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Original Research

Production and Economic Results of Spelt Wheat Cultivation Under Various Conditions of Fungicide Protection and Nitrogen Fertilization

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Abstract

The present study aimed to assess the profitability of the cultivation of spelt wheat cv. Rokosz in different variants of fungicide protection and nitrogen fertilization. It was conducted in 2019-2021 with four fungicide protection variants and four nitrogen fertilization levels as experimental factors. Study results demonstrated significant grain yield and production profitability differences between cultivation variants and individual study years. In 2019, the most profitable turned out to be the spelt cultivation variant without the fungicide treatment and with nitrogen fertilization at 100 kg·ha^{-1}; in 2020, it was the variant without chemical treatment against fungal diseases and with nitrogen fertilization at 70 kg·ha^{-1}; in 2021, it was the variant with the fungicide treatment and with nitrogen fertilization at 70 kg·ha^{-1}. Despite lower grain yields achieved on the plots with extensive spelt production technology, these cultivation variants ensured higher incomes due to lower production costs. In addition, these technologies reduced the workload and had a lesser adverse impact on the natural environment than intensive plant cultivation, which is desirable in the context of sustainable development assumptions.

Keywords: spelt wheat, fungicide protection, nitrogen fertilization, grain yield, production profitability

Introduction

Food producers increasingly often reach for forgotten crop species, which is driven by, among other things, the growing fashion for low-processed, organic, and ecological products [1]. One such crop is spelt wheat (*Triticum spelta* L.), characterized by higher contents of protein, fats (including unsaturated fatty acids), and dietary fiber, and also a lower energy value compared to common wheat [2-3]. Most modern spelt cultivars are crosses between specific cultivars of common wheat and spelt [4-5]. Despite its strong relationship with common wheat, spelt strongly stands out in terms of morphology as well as soil and agrotechnical demands [6]. The grain of spelt wheat, of ancient cultivars in particular, is non-threshable, which is considered a drawback in further processing. However, spelt outperforms wheat in certain agronomical aspects because it is more resistant to

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selected biotic factors (e.g., diseases) and abiotic stress (e.g., cold). In addition, it has fewer demands regarding seed dressing, chemical crop protection, and nitrogen fertilization, which makes it a viable candidate for organic or low-input agricultural practices, especially in regions with poorer conditions for common wheat cultivation [5]. On the other hand, a low yielding potential of spelt wheat presents a bottleneck that impedes its cultivation [7]. There is a paucity of data in the available literature on the impact of intensifying cultivation technology on grain yield and cultivation profitability; hence, investigations addressing these problems are still relevant.

Actions undertaken by agricultural producers aim at maximizing incomes [8] since economic effectiveness is one of the major aspects of cereal production, next to grain yields and quality [9]. However, most research has focused only on producing high grain yields while neglecting the importance of economic outcomes [10]. Meanwhile, Jat et al. [11] emphasized that harnessing various cultivation technologies may affect cultivation profitability due to differences in yields and production costs. The cultivation of cereals is facilitated by relatively easy production technology, relatively low labor intensity, and convenience of storage and transport [12]. Nevertheless, decisions made by farmers are always associated with the risk of production outcomes [13] and the possibilities and prices of sales. Today, the choice of a crop species for production is mainly driven by the income expected per 1 h of crops [14]. Making production decisions in agriculture in the current conditions becomes even more difficult because agricultural producers are obliged to comply with the requirements of the common agricultural policy from a new financial perspective and because of the unstable situation in the grain market [15].

Therefore, choosing the cultivation method of cereals, including spelt wheat, depends not only on natural determinants or expected quality outcomes but also on economic factors [16]. Both the inputs related to the cultivation system and the effects achieved are important elements determining cultivation profitability [17]. Direct production costs (seed material, fertilizers, plant protection agents, and plantation insurance) play a crucial role in this case. In light of sustainable development assumptions and the implementation of the European Green Deal, environmental conditions are also increasingly often considered as drivers of production decisions on farms [18]. The EU strategy assumes, i.e., a substantial reduction in the use of plant production agents and mineral fertilizers by 2030 [19]. Taking care of the quality of the natural environment and natural resources is not only a requirement of civilization but also a prerequisite for effective agricultural production [20]. Therefore, when making decisions on the choice of production technology, it is worth taking into account not only the economic results but also the level of production intensity, which determines the extent of agriculture's impact on the natural environment. The most frequently used indicators of agricultural production intensity, understood as the intensity of production, include the level of inputs incurred per unit of agricultural land area [21].

Due to changing market conditions and increasing environmental requirements, there is a need to monitor agricultural production technologies so that production decisions are based on economic and environmental premises. Taking this into account, this study aimed to assess the production and economic results of spelt wheat cultivation under different fertilization and fungicide protection conditions.

Materials and Methods

The study was conducted at the Experimental Station in Czesławice, the University of Life Sciences in Lublin (Poland). In three replications, a field experiment was established on loess-derived soil, classified as an II soil quality class, in the split-block system. The single plot area was 15.0 m^2, and the winter form of spelt wheat cv. Rokosz was tested. This cultivar was listed in the COBORU register in 2012 and is characterized by a high-yielding potential and a low chaff contribution to the crop yield. The seed rate was 130 $kg \cdot ha^{-1}$. Common wheat was used as the previous crop.

The experiment aimed to examine the response of spelt wheat to various strategies of crop protection against fungal diseases and various levels of nitrogen fertilization. Fungicide protection variants were as follows:

A – no fungicide protection – control plot,

B – double fungicide treatment – Yamato 303 SE (methyl thiophanate + tetraconazole) at the BBCH–30-31 stage (dose: 1.5 $L \cdot ha^{-1}$), and Optan 183 SE (pyraclostrobin + epoxiconazole) at the BBCH–30-59 stage (dose: 1.5 $L \cdot ha^{-1}$),

C – three-fold fungicide treatment – Yamato 303 SE (methyl thiophanate + tetraconazole) at the BBCH–30-31 stage (dose: 1.5 $L \cdot ha^{-1}$), Optan 183 SE (pyraclostrobin + epoxiconazole) at the BBCH–30-59 stage (dose: 1.5 $L \cdot ha^{-1}$), Wirtuoz 520 EC (prochloraz + tebuconazole + proquinazide) at the BBCH–20-59 stage (dose: 1.0 $L \cdot ha^{-1}$),

D – four-fold fungicide treatment – Yamato 303 SE (methyl thiophanate + tetraconazole) at the BBCH–30-31 stage (dose: 1.5 $L \cdot ha^{-1}$), Optan 183 SE (pyraclostrobin + epoxiconazole) at the BBCH–30-59 stage (dose: 1.5 $L \cdot ha^{-1}$), Wirtuoz 520 EC (prochloraz + tebuconazole + proquinazide) at the BBCH–20-59 stage (dose: 1.0 $L \cdot ha^{-1}$), and Tilt Turbo 575 EC (propiconazole + fenpropidin) at the BBCH–30-59 stage (dose: 0.9 $L \cdot ha^{-1}$).

The second experimental factor was nitrogen fertilization doses, i.e.:

N_0 – no nitrogen fertilization (control plot)

N_1 – 70 $kg \cdot ha^{-1}$

N_2 – 100 $kg \cdot ha^{-1}$

N_3 – 130 $kg \cdot ha^{-1}$

Table 1. Acronyms of technological variants of spelt wheat cultivation.

Crop protection	Nitrogen fertilization			
	N_0	N_1	N_2	N_3
A	AN_0	AN_1	AN_2	AN_3
B	BN_0	BN_1	BN_2	BN_3
C	CN_0	CN_1	CN_2	CN_3
D	DN_0	DN_1	DN_2	DN_3

Nitrogen was applied in the form of 34% ammonium nitrate in three divided doses: 60% of the dose in the springtime, immediately after the onset of vegetation (BBCH–14-16); 20% of the dose at the stem shoot stage (BBCH–21-23); and 20% of the dose prior to the ear formation stage (BBCH–37-39).

Before spelt wheat sowing, phosphorus and potassium fertilization were applied as follows: P – 26.2 kg·ha^{-1} (triple superphosphate) and K – 58.1 kg·ha^{-1} (potassium salt), and typical plow cultivation was performed. In each study year, wheat was sown with a plot seeder in the third decade of September.

The same protection against weeds and pests was carried out on all experimental plots. Herbicide treatment was carried out at the BBCH–21-29 stage of spelt wheat with the Chisel 75 WG preparation (thifensulfuron-methyl + chlorsulfuron) at 60 g·ha^{-1} with the Trend 90 EC adjuvant (ethoxylated isodecyl alcohol) at a concentration of 0.1%. In turn, Decis Mega 50 EW (deltamethrin) was applied at 0.2 L·ha^{-1} against pests.

The study's time frame was 2019–2021, which enabled the analysis of economic results of spelt wheat cultivation under various market and atmospheric conditions. In order to accomplish the study goal, selected economic categories were used in accordance with the EU income statement and the AGROKOSZTY system, including the gross margin and operating income. The first of these values is the annual value of production obtained from 1 ha of crops reduced by direct costs incurred for this production [22]. Direct costs include cost components that can, undoubtedly, be ascribed to a given activity. Their amount is proportional to the production scale and directly affects the size (volume and value) of production [22]. In turn, the income from activity (operating income) represents the surplus generated after deducting direct and indirect costs from the production value, which is increased by subsidies. The method of calculating these economic categories is presented below [23]:

Gross margin = production value – direct costs (1)

Income from activity = production value – total costs (direct and indirect in total) (2)

Income from activities with subsidies = income from activities + subsidies (3)

The incomes of agricultural producers in the EU are supported by subsidies received under the Common Agricultural Policy (CAP). The operating income was, therefore, increased by the rates of subsidies received on the production of cereals. The calculation of the gross margin and operating income was extended by the analysis of the profitability index and selected economic efficiency indicators:

1) The unit cost of production of 1 dt of grain [EUR·dt^{-1}],

2) The total production value per EUR 1 of direct costs [EUR],

3) The gross margin per 1 dt of the main product [EUR·dt^{-1}].

The profitability index was computed as the ratio of the production value per 1 ha to the total production costs and is expressed in percent:

$$PI = \frac{P}{C} \, x \; 100\% \tag{4}$$

Where:
PI – Profitability Index
P – production value
C – total cost

Individual variants of spelt wheat cultivation were referred to in the subsequent sections of this manuscript, as denoted in Table 1.

Results and Discussion

Grain Yield and Production Values

Grain yield differed between particular variants of spelt wheat cultivation, which affected the production value per 1 ha (Table 2). The lowest grain yield was recorded in plots without nitrogen fertilization in each study year. Also, introducing the fungicide treatment to the crop protection strategy was beneficial to spelt wheat yielding in all vegetation seasons tested; however, its intensification from three to four treatments had no significant effect on grain yield increase.

Table 2. Grain yield [$dt \cdot ha^{-1}$] and value of production [$EUR \cdot ha^{-1}$] of spelt wheat in 2019-2021.

Cultivation variant	2019		2020		2021	
	Grain yield ($dt \cdot ha^{-1}$)	Production value ($EUR \cdot ha^{-1}$)	Grain yield ($dt \cdot ha^{-1}$)	Production value ($EUR \cdot ha^{-1}$)	Grain yield ($dt \cdot ha^{-1}$)	Production value ($EUR \cdot ha^{-1}$)
AN_0	29.4	805.0	44.7	1506.5	41.4	1357.8
AN_1	48.8	1336.1	58.3	1964.8	59.2	1941.8
AN_2	55.4	1516.8	66.5	2241.2	62.4	2046.8
AN_3	58.9	1612.7	65.2	2197.3	63.1	2069.7
BN_0	25.9	709.1	47.4	1597.5	48.2	1581.0
BN_1	44.6	1221.1	62.3	2099.6	60.2	1974.6
BN_2	58.7	1607.2	69.1	2328.8	69.1	2266.5
BN_3	58.1	1590.8	68.5	2308.6	69.2	2269.8
CN_0	26.8	733.8	48.5	1634.5	44.2	1449.8
CN_1	47.6	1303.3	62.2	2096.2	60.6	1987.7
CN_2	54.8	1500.4	54.9	1850.2	69.1	2266.5
CN_3	59.2	1620.9	67.2	2264.7	69.7	2286.2
DN_0	27.5	752.9	48.0	1617.7	42.4	1390.7
DN_1	48.5	1327.9	61.1	2059.2	62.1	2036.9
DN_2	57.3	1568.9	70.5	2376.0	67.8	2223.9
DN_3	59.4	1626.4	70.2	2365.8	65.2	2138.6

The value of agricultural production (Table 2) in the individual study years and variants was determined by the grain yield and purchase price. In 2019, the price of spelt wheat was EUR 273.8; in 2020, it increased to EUR 337; in 2021, it dropped to EUR 328. The production value differed significantly between the fertilization and crop protection variants in the individual study years and was the highest (EUR 2,376) in 2020 in the DN_2 variant, which also allowed the production of the highest grain yield (70.5 dt). The lowest production value was determined in variant BN_0 in 2019 (EUR 709.1). In addition, spelt wheat cultivation in this variant ensured the lowest grain yield (25.9 dt) in this year among all study years. In turn, 2020 brought a significant increase in grain yields in all variants of fertilization and crop protection, whereas these differences had no significant effect on the production value increase in the subsequent year of the experiment. In 2019, the highest yield and production value were determined in variant DN_3 (59.4 dt), whereas in 2021, they were determined in variant CN_3 (69.7 dt).

Production Costs

The costs of spelt wheat production varied between 2019 and 2020 (Tables 3-5) and were observed to increase during this time. In 2021, they increased only in the N_0 variants (without nitrogen fertilization). They decreased in the remaining variants due to a drop in the prices of fertilizers, which significantly affected the cost structure in variants N_1-N_3. The cost of seed material did not differ between the variants but changed in individual study years. In 2019, it reached EUR $60.5 \cdot ha^{-1}$ and increased by EUR $21.4 \cdot ha^{-1}$ in 2020 to EUR $81.9 \cdot ha^{-1}$, whereas in 2021 it decreased minimally to EUR $80.8 \cdot ha^{-1}$. The cost of plant protection agents remained similar across the study years. The greatest differences were noted in the costs of mineral fertilization and fuel. The highest fuel price was recorded in 2019, whereas the lowest was in 2020. In the years analyzed in the study, the main production costs were related to fertilizers and plant protection agents. The lowest costs were incurred in variant AN_0 in 2019 (EUR $296.7 \cdot ha^{-1}$), and this production technology was observed to generate the lowest costs in each study year. In contrast, the highest costs were recorded in variant DN_3 (EUR 602.8) in 2020, which appeared to be the most cost-intensive among the compared cultivation variants. The highest increase in production costs was noted in the variants with the highest number of fungicide treatments. The most intensive fungicide protection (D) increased crop protection crops by EUR $160.9 \cdot ha^{-1}$ in 2019, compared to variant A without the fungicide protection. In turn, fertilization with the highest nitrogen dose tested (N_3) increased production costs by EUR 100 compared to the variants without fertilization (N_0). These differences were comparable in the subsequent years of the study.

Table 3. Production costs of spelt wheat per 1 ha in 2019.

Cultivation variant	Production costs in 2019 (EUR. ha^{-1})						
	Direct costs				Indirect costs		Total costs
	Seed material	Crop protection	Fertilization	Total direct costs	Fuel	Tax	
AN_0	60.5	22.1	90.5	173.2	97.5	26.1	296.7
AN_1	60.5	22.1	144.7	227.3	106.0	26.1	359.4
AN_2	60.5	22.1	168.1	250.7	106.0	26.1	382.8
AN_3	60.5	22.1	191.2	273.8	106.0	26.1	405.9
BN_0	60.5	118.2	90.5	269.2	103.6	26.1	398.8
BN_1	60.5	118.2	144.7	323.1	112.1	26.1	461.5
BN_2	60.5	118.2	168.1	346.7	112.1	26.1	484.9
BN_3	60.5	118.2	191.2	369.9	112.1	26.1	508.1
CN_0	60.5	161.8	90.5	312.8	109.7	26.1	448.6
CN_1	60.5	161.8	144.7	366.9	118.2	26.1	511.2
CN_2	60.5	161.8	168.1	390.3	118.2	26.1	534.6
CN_3	60.5	161.8	191.2	413.5	118.2	26.1	557.8
DN_0	60.5	183.0	90.5	334.0	115.8	26.1	475.9
DN_1	60.5	183.0	144.7	388.2	124.3	26.1	538.5
DN_2	60.5	183.0	168.1	411.6	124.3	26.1	561.9
DN_3	60.5	183.0	191.2	434.7	124.3	26.1	585.1

The production costs recorded in 2019 ranged from EUR 296.7·ha^{-1} to EUR 585.1·ha^{-1} (Table 3), with the observed increase affected mainly by fungicide protection and fertilization variants. Greater cultivation intensity resulted in increased fuel consumption, which generated a EUR 26.8 increase between variants A and D. In 2020 (Table 4), the costs of production increased as well, mainly due to a ca. 35% increase in the cost of seed material and a ca. 11% increase in the cost of fertilization. The costs incurred on fuel decreased by EUR 18.7·ha^{-1} in the AN_0 variant and by EUR 24.8·ha^{-1} in the DN_3 variant.

In the last year of the study, the costs of spelt wheat production decreased compared to the previous year but were still higher than in 2019 (Table 5). This decrease was due to lower costs related to fertilizers and crop protection agents, which, in variant A, equaled the respective costs generated in 2019. In variant B, the costs of plant protection agents were EUR 2.7 lower than in 2019. A similar tendency was observed in the remaining variants. The cost of fertilizers returned to a similar value as in 2019. Compared to 2020, fuel costs increased by ca. 17% but were still lower than in 2019.

Gross Margin and Income

The income from growing spelt wheat was very diverse and dependent on plant protection and fertilization variants (Table 6). It varied over the years and was influenced by market conditions, including the sales price and grain yield. Cultivation variants producing the highest yields and requiring the highest financial outlays did not generate the highest income. On the other hand, the variants generate the lowest costs and a significant decrease in yield, which reduces the profitability of cultivation. In 2019, the highest income per 1 ha of crops was achieved in variant AN_3 (EUR 1453.5), whereas it was variant AN_2 (EUR 2080.7) in 2020. In the last experimental year, the most profitable turned out to be the BN_2 variant, generating an income of EUR 2009.1 per 1 ha. Across the study years, the lowest income was achieved in variant DN_0 in 2019, i.e., EUR 525.6. This variant generated the lowest income in all three years of the experiment. In 2019, the most labor-intensive and cost-intensive variant (DN_3) generated an income lower by EUR 162.1 than the most profitable variant. In 2020, the respective difference reached EUR 60.4, whereas in 2021, it was EUR 224.9.

Indices of Profitability and Economic Efficiency

The analysis of profitability was extended with selected indices of economic efficiency (Tables 7 and 8), the values of which point to significant differences in the profitability of spelt wheat production between the experimental year 2019 and the other years examined.

Table 4. Production costs of spelt wheat per 1 ha in 2020.

Cultivation variant	Production costs in 2020 (EUR·ha^{-1})						
	Direct costs				Indirect costs		Total costs
	Seed material	Crop protection	Fertilization	Total direct costs	Fuel	Tax	
AN_0	81.9	22.5	99.8	204.1	78.8	25.2	308.2
AN_1	81.9	22.5	160.9	265.3	85.7	25.2	376.2
AN_2	81.9	22.5	187.4	291.8	85.7	25.2	402.7
AN_3	81.9	22.5	213.5	317.9	85.7	25.2	428.8
BN_0	81.9	117.9	99.8	299.6	83.8	25.2	408.5
BN_1	81.9	117.9	160.9	360.8	90.7	25.2	476.6
BN_2	81.9	117.9	187.4	387.2	90.7	25.2	503.0
BN_3	81.9	117.9	213.5	413.3	90.7	25.2	529.2
CN_0	81.9	160.9	99.8	342.5	88.7	25.2	456.4
CN_1	81.9	160.9	160.9	403.7	95.6	25.2	524.5
CN_2	81.9	160.9	187.4	430.2	95.6	25.2	550.9
CN_3	81.9	160.9	213.5	456.3	95.6	25.2	577.1
DN_0	81.9	181.7	99.8	363.3	93.6	25.2	482.1
DN_1	81.9	181.7	160.9	424.5	100.5	25.2	550.2
DN_2	81.9	181.7	187.4	450.9	100.5	25.2	576.6
DN_3	81.9	181.7	213.5	477.0	100.5	25.2	602.8

In 2019, analyses demonstrated a higher unit cost and a lower production value per 1 EUR of direct costs. The main product's gross margin per 1 dt was also substantially lower. A lower production profitability index also confirms the lower profitability recorded in 2019. To the greatest extent, this economic result was affected by a decrease in grain yield compared to the subsequent years and by the lowest grain purchase price among the study years. Differences recorded in profitability and value of the remaining indices between 2020 and 2021 were negligible. The highest profitability index was recorded in 2020 in variant AN_2 (556.6%), and the lowest in 2019 in variant DN_0 (158.2%). Still, spelt wheat production was profitable for each tested variant. In addition, variant DN_0, which was applied in 2019, generated the highest unit cost, the lowest production value per 1 EUR of direct costs, and the lowest gross margin per 1 dt of the main product. In the study timeframe of 2019-2021, the least profitable variants turned out to be those limiting the use of plant protection agents.

Discussion

High consumer demand for food products eliciting health-promoting benefits, awareness of agricultural producers about the need to protect the natural environment, and programs promoting pro-environmental activities mean that agricultural producers are inclined to choose crop species that tolerate minimized mineral fertilization and limited plant protection and have a unique chemical composition [24-27]. Spelt wheat perfectly fits the needs of today's food market and trends in agricultural production [28]. Many studies addressing spelt wheat have focused on its productivity and nutritional value, but no studies merge production and economic aspects. In this study, the profitability of spelt wheat cultivation was assessed based on grain yields, which depended on the intensification of nitrogen fertilization and fungicide protection.

Nitrogen fertilization is a key element of agricultural technology that affects crop yields [29-30], whereas, as Suchowilska et al. [31] claimed, spelt responds poorly to high nitrogen doses compared to common wheat. The study demonstrated that spelt wheat grain yield increased with increasing fertilization doses, but in some protection variants, only up to a nitrogen dose of 100 kg·ha^{-1}. Similar results were obtained by Hury et al. [30], who showed that nitrogen fertilization caused a significant linear increase in grain yield up to a certain threshold, which resulted in a decline in grain yield. In addition, they emphasized that the response of spelt wheat to the intensity of nitrogen fertilization also depended on genetic traits – old spelt cultivars may

Table 5. Production costs of spelt wheat per 1 ha in 2021.

Cultivation variant	Production costs in 2021 (EUR·ha^{-1})						
	Direct costs				Indirect costs		Total costs
	Seed material	Crop protection	Fertilization	Total direct costs	Fuel	Tax	
AN_0	80.8	22.1	92.6	195.5	92.8	24.5	312.8
AN_1	80.8	22.1	145.8	248.7	101.0	24.5	374.2
AN_2	80.8	22.1	168.8	271.7	101.0	24.5	397.2
AN_3	80.8	22.1	191.5	294.4	101.0	24.5	419.9
BN_0	80.8	115.5	92.6	288.9	98.6	24.5	412.1
BN_1	80.8	115.5	145.8	342.1	106.8	24.5	473.4
BN_2	80.8	115.5	168.8	365.1	106.8	24.5	496.4
BN_3	80.8	115.5	191.5	387.9	106.8	24.5	519.2
CN_0	80.8	158.2	92.6	331.6	104.4	24.5	460.6
CN_1	80.8	158.2	145.8	384.8	112.6	24.5	521.9
CN_2	80.8	158.2	168.8	407.8	112.6	24.5	544.9
CN_3	80.8	158.2	191.5	430.6	112.6	24.5	567.7
DN_0	80.8	179.6	92.6	353.0	110.2	24.5	487.7
DN_1	80.8	179.6	145.8	406.2	118.4	24.5	549.1
DN_2	80.8	179.6	168.8	429.2	118.4	24.5	572.1
DN_3	80.8	179.6	191.5	451.9	118.4	24.5	594.8

be less responsive to a fertilizer dose increase, while the new ones respond more intensively to fertilization. This is because spelt wheat is genetically diverse, and its old cultivars differ from their new breeding lines in terms of agrotechnical, environmental, and productivity requirements [32]. Various responses of spelt wheat to mineral fertilization were also demonstrated by Stępień et al. [33], Andruszczak et al. [24], and Andruszczak [34]. Many studies have also pinpointed that spelt stands do not require intensive chemical protection [35-36]. In the present study, the grain yield of spelt wheat varied in the individual experimental years under the influence of intensified crop protection. In each growing season and all variants of nitrogen fertilization, introducing a fungicide treatment for protection increased the grain yield of spelt wheat, while increasing the number of fungicide treatments from 3 to 4 usually caused no increase in the grain yield. An experiment conducted by Pospišil et al. [37] showed that the fungicide treatment had a significant effect on the grain yield only in one of the two years studied due to severe attacks of powdery mildew (*Blumeria gramini*) and leaf rust (*Puccinia recondita*). Other studies have also confirmed the high tolerance of spelt wheat to minimize crop protection and its suitability for organic cultivation [24, 36, 38-39], while, as shown in a previous study by Haliniarz et al. [28], the response of this species to extensive crop protection was cultivar-dependent. Production outcomes, environmental concerns, and economic effects should be considered when choosing a spelt production technology. Dolijanović et al. [40] have emphasized that intensive agriculture makes the soil barren and contributes to excessive water consumption and greenhouse gas emissions without ensuring the necessary sustainability of food production. Modern agriculture is based on the so-called sustainable intensification of agricultural production, which involves increasing agricultural production with no adverse effects on the natural environment and no need to convert more non-agricultural land [41]. Within this concept, a key role is played by integrated plant protection, which places great emphasis on reducing the use of chemical plant protection agents [42], and integrated nutrient management, which involves the careful use of chemical fertilizers [43]. The choice of production systems requiring lesser inputs is a key driving force for the transformation of the agricultural sector towards a sustainable production system since sustainable agriculture is associated with food security, which requires the availability of food with a high nutritional value as well as the security and economic stability of the human population [44].

The changing situation in the agricultural market requires continuous monitoring of farmers' costs and income. This is also confirmed by the research by Skarżyńska and Pietrych [12], who pointed to the need

Table 6. Gross margin and income from spelt wheat cultivation in 2019-2021 (EUR·ha^{-1}).

Cultivation variant	2019		2020		2021	
	Gross margin (EUR·ha^{-1})	Income with subsidies (EUR·ha^{-1})	Gross margin (EUR·ha^{-1})	Income with subsidies (EUR·ha^{-1})	Gross margin (EUR·ha^{-1})	Income with subsidies (EUR·ha^{-1})
AN_0	631.8	753.2	1302.3	1438.9	1162.5	1281.5
AN_1	1108.8	1223.3	1699.5	1830.8	1693.1	1805.5
AN_2	1266.1	1380.7	1949.4	2080.7	1775.1	1887.5
AN_3	1338.8	1453.3	1879.5	2010.8	1775.3	1887.7
BN_0	440.0	556.4	1297.9	1430.7	1292.1	1406.4
BN_1	897.8	1007.4	1738.9	1866.3	1632.5	1740.1
BN_2	1260.5	1370.0	1941.6	2069.1	1901.4	2009.1
BN_3	1220.9	1330.5	1895.2	2022.7	1881.9	1989.6
CN_0	421.0	532.5	1292.0	1421.0	1118.2	1227.7
CN_1	936.3	1041.0	1692.5	1816.2	1602.9	1705.9
CN_2	1110.1	1214.7	1420.1	1543.8	1858.7	1961.7
CN_3	1207.4	1312.1	1808.5	1932.1	1855.6	1958.6
DN_0	418.9	525.6	1254.4	1379.6	1037.8	1142.6
DN_1	939.8	1039.5	1634.7	1754.6	1630.7	1729.0
DN_2	1157.3	1257.0	1925.0	2044.9	1794.7	1893.0
DN_3	1191.7	1291.4	1888.8	2008.7	1686.7	1784.9

to minimize production costs in order to maximize income. Furthermore, Boczar and Błażejczyk-Majka [45] have explained that economic efficiency is influenced not only by the incurred expenditures but also by production costs and production value, which is, in turn, a result of grain yield and grain sales price. Research on the profitability of cereal cultivation has proven its variability, but recent years have brought greater than usual instability to the cereal market. There is a clear research gap regarding the profitability of spelt production, especially in various conditions related to production technology. Therefore, it is difficult to directly relate the present research results to the findings reported by other authors. However, such comparative analyses can be found in relation to organic spelt wheat production. For example, based on research conducted in Serbia, Đuričin et al. [1] showed that organic spelt production was economically profitable, primarily due to its significantly higher market price than conventional production. Similar conclusions were reached by Rapčan et al. [46], who conducted a two-year experiment with spelt cultivation in Croatia, and by Dolijanović et al. [40], who formulated a recommendation that the spelt production management strategy should harmonize with the soil and agroecological features of the region and aim at cost reduction. Winnicki and Żuk-Gołaszewska [25] have also emphasized that knowledge of production costs is an important element in improving the competitiveness of spelt cultivation. Their research on comparing production and economic results of organic cultivation of common wheat and spelt wheat showed that the total costs associated with spelt production cultivars significantly exceeded those of common wheat production. This difference was attributed to direct costs, particularly seed prices. Spelt generated slightly higher incomes, which was the effect of higher market prices for spelt grain. Furthermore, research by Sugár et al. [47] has demonstrated that spelt is a viable alternative to common wheat in low-N production on both low-quality and fertile soils despite the increasing risk of lodging with increasing nitrogen fertilization levels.

Conclusions

A specific trait of plant production is its dependence on weather conditions. However, as studies have shown, this is not the only factor affecting grain yields and profitability of production. Because farmers are price-takers, their incomes depend to a large extent on market conditions. Therefore, decisions regarding the choice of production technology should be based on economic aspects on the one hand and environmental concerns on the other. The need to alleviate the adverse impact of agricultural production on the natural environment results from the assumptions of the sustainable

Table 7. Unit cost [EUR·dt^{-1}] and total production value per 1 EUR of direct costs [EUR] of spelt wheat production in 2019-2021.

Specification	Unit cost (EUR·dt^{-1})			Total production value per 1 EUR of direct costs (EUR)		
	2019	2020	2021	2019	2020	2021
AN_0	10.1	6.9	7.6	1.1	1.7	1.5
AN_1	7.4	6.5	6.3	1.4	1.7	1.7
AN_2	6.9	6.1	6.4	1.4	1.7	1.6
AN_3	6.9	6.6	6.7	1.4	1.6	1.5
BN_0	15.4	8.6	8.5	0.6	1.2	1.2
BN_1	10.3	7.6	7.9	0.9	1.3	1.3
BN_2	8.3	7.3	7.2	1.1	1.4	1.4
BN_3	8.7	7.7	7.5	1.0	1.3	1.3
CN_0	16.7	9.4	10.4	0.5	1.1	1.0
CN_1	10.7	8.4	8.6	0.8	1.2	1.1
CN_2	9.8	10.0	7.9	0.9	1.0	1.2
CN_3	9.4	8.6	8.1	0.9	1.1	1.2
DN_0	17.3	10.0	11.5	0.5	1.0	0.9
DN_1	11.1	9.0	8.8	0.8	1.1	1.1
DN_2	9.8	8.2	8.4	0.9	1.2	1.1
DN_3	9.8	8.6	9.1	0.9	1.1	1.0

Table 8. Gross margin per 1 dt of the main product [EUR·dt^{-1}] and profitability index [%] of spelt wheat production in 2019-2021.

Specification	Gross margin per 1 dt of the main product (EUR·dt^{-1})			Profitability index (production value/total costs (%)		
	2019	2020	2021	2019	2020	2021
AN_0	21.5	29.1	28.1	271.3	488.8	434.0
AN_1	22.7	29.2	28.6	371.8	522.2	519.0
AN_2	22.9	29.3	28.4	396.3	556.6	515.3
AN_3	22.7	28.8	28.1	397.3	512.4	492.9
BN_0	17.0	27.4	26.8	177.8	391.0	383.7
BN_1	20.1	27.9	27.1	264.6	440.5	417.1
BN_2	21.5	28.1	27.5	331.4	462.9	456.6
BN_3	21.0	27.7	27.2	313.1	436.3	437.2
CN_0	15.7	26.6	25.3	163.6	358.1	314.8
CN_1	19.7	27.2	26.5	254.9	399.7	380.8
CN_2	20.3	25.9	26.9	280.6	335.8	415.9
CN_3	20.4	26.9	26.6	290.6	392.5	402.7
DN_0	15.2	26.1	24.5	158.2	335.5	285.1
DN_1	19.4	26.8	26.3	246.6	374.3	371.0
DN_2	20.2	27.3	26.5	279.2	412.1	388.7
DN_3	20.1	26.9	25.9	278.0	392.5	359.5

development concept and the CAP strategies adopted in the EU.

The present study attempted to fill the research gap in the economic aspects of spelt cultivation. Its scope covered the profitability of spelt production in three years, differing in terms of market conditions. In addition to production technology, it determined the profitability of cultivation in individual variants of nitrogen fertilization and fungicide protection.

The study results showed that the profitability of spelt wheat production was determined by multiple factors, i.e., market conditions (such as purchase prices and costs) and weather conditions, as shown by grain yield differences in the individual study years. However, the greatest income differences were due to fertilization and fungicide protection variants. Production intensification increased spelt wheat yields but also generated higher costs. The most intensive cultivation variant allowed for the highest yield to be achieved, which did not increase proportionally to the costs incurred. On the other hand, the highest income was obtained from plots with pro-ecological variants of fungicide protection and nitrogen fertilization, i.e., variant AN_3 in 2019, variant AN_2 in 2020, and variant BN_2 in 2021. In these conditions, the spelt wheat grain yield was lower than the highest yield obtained in a given year by only 1% in 2019 and 2021 and 6% in 2020. This justifies the advisability of growing spelt wheat using a technology based on moderate mineral fertilization and limited chemical protection.

The study's results also show how important it is to rationalize farm costs and calculate crop cultivation's profitability. This allows for a more effective selection of production technology and crop rotation on the farm. Despite lower grain yields, a higher income was obtained, and the workload and the use of plant protection products and fertilizers were also reduced, which should be assessed positively in the context of the environmental goals of sustainable development. In addition, these findings indicate that production decisions in agriculture require a multi-faceted approach, including both technological aspects and related yields, as well as the market (economic) perspective and environmental concerns.

Conflict of Interest

The authors declare no conflict of interest.

References

1. ĐURIČIN S., GREGORIC E., SAVIĆ S., MATOVIĆ G., JOVANOVIĆ O. Profitability of organic farming of spelt in the climate conditions of Serbia. Ekonomika Poljoprivrede, **71** (1), 99, **2024.**
2. VOJNOV B., MANOJLOVIĆ M., LATKOVIĆ D., MILOŠEV D., DOLIJANOVIĆ Ţ., SIMIĆ M., BABEC B., ŠEREMEŠIĆ S. Grain yield, yield components and protein content of organic spelt wheat (*Triticum spelta* L.) grown in different agro-ecological conditions of northern Serbia. Ratarstvo i Povrtarstvo, **57** (1), 1, **2020**.
3. RAKSZEGI M., TÓTH V., MIKÓ P. The place of spelt wheat among plant protein sources. Journal of Cereal Science, **114**, 103813, **2023**.
4. WANG J., BARANSKI M., KORKUT R., KALEE H.A., WOOD L., BILSBORROW P., JANOVSKA D., LEIFERT A., WINTER S., WILLSON A., BARKLA B., LEIFERT C., REMPELOS L., VOLAKAKIS N. Performance of modern and traditional spelt wheat (*Triticum spelta*) varieties in rain-fed and irrigated, organic and conventional production systems in a semi-arid environment; Results from exploratory field experiments in Crete, Greece. Agronomy, **11**, 890, **2021**.
5. HELLIN P., ESCARNOT E., MINGEOT D., GOFFLOT S., SINNAEVE G., LATEUR M., GODIN B. Multiyear evaluation of the agronomical and technological properties of a panel of spelt varieties under different cropping environments. Journal of Cereal Science, **109**, 103615, **2023**.
6. BARAŃSKI M., LACKO-BARTOŠOVÁ M., REMBIAŁKOWSKA E., LACKO-BARTOŠOVÁ L. The effect of species and cultivation year on phenolic acids content in ancient wheat. Agronomy, **10** (5), 673, **2020**.
7. KRASKA P., ANDRUSZCZAK S., KWIECIŃSKA-POPPE E. Reaction of spelt wheat cultivars (*Triticum aestivum* ssp. *spelta*) to foliar fertilization. Agronomy Science, **74** (2), 37, **2019**.
8. AUGUSTYŃSKA I., CZUŁOWSKA M. (ed.), Production, costs and income of selected agricultural products in the years 2020-2021. IERiGŻ-PIB: Warsaw, Poland, pp. 98, **2022** [In Polish].
9. SIAD S.M., GIOIA A., HOOGENBOOM G., IACOBELLIS V., NOVELLI A., TARANTINO E., ZDRULI P. Durum wheat cover analysis in the scope of policy and market price changes: A case study in Southern Italy. Agriculture, **7**, 12, **2017**.
10. ZARGAR M., POLITYKO P., PAKINA E., BAYAT M., VANDYSHEV V., KAVHIZA N., KISELEV E. Productivity, quality and economics of four spring wheat (*Triticum aestivum* L.) cultivars as affected by three cultivation technologies. Agronomy Research, **16** (5), 2254, **2018**.
11. JAT R.K., SAPKOTA T.B., SINGH R.G., JAT M.L., KUMAR M., GUPTA R.K. Seven years of conservation agriculture in a rice-wheat rotation of eastern Gangetic Plains of South Asia: yield trends and economic profitability. Field Crops Research, **164**, 199, **2014**.
12. SKARŻYŃSKA A., PIETRYCH Ł. Projekcja opłacalności uprawy zbóż w Polsce w 2022 roku na tle prognozy produkcji zbóż w Unii Europejskiej do 2030 roku. Zeszyty Naukowe SGGW w Warszawie, Problemy Rolnictwa Światowego, **18** (1), 224, **2018**.
13. ŚMIGLAK-KRAJEWSKA M. Agricultural risk and its perception among protein plant farmers. Annals of The Polish Association of Agricultural and Agribusiness Economists, **3**, 459, **2019**.
14. SUŁEK A., HARASIM A. Yields and economic effects of winter and spring wheat production in a post-sugar beet stand. Agronomy Science, **77** (2), 91, **2022**.
15. NOWAK A., WNUCZEK R. Evaluation of the profitability of winter wheat and spring barley production in different market conditions. Agronomy Science, **79** (2), 121, **2024** [In Polish].
16. KRASOWISZ S. Rola oceny ekonomicznej w badaniach

rolniczych. Journal of Agribusiness and Rural Development, **2** (12), 93, **2009**.
17. SUŁEK A., HARASIM A. Yields and economic effects of winter and spring wheat production in a post-sugar beet stand. Agronomy Science, **77** (2), 91, **2022**.
18. PAWŁOWSKI K.P., SOŁTYSIAK G. The potential impact of the European Green Deal on farm production in Poland. Sustainability, **16**, 11080, **2024**.
19. JAROSZ Z. The European Green Deal – challenges for agriculture and the agri-food sector. Polish Journal of Agronomy, **52**, 90, **2023**.
20. WRZASZCZ W., WIGIER M. Environmental and climatic conditions of agricultural development. In. Environmental and climatic determinants of the development of agriculture and rural areas in Poland in 2004-2030. Wrzaszcz W., Wigier M. Eds. IERiGŻ PIB, Warsaw, Poland, Volume 201, pp. 204, **2024** [In Polish].
21. ZAKRZEWSKA A., NOWAK A. Diversification of agricultural output intensity across the European Union in light of the assumptions of sustainable development. Agriculture, **12**, 1370, **2022**.
22. SKARŻYŃSKA A. Unit costs and income from selected products in 2019 – research results in the AGROKOSZTY system. Problems of Agricultural Economics, **367** (2), 148, **2021**.
23. ŻEKAŁO J. Economic results of winter wheat and winter rye production in organic farms – a case study. Problems of World Agriculture, **19** (2), 248, **2019**.
24. ANDRUSZCZAK S., KWIECIŃSKA-POPPE E., KRASKA P., PAŁYS E. Yield of winter cultivars of spelt wheat (*Triticum aestivum* ssp. *spelta* L.) cultivated under diversified conditions of mineral fertilization and chemical protection. Acta Scientiarum Polonorum Agricultura, **10** (4), 5, **2011**.
25. WINNICKI T., ŻUK-GOŁASZEWSKA K. Agronomic and economic characteristics of common wheat and spelt production in an organic farming system. Acta Scientiarum Polonorum, Agricultura, **16** (4), 247, **2017**.
26. RATAJCZAK K., SULEWSKA H., SZYMAŃSKA G., MATYSIK P. Agronomic traits and grain quality of selected spelt wheat varieties versus common wheat. Journal of Crop Improvement, **34** (5), 1, **2020**.
27. BERNAT E., CHOJNACKA S., WESOŁOWSKA-TROJANOWSKA M., GAWĘDA D. KWIECIŃSKA-POPPE E., HALINIARZ M. Effect of crop protection intensity and nitrogen fertilisation on the quality parameters of spelt wheat grain cv. 'Rokosz' grown in South-Eastern Poland. Agriculture, **14**, 1815, **2024**.
28. HALINIARZ M., GAWĘDA D., NOWAKOWICZ-DĘBEK B., NAJDA A., CHOJNACKA S., ŁUKASZ J., WLAZŁO Ł., RÓŻAŃSKA-BOCZULA M. Evaluation of the Weed Infestation, Grain Health, and Productivity Parameters of Two Spelt Wheat Cultivars Depending on Crop Protection Intensification and Seeding Densities. Agriculture **10** (6), 229, **2020**.
29. LABUSCHAGNE M.T., MEINTJES G., GROENEWALD F.P.C. The influence of different nitrogen treatments on the size distribution of protein fractions in hard and soft wheat. Journal of Cereal Science, **43**, 315, **2006**.
30. HURY G., STANKOWSKI S., JAROSZEWSKA A., MICHALSKA B., GIBCZYŃSKA M. The effect of tillage system and nitrogen fertilization on yield and yield components of winter spelt cultivars (*Triticum aestivum* ssp. *spelta* L.). Polish Journal of Agronomy, **41**, 11, **2020**.
31. SUCHOWILSKA E., WIWART M., KRSKA R., KANDLER W. Do *Triticum aestivum* L. and *Triticum spelta* L. Hybrids Constitute a Promising Source Material for Quality Breeding of New Wheat Varieties? Agronomy, **10**, 43, **2020**.
32. WANG J., BARANSKI M., HASANALIYEVA G., KORKUT R., KALEE H.A., LEIFERT A., WINTER S., JANOVSKA D., WILLSON A., BARKLA B., IVERSEN P.O., SEAL C., BILSBORROW P., LEIFERT C., REMPELOS L., VOLAKAKIS N. Effect of Irrigation, Fertiliser Type and Variety on Grain Yield and Nutritional Quality of Spelt Wheat (*Triticum spelta*) Grown Under Semi-Arid Conditions. Food Chemistry, **358**, 129826, **2021**.
33. STĘPIEŃ A., WOJTKOWIAK K., ORZECH K., WIKTORSKI A. Nutritional and technological characteristics of common and spelt wheats are affected by mineral fertilizer and organic stimulator Nano-Gro®. Acta Scientiarum Polonorum, Agricultura, **15** (2), 49, **2016**.
34. ANDRUSZCZAK S. Spelt wheat grain yield and nutritional value response to sowing rate and nitrogen fertilization. The Journal of Animal & Plant Sciences, **28** (5), 1476, **2018**.
35. ESCARNOT E., JACQUEMIN J., AGNEESSENS R., PAQUOT M. Comparative study of the content and profiles of macronutrients in spelt and wheat: A review. Biotechnology, Agronomy, Society and Environment, **16** (2), 243, **2012**.
36. KWIATKOWSKI C.A., HALINIARZ M., TOMCZYŃSKA-MLEKO M., MLEKO S., KAWECKA-RADOMSKA M. The content of dietary fiber, amino acids, dihydroxyphenols and some macro- and micronutrients in grain of conventionally and organically grown common wheat, spelt wheat and proso millet. Agricultural and Food Science, **24** (3), 195, **2015**.
37. POSPIŠIL A., POSPIŠIL M., SVEČNJAK Z., MATOTAN S. Influence of crop management upon the agronomic traits of spelt (*Triticum spelta* L.). Plant, Soil and Environment, **57** (9), 435, **2011**.
38. KWIECIŃSKA-POPPE E., ANDRUSZCZAK S., KRASKA P., PAŁYS E. The influence of chemical protection levels on quality of spelt wheat (*Triticum spelta* L.) grain. Progress in Plant Protection, **51** (2), 986, **2011**.
39. KOWALSKA I., PAWELEC S., PECIO Ł., FELEDYN-SZEWCZYK B. The Effects of a Cultivar and Production System on the Qualitative and Quantitative Composition of Bioactive Compounds in Spring Wheat (*Triticum* sp.). Molecules, **29**, 4106, **2024**.
40. DOLIJANOVIĆ Ž., NIKOLIĆ S.R., SUBIĆ J., JOVOVIĆ Z., OLJAČA J., BAČIĆ J. Organic spelt production systems: Productive and financial performance in three orographic regions. Italian Journal of Agronomy, **17** (2), **2022**.
41. STRUIK P.C., KUYPER T.W. Sustainable intensification in agriculture: the richer shade of green. A review. Agronomy for Sustainable Development, **37** (5), 1, **2017**.
42. FINGER R., SOK J., AHOVI E., AKTER S., BREMMER J., DACHBRODT-SAAYDEH S., DE LAUWERE C., KREFT C., KUDSK P., LAMBARRAA-LEHNHARDT F., MCCALLUM C., OUDE LANSINK A., WAUTERS E., MÖHRING N. Towards sustainable crop protection in agriculture: A framework for research and policy. Agricultural Systems, **219**, 104037, **2024**.
43. SELIM M.M. Introduction to the Integrated Nutrient Management Strategies and Their Contribution to Yield and Soil Properties. International Journal of Agronomy, **2020** (1), 1, **2020**.

44. PAWLAK K., KOŁODZIEJCZAK M. The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. Sustainability, **12**, 5488, **2020**.
45. BOCZAR P., BŁAŻEJCZYK-MAJKA L. Economic efficiency versus energy efficiency of selected crops in EU farms. Resources, **13**, 123, **2024**.
46. RAPČAN I., SUBAŠIĆ D.G., RANOGAJEC L., HAJDUK S. Organic farming of spelt (*Triticum spelta* L.) and economic results. Agronomski Glasnik, **3**, 135, **2020**.
47. SUGÁR E., FODOR N., SÁNDOR R., BÓNIS P., VIDA G., ÁRENDÁS T. Spelt wheat: An alternative for sustainable plant production at low N-levels. Sustainability, **11**, 6726, **2019**.