

STUDY ON THE AGRONOMIC AND PRODUCTIVE TRAITS OF WINTER CEREALS GROWN SOLE AND AS MIXED CROPS

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Abstract

There is a limited information for the growing of winter cereals in mixed cropping system. Therefore, a field experiment in two growing seasons (2023/2024 and 2024/2025) was conducted. The trial was performed on the lands of the Agricultural University of Plovdiv, Bulgaria. Variants of the experiment were: 1. Winter wheat - variety 'Sofru' (sole crop); 2. Winter wheat - variety 'Solindo' (sole crop); 3. Winter wheat - variety 'Sofru' + winter wheat - variety 'Solindo' (mixed crop); 4. Winter barley - variety 'Odyssey' (sole crop); 5. Winter barley - variety 'Odyssey' + winter wheat - variety 'Sofru' (mixed crop); 6. Winter barley - variety 'Odyssey' + winter wheat - variety 'Solindo' (mixed crop); 7. Rye, variety 'Millennium' (sole crop). Differences were found in the height of the plants and the ear length, as well as the 1000 grain weight and the hectoliter mass of the seeds in mixed crops. The highest yield was recorded when the wheat variety 'Solindo' was sown alone. Regarding barley, a higher yield was recorded when it was grown together with the wheat variety 'Solindo'.

Key words: winter cereals, sole crops, mixed cropping.

INTRODUCTION

Mixed cropping is a cropping system in which different types of crops are grown together in a field so that nutrient requirements are shared. This reduces risk and provides some insurance against the failure of one crop. It is one of the oldest agricultural production systems (Plucknett and Smith, 1986).

Cropping systems based on carefully designed crop mixtures have shown several advantages under different farming conditions (Willey, 1979; Malézieux, 2009).

Some advantages of intercropping are nutrient use efficiency and yield stability (Lizarazo et al., 2020).

As described by Silvertown (1982), in mixed cropping two or more crops are grown together at the same time on the same area. For example, the forage of cereal-legume-cereal intercropping has a higher crude protein content and a higher relative feeding value for the animals (Strydhorst et al., 2008).

According to Lauk and Lauk (2009), the highest yield was found for the combination of pea-oat mixture. After growing pea+barley and pea+oilseed rape as intercropping, the yield was higher than that of single crops (Malhi, 2012).

Sibma (1977) and Spitters and Kramer (1986) have indicated that knowledge of differences in growth characteristics contributes to a better understanding of competitive differences or complementarities between varieties or crop species in mixtures. The growth rate of crop plants is determined by a number of factors, among which are the crop species/varieties grown in a mixed crop (Harris, 1990).

Wang et al. (2021) tested the intercropping of lentil (*Lens culinaris*) with five spring-sown companion crops: (*Hordeum vulgare*), wheat (*Triticum aestivum*), oats (*Avena sativa*), seed flax (*Linum usitatissimum*) and buckwheat (*Fagopyrum esculentum*). The intercropping was compared with single crops of these crops at the Kleinhohenheim Organic Research Station, University of Hohenheim, Germany, in 2009 and 2010. The aim of the study was to identify the most suitable intercropping and intercropping ratio for lentil in terms of yield, weed control and lodging under temperate climatic conditions. Intercropping of wheat and barley with lentil in Central Europe has significant benefits in terms of grain yield, weed control and crop resistance to lodging.

Mixed cultivation of peas together with camelina showed a significant suppressive effect on the weed flora.

Study conducted by Poggio (2005), mixing plant species can also reduce weed diversity. According to Leclère et al. (2019), the co-cultivation of camelina with peas or barley showed a reduction in weed biomass. The weed suppression is probably due to the mutually increased competitiveness of the two crops, indicating a mechanism based on resource allocation (Saucke and Ackermann, 2006).

Liebman and Dyck (1993) found that the composition of two or more crops reduced the weed biomass in the system compared to the crops grown alone.

In the mixed sowing of camelina genotype sown together with pea and vetch the development of the weeds *S. halepense* and *S. viridis* was severely suppressed (Neshev et al. 2023).

The information about the growing winter cereals in mixed cropping systems is still scarce. Therefore, this experiment's goal was to evaluate the systems effect on some agronomic and productive traits of different grain crops sown alone and mixed together.

MATERIALS AND METHODS

The research was conducted at the Experimental Field of Agricultural University – Plovdiv, Bulgaria. The study was performed in two growing seasons of the winter cereals – 2023/2024 and 2024/2025.

For the aim of the trial, the winter wheat varieties “Sofru” and “Solindo” were grown, the barley variety grown was “Odyssey”, and the rye variety “Millennium”. The experiment was based on the “long plots” method.

The following variants were under evaluation:

1. Winter wheat variety “Sofru” (sole crop – 200 kg ha⁻¹ sowing rate);
2. Winter wheat variety “Solindo” (sole crop – 200 kg ha⁻¹ sowing rate);
3. Winter wheat varieties “Sofru” + “Solindo” (mixed crop – 100:100 kg ha⁻¹ sowing rates);
4. Winter barley variety “Odyssey” (sole crop – 180 kg ha⁻¹ sowing rate);
5. Winter barley variety “Odyssey” + wheat variety “Solindo” (mixed crop – 90:100 kg ha⁻¹ sowing rates);
6. Winter barley variety „Odyssey“ + wheat variety “Sofru” (mixed crop – 90:100 kg ha⁻¹ sowing rates);
7. Winter rye variety

“Millennium” (sole crop – 200 kg ha⁻¹ sowing rate).

The preceding crop was maize. The soil preparation performed before sowing was deep plowing, followed by discing and harrowing. Before sowing, fertilization was performed with 300 kg ha⁻¹ of NPK. The spring dressing was done with 300 kg ha⁻¹ of ammonium nitrate.

The following biometrical parameters were evaluated:

- Visual assessment of area coverage by single and mixed crops - according to the Braun-Blanquet (1932) abundance-dominance scale (%). The assessment was done in two stages – first at tillering and second at flowering of the plansts;

- Stem length (cm);

- Ear length (cm).

The Biometric measurements were performed in three replicates for each variant of a given sole crop and mixed cropping system. A replicate was 30 plants (90 plants and ears total were measured).

Grain parameters studied were 1000 grain weight (g) and Hectoliter grain weight (kg).

The evaluation of these parameter was in three replications per variant.

The productivity of the sole and mixed crops (t ha⁻¹) were determined after harvesting the entire experimental plot of each variant. Harvesting was carried out with a combine harvester for plot trials of the company Wintersteiger®.

The agrometeorological data was taken from a weather station Meteobot® Pro.

For the processing and interpretation of the experimental data, Duncan's Multiple Range Test (Duncan, 1955) by SPSS 19 program was used. Differences were considered significant at $p < 0.05$.

RESULTS AND DISCUSSIONS

On Table 1 is presented the amount of precipitation and the average minimum and maximum temperatures during the vegetation of the sole and mixed crops. According to the meteorological data, we can determine how agrometeorological conditions affect the plants. In the two research years (2023/2024 and 2024/2025) the amount of precipitation in October, when the sowing of the sole and mixed

crops was carried out, was low. In the two years, the vegetation began in November, when 52.8 mm fell in 2023 and 22.8 mm in 2024. Lower precipitation was recorded in February, 2024 as well – 6.8 mm. The minimum and maximum

temperatures were relatively favourable for plants' development. Despite the high winter temperatures, no negative impact of the warm winter months on the growth and development of crops was recorded.

Table 1. Average monthly precipitation and minimum and maximum monthly temperatures during the trial seasons

Years / Months	Precipitation, mm	min. t, C°	max. t, C°	Precipitation, mm	min. t, C°	Max. t, C°
	2023/2024	2023/2024	2023/2024	2024/2025	2024/2025	2024/2025
October	2.3	8.6	26.5	4.2	5.3	23.9
November	52.8	3.9	15.8	22.8	-0.4	14.1
December	51.1	-0.2	12.1	150.3	2.12	9.7
January	47.8	-1.9	9.9	22.6	-1.9	10.9
February	6.8	2.6	17.4	25.3	-3.2	8.3
March	39.3	4.9	17.7	67.2	3.3	19.3
April	37.3	8.4	25.8	72.8	5.6	21.1
May	74.5	11.2	24.3	55.1	10.6	25.2
June	5.3	17.5	35.1	11.5	15.4	34.9

In the first observation (in the tillering stage), the percentage of area coverage was the highest in the sole crop of barley – 95% in 2024 and 85% in 2025 (Table 2). The sole crop of the wheat varieties also show a high percentage of area coverage – 90% in 2024 and 80% in 2025. In this assessment, it is observed that in the mixed cropping systems of “Odyssey” + “Sofru”, as well as in that of “Odyssey” + “Solindo”, a predominance of barley was observed over wheat, and this was more severely pronounced in the mixed cropping of barley with the wheat

variety “Solindo”. Rye, in turn, has a lower area coverage – 80% in individual years.

In the second assessment, the highest percentage of area coverage was in the sole crops of barley and the winter wheat varieties (Table 2). Sole crops of wheat varieties increased the percentage of area coverage to 95% in 2024 and up to 90% in 2025. In the mixed crop of the two wheats, a 50:45% coverage was found in 2024 and in 2025 the coverage was 50:50. During this period, the excess of barley over wheat varieties in the mixed crop of these crops increased.

Table 2. Crops' abundance-dominance by Braun-Blanquet's scale (%)

Variants	2024	
	1 st – tillering	2 nd – flowering
1. Sofru	90	95
2. Solindo	90	95
3. Sofru + Solindo	40: 45	50: 45
4. Odyssey	95	95
5. Odyssey + Sofru	60: 35	65: 40
6. Odyssey + Solindo	60: 35	70: 25
7. Millennium	85	90
Variants	2025	
	1 st – tillering	2 nd – flowering
1. Sofru	80	90
2. Solindo	80	90
3. Sofru + Solindo	45: 55	50: 50
4. Odyssey	85	95
5. Odyssey + Sofru	50: 40	65: 30
6. Odyssey + Solindo	55: 40	70: 25
7. Millennium	80	95

Table 3 presents the height of the plants at the end of the growing season. Genetically, rye has the tallest plants, which is also confirmed in the current experiment. According to Trenbath (1976) if grown as mixed rather than as a sole crop, the plants may reach an equivalent size or either dominants or suppressed plants in the sole crop's stand. In our study differences in the height of the plants grown in mixed crops were established.

It was observed that when growing the two varieties of wheat ("Sofru" + "Solindo") as a

mixed crop, the height of the plants of the "Sofru" variety decreases, and that of the "Solindo" variety increases. This was less pronounced when wheat is grown in a mixed crop with barley. When barley is grown in a mixed crop with the wheat variety "Sofru", the plants were shorter than those of the barley alone, and the wheat of the "Sofru" variety in the mixed crop increased its height. When barley was mixed with "Solindo", the barley developed better and its height slightly decreased, while the wheat was higher.

Table 3. Plant height at the end of the vegetation (cm)

Variants	2024	2025	Average
1. Sofru	75.42	74.24	74.83
2. Solindo	70.11	77.54	73.83
3. Sofru + Solindo	66.40 + 81.41	70.22 + 85.27	68.31 + 83.34
4. Odyssey	85.15	88.57	86.86
5. Odyssey + Sofru	67.51 + 78.90	74.12 + 79.34	70.82 + 79.12
6. Odyssey + Solindo	85.90 + 81.80	87.78 + 80.09	96.84 + 80.95
7. Millennium	163.98	174.35	169.17

On Table 4 is the ear length. Differences were found in this indicator when the plants were grown sole or as mixed crops. It was observed that when the wheat varieties were grown as a mixed crop, the length of their ears was

decreased. This was more pronounced when the winter wheats were grown in a mixed crop with barley. It was also observed that the barley ears also decreased in length when the wheats were grown mixed crop with barley.

Table 4. Ear length at the end of the vegetation (cm)

Variants	2024	2025	Average
1. Sofru	11.21	12.05	11.63
2. Solindo	10.78	11.27	11.03
3. Sofru + Solindo	10.20 + 10.60	11.41 + 10.47	10.81 + 10.54
4. Odyssey	10.35	11.42	10.86
5. Odyssey + Sofru	9.79 + 9.52	10.27 + 10.23	10.03 + 9.88
6. Odyssey + Solindo	10.20 + 9.31	10.54 + 10.07	10.37 + 9.69
7. Millennium	10.24	11.13	10.66

Table 5 shows the data for the 1000 grain weight. In different years the 1000 grain weight may differ in mixed cropping systems (Xiao et al, 2026). In our research it was established in the sole crops of the wheat variety "Solindo" the indicator was with the highest values. It was noted that in the mixed sowing of the two wheat

varieties, the 1000 grain mass was decreased. It should be noted as well that the 1000 grain weight from the mixed crops of barley with the two wheat varieties slightly decreased compared to the sole crop of barley. The lowest 1000 grain weight was measured for rye, which in turn is again genetically justified.

Table 5. 1000 grain weight (g)

Variants	2024	2025	Average
1. Sofru	37.56 b	38.25 b	37.91
2. Solindo	38.47 a	40.57 a	39.52
3. Sofru + Solindo	37.65 b	38.04 b	37.85
4. Odyssey	36.84 c	38.25 b	37.55
5. Odyssey + Sofru	37.80 b	36.41 c	37.11
6. Odyssey + Solindo	37.57 b	35.51 c	36.54
7. Millennium	29.84 d	31.29 d	30.57

Values with different letters are with proven differences according to Duncan's Multiple Range test ($p < 0.05$).

The hectoliter mass of the grain follows the trend established for the 1000 grain mass of the seeds. The highest hectoliter mass of the seeds was established for the independent sowing of the variety "Solindo" - 80.14 kg. Here it was also noticeable that for the mixed sowing of the two varieties of wheat the hectoliter mass of the

grain slightly decreased to 78.16 kg. It should be noted that the hectoliter mass of the grain from the mixed crops of barley with the two varieties of wheat increases slightly compared to the sole sowing of barley, with the increase being in favor of the mixed crop of "Odyssey" + "Solindo" - 74.61 kg (Table 6).

Table 6. Hectoliter weight (kg)

Variants	2024	2025	Average
1. Sofru	76.48 c	78.56 b	77.52
2. Solindo	79.02 a	81.26 a	80.14
3. Sofru + Solindo	77.12 b	79.19 b	78.16
4. Odyssey	69.77 e	71.09 d	70.43
5. Odyssey + Sofru	73.47 d	75.45 c	74.46
6. Odyssey + Solindo	73.54 d	75.67 c	74.61
7. Millennium	68.23 f	70.78 e	69.51

Values with different letters are with proven differences according to Duncan's Multiple Range test ($p < 0.05$).

Grain yields are genetically justified for each plant species, and are also influenced by growing conditions.

According to Willey (1979), Reddy and Reddy (1981), Kara et al. (2010) and Wang et al. (2021) the yield was significantly increased by mixed cropping compared to the sole crops. Our obtained results for the plants' productivity from the sole and mixed crops are in Table 7.

Overall, the highest yield was recorded with single cropping of wheat variety Solindo – 6.88

t ha⁻¹ average for the period. It should be noted that the average yield from the mixed cropping of the two wheat varieties was 6.68 t ha⁻¹, which in turn was close to that of sole cropping of Sofru variety – 6.55 t ha⁻¹ average for the period of the study.

Regarding barley, a higher yield was recorded when it was grown together with the winter wheat variety Solindo – 5.89 t ha⁻¹.

Rye has a low yield potential, with grain yields of 2.11 t ha⁻¹ obtained from it.

Table 7. Grain yields (t ha⁻¹)

Variants	2024	2025	Average
1. Sofru	6.30 a	6.79 b	6.55
2. Solindo	6.54 a	7.21 a	6.88
3. Sofru + Solindo	6.39 a	6.96 b	6.68
4. Odyssey	5.60 b	5.96 c	5.78
5. Odyssey + Sofru	5.49 b	5.84 c	5.67
6. Odyssey + Solindo	5.75 b	6.04 c	5.89
7. Millennium	1.97 d	2.24 d	2.11

Values with different letters are with proven differences according to Duncan's Multiple Range test ($p < 0.05$)

CONCLUSIONS

The abundance-dominance of the studied crops was in favour of the barley variety "Odyssey" grown as sole crop. In mixed crops the barley prevailed in the covered area while the sowing of the two winter wheat varieties together on the same area showed that both winter wheat varieties cover approximately the same area. When grown together, the plant height of the winter wheat variety "Sofru" decreased in comparison to the height of the plans of the

"Solindo" variety where an increase was found when compared to the sole crops. It was also found for the ear length. Similar results were recorded for barley grown as mixed crop with the winter wheat varieties.

The indicator 1000 grain weight was the highest for the winter wheat variety "" grown as sole crop. In mixed roping with "Sofru" and the barley, the parameter was diminished.

When barley was grown together with winter wheat the 1000 grain weight increased. The

hectolitre seed mass follows the tendency of the 1000 grain weight.

The highest yield was recorded for the sole crop of the winter wheat variety "Solindo". Regarding barley, a higher yield was recorded when it was grown together with "Solindo".

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