Ph.D. Thesis

INTERACTIVE ANALYSIS OF SOWING TIME, CULTIVAR AND FUNGICIDE APPLICATION OF SUNFLOWER IN THE HAJDÚSÁG REGION

Novák Adrienn

Supervisor:
Dr. Pepó Péter
professor

UNIVERSITY OF DEBRECEN

Hankóczy Jenő Doctoral School of Crop Production, Horticulture and Food Sciences

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1. INTRODUCTION, OBJECTIVES

Oil plants are one of the most populous groups of field crop plants today. They have become one of the most dynamically developing sectors of global agriculture in the past decades. This is due to the fact that plant oils have been increasingly utilized for both food and industrial purposes. World oil production, consumption and trade are covered by only a small rate of oil plants. Soy beans, oil palm, rapeseed and sunflower play dominant role in plant oil production. While sunflower is the 4th most important oil plant worldwide (with a share of 9%), the national plant oil sector has been mainly based on sunflower for several decades. The demand for sunflower in Hungary shows continuously increasing tendency due to the increasing demand for quantity, the expanding industrial utilization possibilities; just as the progressing energy use. Genetic development, targeted research and practical technology development altogether resulted in a significant nationwide yield increment, at the same time deviances in yield amounts have increased too. These deviances in yield amounts can be explained by the negative effects of climate change on the one hand, but on the other hand the changes in biological bases, just as agrotechnical elements through the decades are often not sufficiently harmonized, the coordination between factors is deficient. Critical elements of production technology (choice of hybrids, sowing technology, plant protection management etc.) highly determine the amount of yield. Thus in order to increase yield safety the investigation, optimisation and harmonization of these factors is of particular importance. Especially because the increasing productivity of sunflower hybrids resulted higher sensitivity towards agroecological and production technology management factors, just as higher susceptibility towards phytopathogens.

Within the confines of the present research activity the reaction of sunflower hybrids of different genotypes towards sowing time have been studied by the application of different fungicide application intensities (application time, active substance) models. The aim of the research was to reveal cause-effect relationships of sowing time × fungicide treatment interaction under different crop year conditions in the Hajdúság region. Beside the determination of yield amounts and oil content of seeds further agronomical, physiological and phytopathological investigations have been carried out in order to get exact answers to the cause-effect relationships of changes in the quantity and quality of the yield as affected by the applied treatments.

The research activity covered following investigations:

- the effect of crop year, sowing time and fungicide treatment on the agronomical properties of sunflower hybrids
- the effect of crop year and agrotechnical factors (sowing time, fungicide treatment) on the physiological properties of sunflower hybrids
- introduction and elaboration of new physiological indicators
- the effect of crop year, sowing time and fungicide treatment on the phytopathological properties of sunflower hybrids
- the effect of weather and agrotechnical factors (sowing time, fungicide treatment) on the yield of LO and HO sunflower hybrids, just as their oil content and the oil yield per hectare
- the determination of relationships between agronomical, phytopathological, physiological properties and the yield, oil content and oil yield of sunflower
- the effect of crop year, sowing time and fungicide treatment on the oil quality of sunflower hybrids (oleic acid, linoleic acid, stearic acid)

The results of the present research work enable the determination of genotype (G) ×environment (E) interactions, the better knowledge of vegetative and generative plant processes, just as ecological and agrotechnical factors affecting them. Based on these results farmers can take a significantly more effective choice of hybrids. With the better knowledge of reaction of the studied hybrids towards agrotechnical elements practically optimized sowing technology, integrated and effective plant protection can be implemented. As results of these, yield amount, oil content and yield safety can be improved.

2. MATERIALS AND METHODS

2.1. Location and soil properties of the experimental field

The research work has been carried out at the Látókép Research Site of the University of Debrecen, Centre for Agricultural Sciences, Farm and Regional Research Institute. The research site is located 15 km far from Debrecen, along the main road nr. 33., in the territory of the Hajdúság loess ridge. The experimental soil is based on loess, with deep humus layer; it is medium set calcareous chernozem in good agricultural state. Regarding its soil physical properties it can be classified as a loam, its pH is nearly neutral. The phosphorous supply of the soil is medium, while its potassium supply is rather medium-good. Humus content is also medium; the humous soil layer is about 80 cm deep. According to the data published by Várallyay the soil can be classified into the 4^{th} water management category which means medium water infiltration rate.

2.2. Experimental settings and arrangement

The carefully designed experiment was carried out between March 2012 and September 2014. Each experimental plot – sized 15.2 m^2 – was set up in four replications, randomized. One of the studied agrotechnical factors was sowing time. Early (end of March), average (middle of April), just as late (beginning of May) sowing times were applied. The other studied agrotechnical factor was fungicide plant protection of which three different application models were set up. There was no fungicide treatment in the control treatment, while in case of the 1-time fungicide treatment model fungicides (in the year 2012 and 2013 dimoxistrobin + boscalid; in 2014 trifloxystrobin +cyproconazole) were applied once (in the plant development state of 8-10 pairs of leaves) and in case of the 2-times fungicide treatment model twice (in the plant development state of 8-10 pairs of leaves and in the flowering state resp.). Sunflower hybrids of 7 different genotypes were involved into the experiment: NK Neoma (LO), P63LE13 (LO), NK Ferti (HO), Tutti (HO), SY Revelio (HO) (2012-2013), P64HE39 (HO) and PR64H42 (HO).

2.3. Weather characters of the studied crop years

Trends of weather factors are shown in *Figure 1*. The amount of precipitation during the months before the vegetation period of 2012 (from the beginning of December till the end of March) was rather low (118.3 mm). However the amount of precipitation within the vegetation was higher (253.7 mm), but its distribution was unfavourable (May: 79.1 mm, June: 91.7 mm, July: 65.3 mm). From the aspect of grain development it was unfavourable that the average temperature of the months June, July and August exceeded the 30-years average values by 2.2-3.0 ˚C, that means significantly. These factors affected grain setting, just as grain development and filling processes negatively.

Weather effects during the vegetation of 2013 tried the adaptation ability of sunflower extremely. Weather in April and May was favourable for the vegetative development of sunflower populations. Excellently developed sunflower plants were able to tolerate the drought (June: 30.8 mm, July: 15.6 mm, August: 32.2 mm) and heat waves (June: 19.6 ˚C, July: 21.2 ˚C, August: 21.5 ˚C). Flowering, grain setting, grain development and filling of populations was sufficient. Smaller amounts of precipitation that fell continuously before harvest hindered drying processes and harvest of populations.

Overall, weather effects – apart from some short periods – were favourable for the vegetative and generative development, just as the grain production of sunflower. Weather in April stimulated shooting and early development of sunflower. The significant amount of precipitation in July fell periodically, thus grain setting, development and filling of populations were even. Due to the dry weather in June plant diseases turned up in the populations relatively late and in moderate extent. Weather conditions in the end of August - in the beginning of September were favourable for the ripening processes, but the wet weather afterwards was unfavourable for both the harvest and the yield amount.

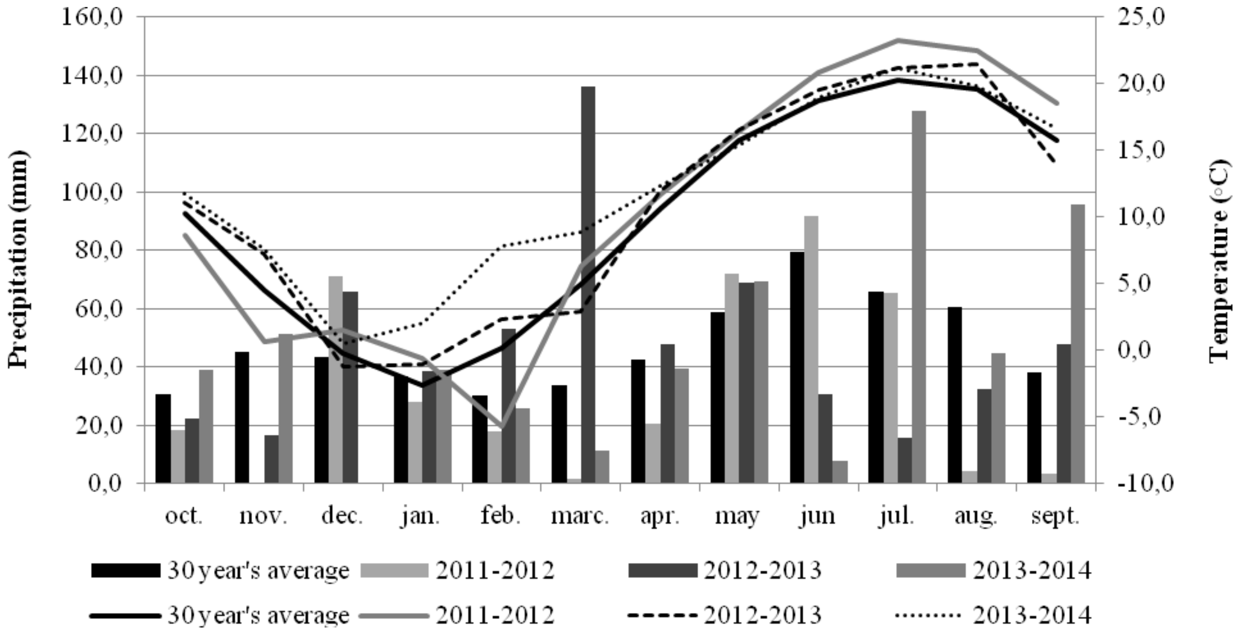


Figure 1. Development of temperature and precipitation data and their comparison with 30-years average values (Debrecen 2011-2014)

2.4. Research methods applied in the experiment

The most important agronomical parameters of populations (stalk bending, plant height) have been determined in the research work. Measurements were performed in order to determine the leaf area (LAI) and relative chlorophyll concentration of populations. Leaf area per 1 m^2 (Leaf area index – LAI) was determined by a SunScan Canopy Analysis Systems (SS1) portable leaf area assessment equipment. For the determination of relative chlorophyll content of sunflower leaves a Soil Plant Analysis Development (SPAD-502 Plus, Konica Minolta) chlorophyll measuring instrument was used. Plant physiological measurements were executed in case of the hybrids NK Neoma, NK Ferti, SY Revelio and PR64H42 for the early, average and late sowing time, just as for the control and 2-times fungicide plant protection treatment models. During the researches we determined the degree of infections for the most important phytopathogenics (*Diaporthe helianthi, Phoma macdonaldii, Alternaria helianthi, head diseases*). At the harvest raw yield and its moisture content were determined for each plot too. Based on these data yield results were standardized to 8% moisture content. Oil content and composition were determined as a percentage of dry matter. Oil content was measured with extraction according to the Standard MSZ ISO 659. The composition of fatty acids was determined with gas-chromatographic method according to the Standard MSZ ISO 5508:1992. The determination of seed oil content, just as the composition of fatty acids were executed in case of the hybrids NK Neoma, P63LE13, NK Ferti, Tutti, SY Revelio, P64HE39, PR64H42 for the early, average and late sowing time, just as for the control and 2-times fungicide plant protection treatment models. Oil yield was calculated upon the oil content and the yield as per grain moisture content of 8%.

2.5. Method for the evaluation of experimental results

Computer programmes Microsoft Excel 2013 and SPSS for Windows 13.0 were used for data processing and statistical evaluation. Results were analysed with one-, two and three-factors analysis of variance. For the determination of the relationship between the studied factors Pearson correlation coefficients were calculated. In order to define the stability of the yield and oil content of the studied hybrids Kang's stability analysis was used. For the quantification of the effect of agrotechnical factors on yield the components of variance were partitioned.

3. RESULTS AND DISCUSSION

3.1. Effect of ecological and agrotechnical factors on the physiological parameters of sunflower hybrids

Development of sunflower grain yield is determined by leaf area and its formations as well. The dynamics of leaf area index showed deviances in the studied crop years. Strong increment could be observed in the development of leaf area index over time that was afterwards followed by either a slower or stronger decrease. Sunflower populations reached the maximal LAI values in different times of the studied three crop years. In contrast to the control populations, 2-times treated populations showed slower decease of leaf area index after reaching maximal LAI values in the crop years 2013 and 2014. There were only minor differences between the leaf area index values of the studied hybrids; significant differences were confirmed only in a few cases. Weather conditions of the given crop year also played determining role in development of sunflower leaf area. Maximum leaf area index (LAI) values varied between 4.8-5.5 m^2 m^{-2} in 2012, just as 4.5-4.7 m^2 m^{-2} in 2013 and 5.0-5.5 m^2 m^{-2} in 2014 respectively, depending on the hybrid in the average of sowing times and fungicide treatments. The effect of sowing time on the maximum leaf area index value of sunflower was influenced by the given crop year. As a result, in contrast to the average sowing time maximum LAI values were decreased by late sowing (r=-0.915**, r=-0.701**) in 2013 and 2014. Higher maximum LAI values in case of the average sowing time enabled the production of favourable yields (r=0.547**, r=0.600**). In the crop year of 2012 sowing time had no statistically verifiable effect on maximum LAI values.

According to our results sunflower SPAD values showed to be relatively stable. No significant difference was observed in SPAD values from the beginning of the vegetation period until the end of the flowering phenological phase. SPAD values showed no remarkable difference during the period between the end of May and the end of July of any of the three studied crop years. In the average of different sowing times and fungicide treatments maximum relative chlorophyll content ranged – depending on the hybrid – between the values 43.0 and 43.5 in 2012, just as 40.9 and 42.2 in 2013, and 45.5 and 46.9 in the crop year of 2014. The studied agrotechnical factors (sowing time, fungicide treatment) had no measurable effect after the phenological phase of the flowering. In 2013 and 2014 the relative chlorophyll content of leaves showed decreasing tendency toward the end of the vegetation period. In contrast to the control populations the decrease of SPAD values showed slower tendency in the 2-times fungicide treatment populations.

There was no significant difference between the leaf area indexes (LAI) and relative chlorophyll contents of control and 2-times fungicide treatment populations, however comparing maximal yield amount a deviance of almost 1 ton could be revealed. In order to realize and prove the yield increasing effect of fungicide treatments several new indexes (cumulated assimilation area, productivity index, SPAD efficiency) were elaborated and the Ph.C. index (photosynthetic capacity) was used as well.

Cumulated assimilation area

Cumulated assimilation area (KAT) was calculated from the LAI values of different times according to the following formula:

$$KAT = LAI_1 \ x \ LAI_2 \ x \dots LAI_x$$

The abbreviations in the formula cover following parameters:

KAT = Cumulated assimilation area

LAI_1 = Leaf area index (LAI) in the first measurement time

LAI_2 = Leaf area index (LAI) in the second measurement time

LAI_x = Leaf area index (LAI) in the x^{th} measurement time

The calculation was executed for the crop years 2013 and 2014 in the average of hybrids (*Table 1.*). The cumulated assimilation area of the 2-times fungicide treated populations was larger in both crop years and in case of all three sowing times than that of the control populations (except for the early sowing time of 2013). In the crop year of 2014 strong correlation was found between the 2-times fungicide treatment against phytopathogenes and the cumulated assimilation area (r=0.778**). The larger cumulated assimilation area resulted in the production of higher yield as an effect of fungicide treatment (r=0.590**).

Table 1. Effect of fungicide treatment on the Cumulated assimilation area of sunflower (average of hybrids) (Debrecen, 2013-2014)

Sowing time	Fungicide treatment	Cumulated assimilation area	
		2013	2014
Early	control	132.8	85.7
	2-times treated	115.6	166.8
Average	control	59.6	99.7
	2-times treated	68.8	135.1
Late	control	19.8	76.1
	2-times treated	82.2	167.2
Average	control	**70.7**	**87.2**
	2-times treated	**88.8**	**156.4**
$LSD_{5\%}$ fungicide treatment		*40.4*	*24.7*

Productivity index

Productivity index calculation was based on the leaf area durability (LAD) and yield. Leaf area durability (LAD) – the area under the curve of leaf area index over time – gives a quantitative explanation on how long a population is able to sustain the photosynthesising active leaf surface (*Berzsenyi* 2000).

Leaf area durability (LAD) and productivity index (PM) are calculated with the following formula:

$$LAD = \frac{LAI_1 + LAI_2}{2} * (t_1 - t_2) \qquad Productivity\ index = \frac{Yield}{LAD}$$

The abbreviations in the formula cover following parameters:

LAD = Leaf area durability

LAI = Leaf area per 1 m^2 field area

t = Time

Productivity index was calculated for all three studied crop years in case of the average sowing time for the average of the hybrids. It can be stated that populations treated 2-times with fungicides against plant phytopathogenes showed higher productivity indexes than control treatments due to the chemical disease control (*Table 2.*). In the crop year of 2014 fungicide treatment had no significant effect on productivity index, while in 2012 and 2013 strong positive correlation was found between 2-times fungicide treatment and productivity index (r=0.798**, r=0.809**). Evaluating the index it has been stated that the long term sustained active photosynthesising plant surface contributes significantly to the production of higher yield amounts. Strong positive correlation has been found in all three crop years between productivity index and yield amounts (r=0.842**-0.953**).

Table2. Effect of crop year and fungicides treatment on the Productivity index of sunflower (in the average sowing time, average of hybrids) (Debrecen, 2012-2014)

Crop year	Fungicide treatment	LAD	Yield	**Productivity index**
2012	control	239	3597	**15.1**
	2-times treated	236	4143	**17.5**
$LSD_{5\%}$ fungicide treatment		*1.8*		
2013	control	257	4351	**16.9**
	2-times treated	265	5158	**19.5**
$LSD_{5\%}$ fungicide treatment		*1,9*		
2014	control	313	4153	**13.3**
	2-times treated	327	4778	**14.7**
$LSD_{5\%}$ fungicide treatment		*2.3*		

SPAD-efficiency – chlorophyll functioning effectiveness

Photosynthesis (among several other factors) is significantly determined by the size of leaf area and the chlorophyll content. Molecules of chlorophyll are degraded during the ageing of plants, but beside this phytopathogenes may even destroy them. As a consequence, fungicide treatment contributes to the protection of chlorophyll molecules by decreasing the harm of phytopathogenes. Thereby it improves photosynthetic activity as well, which is highly depending on chlorophyll content. In order to prove this the index of SPAD efficiency, which informs on the effectiveness of chlorophyll functioning, has been drawn up. It is calculated using the minimum and maximum SPAD values according to the following formula:

$$SPAD - efficiency = \frac{SPAD_{min}}{SPAD_{max}}$$

SPAD efficiency was calculated for all three sowing times in the average of the hybrids for the crop years 2013 and 2014 (*Table 3.*). It has been stated that as a result of 2-times fungicide treatment the chlorophyll functioning effectiveness of 2-times treated populations was higher in case of all three sowing times and both crop years than that of the control populations. In the crop year of 2013 and in the average of sowing times SPAD efficiency value of control treatment was 0.537, while 2-times treated populations had a value of 0.628. Analogously control populations had significantly lower SPAD efficiency value (0.227) than population treated 2-time with fungicides (0.329) in 2014. Fungicide treatment of populations had positive effect on sunflower chlorophyll functioning effectiveness in 2014 (r=0,482**). Better chlorophyll functioning effectiveness (higher SPAD efficiency) enabled the production of higher yield amounts in both 2013 and 2014 (r=0.664**, r=0.666**).

Table 3. Effect of sowing time and fungicides treatment on the Chlorophyll functioning effectiveness of sunflower (average of hybrids) (Debrecen, 2013-2014)

Crop year		2013			2014		
Sowing time	Fungicide treatment	SPAD min	SPAD max	**SPAD efficiency**	SPAD min	SPAD max	**SPAD efficiency**
Early	control	24.5	41.6	0.590	10.1	46.6	0.216
	2-times treated	27.7	41.3	0.669	15.1	47.2	0.321
Average	control	27.3	40.7	0.671	15.8	46.6	0.340
	2-times treated	30.4	41.2	0.738	19.9	47.2	0.423
Late	control	14.9	42.7	0.349	5.8	46.6	0.124
	2-times treated	20.5	43.1	0.476	11.6	47.3	0.244
Average	**control**	**22.2**	**41.6**	**0.537**	**10.6**	**46.6**	**0.227**
	2-times treated	**26.2**	**41.9**	**0.628**	**15.5**	**47.2**	**0.329**
$LSD_{5\%}$ fungicide treatment		0.13			0.08		

Photosynthetic capacity (Ph.C.)

Photosynthetic capacity (Ph.C.) is calculated using maximal SPAD values, maximal leaf area (LAI) values and maximal yield:

$$Ph.C. = \left(\frac{Yield_{max}}{LAI_{max}} * \frac{Yield_{max}}{SPAD_{max}}\right)/1000$$

Ph.C. values were calculated regarding the average of hybrids for all crop years and all three fungicide treatment models (*Table 4.*).

Table 4. Effect of sowing time and fungicides treatment on the Photosynthetic capacity (Ph.C.) of sunflower (average of hybrids) (Debrecen, 2013-2014)

<table>
<tr><th>Crop year</th><th>Sowing time</th><th>Fungicide treatment</th><th>Yield (kg ha^{-1})</th><th>LAI max (m^2 m^{-2})</th><th>SPAD max</th><th>Ph.C.</th></tr>
<tr><td rowspan="9">2012</td><td rowspan="2">Early</td><td>control</td><td>3327</td><td>4.7</td><td>42.8</td><td>55</td></tr>
<tr><td>2-times treated</td><td>3823</td><td>5.0</td><td>43.5</td><td>68</td></tr>
<tr><td rowspan="2">Average</td><td>control</td><td>3597</td><td>4.9</td><td>43.0</td><td>62</td></tr>
<tr><td>2-times treated</td><td>4143</td><td>5.0</td><td>42.8</td><td>82</td></tr>
<tr><td rowspan="2">Late</td><td>control</td><td>4211</td><td>5.1</td><td>43.6</td><td>80</td></tr>
<tr><td>2-times treated</td><td>4874</td><td>4.9</td><td>42.6</td><td>115</td></tr>
<tr><td colspan="2">Average (control)</td><td colspan="4">66</td></tr>
<tr><td colspan="2">Average (2-times treated)</td><td colspan="4">88</td></tr>
<tr><td colspan="2">$LSD_{5\%}$ fungicide treatment</td><td colspan="4">17</td></tr>
<tr><td rowspan="9">2013</td><td rowspan="2">Early</td><td>control</td><td>4141</td><td>5.1</td><td>41.6</td><td>81</td></tr>
<tr><td>2-times treated</td><td>4734</td><td>5.1</td><td>40.6</td><td>109</td></tr>
<tr><td rowspan="2">Average</td><td>control</td><td>4351</td><td>4.5</td><td>40.7</td><td>103</td></tr>
<tr><td>2-times treated</td><td>5158</td><td>4.5</td><td>39.7</td><td>150</td></tr>
<tr><td rowspan="2">Late</td><td>control</td><td>3701</td><td>3.6</td><td>42.7</td><td>90</td></tr>
<tr><td>2-times treated</td><td>4281</td><td>4.4</td><td>42.9</td><td>98</td></tr>
<tr><td colspan="2">Average (control)</td><td colspan="4">91</td></tr>
<tr><td colspan="2">Average (2-times treated)</td><td colspan="4">119</td></tr>
<tr><td colspan="2">$LSD_{5\%}$ fungicide treatment</td><td colspan="4">18</td></tr>
<tr><td rowspan="9">2014</td><td rowspan="2">Early</td><td>control</td><td>4133</td><td>4.9</td><td>46.6</td><td>75</td></tr>
<tr><td>2-times treated</td><td>4891</td><td>5.5</td><td>47.2</td><td>93</td></tr>
<tr><td rowspan="2">Average</td><td>control</td><td>4153</td><td>5.7</td><td>44.8</td><td>68</td></tr>
<tr><td>2-times treated</td><td>4778</td><td>5.5</td><td>45.6</td><td>92</td></tr>
<tr><td rowspan="2">Late</td><td>control</td><td>3448</td><td>4.4</td><td>46.6</td><td>60</td></tr>
<tr><td>2-times treated</td><td>4219</td><td>5.2</td><td>47.3</td><td>75</td></tr>
<tr><td colspan="2">Average (control)</td><td colspan="4">68</td></tr>
<tr><td colspan="2">Average (2-times treated)</td><td colspan="4">87</td></tr>
<tr><td colspan="2">$LSD_{5\%}$ fungicide treatment</td><td colspan="4">14</td></tr>
</table>

On the basis of the results it has been stated that the photosynthetic capacity of sunflower was significantly influenced by the fungicide treatment of populations. Control populations showed significantly lower Ph.C. values (in the average of sowing times: 66, 91, 68) than populations treated 2-times with fungicides (in the average of sowing times: 88, 119, 87) in all three studied crop years. Sunflower photosynthetic capacity (Ph.C.) was affected by sowing time as well. Ph.C. showed the highest values in 2012 in case of the late (control: 80, 2-times treated: 115), in 2013 in the average (control: 103, 2-times treated: 150) sowing time. In 2014 Ph.C. values of late sowing time treatments (control: 60, 2-times treated: 75) were lower than those of the early (control: 75, 2-times treated: 93) and average sowing time populations (control: 68, 2-times treated: 92). It has been stated that fungicide treatment had a contribution to the maintenance of sunflower photosynthetic capacity (r=0.514**, r= 0.570**, r=0.517**). Strong positive correlation was found between Ph.C. value and yield (r=0.949**, r=0.823**, 0.857**).

3.2. Effect of ecological and agrotechnical factors on the phytopathological properties of sunflower hybrids

In order to characterize the overall phytopathological state, i.e. total infection of studied crop years infection index (a value without dimension) has been used. For the calculation of the infection index first the rates of infection of monitored phytopathogenes (Diaporthe, Phoma, Alternaria, head diseases) were drawn up (in the average of hybrids) on a radial diagram for all three crop years. After that the size of the surface area demarcated by the phytopathogenes has been determined. The area bounded by the phytopathogenes was divided to four right triangles in order to execute the calculation. The area of each triangle was determined, and then by the addition of the part-areas the infection index (Ii) could be calculated. Accordingly, infection index is calculated upon the following formula:

$$Ii = \left[\frac{D*T}{2} + \frac{D*P}{2} + \frac{A*T}{2} + \frac{A*P}{2}\right]/100$$

The abbreviations in the formula cover following parameters:

Ii =Infection index

D = Diaporthe infection

T = Head diseases infection

P = Phoma infection

A = Alternaria infection

Infection indexes that represented the studied crop years showed significant differences (*Table 5.*). While weather conditions in 2012 favoured the infection by pathogens, the monitored phytopathogenes occurred and damaged in a lower extent in the crop years of 2013 and 2014. Consequently the infection index of 2012 was extremely high (in the average of sowing times and fungicide treatments: Ii=42.4). Infection index of sunflower populations lag significantly behind this value in both 2013 (Ii=13.4) and 2014 (Ii=8.0). Depending on sowing times and fungicide treatments infection index values ranged in 2012 in a rather wide (Ii: 4.5-93.6), while in 2013 (Ii: 3.1-29.7) and 2014 (Ii: 1.6-22.7) in a relevantly more narrow interval.

Table 5. Effect of sowing time and fungicides treatment on the Infection index of sunflower (Debrecen, 2012-2014)

Crop year	Sowing time	Fungicide treatment	Diaporthe	Phoma	Alternaria	Head diseases	**Infection index**
2012	Early	Control	73	61.8	84.1	57.3	**93.6**
		1-time treated	61	51.1	70.8	51.4	**67.4**
		2-times treated	46	41.3	56.2	40.4	**41.9**
	Average	Control	64	53.5	76.4	50.1	**72.8**
		1-time treated	54	45.5	65.1	43.8	**53.2**
		2-times treated	38	34.0	48.7	30.8	**28.1**
	Late	Control	30	19.6	34.4	15.7	**11.3**
		1-time treated	24	17.5	29.1	13.9	**8.4**
		2-times treated	17	13.2	21.1	10.7	**4.5**
	$LSD_{5\%}$ sowing time		*7.4*				
	$LSD_{5\%}$ fungicide treatment		*5.8*				
	$LSDD_{5\%}$ interaction		*10.0*				
2013	Early	Control	46	33.4	42.3	33.5	**29.7**
		1-time treated	38	27.6	33.2	28.7	**20.1**
		2-times treated	30	19.4	26.1	22.5	**11.8**
	Average	Control	37	28.5	35.8	29.1	**20.8**
		1-time treated	29	22.4	29.1	24.9	**13.7**
		2-times treated	25	17.4	22.2	19.3	**8.6**
	Late	Control	25	15.7	25.9	15.3	**7.8**
		1-time treated	21	12.7	20.1	12.9	**5.2**
		2-times treated	16	10.2	15.3	9.3	**3.1**
	$LSD_{5\%}$ sowing time		*1.4*				
	$LSD_{5\%}$ fungicide treatment		*1.2*				
	$LSDD_{5\%}$ interaction		*2.0*				
2014	Early	Control	31	27.1	43.8	34.0	**22.7**
		1-time treated	25	21.7	36.6	28.0	**15.4**
		2-times treated	22	18.1	30.0	23.1	**10.7**
	Average	Control	23	21.4	36.5	29.1	**15.1**
		1-time treated	20	17.7	30.9	23.2	**10.3**
		2-times treated	17	14.6	25.4	19.7	**7.2**
	Late	Control	14	12.6	18.9	15.2	**4.5**
		1-time treated	11	9.9	16.1	12.3	**3.0**
		2-times treated	7	7.5	12.0	9.4	**1.6**
	$LSD_{5\%}$ sowing time		*2.5*				
	$LSD_{5\%}$ fungicide treatment		*1.5*				
	$LSDD_{5\%}$ interaction		*2.5*				

Infection indexes for different sowing times sowed significant differences in all three studied crop years. In the average of fungicide treatments the highest infection index values were found in case of the early sowing time treatments (2012: Ii=67.6; 2013: Ii=20.5; 2014: Ii=16.3). The infection index of populations sown in May was relatively low in all three years (2012: Ii=8.1; 2013: Ii=5.4; 2014: Ii=3.0).

In contrast to the control plots treatments with 1-time or 2-times fungicide application were characterized by relevantly lower infection indexes. The greatest decrement of infection index value was found in case of the combination of late sowing time and the application of 2-times fungicide treatment. Infection index of populations sown at an early sowing time and treated with no fungicide application was relatively high in all three crop years (2012: Ii=93.6; 2013: Ii=29.7; 2014: Ii=22.7). In contrast, the infection index of populations of late sowing time and 2-times fungicide application was minimal (2012: Ii=4.5; 2013: Ii=3.1; 2014: Ii=1.6).

According to the results of the Pearson correlation analysis it can be stated that the development of infection indexes depended mainly on the sowing time in the studied crop years which was confirmed by the strong negative correlation between the two factors as well (r=-0.806**, r=-0.755**, r=-0.825**). Fungicide application had significant contribution to the moderation of the unfavourable effect of sowing time in all three years and thus it decreased the infection index of sunflower populations (r=-0.464**, r=-0.578**, r=-0.471**). Infection index showed extreme high values only in the crop year of 2012. Consequently, great extent of infection resulted in relevant decrement of yields only it this particular crop year (r=-0.916**).

Disease resistance of hybrids can be characterized in a complex way (with the comprehensive evaluation of the most relevant diseases = Infection index). In the average of the three years the hybrid P63LE13 showed favourable tolerance against diseases (Ii=15.2), while the hybrid Tutti showed the highest susceptibility to the studied pathogens (Ii=21.5).

3.3. Effect of ecological and agrotechnical factors on the yield of LO and HO sunflower hybrids

In our experiment the development of sunflower yield was affected by sowing time, fungicide treatment and genotype as well, however the effect of these factors was influenced by the given crop year. Partitioning the components of variance the percentile extent of the studied factors' influence on the development of sunflower yield in different crop years have been determined (*Figure 2.*). The minimal yield amount in the crop year of 2012 weighed 2673 kg ha^{-1}, that reached not even the half of the maximal yield amount (6319 kg ha^{-1}). Yield surplus (3646 kg ha^{-1}) was produced mainly due to the right choice of sowing time, which had a contribution rate of 44.6% to the yield increment. The crop year of 2012 was favourable for the occurrence and damage through fungal diseases, therefore susceptibility of the genotype for diseases proved to be determining for the yield (31.6%, 1152 kg ha^{-1}). Due to the large extent of disease infection in 2012 the effect of fungicide treatment was only moderate (23.8%) in yield surplus.

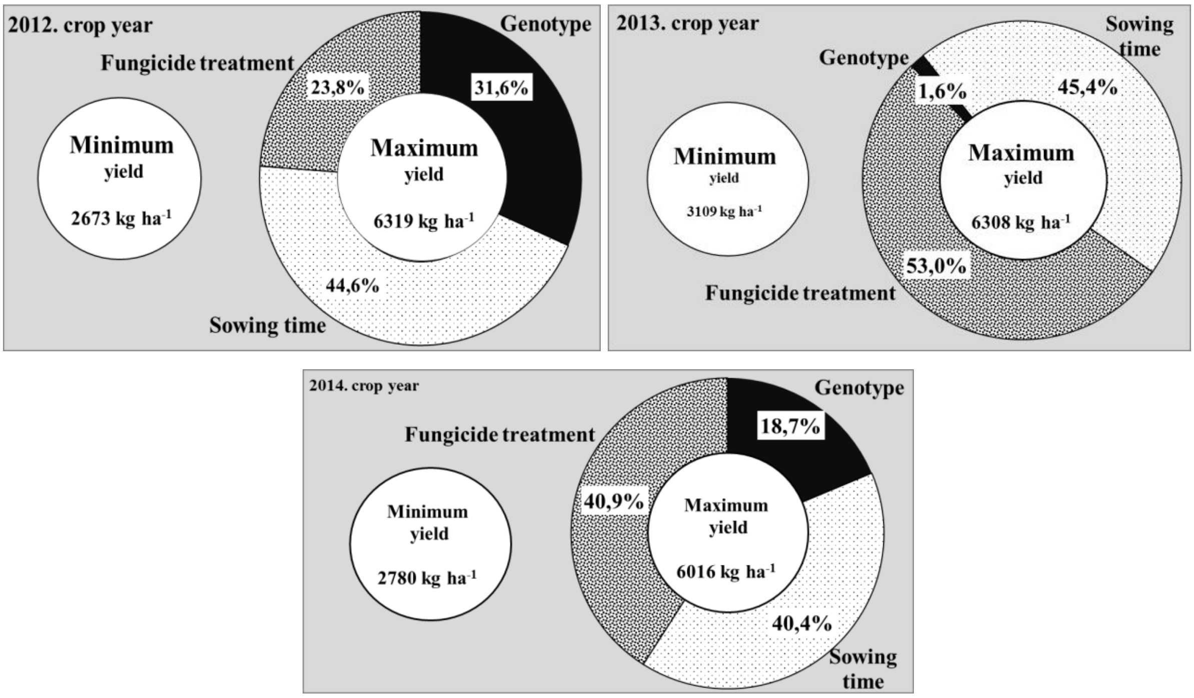


Figure 2. The roles of genotype, sowing time, fungicide treatment and the crop year in the yield of sunflower (Debrecen, 2012-2014)

Minimal yield in 2013 was 3109 kg ha^{-1}; in contrast the maximal yield weighed 6308 kg ha^{-1}, which meant 3199 kg ha^{-1} surplus. Plant protection against fungal diseases proved to be the most important agrotechnical factor in 2013, which had 53.0% contribution to yield surplus. From the aspect of yield increment – similar to the crop year of 2012 – the right choice of sowing time was determining as well, that contributed to the production of yield surplus by 45.4% (1453 kg ha^{-1}). The effect of genotype was negligible for it has affected yield amount only by 1.6% (49.8 kg ha^{-1}).

The minimum sunflower yield in 2014 was 2780 kg ha^{-1} that was 3236 kg ha^{-1} lower than the maximal yield (6016 kg ha^{-1}). In the production of yield surplus fungicide plant protection (40.9%) and sowing time (40.4%) had similar share, they resulted almost the same yield surplus (fungicide application: 1325 kg ha^{-1}, sowing time: 1307 kg ha^{-1}). Genotype had a more expressed effect on yield amount than in 2013. Its contribution to the yield surplus was 604 kg ha^{-1}, that was 18.7% (*Figure 2.*).

In 2012 delayed sowing time significantly reduced Diaporthe, Alternaria, Phoma and head diseases infection of sunflower populations and thus it resulted in a significant yield increment (r=0.624**). In contrast to the results of 2012 late sowing (in May) resulted in the decrease of yield amount in 2013 and 2014 resp. (r=-0.334**, r=-0.434**). Consequently, regarding yield amount late sowing time in 2012 (4808 kg ha^{-1}) was optimal, while in 2013 average sowing time resulted in the highest yield (4980 kg ha^{-1}) and in 2014 early and average sowing times had similar yield results (4767 kg ha^{-1}, 4779 kg ha^{-1}).

The hybrid Tutti showed a particular sensitive reaction towards sowing time, but hybrids NK Ferti (in 2012) and P63LE13 (in 2013) had significant sensitivity towards sowing time as well. The application of different sowing times resulted in the lowest extent of variations in yield amounts in case of the hybrids PR64H42 and NK Neoma. Regarding the evaluation of variations in hybrids' yield the hybrid P63LE13 proved to be the most effective one for production, since it realized favourable yield (4706 kg ha^{-1}) by far lower variation (247 kg ha^{-1}) than the average (549 kg ha^{-1}) in the three studied crop years. The hybrid Tutti produced good yield amount (4681 kg ha^{-1}) but under unfavourable production conditions it showed higher variance in yield (597 kg ha^{-1}). The production of hybrids PR64H42, NK Ferti and P64HE39 can be considered as less effective, since they produced yield amounts below average by yield variance significantly above the average (*Figure 3.*).

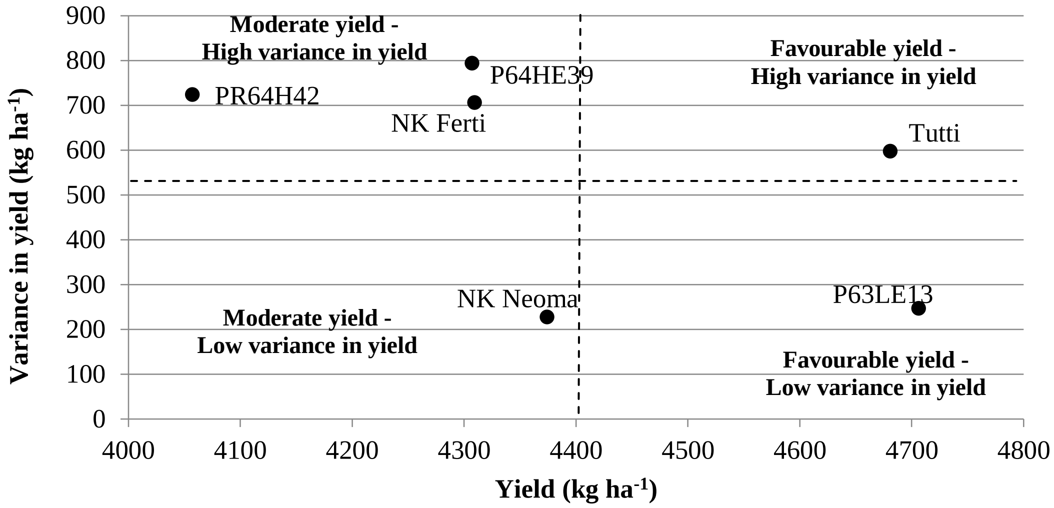


Figure 3. Distribution of the studied sunflower hybrids by productivity and yield stability (Debrecen 2012-2014)

3.4. The effect of ecological and agrotechnical factors on the oil content, oil yield and oil quality of HO and LO hybrids

Oil content

In our experiment weather conditions of the crop year affected oil content. Consequently, the oil content measured in 2014 (44.9%) was slightly behind the result of

2012 and 2013 (45.8%, 46.2%). Significant differences were observed in the oil content and the stability of oil content of hybrids. The hybrid PR64H42 produced the lowest (44.1%) and the most stable (b=-0.0525) oil content through the three crop years. Hybrids NK Neoma (b=0.9506), NK Ferti (1.1494) and P63HE39 (b=0.8594) showed average variation in oil content. Hybrids with high oil content (46.3%, 46.8%), i.e. Tutti (b=1.5518) and P63LE13 (b=1.4106) proved to have oil content that was sensitive to production circumstances, because these two hybrids could be characterized by significant variances in oil content through the studied crop years (*Figure 4.*).

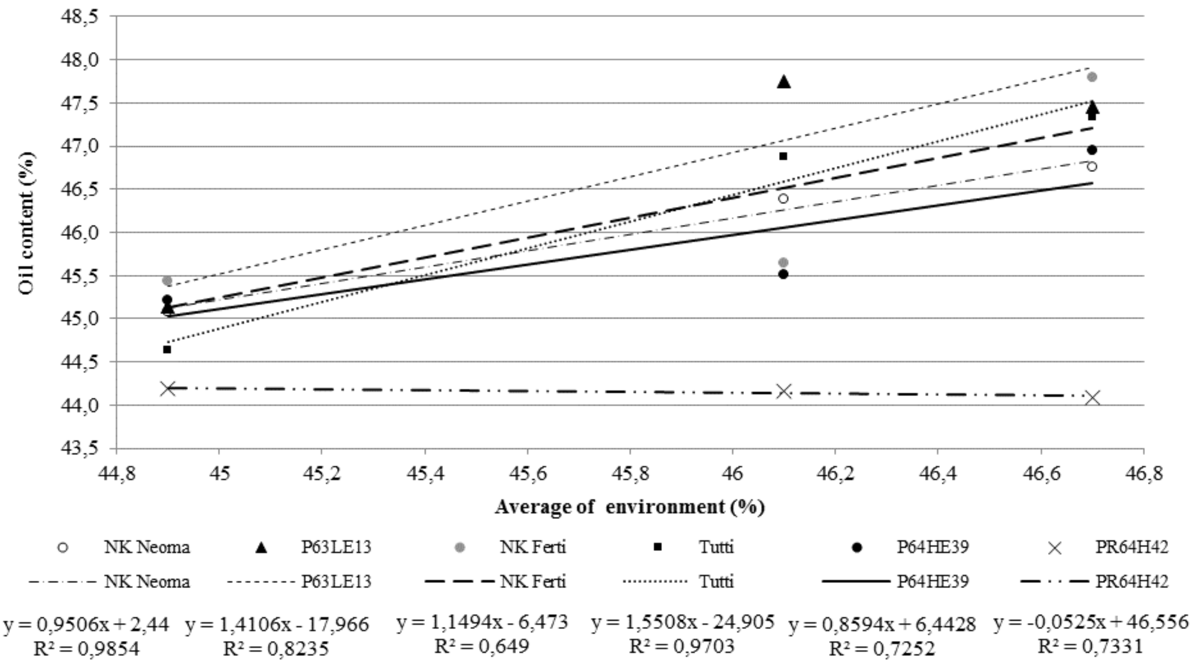


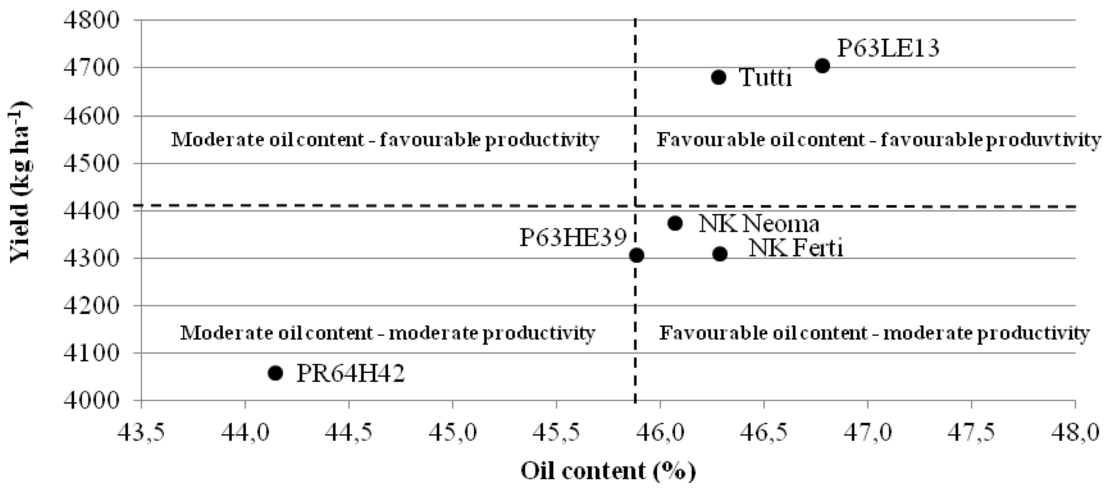
Figure 4. The oil content stability of sunflower hybrids in the investigated crop years (Debrecen, 2012-2014)

The effect of sowing time on the oil content was determined by the given crop year. The delay of sowing time resulted in the increment of oil content in both 2012 and 2103 (r=0.494**, r=0.444**), while in 2014 negative correlation was found between sowing time and oil content (r=-0.372**). Consequently, from the aspect of oil content late sowing time can be considered as optimal in 2012 and 2013 (47.3%, 47.7%), while in 2014 it was the early sowing time (45.9%). 2-times fungicide treatment affected the development of oil content positively in 2013 (r=0.226**). Regarding the average of hybrids and sowing times the oil content of the 2-times fungicide treated populations was by 1.3% higher than that of the control populations. Sunflower stalk bending resulted in a small extent decrease of oil content (r=-0.159*, r=-0.399**) in 2012 and 2013. Beside this the strong infection through fungal diseases – mainly head diseases – reduced the oil content (r=-0.331** – -0.507**) as well.

The average, or below average rate of infection in 2013 and 2014 had less negative effect, but in case of 2013 it still resulted in the slight decrease (r=-0.250** – -0.430**) of oil content.

Oil yield

The high extent of infection resulted yield decrement of sunflower populations in 2012 and therefore oil yield (1755 kg ha^{-1}) was lower than the oil yield measured in 2013 (1895 kg ha^{-1}) and 2014 (1855 kg ha^{-1}). Genotype had also determining role in oil yield development. Hybrids P63LE13 (LO) and Tutti (HO) with high oil content (46.8%, 46.3%) and good productivity (4706 kg ha^{-1}, 4681 kg ha^{-1}) could be characterized by favourable oil yield results (2067 kg ha^{-1}, 1905 kg ha^{-1}). In case of the hybrid PR64H42 (HO) low oil content (44.1%) was associated with productivity below the average which was unfavourable from the aspect of oil yield (1537 kg ha^{-1}). Although the oil contents of the hybrids NK Neoma (LO), NK Ferti (HO) and P64HE39 (HO) were favourable (46.1%, 46.3%, 45.9%), their productivity laid below the average (4374 kg ha^{-1}, 4309 kg ha^{-1}, 4307 kg ha^{-1}), and therefore they produced average oil yield (1873 kg ha^{-1}, 1712 kg ha^{-1}, 1710 kg ha^{-1}) (*Figure 5.*).



5. ábra. Distribution of the studied hybrids by oil content and yield (Debrecen 2012-2014)

It can be stated that the effect of sowing time on the oil yield was determined by the crop year. In 2012 the delay of sowing time resulted in the increment of oil yield amount (r=0.607**); thus from the aspect of oil yield late sowing time can be considered as optimal (2095 kg ha^{-1}). In contrast late sowing time (in May) decreased the oil yield in 2013 – when average sowing time was optimal from the aspect of oil yield (2105 kg ha^{-1}) – and in 2014 (r=-0.151**, r=-0.451**). The oil yield results of the early and (1989 kg ha^{-1}) average sowing time (1927 kg ha^{-1}) were about the same in 2014. Fungicide application contributed to the increase of oil yield per hectare by increasing the yield amount (r=0.336**-0.496**). Oil yield amount was mainly determined by yield amount (r=0.942**-0.984**), while oil content affected oil yield per hectare only slightly in 2013 (r=0.456**) and 2014 (r=0.275**), however the extent of this modifying effect was significant in 2012 (r=0.752**). The large infection rate reduced the oil yield in 2012 (r=-0.627** – -0.741**). Stalk bending affected oil production negatively in all three crop years (r=-0.401**, r=-0.311**, r=-0.498**).

Oil quality

The composition (the amount of saturated and unsaturated fatty acids) of sunflower oil is genetically determined. However, several climatic and agrotechnical factors affect the synthesis of particular fatty acids and thus their rate in sunflower oil as well. The oleic acid and linoleic acid content of hybrids were primarily determined by the genotype among the studied factors, however in case of the HO hybrids and the crop year of 2012 a very weak negative correlation was found between sowing time and oleic acid content (r=-0.218**), while a very weak positive correlation was found between sowing time and linoleic acid content (r=0.214**). Sowing time had no statistically verifiable effect on the oleic and linoleic acid content in 2013. Considering the LO hybrids the oleic acid content (2012: 42.2%, 2013: 36.8%) of the hybrid P63LE13 was higher than that of the hybrid NK Neoma in both years. Regarding the HO hybrids the hybrids P64HE39 (2012: 89.8%, 2013: 88.8%) and PR64H42 (2012: 90.0%, 2013: 88.3%) had extreme high oleic acid content, while the hybrid NK Ferti resulted the lowest oleic acid content in both crop years (2012: 81.4%, 2013: 83.3%). With regard to the fact that the synthesis of oleic and linoleic acid was strongly negatively correlated (r=-0.918**-0.996**) the opposite of these tendencies were observed in case of the linoleic acid content of the studied hybrids. Late sowing time resulted in the decrease of the stearic acid content of LO hybrids in 2012 (r=-0.494**), while the delay of sowing time in 2013 resulted in the decrease of stearic acid content of both LO (r=-0.744**) and HO (r=-0.447**) hybrids respectively. Highest stearic acid content among HO hybrids was measured in case of the hybrid NK Ferti (2012: 3.3%, 2013: 3.3%), while the lowest stearic acid content was measured in case of the hybrid PR64H42 (2012: 2.3%, 2013: 2.6%) in both crop years. Stearic acid content of HO hybrids showed decreasing tendency parallel to the increasing oil content (r=-0.481**, r=-0.443**), and an increasing tendency parallel to the increasing linoleic acid content (r=0.465**, r=0.444**). No significant effect on oil quality could be revealed due to the 2-times fungicide application.

According to the recommendations of major plant breeding and seed trade companies, in order to ensure adequate oleic acid content during the production of high-oleic hybrids an isolation distance of 100-200 metres should be left from any other oil industry, food or birdseed purpose sunflower hybrid. In our experiment no isolation distance was left between LO and HO hybrids. Evaluating the oleic acid content it has been stated that the omission of isolation distance had no effect on oleic acid content of high-oleic hybrids. Regarding the average of sowing times and fungicide treatments the oleic acid content of the studied hybrids ranged between 81.4 and 90.0%.

4. NOVEL SCIENTIFIC RESULTS

1. Nowadays there is no difference between the productivity and oil content of advanced LO and HO type sunflower hybrids. However hybrid-specific differences could be stated between sunflower genotypes of the given type. These values, just as the infection and stalk strength of hybrids were determined by the crop year, sowing time, fungicide application and genotype as well. 1-time treatment of the population (active substance: dimoxistrobin + boscalid, and trifloxystrobin +cyproconazole resp.) decreased the extent of infection by 16.6%, while 2-times treatment by 35.3%.

2. Beside the LAI_{max} (4.4-5.5 m^2 m^{-2}) and $SPAD_{max}$ (39.7-47.2) values it has been proven that the dynamics of leaf area and relative chlorophyll content play determining role in the production of high yields. LAI_{max} was measured in the phonological phase of flowering, while SPAD values proved to be relatively stable from the early stage of vegetation period until the end of flowering.

3. In order to characterize the yield and oil production processes of sunflower hybrids photosynthetic capacity (Ph.C.) value was introduced and further physiological indicators have been calculated that inform about the effect of crop year and agrotechnical elements (sowing time, fungicide application) more appropriate. Cumulated assimilation area (KAT), productivity index (PM) and SPAD efficiency values of sunflower have been determined.

4. In order to characterize the phytopathological properties of sunflower hybrids in a complex way infection index (Ii) has been elaborated. Infection index values were affected by crop year, sowing time, fungicide treatment and genotype as well. Fungicide treatments reduced Ii values significantly (control: 30.9, 1-time treated: 21.8, 2-times treated: 13.1).

5. Partitioning the components of variance it has been stated, that sunflower yields were mainly determined by sowing time (40.4-45.4%) and fungicide treatment (40.9-53.0%) in case of a crop year with favourable phytopathogenic conditions. In case of a crop year with unfavourable phytopathgenic conditions genotype affected the development of yield amounts also significantly (31.6%), because the disease resistance of hybrids also played important role in such cases.

6. Using Pearson correlation analysis in case of LO and HO hybrids it has been stated that oil yield of hybrids was mainly determiend by seed yield amount (r=0.942-0.984), while only in a lower extent by its oil content (r=0.275-0.752). Depending on the sowing time, genotype and fungicide treatment oil yield varied between 1203 and 2617 kg ha^{-1} in 2012, while in 2013 between 1304 and 2591 kg ha^{-1}, just as between 1282 and 2336 kg ha^{-1} in 2014.

7. According to the present research results it has been confirmed that the oleic acid content of advanced HO hybrids did not decrease in case of their common production with LO hybrids. There is no need to keep isolation distance. In case of the HO hybrids negative correlation was found between their stearic and oleic acid content, while positive correlation was observed for the linoleic acid.

5. RESULTS APPLICABLE IN THE PRACTICE

1. Despite the difference in crop year types the yield level of LO and HO hybrids can be kept at a level of about 5 t ha^{-1} in the Hajdúság region using optimal agrotechnical management. Advanced sunflower hybrids with high potential productivity require favourable agroecological conditions (chernozem soil) and up-to-date agrotechnical management (optimal sowing time, fungicide application) in order to realize high yield amounts. In the present experiment the hybrid P63LE13 showed the highest productivity and the highest oil content among LO hybrids, while in case of the HO hybrids it was the hybrid Tutti.

2. Regarding the studied period the optimal sowing time of LO and HO hybrids was the average (the middle of April) in the region of the Hajdúság. The sensitivity of LO and HO hybrids towards sowing time was different.

3. Chemical, fungicide protection of populations is – regardless the crop year – an integrated part of advanced, intensive sunflower production. In contrast to the yield amounts measured in the control populations yield surplus of 300-500 kg ha^{-1} could be realized with 1-time fungicide treatment, and 600-750 kg ha^{-1} with 2-times fungicide treatment of populations.

4. Hybrids have different phytopatological characters. In our experiment the hybrid P63LE13 showed favourable tolerance towards diseases. Disease resistance of hybrids can be characterized in a complex way (with the comprehensive evaluation of the most relevant diseases = Infection index) in the practice.

5. The joint production of LO and HO hybrids had no effect on the oil composition. According to our results it has been proven that there is no need to keep isolation distance between LO and HO hybrids in order to keep the high (above 80%) oleic acid content.

6. These experimental results contribute to the optimisation of the sunflower hybrid assortment, the sowing time and the fungicide application, just as to the improvement of agronomical effectivity in the Hajdúság region.

LIST OF PUBLICATIONS

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Registry number: DEENK/12/2015.PL
Subject: Ph.D. List of Publications

Candidate: Adrienn Novák
Neptun ID: J3T6JS
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MTMT ID: 10040116

List of publications related to the dissertation

Hungarian book chapter(s) (1)

1. **Novák A.**: A vetésidő hatása a napraforgó termésére, olajhozamára, olajtartalmára és kórtani tulajdonságaira eltérő növényvédelmi modellekben.
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Address: 1 Egyetem tér, Debrecen 4032, Hungary Postal address: Pf. 39. Debrecen 4010, Hungary
Tel.: +36 52 410 443 Fax: +36 52 512 900/63847 E-mail: publikaciok@lib.unideb.hu, ¤ Web: www.lib.unideb.hu

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DEBRECENI EGYETEM KENÉZY ÉLETTUDOMÁNYI KÖNYVTÁRA EGYETEMI ÉS NEMZETI KÖNYVTÁR

Address: 1 Egyetem tér, Debrecen 4032, Hungary Postal address: Pf. 39. Debrecen 4010, Hungary
Tel.: +36 52 410 443 Fax: +36 52 512 900/63847 E-mail: publikaciok@lib.unideb.hu, ¤ Web: www.lib.unideb.hu