activity	Reiss, 1989; Iwatsuki et al., 2003; Fardet, 2010;

	Antioxidant activity Inhibit the accumulation of triglycerides Antioxidant, anti-inflammatory properties Antitumor properties	Hladyszowski et al., 1998; Agil et al., 2016; Roca-Rodríguez et al., 2014; Prasad et al., 2012; Hucheng Chen et al., 2018;
Polysaccharides	Reduce postprandial responses to glucose and insulin Increases insulin sensitivity in both diabetics and non-diabetics Absorb free radicals Prebiotic action Increase the bioavailability of copper, iron, magnesium and zinc Increases the absorption of calcium	Juntunen et al., 2002; Sierra et al., 2002; Alminger and Eklund-Jonsson, 2008; Malunga et al., 2017; Raschka and Daniel, 2005; Coudray et al., 2006; Lobo et al., 2009; De Modura et al., 2012; Cashman 2003;
Minerals	Functional part of various enzymatic processes in gluconeogenesis The main antioxidant found in cereals	Lee et al., 2000; Rayman, 2000;
Protein	Antioxidant action, anti-inflammatory and anti-tumour properties lower cholesterol	De Lumen, 2005; Nakurte et al., 2012; García-Nebot et al., 2014;

Source: own processing based on information provided by Kamanova et al., 2023

In the diet of domestic and animal farm triticale is used in many ways. Grains, having a high content of protein and carbohydrates, serve to prepare concentrated animal feed. Based on current knowledge on triticale grains used in the production of concentrated animal feeds, the best results are achieved in the feeding of poultry (turkeys and chickens) and dairy cattle. As a forage plant, triticale has a higher yield than other real cereals. The highest quality biomass is obtained by mowing the plants at the beginning of ear formation while the highest yield is achieved by a later mowing. In order to increase the protein value of vegetative biomass, triticale should be sown with some of the grain legumes. The advantage of triticale over other real cereals is a faster spring rise and the possibility of a longer mowing time for green feed, as it grinds later than rye or oats (Glamočlija et al., 2018).

The perspective of the sustainable development of triticale

The increasing trend in global population and increased meat and dairy consumption implies a greater demand for livestock feed. Triticale is a suitable grain for cultivation in water-stressed areas (Moeinoddini et al., 2017) and it also has the potential to replace corn grain as a source of energy and protein with a well-balanced profile of essential amino acids. In the same time, it is well known that triticale is resistant to drought conditions and diseases, is favorable for low-input farming because of its low demand of pesticides application and can be cultivated on more marginal lands.

Despite the fact that triticale is a crop on which meet pathogens of wheat and rye like Edward Arseniuk said in 2018 in "Triticale Diseases- a Review", triticale over a long time has been considered as resistant to diseases. The first triticale disease which occurred in epidemic proportions was stem rust (*Pucinia graminis* f. sp. *tritici*) in Australia. Leaf and stripe rusts (*P. recondita* f. sp. *tritici* and *P. striiformis*) are also gaining in importance everywhere triticale is grown. The same concerns several facultative pathogens, such as the most damaging to triticale *Septoria nodorum*, *Fusarium spp*., *Bipolaris sorokiniana*, *Pseudocercosporella herpotrichoides*, and *Gaeumannomyces graminis* (Arseniuk, 2018).

Resistance to diseases in triticale has been considered as one of its most important and durable advantages. Although, this advantage disappears with the expanding of cultivated areas and the cultivation time. Anyway, in comparison to wheat and rye triticale still looks as a healthy crop which can be easily cultivated on damaged soils and unfriendly areas.

Today's varieties of triticale have more biological characteristics of wheat than rye due to backcrossing of newly created lines with wheat. Morphological properties of grains are more like these of wheat, with a slight variation in the mass of 1,000 seeds. Also, new varieties of triticale have higher starch content in grains, hence the grain is more energy efficient. However, this has led to a decrease in the total protein content compared to older varieties. Still, the amount and quality of total proteins in triticale grains are more favorable for feeding domestic animals than in other cereals (Varughese et al., 1996a; Boros, 2002; Van Barneveld, 2002 – cited by Glamočlija et al., 2018).

Triticale usually exceeds wheat, barley and other cereals in the amount of straw produced, especially in dry and semi-dry areas (Mergoum et al., 1992)..

CONCLUSIONS

To develop a crop that would be competitive with other cereals, end-use quality is one of the major concerns to be addressed. The world's triticale production has risen steadily in recent years. Triticale grain has a higher biological value than wheat and rye. However, the utilization of triticale flours in food production, even if limited by poor end-use quality, is gained by the nutritional value conferred by a more balanced amino-acid composition and higher content of protein and health promoting compounds compared to wheat, such as dietary fiber and polyphenols. Triticale flour includes important minerals such as potassium, phosphorus, copper, manganese, and others, in addition to high-quality protein. Furthermore, it demonstrates high hardiness therefore would increase the cereal world production, especially under poor and stress growth conditions.

Triticale are also used successfully in animal feed, but less for the moment in human food. This is one of the reason why scientists concentrate their attention to study the impact, importance and uses of triticale in human food. Triticale is a resistant crop to diseases compared with other cereals, has good results on unfriendly areas like dry soils or poor in nutrients.

In the perspective of more sustainable agriculture, the environmental adaptation plasticity of triticale with low inputs and its end-use versatility, could be exploited and improved to face the demand of health benefits foods and the need to growth cereals in marginal lands in order to feed a constantly increasing world population.

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