

Article

Impact of Linseed Variety, Location and Production Year on Seed Yield, Oil Content and Its Composition

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Abstract: Linseed (*Linum usitatissimum* L.) is a traditional oilseed crop in Europe that represents a valuable alternative for cropping systems because of the high quality of the seed oil, which is being increasingly appreciated by consumers, food, cosmetic and ecomaterials industries. The aim of this study was to evaluate the influence of linseed variety and year of production in relation to weather conditions on seed yields, oil content and its quality, with a focus on human nutrition value, through a field study carried at four different locations in Slovenia. Six early French linseed varieties were studied: Recital, Niagara, Princess, Altess, Comtess and Duchess. The seed yield was significantly affected by the year of production (413 kg/ha higher in 2012 compared to 2013), the location and the variety. The environmental factors that negatively affect seed yield are high temperatures in summer, water shortage and wet and cold soil in spring. The highest seed yield was reached at mid-heavy soil (1907 kg/ha) in the region with higher precipitation amount, while the lowest on light soil (1052 kg/ha) in the region with a lower precipitation amount. Comtess and Altess varieties, followed by Duchess, would be recommendable for Slovenian environmental conditions. Comtess variety gave the significantly highest oil yield. There were no significant differences in oil content between varieties. The content of α -linolenic acid was highly related to genetic and environmental factors. The ratio of omega-3 and omega-6 fatty acids was recognized as favorable for human health for all studied varieties. The content of α -linolenic acid in seeds from the Altess, Comtess and Duchess varieties exceeded the averages of 2012 and 2013, at 50.3% and 51.6%, respectively. The omega-3:omega-6 ratio ranged from 3:1 to 4:1 among varieties.

Keywords: *Linum usitatissimum* L.; linseed; seed yield; nutrition quality; oil; field production; growth conditions

1. Introduction

Linseed (*Linum usitatissimum* L.) is a traditional oilseed crop that represents a valuable alternative for cropping systems due to its adaptability to poor soils and its high economic value relative to the high quality of the seed oil, which is being increasingly appreciated by consumers, the food industry and the cosmetics and ecomaterials industries [1]. Several findings all over Europe suggest that the species has played an important role in nutrition and handcraft since the Neolithic period; presumably, the domestication of *Linum bienne* started in central Europe to obtain oil and fibers; cultivation in central Europe peaked during the eighteenth century due to the fabrication of linen textiles [2]. Although linseed is a plant species with a high adapting capacity to unfavorable environmental conditions, which enables expansion of the cultivated land area under various agroecological conditions, the cultivated

area of linseed is limited (nearly 2,800,000 ha in the world in 2017 and nearly 3,300,000 ha in 2018) with an average yield of about 1 ton. In Europe, in the last five years, the area is between 800,000 ha and 900,000 ha, with a yield of 0.8 t/ha to 1.1 t/ha [3]. Nevertheless, for example, in Germany, varietal range in seed yield has been observed from 2.35 to 2.6 t/ha in conventional farming, and from 1.4 to 1.9 t/ha in Switzerland in organic farming [2].

Oil content and its fatty acids composition are the main parameters for linseed when evaluating nutrition quality. Linseed seed yield in European countries is highly variable [4]: linseed thrives best in regions with temperate climates with moderate warmth, high humidity and well-drained medium-heavy soils [5]. In order to reach high linseed oil yield and quality, it is necessary to understand the factors of influence. Cool climates usually result in high oil and low protein content in seed [6]. Seed quality and quantity are known to be influenced by genotype, growing season, geographic location and agronomic practices [7]. Weather conditions (temperature and rainfall regime) could also have an important effect on the yield and quality of produced seeds [8]. Environmental conditions influence crop growth and development, which are the most vital factors in reducing crop productivity [9]. Cool climatic conditions in temperate regions lead to a high share of omega-3 fatty acids. Continental temperate climate influences a higher content of polyunsaturated fatty acid (ALA) and lower content of oleic acid (monounsaturated fatty acid) in comparison to crops from Mediterranean and subtropical regions [2]. Oil content is higher when linseed grows at lower temperatures. It has a rather high demand for water—400 to 450 mm in the growth period (140 days). The increase of plant-available water in the soil from 40% to 80% increased the seed yield per plant by a factor of 1.89, while oil content rose by about 2.5% [2].

Seeds are rich in omega-3 fatty acids (FA) and lignans, are a source of high-quality protein and soluble fiber and also have considerable potential as a source of phenolic compounds [6]. The oil content of linseed seed ranges between 35% and 45% (*w/w*), although even higher values have been reported [10]. Generally, linseed seed oil contains approximately 9–11% saturated (5–6% palmitic acid and 4–5% stearic acid) and 75–90% unsaturated FA (50–55% α -linolenic acid, 15–20% oleic acid) [11]. Compared to other oilseed crops, linseed oil is the richest source of omega-3 and α -linolenic acid (ALA) [12]. Linseed seed oil also has a beneficial ratio (n-6:n-3) of fatty acid (FA) of approximately 0.3:1 [13,14]. Genetic and environmental factors such as soil and climate can influence linseed seed yield, oil content and the FA composition of seed oil and seed press cake [6,15,16]. The linseed variety influences the quality of the seeds, and respective varieties must be chosen to improve the linseed product quality [2]. Assessment of linseed varieties in different environmental conditions becomes essential before planning an appropriate cultivation strategy [17].

The aim of this study was to evaluate the influence of linseed variety, year of production in tight relation to weather conditions on seed yields, oil content and its quality, with a focus on human nutrition value, through a field study carried on four different locations in Slovenia.

2. Materials and Methods

2.1. Description of Site and Weather Conditions

Varietal field trials were conducted in Slovenia at four different locations—two in the Savinja Valley (Žalec) and two in East Slovenia (Murska Sobota and Rakičan)—in 2012 and 2013. Location characteristics are presented in Table 1.

The spring of 2012 was warm and dry, with scarce rainfall lasting from autumn 2011 to spring of 2012. Winter and spring of 2013 were very wet: the spring was cold, and the soil remained wet for a long time. The summer of 2013 was dominated by a shortage of rainfall, accompanied by very high temperatures (up to 40 °C) (Figures 1 and 2). During the growing season (from the beginning of April to mid-August), there was 569 mm of rainfall in 2012 and 362 mm in 2013 in the Savinja Valley and, in East Slovenia, 388 mm in 2012 and 258 mm in 2013. Compared to the Savinja Valley, the East

Slovenia locations received considerably less rainfall during the growing seasons in 2012 (a difference of 181 mm) and 2013 (104 mm). The mean temperature and its fluctuations were similar [18].

Table 1. Locations characteristics and some agrotechnical measures.

Abbreviation	Savinja Valley		East Slovenia	
	SV1	SV2	PM1	PM2
	<i>Savinja Valley—heavy soil</i>	<i>Savinja Valley—medium-heavy soil</i>	<i>East Slovenia—heavy soil</i>	<i>East Slovenia—light soil</i>
Coordinates	GKY: 512,835; GKX: 12,2796	GKY: 512,871; GKX: 122,793	Murska Sobota—593,195, GKX: 168,428	Rakičan—GKY: 589,889, GKX: 166,228
Soil type	Alluvial/riparian, brown, medium-deep, texture class clay loam. In deeper horizons, signs of water retention were noticed.	Medium-deep eutric brown soil on a sandy-gravel basis. Upper horizon was loam-sandy clay loam class (medium-heavy soil).	District brown soil, silty clay loam	District brown soil, sandy-gravel
pH	6.8	6.6	5.6	6.2
Plant-available amounts of phosphorus (P_2O_5)	30.1 mg/100 g of soil (excessive supply)	19.9 mg/100 g of soil (oversupplied)	14.6 mg/100 g of soil (well supplied)	51.5 mg/100 g of soil (extremely supplied)
Plant-available amounts of potassium (K_2O)	13.7 mg/100 g of soil (semi-well supplied)	34.5 mg/100 g of soil (oversupplied)	17.6 mg/100 g of soil (semi-well supplied)	23.6 mg/100 g of soil (well supplied)
Soil organic matter content	2.7%	2.5%	3.4%	1.9%
Nmin content of the soil before blossoming in 2013	<15 kg/ha	<15 kg/ha	30 kg/ha	30 kg/ha
Nmin content of the soil after harvest in 2013	44 kg/ha	35 kg/ha	48 kg/ha	58 kg/ha
Date of sowing	3rd April 2012, 20th April 2013	3rd April 2012, 20th April 2013	19th April 2012, 2nd May 2013	19th April 2012, 2nd May 2013
Seed rate	100 kg/ha	100 kg/ha	100 kg/ha	100 kg/ha
Harvest	1st August 2012, 13th August 2013	1st August 2012, 13th August 2013	24th July 2012, 23rd August 2013	24th July 2012, 23rd August 2013

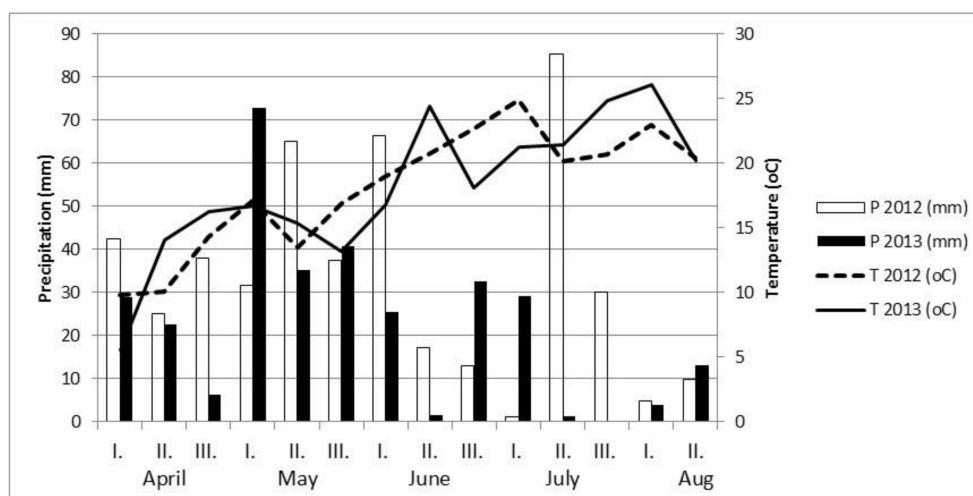


Figure 1. Rainfall (sum) and mean ten-day temperatures in the years 2012 and 2013 in the Savinja Valley region.

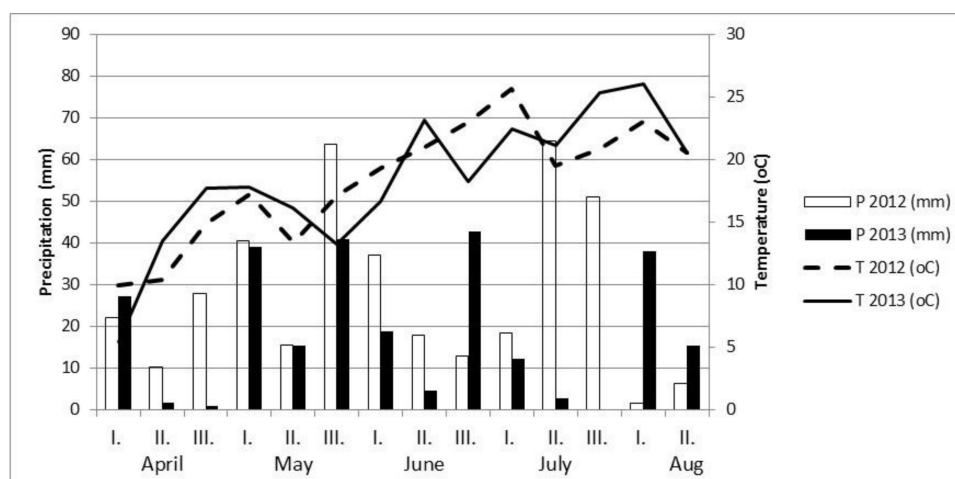


Figure 2. Rainfall (sum) and mean ten-day temperatures in the years 2012 and 2013 in the East Slovenia region.

In both investigated years, hot and dry weather prevailed during the seed ripening. In July 2012, there was heavy hail in the Savinja Valley, while East Slovenia experienced heavy hail, strong winds and rainfall, which negatively affected the growth and development of crops.

2.2. Experimental Design and Treatments

Varietal field trials were conducted as block field trials replicated four times. The size of each plot was 36 m² (6 m × 6 m).

Six linseed varieties, which originated in France and are described as early varieties, with good seed yield and content of oil, were investigated: Recital, Niagara, Princess, Altess, Comtess and Duchess. According to the declaration of varieties (2018), Niagara and Princess contain the most oil (48%), with Princess being rich in omega-3 FA content (60%) and well-suited to southern areas, having stable yield under drought stress conditions. For Altess and Comtess, their high yields are emphasized, while the Comtess variety is also rich in oil and omega-3 content. The Duchess variety has higher productivity than Niagara [19].

2.3. Plot Establishment and Management

For the subsequent sowing, the soil was well prepared in autumn. Seeding was done using an experimental plot seeder (Wintersteiger Plotseed TC, Ried im Innkreis, Upper Austria) at a rate of 100 kg/ha in spring. In 2013, due to the constant rainfall resulting in wet and cold ground, the soil could not be prepared until mid-April, so the sowing was carried out later than in 2012. The sowing times are presented in Table 1. No irrigation was included. Basagran 480 (1.8 L/ha)—a selective contact herbicide intended to eliminate annual and some perennial broadleaf weeds—was used after the weeds' emergence. No other phytopharmaceutical products were used. Nitrogen (N) was added in two equally sized amounts (30 kg/ha N) in the form of KAN fertilizer (after the sowing and at the start of blossoming). Before the second N fertilization and after the harvest in 2013, the Nmin (nitrate and ammonium form of N) content of the soil was measured (Table 1). Harvesting was carried out, plot-by-plot, using a plot-harvester at the technical maturity of the crops: the timing is presented in Table 1.

2.4. Data Collection and Computation

Yield per plot was weighed immediately after harvest, and samples per plot for moisture content (Analytica EBC 7.2, 1998) and oil content (Soxhlet method; SIST EN ISO 659:1998) were taken promptly. The seeds were ground in a grinder to a granulation below 2 mm. 10 g of the ground sample

was transferred to a flask fitted with a Soxhlet apparatus. We added 150 mL of hexane solvent (Sigma-Aldrich, St. Louis, MO, USA). The extraction was performed for 6 h. The solvent was removed from the sample by drying at 105–107 °C to the constant weight. The oil content was calculated from the mass difference. All determinations were made in two replicates. Yields of seed dry matter and oil per plot/treatment were calculated.

Seed samples of average weight (8 kg), selected by variety (treatment) at the location PM2 (East Slovenia, light soil) in both experimental years, were pressed with an experimental screw mill. Compression was performed in two stages: the press cake, after the first compression, was fed into the screw mill again, followed by further compression. In the first stage, the rotational speed of the mill's screw was 19 turns/min; at the second stage, it was 13.5 turns/min. The quality and quantitative composition of essential and non-essential fatty acids after their derivatization into methyl esters were determined by gas chromatography (according to the method SIST EN ISO 12966: 2015).

2.5. Statistical Analysis

The results for seed yield, oil content and oil yield were processed by multifactor ANOVA using Statgraphics Centurion XV (Statgraphics Technologies Inc., The Plains, VA, USA) statistical software. Main effects and two-way interactions were determined. Three-way interactions were pooled into the residual (error) term in order to compute statistics (F-ratio, p -value). Differences between treatments were interpreted by Duncan's multiple range test ($p = 0.05$). Statistical results are provided in the Results and Discussion section and as Supplementary Materials (Tables S1, S2 and S3).

3. Results and Discussion

3.1. Seed Yield

The seed yield was significantly affected by the year of production, the production location and the variety (Tables 2 and 3). Weather conditions were more favorable in 2012 compared to 2013; the difference in average seed yield was 413 kg/ha in favor of 2012. In 2013, the soil was wet and cold for a long time in the spring, causing the growth and development of linseed at the beginning of the growing season to be poor and the crop infrequent. In addition, there was a prolonged lack of precipitation in the summer of 2013, accompanied by high temperatures. Similarly, in the experiments by Casa et al. [20] in Italy, linseed seed yields varied greatly in response to weather and soil type: the environmental factors most likely to affect yield were high temperature and water shortage. By contrast, as reported by Angelini et al. [15] for field experiments during 2011–2014 in two regions of Italy, seed and oil yields were stable, irrespective of yearly differences in weather conditions. The reasons for diverse conclusions may vary, but one of the crucial factors may be the studied variety, which was not included in our investigation (variety Sideral).

The effect of the variety on the seed yield depended to some degree on the location (Table 3: F-ratio = 7.22; $p < 0.05$) (Figure 3), but not on the year (F-ratio = 1.54; $p > 0.05$). In addition to the statistically significant effects of the factors year (F-ratio = 360; $p < 0.05$) and location (F-ratio = 290; $p < 0.05$), their interaction (Figure 4) was also quite strong (F-ratio = 169; $p < 0.05$), which can mainly be attributed to much poorer linseed production in both the Savinja Valley locations in 2013 compared to 2012. Changing weather conditions apparently had a considerably lower detrimental impact on the yield in the East Slovenia locations.

Table 2. Linseed seed yield, oil content in seed and oil yield with regard to variety, location and year of production (2012, 2013).

		Seed Yield (kg Dry Matter/ha)	Oil Content (% of Dry Matter)	Oil Yield (kg/ha)
Variety	Recital (S1)	1350 bc *	37.7 a	509 b
	Niagara (S2)	1324 c	39.2 a	515 b
	Princess (S3)	1305 c	38.7 a	505 b
	Altess (S4)	1461 a	37.1 a	527 b
	Comtess (S5)	1482 a	38.4 a	566 a
	Duchess (S6)	1406 ab	37.4 a	523 b
Location	Savinja Valley—heavy soil, pH = 6.8 (SV2)	1379 b	37.8 ab	685 a
	Savinja Valley—medium-heavy soil, pH = 6.6 (SV1)	1907 a	36.6 b	528 b
	East Slovenia—heavy soil, pH = 5.6 (PM1)	1213 c	39.2 a	478 c
	East Slovenia—light soil, pH = 6.2 (PM2)	1052 d	38.6 a	405 d
Year	2012	1594 a	34.8 b	559 a
	2013	1181 b	41.3 a	489 b

* The same letter in the column for a particular factor indicates that there is no significant difference between the factor level means (Duncan's multiple range test, $p = 0.05$).

Table 3. ANOVA table for the seed yield, oil content and oil yield.

SEED YIELD	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A: Variety	860,618	5	172,124	7.56	0.0000
B: Block	399,415	3	133,138	5.85	0.0008
C: Location	19,805,300	3	6,601,760	290.14	0.0000
D: Year	8,191,570	1	8,191,570	360.01	0.0000
INTERACTIONS					
AC	2,463,350	15	164,223	7.22	0.0000
AD	174,963	5	34,992.6	1.54	0.1811
CD	11,560,600	3	3,853,520	169.36	0.0000
RESIDUAL	3,549,570	156	22,753.7		
TOTAL (CORRECTED)	47,005,300	191			
OIL CONTENT					
MAIN EFFECTS					
A: Variety	26.6985	5	5.33971	1.33	0.3030
B: Location	44.4273	3	14.8091	3.70	0.0357
C: Year	503.755	1	503.755	125.84	0.0000
INTERACTIONS					
AB	79.469	15	5.29793	1.32	0.2971
AC	11.7885	5	2.35771	0.59	0.7086
BC	143.902	3	47.9674	11.98	0.0003
RESIDUAL	60.049	15	4.00326		
TOTAL (CORRECTED)	870.09	47			
OIL YIELD					
MAIN EFFECTS					
A: Variety	19,543.7	5	3,908.73	4.36	0.0119
B: Location	507,398	3	169,133	188.67	0.0000
C: Year	58,940.1	1	58,940.1	65.75	0.0000
INTERACTIONS					
AB	133,044	15	8,869.63	9.89	0.0000
AC	4,148.67	5	829.733	0.93	0.4915
BC	682,685	3	227,562	253.85	0.0000
RESIDUAL	13,446.5	15	896.433		
TOTAL (CORRECTED)	1,419,210	47			

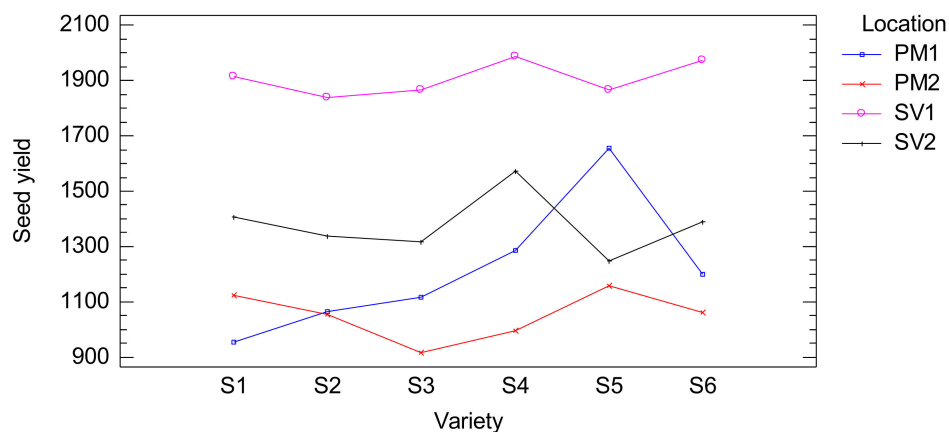


Figure 3. Interactions between linseed variety and location for seed yield (S1 = variety Recital, S2 = variety Niagara, S3 = variety Princess, S4 = variety Altess, S5 = variety Comtess, S6 = variety Duchess).

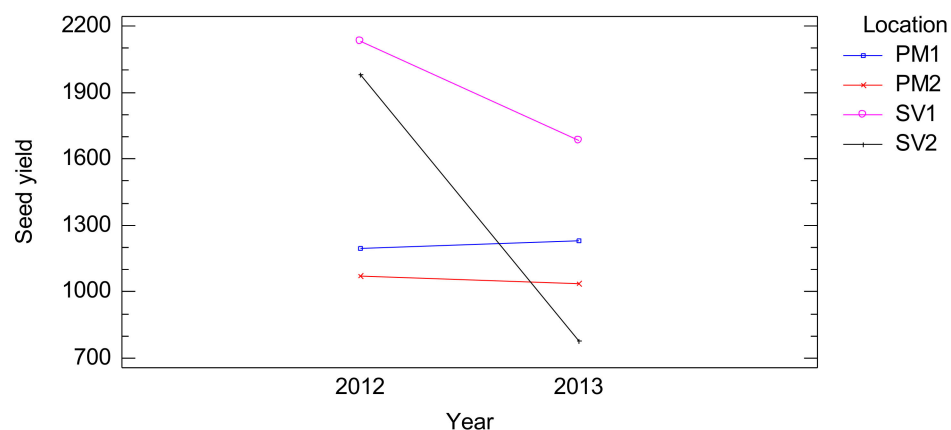


Figure 4. Interactions between production year and location for seed yield.

Achieved seed yields were above average according to global data on linseed seed yields, ranging from 120 in Iran to 2450 kg/ha in Switzerland in 2018, with an average of approximately 1000 kg/ha [3]. In favorable years, intensive cultivation can yield up to 4000 kg/ha.

Linseed varieties for oil production have a low need for water supply (a transpiration coefficient between 300 and 400). To achieve higher yields, a minimum of 120 mm of water is required in May and June. At all locations, this parameter was achieved or even exceeded: in 2012, the total precipitation in May and June in the Savinja Valley was 231 mm, and in 2013, 208 mm, while in East Slovenia, it was 187 mm in 2012 and 161 mm in 2013. However, Jacobsz and van der Merve [4] reported that, under rainfed conditions, linseed requires 450–750 mm of rain, spread evenly through the growing season. The Savinja Valley was found to be more favorable for linseed seed production compared to the East Slovenia region (lower precipitation amounts) in the investigated years: both locations in this geographical region achieved significantly higher yields (an average of 1643 kg/ha in the Savinja Valley compared to 1133 kg/ha in East Slovenia; Table 2). In East Slovenia, a higher seed yield was obtained at the location with heavy soil (with higher water holding capacity) compared to the location with light soil. Significantly higher seed yield was achieved on medium–heavy soil compared to heavy soil in the Savinja Valley (the region with higher precipitation amount).

Weather conditions and soil properties can have a great impact on the length of the linseed growing season [21]. The environmental factors most likely to affect yields are high temperatures and water shortages, which shortening the growing cycle. It was expressed in our experiments in a way that the

linseed had a growing season from 96 days (East Slovenia) to 120 days (Savinja Valley) in the year 2012 and around 117 days at both locations in the year 2013. Zimmermann et al. [22] reported that linseed yield differed considerably between experimental locations in Spain and Germany: five different varieties grown in Spain produced only 39% of seed yields compared to those grown in Germany.

The significantly highest seed yield average (1907 kg/ha) was achieved on medium-heavy soil in the Savinja Valley, which was also, importantly, the location with the highest yield in both examined years. However, the yield in East Slovenia, on light soil, did not differ between the examined years (1070 kg/ha in 2012, 1034 kg/ha in 2013).

Heavy clays and dry, sandy soils are unsuitable for linseed production [4]. As depicted in Figure 4, the lowest seed yield was achieved in 2013 on heavy soil in the Savinja Valley (from 700 to 900 kg/ha with regard to variety, the difference in yield across varieties being insignificant), in the year when the soil was wet and cold for a prolonged period in the spring. In East Slovenia, where there was less rain in the spring during that year, the seed yield was significantly higher at the location with heavy soil (1230 kg/ha) compared to the location with light soil (1034 kg/ha), for all investigated varieties.

The highest seed yields, on average, came from the Comtess and Altess varieties, followed by Duchess (Table 2). By year, the significantly highest yield in 2012 at both locations in the Savinja Valley was achieved from the Altess variety (2265 kg/ha and 2288 kg/ha, respectively). In East Slovenia, the significantly highest yield in 2012 gave at both locations Comtess variety (1596 kg/ha and 1239 kg/ha, respectively), followed by the Altess variety on heavy soil and the Recital variety on light soil. In 2013, at both locations in Savinja Valley, there were no significant differences in the yield between varieties, which gave, on average, 778 kg/ha on heavy soil and 1683 kg/ha on medium-heavy soil. In East Slovenia, the significantly highest yield at the location on heavy soil gave Comtess variety (yielded 1714 kg/ha) and on light soil Recital variety (1131 kg/ha), which yield did not differ significantly from the Comtess variety yield. The Comtess variety's high yield is also emphasized in its profile description [19].

Crop yield levels in both environments were in line with previous results obtained for different varieties in other countries. In the field experiments by Stafecka et al. [21], from 2010 to 2013 in Latvia, the Duchess variety produced an average seed yield of 1970 kg/ha (the lowest yield being 1600 kg/ha), and adequate water supply was appreciated by this variety (2600 kg/ha in 2012). The Princess variety yielded from 1100 to 2200 kg/ha according to the year, giving a 200 kg/ha higher yield than the Duchess variety. The opposite was found in our locations.

3.2. Oil Content and Oil Yield

There were no significant differences between varieties regarding oil content (Table 3: $p > 0.05$), but a significantly higher seed oil content was achieved in 2013 compared to 2012. In 2013, the crop was infrequent because of the wet and cold soil in spring; there was also a prolonged lack of precipitation in the summer, accompanied by high temperatures what followed by lower seed yield, but in contrary higher oil content. In addition, among the locations, the significantly lowest oil content was achieved in the Savinja Valley, on medium-heavy soil, where the seed yield was significantly the highest (Table 2), so we think there was a dilution effect. Considering years and locations separately, there were always Niagara and Princess varieties in the Savinja Valley with the highest oil content, followed by Recital variety.

Niagara was the variety with the highest average oil content (Table 2; 39.2%), and this variety is described in its declaration to have a very high oil content [19]. However, in East Slovenia, the oil content differed according to variety and year. In 2013, a significantly lower oil content was achieved by Comtess and Duchess varieties on heavy soil (42.1% and 42.3%, respectively), but on light soil, these two varieties achieved significantly higher oil content (44.6% and 46.4%, respectively) compared to other varieties in the same year. However, Duchess variety produced the lowest oil content in East Slovenia on light soil in 2012. There were considerable differences in oil content for the East Slovenia locations between the examined years: in 2012, the content ranged between 30.0% and 38.9% according

to the variety and location, while in 2013, it ranged between 42.1% and 46.4%. Differences between years were not as great in the Savinja Valley locations. In the experiment by Smolova et al. [23] in the Czech Republic, the oil content of four different varieties, including the Recital variety (41.5%), ranged from 38.9 to 42.5%. In 2013, the oil content of seeds mostly exceeded 40%, excluding the Savinja Valley location, on heavy soil. These results are comparable to those reported by Elayan Sohair et al. [16] and Andruszczak et al. [24] but are higher compared to Bayrak et al. [25] and Rasouli et al. [26]. In the field experiments conducted by Stafecka et al. [21] from 2010 to 2013 in Latvia, the Duchess variety had 44.9% oil content, and Princess had 49.1%, while in our experiments, the oil content was lower for both varieties in both studied years.

The average oil yield and its content in seed dry mass vary greatly, depending on the source material (varieties, lines and population) [16,24] and agronomical conditions, including the location of production, soil type, water supply, fertilization, sowing date and weather conditions [10,15,24–27]. The great variability of oil content, probably depending on the above-mentioned parameters, was evident in our experiments also: the oil yield of the studied linseed varieties, presented in Table 2, ranged from 292 kg/ha to 828 kg/ha in the year 2012 and from 241 kg/ha to 747 kg/ha in the year 2013, with averages of 559 kg/ha and 489 kg/ha, respectively. In East Slovenia, the oil yield of linseed in 2012 was lower than in 2013, but by contrast, in the Savinja Valley, the oil yields were higher in 2012, especially on heavy soil, while yields in 2013 were very low (on average 291 kg/ha). In both years, the highest oil yield was achieved in the Savinja Valley: 27% higher than in the East Slovenia region. In Germany, oil yield was reported from 0.57 t/ha to 1.06 t/ha with regard to variety in conventional farming and in Switzerland from 0.49 t/ha to 0.67 t/ha in organic farming.

The highest oil yield was observed in both years for the Comtess, Altess and Duchess varieties, averaging 566 kg/ha, 527 kg/ha and 523 kg/ha, respectively. The general trend of oil yield was opposite to the trend of oil content in seeds in both years and could be attributed to the dilution effect.

Our results are in accordance with the findings of other studies. The linseed is sensitive to drought at the initial development stage, at flowering and during early seed development, indicating that seed yield and oil content can be maximized by maintaining soil moisture to adequate levels during the corresponding periods [28]. Water stress limits linseed growth by hastening physiological maturity, and consequently, the period of seed oil synthesis and deposition. As Anastasiu et al. [8] proposed, such data can be further used to estimate the oil production of a variety regarding a given meteorological annual forecast.

3.3. Fatty Acid Composition of Cold Pressed Oil

The fatty acids profiles for the studied varieties, produced in 2012 and 2013 (average sample from all experimental locations), are shown in Table 4. Linseed oil consists mainly of α -linolenic, linoleic, oleic, palmitic and stearic acids. The main fatty acid is α -linolenic, an omega-3 tri-unsaturated fatty acid ranging from 47.36% (Recital) to 53.01% (Comtess) in the year 2012 and from 50.40% (Niagara) to 53.03 (Recital) in the year 2013. The commonly recognized high content of α -linolenic acid is above 50% [15,24,29]. In 2013, all the varieties in our study exceeded 50%, while in 2012, the Recital and Niagara varieties fell below this level. From the point of view of the α -linolenic acid content, Altess and Duchess cultivars are observed as high-leveled in both years (above the average for both studied years 2012 and 2013; 50.27% and 51.61%, respectively); at the opposite pole is Niagara, with modest α -linolenic acid levels for both studied years (47.36% and 50.40%, respectively). In terms of the linoleic acid concentration (mean values 13.97% and 14.74%, respectively for 2012 and 2013), varieties Niagara and Comtess reached the content above average in both years. Recital differs from the other five varieties with respect to oleic acid content in 2012 (24.78%, compared to the other five varieties ranging from 19.97 to 23.37%), while in 2013 variety Niagara differs (23.09%, compared to other five varieties ranging from 21.79% to 22.79%). The main saturated fatty acids (palmitic and stearic) are found in amounts below average (6.05% and 6.09%, respectively for 2012 and 2013) for two varieties in 2012 and

for four in 2013. Arachidic and gonodolic acids were detected in trace amounts (on average less than 0.5%). Overall, these results agree with other papers dealing with linseed oil composition [6,30].

Table 4. The content of some fatty acids in cold-pressed oils from different linseed varieties, produced in East Slovenia on light soil, in years 2012 (1st) and 2013 (2nd) (in %).

Variety	C16:0 *		C18:0 *		C18:1 *		C18:2 *		C18:3 *		C20:0 *		C20:1 *		ω 3: ω 6	
Year	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Recital	6.46	5.89	4.98	4.51	24.78	21.79	14.43	14.13	47.36	53.03	0.47	0.44	1.22	0.03	3.3:1	3.8:1
Niagara	5.30	6.25	5.83	4.80	22.51	23.09	16.12	15.11	49.01	50.40	0.36	0.14	0.52	0.03	3.0:1	3.3:1
Princess	6.55	6.19	5.53	4.67	22.98	22.79	12.82	15.02	50.76	50.98	0.45	0.17	0.64	0.03	4.0:1	3.4:1
Altess	6.10	6.05	6.06	4.57	23.37	22.34	12.65	14.63	50.42	52.05	0.41	0.15	0.64	0.03	4.0:1	3.6:1
Comtess	6.47	6.07	5.70	4.57	19.97	22.49	14.17	14.89	53.01	51.34	0.39	0.43	0.00	0.03	3.7:1	3.4:1
Duchess	5.40	6.08	5.95	4.62	22.96	22.43	13.63	14.66	51.05	51.86	0.72	0.15	0.00	0.03	3.7:1	3.5:1
Lipid Number		Common name		Systematic Name												
C _{16:0}		Palmitic acid		Hexadecanoic acid												
C _{18:0}		Stearic acid		Octadecanoic acid												
C _{18:1}		Oleic acid		<i>cis</i> -9-Octadecenoic acid												
C _{18:2}		Linoleic acid		<i>cis, cis</i> -9,12-Octadecadienoic acid												
C _{18:3}		α -Linolenic acid		<i>cis, cis, cis</i> -9,12,15-Octadecatrienoic acid												
C _{20:0}		Arachidic acid		Eicosanoic acid												
C _{20:1}		Gonodolic acid		<i>cis</i> -Eicos-11-enoic acid												

* Legend for fatty acids.

In addition, as it is evident from Table 4, the fatty acid profile of linseed oil varies not only depending on the variety but also on the year of production. The same variety (Recital) may produce in one year the highest amount of the most important component of linseed oil, an α -linolenic acid, while in another year the lowest (47.36% and 53.03%, respectively for 2012 and 2013), most probably related to specific weather conditions of studied years. In accordance with data obtained in other studies [8,26], weather conditions (temperature and rainfall regime) may have an important effect not only on the oil production but also on linseed oil quality or fatty acid composition.

In comparison to other oilseed crops, linseed is the richest source of n-3 α -linolenic acid, the omega-3 fatty acid, which has been recognized as beneficial for human health, especially cardiovascular health [31,32]. In addition, the omega-3 and omega-6 fatty acids in linseed oil have a favorable ratio for human health [33]. The content of α -linolenic acid ranged from 47.4% to 53.0% (average 50.3%) in 2012 and from 50.4% to 53.0% (average 51.6%) in 2013 (Table 3), while the content of linoleic acid ranged from 12.7% to 16.1% (average 14.0%), in 2012 and 14.1% to 15.1% (average 14.7%) in 2013. The omega-3:omega-6 ratio, presented in Table 3, ranged from 3.0–4.0:1 in 2012 and 3.2–3.81 in 2013. Observed ratios were in the range of 3:1 to 4:1, which is in accordance with other studies and has been recognized as favorable for human health [13,33–35].

4. Conclusions

Observed linseed varieties were monitored in Slovenia for two years (2012 and 2013) in a field trial at four locations in order to give a new viewpoint of cultivating linseed, to estimate the seed and oil production regarding weather conditions and locations with different soil characteristics. Results show that the seed yield was significantly affected by the year of production (lower in 2013 by 413 kg/ha), the production location and the variety. From the results of our study and in accordance with reviewed literature, it can be concluded that the environmental factors which most likely negatively affected the seed yield are high temperatures during summer with water shortages. In addition, also wet and cold soil in spring negatively affected the seed yield because of the negative impact on plant emergence.

The highest seed yield was reached at the location with mid-heavy soil in the region with higher precipitation amounts, and the lowest on light soils in the region with lower precipitation amounts.

In regions with lower precipitation amounts, higher seed yield is expected on heavy soil compared to light soil, while in regions with higher precipitation amounts, medium-heavy soils prosper over heavy soils. From the perspective of investigated varieties, Comtess and Altess varieties, followed by Duchess, would be recommendable for Slovenian environmental conditions if we are looking for high seed yield. On the other hand, the Comtess variety also gave the significantly highest oil yield, while there were no significant differences in oil content between varieties. For light soil in the region with a lower precipitation amount, the Recital variety gave the best results besides the Comtess variety. Significantly the highest yield was got in 2012 at both locations in the Savinja Valley by the Altess variety (2265 kg/ha and 2288 kg/ha, respectively).

When high seed yields are reached, a bit lower oil content can be expected because of the dilution effect. In accordance with our findings, the seed yield had a higher impact on oil yield compared to oil content, so the highest oil yields were reached with high seed yield.

In relation to the nutrition value of linseed oil, and its impacts on health, the fatty acid profile of linseed oil can vary significantly. In addition to genetic factors, environmental conditions also play an important role, especially weather conditions (temperature and rainfall regime). When the content of α -linolenic acid, as one of the most important fatty acids from the health aspect, was highly related to genetic and environmental factors, on the other hand, the ratio of omega-3 and omega-6 fatty acids were recognized as favorable for human health for all studied varieties. In the Slovenian experiment, Altess and Duchess varieties were observed as high-leveled in both years; at the opposite pole is Niagara, with modest α -linolenic acid levels for both studied years.

Since it is reported in the literature, cool climatic conditions in temperate regions lead to a high share of omega-3 fatty acids, especially the most important α -linolenic acid, furthermore detailed studies are needed to examine the impact of specific climate conditions on the production of compounds beneficial for human health.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2073-4395/10/11/1770/s1>, Table S1: Least-squares means table for the seed yield with 95% confidence intervals. Table S2: Least-squares means table for the oil content with 95% confidence intervals. Table S3: Least-squares means table for the oil yield with 95% confidence intervals.

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