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Periods of development and dynamic parameters of white lupin, *Lupinus albus* L. yield formation

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ABSTRACT

There is a problem of vegetable protein deficiency for feed, processing and nutrition in many countries: to produce or import? White lupin cultivation in Russia is important due its high potential seed and protein yield. The breeding program for creating cultivars of white lupin with a determinant type of growth and the study of the dynamic parameters of the yield formation was carried out in many years of research in the northern part of the Central-Chernozem region of Russia. Experiments were conducted at the experimental field in Tambov region. Cultivar is one of the main components of resource-saving technologies. For the first time in Russia, under these conditions, cultivars of white lupin with a determinant type of growth were created. Among them are Start, Gamma, Delta, Dega, Deter1, Timiryazevskiy with different plant architectonics. Care adapted to the conditions of the region, ripen steadily, and grain yield of 3-5 ton ha^{-1}. Agrocenosis is a photosynthetic system functions from emergence to beginning of maturity including four biologically distinct periods of crop formation: I- emergence - the beginning of flowering; II- flowering and pod formation; III- pod growth; and IV- seed filling. The length of the periods and the dynamic parameters of the yield formation of white lupin for each period were determined. Among the parameters were the leaf area index (LAI), the total dry matter accumulation (TDM), the crop growth rate (CGR), leaf area duration (LAD), net assimilation rate (NAR), and yield components. Period II was critical in yield formation. Variability of parameters was determined in connection with weather conditions and seed yield. The conducted studies made it possible for white lupin cultivars with determinant type of growth to find out dynamic pattern of yield formation and to estimate the degree of effect of weather conditions on dynamic parameters and seed productivity.

Keywords: *Lupinus albus*, Cultivars, Development, Yield formation, Photosynthetic, Seed yield.
Article type: Research Article.

INTRODUCTION

The most important problem of modern agricultural production is the provision of surging animal husbandry with high-energy and proteinaceous plant food that preserves soil fertility (Gataulina *et al.* 2013; Gataulina 2014; Cesare Sirtori 2015). The key to a successful solution is the cultivation of legumes with a high protein content. Among annual leguminous crops, the most promising is white lupine (Schläfke 2014). Seeds of white lupine, *Lupinus albus* L. contain 30-40% protein and 10-13% fat. The value of the culture lies is a high yield of seeds with a high protein content without nitrogen fertilizers (Annicchiarico 2010; Annicchiarico 2014; Dieterich *et al.* 2015). Currently, white lupine grain is used in the feed industry as a high-protein feed component. Its seeds contain essential amino acids that are well absorbed and can be used to feed all types of animals. The market of seeds and marketable grain of this crop is developing (Baddeley 2013; Visser *et al.* 2014; Lucas *et al.* 2015). The seeds of white lupine, in contrast to soybean seeds, practically do not contain trypsin inhibitors, which avoids their heat treatment for the use as animal feed (Annicchiarico *et al.* 2010; Cernay *et al.* 2015; Georgieva & Kosev 2018). Its cultivation is characterized by a relatively low energy consumption, unpretentiousness to soil fertility and a high nitrogen-fixing ability (Niewiadomska *et al.* 2020; Aslam *et al.* 2020). The main directions are associated with an

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increased potential of seed productivity, the optimal duration of the growing season (110-120 days) in combination with resistance to major diseases, resistance to lodging, drought resistance, etc. Low content of alkaloids and high protein content and fats improves grain quality (Kosev & Vasileva 2019; Yahya 2020; Akbar 2020; Akil & Okant 2020). Agrocenosis as a photosynthesizing system functions from germination to maturation. The dynamic process of the formation of the yield of white lupine includes four biologically justified periods: I - seedlings - the beginning of flowering; II - flowering and fruit formation; III - fruit growth; and IV - seed filling. We have determined the duration of the periods and the dynamic parameters of the production process of white lupine for each period. The parameters include leaf area index (LAI), total dry biomass growth (TDM), average daily crop growth rate (CGR), leaf area duration (LAD), and net assimilation rate (NAR). Period II is critical in the formation of yield. We have determined the variability of the parameters. The conducted studies allowed us to assess the degree of influence of stress factors associated with the influence of weather conditions on the dynamic parameters and seed productivity of varieties. White lupin by its nature and origin is a late-ripening species; in the northern part of the Central Black Earth Region of Russia, plants of all collection accessions remained with green, immature beans in the field in late autumn. The introduction of white lupine into this region became possible due to breeding. As a result of our studies, mutants with a limited (determinant) type of growth were obtained. On their basis, K.A. Timiryazev RSAU-MAA (experimental facilities in the Tambov region) created an original source material for the selection of varieties of white lupine, which are steadily ripening in this region. Here, early ripening varieties of white lupine were bred: Start, Manovitsky, Gamma, Delta, Dega, Deter 1.

Biologically sound periods of crop formation in white lupine and other leguminous crops

After long-term experiments with the culture of white lupine, on the basis of a detailed study of the growth and development of biotypes of this species, we have consistently identified those features of photosynthesis of sowing and the formation of productivity elements in the previous period, which determine a significant change in the state of sowing in the subsequent period and, ultimately account, yield changes and protein accumulation. Such a structural construction of the dynamic system turned out to be quite reasonable for other leguminous crops. All crops are characterized by two periods in development when photosynthesis is absent: the initial - from sowing to the emergence of seedlings, and the final - ripening, when there are no leaves and other green parts on the plants. During the growing season from germination to the beginning of ripening, when the sowing functions as a photosynthetic system, 4 periods are distinguished: I - from germination to the beginning of flowering (until the opening of the first flower on the plant); II - flowering and fruit formation (from the opening of the first flower to the complete end of flowering); III - fruit growth (at the end of the period, the fruits on the lateral shoots or upper tiers of the plant reach their maximum size, the fruit shells reach their maximum mass, the phase of full or shiny beans is noted); IV - filling of seeds (the assimilates and nutrients from the shells of fruits and other organs flow into the seeds; at the end of the period, the dry matter of the seeds is maximum, the moisture of the seeds is high). Ripening of seeds is the final period of their development. During this period, the seeds and fruit shells lose moisture. The ripening rate, characterized by the intensity of the decrease in the moisture content of seeds and fruit shells, depends on weather conditions. The objective of the research was to determine the variability of the dynamic indicators of the production process in white lupine for individual periods of development, as well as the level of yield, elements of the yield structure and their variability based on meteorological factors in different varieties of white lupine in the Central Black Earth Region of Russia.

MATERIALS AND METHODS

The experimental scheme included varieties Deter 1, Start, Gamma, Delta, and Dega, adapted to the conditions of the region and listed in the State Register of Breeding Achievements in Russia. We call these varieties different types in accordance with the architectonics of plants: according to the degree of branching, the ability to form shoots of different orders, the duration of the growing season. These signs are fully manifested only under good moisture supply during the period of vegetative growth and branching of plants. Type I: Deter 1 does not form lateral shoots; its fruits (beans) are formed only on the main shoot. Type II: Start and Gamma have shortened shoots of the 1st order with beans. Type III: Dega and Delta have longer lateral shoots of the 1st and 2nd orders are formed. Manovitsky is Type IV. Plants of this variety with good moisture supply consistently form shoots of the 1st-3rd and higher orders. The experimental plot area was 25 m^2, in quadruplicate. Soils - leached chernozem of medium thickness, $pH_{sal.}$ - 5.7-5.9. The P_2O_5 soil content was 94-98 mg, and K_2O was 210-220 mg kg^{-1} of soil.

Sowing time was maximum early, usually at the end of April. Sowing method - wide row with 45 cm row spacing and seeding rate of 500 thousand/ha of germinating seeds (50 seeds m^{-2}). Fertilizers were not applied for lupine. Experimental plots were kept weed-free. In this study, we used the results of the dynamic parameters of the production process from long-term observations of the formation of the yield of white lupine based on the example of the Start and Dega varieties. The methodology for all biometric counts of growth, development and yield formation in white lupine, including the dynamic parameters of plant photosynthesis in the field agrosystem, is presented.
The studied parameters were as follows:

- Leaf Area Index (LAI)
- Leaf area duration (LAD; 10^3 m^2 d ha^{-1})
- Net Assimilation Rate (NAR; g m^{-2} d^{-1})
- Total wet and Dry matter accumulation (TWM, TDM; ton ha^{-1})
- Crop Growth Rate (CGR; kg ha^{-1} d^{-1})
- Number of pods and seeds m^{-2}

RESULTS AND DISCUSSION

The variability of the duration of “seedlings to ripening” and individual periods in different meteorological years is an important indicator for farmers and enterprises producing lupine grain to assess the cultivation opportunities and risks for this crop. The growing season (seedlings to ripening) in the northern part of the Central Black Earth Region varied from 73 to 115 days, depending on the variety and meteorological conditions of the year (Table 1).

Table 1. Duration of vegetation (days)

№	Year	Variety					Mean	Sigma*	V (%)
		Start	Gamma	Delta	Dega	Deter 1			
1	2007	94	94	94	94	90	93	1.60	1.7
2	2008	114	114	115	114	105	112	3.72	3.3
3	2009	103	102	105	102	97	102	2.64	2.6
4	2010	77	77	78	77	73	76	1.74	2.3
5	2011	90	98	98	98	93	95	3.32	3.5
6	2012	102	102	103	102	96	101	2.53	2.5
7	2013	102	102	104	103	96	101	2.80	2.8
8	2014	102	102	102	102	96	101	2.40	2.4
9	2015	112	111	114	114	100	110	5.23	4.7
Mean		100	100	101	101	94	99	2.66	2.7
Sigma		10.7	10.0	10.4	10.4	8.4			
V (%)		10.7	10.0	10.3	10.4	8.9			

Note: *Sigma in tables: Standard deviation; V (%): Variation coefficient.

The lowest values were in dry years (2007 and 2010). The shortest growing season was in the variety without lateral shoots, i.e., Deter 1. In dry years, all varieties developed as early maturing, the growing season was 37 days shorter (2010). In 2009, 2011 and 2012 arid conditions and high temperatures were noted in certain periods of the second half of the growing season, after the end of flowering. Start, Gamma, Delta, and Dega ripened simultaneously during these years. The growing season of these varieties was 12-15 days shorter than in 2008. The varietal variability of the duration of the "seedling - ripening" period, estimated by the variation coefficient, was three times less than under the influence of weather conditions in different years. Years 2007 and 2010 were arid, which had a certain impact on the duration of the growing season and was 20 -37 days shorter compared to 2008 and 2015. The growth of plants in height during the period of opening of the lower flowers on the main shoot (at the beginning of flowering) was determined not only by varietal characteristics, but also by the amount of moisture during this period, plant growth reached its maximum values at the end of the flowering period and fruit formation. Sufficient moisture supply allowed the plants to form side shoots; the intensity was largely determined by the varietal architectonics of white lupine. Variability of seed yield and productivity elements. The weather conditions of the growing seasons during the years of research had a great influence on the formation of yield and its variability (Table 2). The growing conditions were mainly determined by the prevailing meteorological conditions during this period; the period of the first half of the growing season was especially important.

Table 2. Seed yield (ton ha^{-1}) and its variability.

№	Year	Variety					Mean	Sigma	V (%)
		Start	Gamma	Delta	Dega	Deter 1			
1	2007	2.4	2.38	2.67	2.34	2.26	2.41	0.14	5.7
2	2008	3.85	3.98	3.84	3.9	3.28	3.77	0.25	6.6
3	2009	3.45	3.43	4.16	3.78	3.19	3.60	0.34	9.3
4	2010	2.0	2.0	2.16	1.56	2.0	1.94	0.20	10.4
5	2011	3.58	3.16	3.07	3.53	3.58	3.38	0.22	6.6
6	2012	4.06	3.78	3.53	3.78	4.06	3.84	0.20	5.2
7	2013	2.0	2.31	2.11	2.17	2.07	2.13	0.10	4.9
8	2014	3.24	3.09	3.92	3.35	2.12	3.14	0.58	18.6
9	2015	3.82	5.54	6.1	5.89	4	5.07	0.97	19.0
Mean		3.16	3.30	3.51	3.37	2.95	3.26	0.19	5.8
Sigma		0.76	1.02	1.16	1.19	0.80	0.93		
V (%)		24.2	30.8	33.1	35.4	27.1	28.5		

Note: *Sigma in tables: Standard deviation; V (%): - Variation coefficient.

Weather conditions in different years had a strong impact on the level of yield and its variability. The variation coefficient reflected the degree of stability of yield in the years of research, and the difference in heat and moisture supply (Tables 3-4).

Table 3. Seed yielding capacity, protein and yield components (Start).

Initial data	Unit of measurement	12-year mean	Favorable years	Arid years (6 years)
Seed yielding capacity	Ton ha^{-1}	3.08	4.44	1.82
	V (%)	41.8	12.4	19.2
Protein with seed yield	kg ha^{-1}	1190	1710	720
	V (%)	40.3	12.3	18.4
Number of fruits	pcs m^{-2}	246	360	160
	V (%)	40	20	9
Number of seeds	pcs m^{-2}	800	1120	455
	V (%)	45	34	14
Weight of 1000 seeds	g	390	375	400
	V (%)	9	9	9

Table 4. Elements of productivity in years different by weather conditions (Dega).

Parameters	2010	2011	2012	2013	2014	2015	Mean	V %	Sigma
Beans (m^{-2})	200	435	455	270	390	660	402	36.5	146.5
Pods on the main shoot (%)	82	67.9	67.3	85.1	66.3	50.6	69.9	16.3	11.4
Number of seeds (m^{-2})	600	1600	1215	810	1360	2520	1351	45.9	619.7
Seeds from the main shoot (%)	86.7	80	71	90	70.6	52.4	75.1	16.6	12.5
Weight of 1000 seeds (g)	320	318	320	316	274	290	306	5.8	17.9
Protein (kg ha^{-1})	570	1315	1400	745	1205	2060	1216	39.7	482.2
Wet matter yield (ton ha^{-1})	30.4	52.4	65.5	28	71.5	61.5	51.6	32.6	16.8
Dry matter yield (ton ha^{-1})	5.41	9.17	13.4	5.58	11	12.8	9.56	33.2	3.2
Seed yielding capacity (ton ha^{-1})	1.56	3.53	3.78	2.07	3.25	5.54	3.29	39.0	1.3

Photosynthetic activity of white lupine plants in the field

The analysis of the dynamic indicators of the production process in white lupine plants made it possible to develop a new methodological approach to compare these indicators in growing seasons of different climatic conditions for different varieties (Table 5). The functioning of the agrocenosis of white lupine as a photosynthetic system, during the entire growing season, from seedlings to the beginning of ripening, according to its dynamic characteristics, successively proceeds in four periods: I - from the opening of the first flower on the plant, - II - from the opening of the first flower to the complete end of flowering; III - at the end of the period, the fruits of the upper layer or on the lateral shoots of the plant reach their maximum size, the maximum mass of fruit shells, the pods are full or shiny; IV - the assimilates and nutrients move from fruit shells and other organs into seeds;

maximum dry weight of seeds at high humidity. Photosynthetic activity and its dynamic indicators are considered on the example of the Start variety (Table 5).

Table 5. Dynamic characteristics of the production process, the Start variety (12-year mean).

Indicators	Period				
	I	II	III	IV	I-IV
Duration of the period (days)	36	20	18	20	96
V (%)	11	13	23	12	10
Leaf Area Index (LAI) at the end of the period	1.7	4.0	3.2	0	-
V (%)	30	36	42	-	-
Leaf Area Index (LAI; mean for the period)	0.7	3.2	3.5	1.7	2.1
V (%)	28	31	39	36	30
Leaf area duration (LAD; m^2 d ha^{-1})	260	630	705	405	2000
V (%)	37	31	53	45	38
Net Assimilation Rate (NAR; g m^2 d^{-1})	6.5	4.1	4.2	---	4.5
V (%)	11	15	22	---	9
Dry matter (DM) at the end of the period (ton ha-1)	1.40	4.39	6.90	8.0	-
V (%)	36	30	37	35	-
Dry matter gain (DMG; ton ha^{-1})	1.70	2.50	3.00	0.3	7.50
V (%)	36	36	52	50	35
Crop growth rate (CGR; kg ha^{-1} day^{-1})	47	125	167	20	78

Dry matter gain in white lupine was about 20% of the maximum values during the growing season; there was a sharp increase in the intensity of growth processes during the periods of flowering, fruit formation, maximum leaf area, leaf area duration, and average daily dry matter gains were noted. Dry matter gain during the period of intensive growth of fruits was mainly due to the shells of the fruits; at the end of this period, the maximum yield of wet matter was noted, at 62% (Tables 6-7).

Table 6. Indicators of photosynthesis by periods of growth and development of plants (Dega).

Indicators	Period				
	I	II	III	IV	I-IV
Duration of the period (days)	34	22	18	21	95
Leaf area index (LAI) at the end of the period	1.8	3.7	2.9	0	-
Leaf area duration (LAD; 10^3 m-^{2} d ha^{-1})	310	780	780	245	2115
Net assimilation rate (NAR; g m^{-2} day^{-1})	5.16	4.10	3.92	4.28	4.21
Dry matter (DM) at the end of the period (ton ha^{-1})	1.60	4.80	7.85	8.90	8.90
Dry matter gain (DMG; ton ha^{-1})	1.60	3.20	3.05	1.05	8.90
Crop growth rate (CGR; kg ha^{-1} day^{-1})	47	145	170	50	94

*Mean for 7 years of observations

Table 7. Photosynthetic variability, the Dega variety, V (%).

Indicators	Period				
	I	II	III	IV	I-IV
Duration of the period, days	11	13	23	12	10
Leaf area duration (LAD; 10^3 m-^{2} d ha^{-1})	37	31	53	45	38
Net assimilation rate (NAR; g m^{-2} day^{-1})	11	15	22	---	9
Dry matter (DM) at the end of the period (ton ha^{-1})	36	30	37	35	-
Dry matter gain (DMG; ton ha^{-1})	36	36	52	50	35

CONCLUSION

The variation coefficient of net assimilation rate (NAR) considered in certain periods of the growing season was lower than the variability of neaf area duration (LAD) of the studied varieties of white lupine. Studies revealed a high variation coefficient for leaf area duration (LAD) for certain growing periods (30-54%). A significant change in the leaf area index (LAI) and leaf area duration (LAD) influenced the variability of the dry matter of white lupine plants and the seed yield. This indicates a significant influence of meteorological factors on the formation of the yield of white lupine.

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