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ECONOMICALLY SIGNIFICANT PRODUCTION OF *Secale cereale* L. AS FUNCTIONAL FOODS

SUMMARY

Secale cereale L. is second important bread grain, after wheat, and an economically important crop for functional food. Rye production parameters in world and in Serbia were analysed in this study and quality parameters. The average rye area (4.28 mill. ha) and production (12.12 mil.t) in world, in the five-year period, recorded a growth trend and average grain yield was 3.01 t ha^{-1}. In 2020 in the Republic of Serbia, the average grain yield of rye was 3,23 t ha^{-1}. Rye is considered a healthy cereal due to its high content of dietary fiber and is a rich source of vitamins B and E, minerals: Ca, Fe, F, P, K, Zn, Mn, Cu, K, which is why it is a suitable raw material for the production of functional food. Rye foods have beneficial effects on insulin, which may have positive implications for diabetes prevention. Development of innovative and tasty rye products is crucial in increasing awareness, consumption of rye foods and thus production.

Keywords: rye; production; yield; quality; functional food

INTRODUCTION

Rye (*Secale cereale* L.) is the most important bread grain, after wheat. Among cereals, rye has the highest content of dietary fiber and contains a broad spectrum of bioactive compounds (Koistinen *et al.*, 2018) that have been shown to affect physiological processes relevant to health. The growing

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demand for rye bread is due to the specific taste and aroma of bakery products. Diet is one of the most important environmental factors affecting the risk of developing non-communicable diseases and premature death (Mathers *et al*., 2008). High intake of whole grain cereals has consistently been associated with lowered risk of developing type 2 diabetes, cardiovascular disease, and some cancers (Aune *et al.*, 2016). Rye dietary fiber contain of arabinoxylan, cellulose, β-glucan, fructans, and lignin and are considered as the main driver of the health effects of rye foods. Of bioactive compounds in rye is phenolic acids, lignans, benzoxazinoids, and alkylresorcinols (Koistinen *et al*., 2017). In the list of phytochemicals detected in rye is found at almost 2000 chemical species (FooDB, 2018). Epidemiological studies have revealed that such food items are particularly protective against various diseases when consumed as part of the habitual diet (Schwingshackl *et al*., 2017).

Rye is a rich source of vitamins B and E, which is why it is a suitable raw material for the production of functional food. Rye is considered a healthy cereal due to its high content of dietary fiber (Rakha *et al*., 2010), it also contains minerals (Ca, Fe, F), lysine and oleic acid (Gumul *et al*., 2007). The main product is grain, which mostly used for bread and bakery product and in the industry for the production of alcoholic beverages. Grain of rye is utilised in a lot food products as well, in breakfast cereals, porridges, pasta, etc. Scientific research is focused on studying the possible health benefits and of using it for energy purposes. Rye is a real cereal perfectly adapted to different agroecological conditions, so that it has a very large area of distribution. It is mostly grown in harsher climates thanks to its resistance to frost and disease. Rye is major source of starch and energy. Rye grain contains nutritional components: protein, fat, vitamins (B vitamins), dietary fibre and phytochemicals. Improving drought tolerance has always been an important objective in many crop improvement (Psota *et al.,* 2009; Ikanović *et al.*, 2022). It is mostly grown in harsher climates thanks to its resistance to frost and disease. Rye bread stays fresh for a long time, is rich in vitamins of groups A, B and E and has high digestibility. Rye grain is smaller than wheat grain, which mostly depends on the variety and growing conditions. Grain is the raw material for obtaining starch and producing spirits. Rye sprouts are rich in vitamins, oils and mineral salts and are used in the food and pharmaceutical industry. Rye bread and bakery products play an increasingly important role in a healthy diet, it is recommended in the diet of diabetics and people with high blood pressure (Glamočlija *et al.*, 2015; Rajičić & Terzić, 2022). Because of the content of soluble dietary fiber, rye foods have cholesterol-lowering properties. Considering the many health benefits that rye food can have, its consumption is consumed.

The aim of this study was to determine the growth trend of rye production in the world and in our country and the possibility of using rye in functional food. Development of new tasty rye products, associated health claims, with application good marketing are crucial in order to increase

awareness and consumption of rye foods among consumers therefore, an increase in production.

MATERIAL AND METHODS

Rye production parameters in world and in Serbia were analysed in this study for the period 2016-2020. The research was based on available data from statistical publications (FAO, 2022). Rye quality parameters are also shown. The data (area, ha; yield, kg ha^{-1}; and production, t ha^{-1}) were analyzed by the descriptive statistical and mathematical procedures. The variability of the data was evaluated based on the value of the mean absolute deviations from the average and standard deviation - σ or SD. The seed production are presented by tables and figures.

RESULTS AND DISCUSSION

Rye production parameters. The average rye area (4.28 mill. ha) and production (12.12 mil.t) in world, in the five-year period, recorded a growth trend and average grain yield was 3.01 t ha^{-1}, Table 1. According to FAO data, the area under rye in the world, in 2020, in about 60 countries in the world was 4,446,927.00 ha, the total grain production was 15,022,273.00 tons and the average world yield was 3.38 t ha^{-1}. In the Republic of Serbia, the average yield of rye for the same year was 3,23 t ha^{-1}, Table 1.

Table 1. Average values of rye production in world and Serbia, 2016-2020

Parameter	Area, ha		Yield, t ha^{-1}		Production, t	
Year	**World**	**Serbia**	**World**	**Serbia**	**World**	**Serbia**
2020	4446927	4725	3.38	3.23	14022273	15240
2019	4249344	5046	3.02	2.57	12824590	12963
2018	4010321	4736	2.67	2.83	10716767	13418
2017	4299205	4673	3.03	2.41	13004048	11248
2016	4401000	4891	2.95	2.90	12999190	14200
Average	4281359	4814	3.01	2.79	12713374	10671
Std.dev.*	170684	153	0.25	0.32	1212251	5226
Source: FAO, 2022, *Authors calculation						

The largest production by countries, by top 10 in world, of rye in 2020 was in Rusia, Poland, Germany, Belarus, China, Canada, Spain, Ukraine, USA, Denmark and Argentina, Figures 1 - 2. The largest areas under rye in 2020 were in Russia 975.44 ha with a tendency to increase areas. In second place is Poland with 843.62 hectares. Germany, with 636,000 hectares, is the third in the world in sown areas and with an average grain yield above 5.5 t ha^{-1} (Rajičić &Terzić, 2022). The highest yields of rye in 2020 were achieved in Sweden at 6.20 t ha^{-1} and in Denmark at 6.07 t ha^{-1}.

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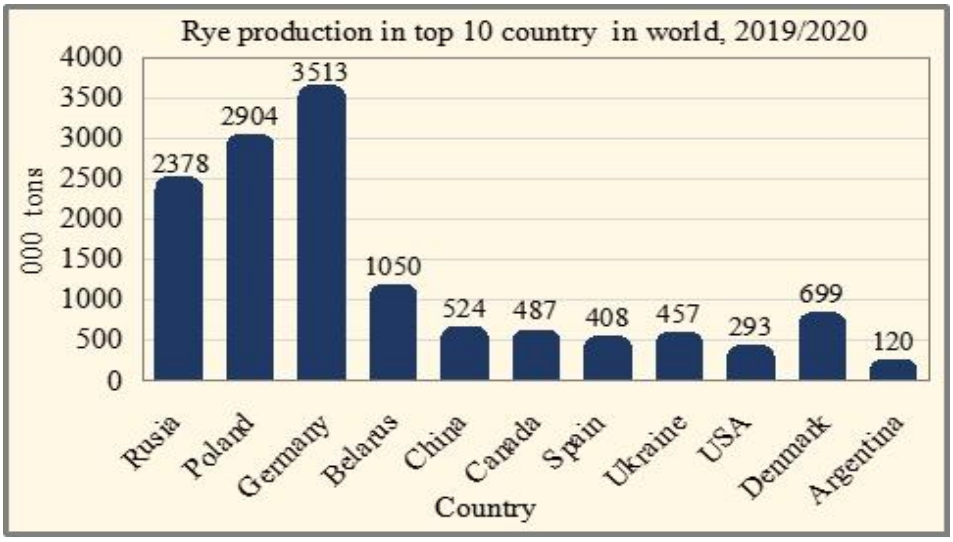

Figure 1. Average values of 10 top rye production in world, 2020

Rye is suitable for production according to the principles of organic agriculture because they have modest requirements for mineral substances, species and varieties are resistant or tolerant to diseases and pests, they have strong competitive or allelopathic properties in the fight against weeds (Ikanović & Popović, 2020). Oscillations in the temperature and the amount of precipitation during vegetation period rye are the main one factors of the yield instability. The drought has a main limiting factor of the plant production in Serbia and in the world. The introduction new of breeding programs for stress conditions will increase in the world. Areas have been increasing in recent years, both due to the interest of rye in organic production, production on acidic soils, and also due to the growing interest in biofuel production (Ikanović *et al*., 2022).

The best-known variety of rye in our country is NS Savo. NS Savo - is a mid-late, winter variety of rye, selected in the Institute of Field and Vegetable Crops, extremely stable and good yield, adaptable, high nutritional value and excellent resistance to low temperatures, to winter. Due to the longer spring period compared to other small grains, it is recommended to sow earlier, from September 20 to October 5. NS Savo has a plant height of 125-130 cm. Very good resistance to diseases and very good resistance to laying. Has an extremely stable and good yield, adaptable, high nutritional value and excellent resistance to

low temperatures, to winter. It is characterized by a weight of 1000 grains of 28-30 g, a hectoliter weight of 75-80 kg, an average protein content of 10-11%. The grain is rich in carbohydrates, plant fibers, minerals and vitamins (Rajičić & Terzić, 2022).

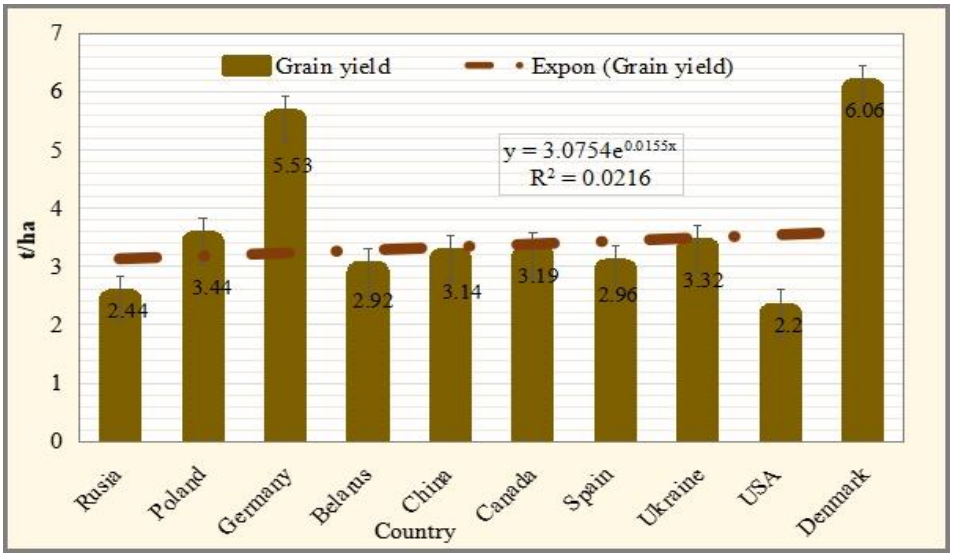

Figure 2. Average values of rye grain yield in 10 top in world, 2020

In Europe, wheat is grown on about 58 mil. ha, with an average yield of 3.72 t ha^{-1}, which gives total production of over 215 mil. tons. The biggest producers of wheat in the world are China, India, USA, Russia, France, while the largest European producers are: Russia, France, Germany, Ukraine and Great Britain. In Serbia, wheat is grown on an area of about 518 thousand ha, with with an average yield of 3.99 t ha^{-1} and with a total production of about 2.1 million tons, in Vojvodina grows wheat on an area of about 264 thousand ha, with an average yield of 4.50 t ha^{-1} and with a total production of about 1.19 mil. Tons (Aćin, 2016). Progress in breeding and cereals cultivation technology in the second half of the 20th century was very successful. Yield growth no longer follows the trend that had in the period from the 50^{s}-90^{s} of the last century and if the expected expansion of the human population continues, food shortages will become inevitable, and it is necessary that the growth of agricultural production at least follows the increase population (Khush, 1999). Climate change that stands out with rising temperatures, increasing evapotranspiration and decreasing precipitation, they will have significant negative effect on agricultural production (Popović *et al*., 2020a; 2020b, 2022). Dixon *et al.,* (2009), state that it will the number of people in the world by 2030 increase by about 40%. In order to meet the needs in that case for food, it would be necessary to stabilize agricultural areas at around 1.5 billion ha with a simultaneous annual increase in yield of 2%. Production based on respect for variety specificities is an untapped potential for

increasing the yield cereals, especially in the conditions of a changed climate (Janković *et al*., 2016; Aćin, 2016; Lakić *et al*., 2018; Filipović *et al*., 2020; Kolarić *et al*., 2021; Ljubičić *et al.*, 2021; Rakaščan *et al.*, 2021; Dražić *et al*., 2021). According to Glamočlija (2012), the influence of variety on height yield is about 40%, cultivation technology about 31-40%, and weather conditions of the year about 20-29%. It means that variety and cultivation technology are almost equal factors in achieving cereals yield. Only with respect demands of each genotype and by mitigating unfavorable weather phenomena through agrotechnical ones measure, conditions for high and stable production can be created. In the conditions of climate change the optimal sowing period can influence the reduction of the negative effects of unfavorable weather occurrence, in the sense of avoiding them in the critical stages of growth (Marinković *et al.*, 2010). One of the extremely negative phenomena in the predicted global warming will be frequent heat waves shocks that in the grain filling phase can have catastrophic consequences for yield and quality. Breeding, with better application of agrotechnical measures (first of all by adjusting sowing time), will play a major role in meeting the challenges of global change climate (Kobiljski & Denčić, 2001) in the evident conditions of global climate change.

Chemical composition of rye compared to wheat. Rye (*Secale cereale* L.) is the second most important crop after wheat for production of bread and other bakery products. The distribution of rye production differs from that of wheat, due to its demand for cooler growth temperatures and large differences in regional preferences for rye-based products (Mihhalevski *et al*., 2012; Poutanen *et al*., 2014; Wrigley & Bushuk, 2017). Rye is a rich source of vitamins B and E, which is why it is a suitable raw material for the production of functional food. Rye is considered a healthy cereal due to its high content of dietary fiber (Rakha *et al.,* 2010), it also contains minerals (Ca, Fe, F, P, K, Zn, Mn, Cu, K), lysine and oleic acid (Gumul *et al.*, 2007). Europe provides more than 85% of the world's rye production (12.8 million tons, 2019), including the leading rye producing countries: Germany, Poland, Russia, Denmark, and Belarus (FAO, 2022). Rye is important raw material for healthy safe foods. Rye chemical composition shows similarities with other cereals (e.g. wheat, barley, and triticale), however, it can be characterised by higher fibre (especially pentosan) (Mihhalevski *et al.,* 2012). Protein content of rye can vary in a wide range (8–15%) depending mainly on growth conditions. On the value of yield genotype has the higher influence ofcompared to environmental effect. The amino acid composition of rye proteins is better than that of wheat because there is a bigger one lysine content, but less in tryptophan and isoleucine. Starch dominates in rye and similarly to other cereals. The starch content of the rye grain varies 55-65%, in wheat 63–72%, and of barley, 50–64%. The lipid content of rye is similar to that of wheat (2–3%), also fatty acid composition shows similarities having linoleic acid (18.9–59.3%) as a major component. Mineral and vitamin composition of rye resembles to that of wheat (Table 2).

Table 2. Quality grain, mineral and vitamin contents of rye compared to wheat

Parameters	Rye	Wheat
Protein content (%)	10-14	13-17
Lipid content (%)	2-3	2-3
Starch content (%)	55-65	55-70
Faling number (s)	230-300	200-300
Minerals (mg)		
Phosphorus (P, mg)	1,806–4,220	1,500–5,400
Potassium (K, mg)	3,480–6,148	2,900–6,200
Calcium (Ca, mg)	157-1,447	370–1,220
Magnesium(Mg, mg)	920–1,602	900–2,900
Iron (Fe, mg)	27–129	28–42
Zinc (Zn, mg)	21–52	19–32
Manganese (Mn, mg)	20–75	5–49
Copper (Cu, mg)	3–13	4–7
Vitamins (mg kg^{-1})		
Thiamin (B1, mg)	4.0–4.6	5.0-12
Riboflavin (B2, mg)	1.8–1.9	1.0–3.1
Niacin (B3, mg)	12–15	41–64
Pantothenic acid (B5, mg)	10	7.7–9.1
Pyridoxine (B6, mg)	3.0–3.4	3.0–4.7
Folate (B9, mg)	0.48–0.52	0.35–0.56
α–Tocopherol (E, mg)	10–12	5–12

Source: Michela *et al.,* 1976; Frølich *et al.,* 2013; Sapirstein & Bushuk, 2016; Linina *et al.*, 2019; Bağcı *et al.*, 2019; Biel *et al*., 2020; Sakr *et al*., 2021;

The proportion of macronutrients (starch, lipids, proteins) in rye is the same as in other cereals. Unlike wheat, it contains a higher proportion of pentosan (about 10%), sugar and fiber, and a lower proportion of starch and protein, which affects the technological properties of rye flour. Rye proteins are low in gluten, which is why rye flour has weaker properties for the production of bakery products (Glamočlija *et al.,* 2015). Consuming rye grain products provides is the source of dietary fibre and bioactive compounds with potentially positive health implications. Cultivar, crop-year (weather conditions) and cultivar×crop-year interaction significantly ($P < 0.05$) affected rye grain protein content, starch content and Hagberg falling number. Protein content is in a significant negative correlation in relation tostarch content $r = -0.937$ (in population grain), $r = -0.944$ (cultivars grain), and protein content is in a medium strong negative correlation with falling number, $r = -0.549$ and $r = -0.573$ respective (Linina et al., 2019). The reduction in the amount of starch was accompanied by a significant change in the amylopectin/amylose ratio (Sakr *et al.*, 2021).

Rye and wheat represent the most important bread grains. Compared to wheat, rye contains less starch and protein, and more dietary fiber and free sugars.

Due to its increased fiber content and high vitamin and mineral content, rye can be successfully used in functional food formulations. Linoleic acid is the most abundant fatty acid in rye grain (55.6%). Rye contains it in slightly larger amounts compared to other cereals, followed by palmitic (16.5%), oleic (15.6%), linoleic (10.4%), eicosane (1.3%) and stearic acid (0.6%) (Arendt & Zannini, 2013).

Rye has higher iron, zinc, manganese, and copper contents, compared to other cereals. Rye is good source of α-tocopherol similarly to wheat, however, oat can be characterised by the highest vitamin E content (Mihhalevski *et al.*, 2012; Bağcı *et al.*, 2019; Frølich *et al.*, 2013; Sapirstein & Bushuk, 2016). Cereals are considered as good sources of phosphorus, potassium, and magnesium, as well as B vitamins (thiamin, riboflavin, niacin, pantothenic acid, and pyridoxine) and folate (Michela *et al.,* 1976).

Metabolic and healty effects of rye-based foods. Rye bread stays fresh for a long time, is rich in vitamins of groups A, B and E and has high digestibility. Rye grain is smaller than wheat grain, which mostly depends on the variety and growing conditions. Grain is the raw material for obtaining starch and producing spirits. Rye sprouts are rich in vitamins, oils and mineral salts and are used in the food and pharmaceutical industry. Rye bread and bakery products play an increasingly important role in a healthy diet, it is recommended in the diet of diabetics and people with high blood pressure (Glamočlija *et al.*, 2015; Rajičić & Terzić, 2022). Due to their extremely favorable nutritional value, rye is of great importance for health purposes. Many studies point to beneficial effects of rye-based foods on satiety, which is one plausible mechanism behind recently demonstrated beneficial effects on weight management. Also, they indicate beneficial effects of rye intake on inflammation and blood lipids. A challenge with rye-based foods is making them palatable and widely acceptable to consumers (Jonsson *et al.*, 2018).

Rye foods have beneficial effects on insulin metabolism compared with wheat bread under isocaloric conditions and at standardized amounts of available carbohydrates, which may have positive implications for diabetes prevention. An overview of potential health implications of rye consumption is provided in Figure 3, (Jonsson *et al.*, 2018).

Development of innovative and tasty rye products is crucial in increasing awareness, consumption of rye foods and thus production. The use in nutrition of whole grain foods may be beneficial in prevention of disease, for cardiovascular disease, type 2 diabetes, and colorectal cancer. Whole grain foods are one of the most relevant dietary factors for prevention of non-communicable diseases (Jonsson *et al.*, 2018). Rye breads, in comparison with wheat-based products, reduce the demand for insulin (Rosen *et al.*, 2009).

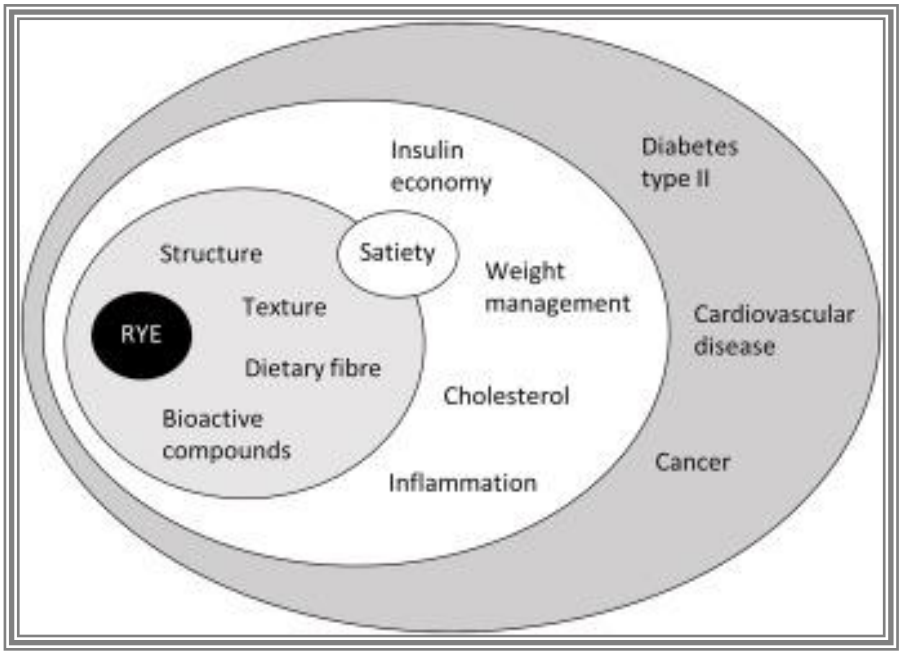

Figure 3. Overview of rye and potential health effects.

Rye is a cereal that is grown primarily for human consumption, and less often in the diet of domestic animals. Jovanović *et al*. (1984) point out that it is used in the diet of domestic animals smaller and narrow grain of rye, which, compared to whole grain, is richer in protein and cellulose, and poorer in starch. Rye can be used to feed all types of domestic animals, except for poultry, which is given less often. It should not be given in large quantities, and it is best to mix it with other cereals (Glamočlija *et al*., 2015; Rajičić & Terzić, 2022). Fresh above-ground biomass is used in mixtures with fodder peas, vetch or oilseed rape as voluminous fodder.

CONCLUSIONS

Small grains are of great economic importance in ensuring the food security of the population in the world and in our country. Grain and rye sprouts are rich in vitamins, oils and mineral salts, which is why the demand for rye in the world and production has increased. The area under rye in the world, in 2020, was 4,446,927.00 ha, the total grain production was 15,022,273.00 tons and the average world yield was 3.38 t ha^{-1} In the Republic of Serbia, the average yield of rye for the same year was 3.23 t ha^{-1}.

Due to their extremely favorable nutritional value, rye is of great importance in the food, pharmaceutical industry and for health purposes. Rye bread and bakery products play an increasingly important role in a healthy diet, it is recommended in the diet of diabetics and people with high blood pressure. Rye

play a very important role in providing complete functional nutrition for humans and domestic animals.

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