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Coat Colour Grading of the Scots Pine Seeds Collected from Faraway Provenances Reveals a Different Germination Effect

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Abstract: The physiological quality of pine seeds is characterized by laboratory and field germination. The present paper is intended for technologists of seed plants and specialists of forest nurseries. It offers a solution to improve the seeding characteristics of small seeds by their pre-sowing preparation. The success of reforestation activities directly depends on the quality of the seeds. The influence of seed sorting by seed size and seed coat colour has been theoretically substantiated and repeatedly tested in practice. However, the response of seeds in germination can vary depending on the year and place of seed collection. Scots pine (*Pinus sylvestris* L.) seeds were germinated under controlled conditions. Seedlings were obtained from seeds pre-sorted by seed coat colour into white, brown, and black groups, and further divided by size. The results of sorting by the colour of seed coat indicate a different effect of this pre-sowing treatment on the sowing qualities of seeds. Brown seed coat colour showed the highest percentage degree in the seedlots of all provenances. The seeds from the southern provenance with the brown seed coat colour shown the maximum germination. That said, the study raises new questions, indicating more comprehensive research in the future. Does the pattern of germination parameter distribution remain constant for seeds of other harvest years but of the same provenance? Does the variability of the germination factor the result of internal factors of the container location in the greenhouse? Is the genetic diversity of seedlings disturbed by sorting by size?

Keywords: forest seed grading; seed coat colour; small-size forest seeds; *Pinus sylvestris* L.; forest seed germination; germinant morphological properties; forest landscape restoration

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1. Introduction

Scots pine (*Pinus sylvestris* L.) has a wide range of habitat [1] and is one of the primary sources of wood raw materials in boreal countries. The seeds of Scots pine as integral components of forest reproductive material (FRM) [2] are valuable products, moved by trade operations, as shown in [3], for significant distances, and to some extent determining the rate of forest landscape restoration technology (FLR technology) [4,5]. Thus, the leading importer of Scots pine seeds in Europe is Sweden (about 175 kg per year, the total amount for Europe is 272.76 kg), and the origin of these seeds belongs exclusively to Finland. Quality, defined by appropriate indicators, characterizes any product. Improvement of quality indicators and competitiveness of forest seeds is one of the promising directions of the development of forest seed production. This direction assumes the active interaction of private forest users with forest seed producers, which is consistent with the realities in

the forest legislation and the basic provisions of Restoration Opportunities Assessment Methodology [6] for use in global reforestation initiatives [7–9].

One of the important quality indicators for the seeds of Scots pine is ground germination. Germination depends on the «year of stand formation, stratification substrate, and individual characteristics of mother trees» [10], temperature conditions [11] and seed viability [12]. The outdoor germination test carried out in a container nursery [12] differs sharply from the test values in the open ground only when the seed viability is low. Germination in the ground of conifer seeds is closely related to temperature conditions [11] and occurs more slowly and unstably [13] compared to seeds of agricultural crops, which leads to additional costs for greenhouse heating in nurseries.

The operation of conifer seed sorting [14] before sowing [15] to improve the quality of produced seedlings is laid by the world's leading manufacturers of forest nursery equipment (for example, BCC AB, Sweden), setting the pace of development of forest reproductive material technology. Traditionally, seeds are consistently separated in such technology using a standard machine [16] according to geometrical and gravitational, i.e., quantitative, traits. However, the spectrometric properties [17–22] of seeds should not be neglected either, since their use provides non-invasive quality (seed viability) control [23].

The basis for the study was the relatively small amount of data on germination in containers of Scots pine seeds separated using optical graders [24,25] by the seed coat colour and quantitative traits. Novikov et al. [26], conducting theoretical studies of the single seed detection process of Scots pine, point out that «the seed spectrometric feature, both in the visible (VIS) and near-infrared (NIR) regions has a low identification error [27], and is best suited for automating seed grading processes [28]».

The seeds of Scots pine within the range are characterized by a large variety of seed coat colours [29,30]. The individuality of seed colour of Scots pine and its stability in the course of pine ontogenesis [31] has been noted in studies [32–36]. Seed colouration is a phenotypic marker in the taxonomy and ecological and geographical differentiation of this species. Therefore, this trait is used to characterize the genotypic composition of populations representing this polymorphic species and other morphophysiological traits. Currently, 50 variations of this trait have been identified in pine. It is also known that the colouration of mature, full-grown seeds is uniform within the crown of one tree and does not change in ontogeny, which allows effective use of this trait of the maternal individual, preserved in vegetative progeny.

Various explanations for seed polymorphism of *Pinus sylvestris* L. are known: protection of seeds from eating by birds [37], the influence of growing conditions [35], and the impact of environmental factors. Studies on the relationship between seed colouration and germination are heterogeneous and contradictory [38,39]. Several forms of *Pinus sylvestris* L. are distinguished [35]: black—*Pinus sylvestris* L. var. *melanosperma* Litv.; yellow—*Pinus sylvestris* L. var. *leucosperma* Litv.; brown—*Pinus sylvestris* L. var. *phoeosperma* Litv.; and mottled—*Pinus sylvestris* L. f. *cinnamomeosperma* mihi. In her dissertation, Pinaevskaya [40], according to the literature data, provides information on the forms of pine with mono- and polychromatic colour variants, noting that many authors establish at least three forms—black, brown, and light/yellow/white.

The idea of using seed colour polymorphism is to form a forest plantation of pine trees with one form (i.e., with seeds of the same colour), which will stabilize the seed quality in each lot. If there are differences in sowing qualities of seeds of different colours, using seed colour sorting devices can produce more productive plantations. If there are no differences in seed quality, sorting by colour makes sense for more complete control of the origin of the seed.

Thus, the study aims to determine the effect of seed coat colour, seed size, and seed provenance on the seed quality of Scots pine species.

2. Materials and Methods

2.1. Seed Sampling

In this study, the seeds of *Pinus sylvestris* L. species (hereinafter referred to as seeds) were used. Seeds were obtained using standard technology [14] from cones collected in 2017 and 2019 in the natural stand of the Lisinsky educational-and-experimental forestry farm (Leningrad region, Lisino-Korpus, Russia) [41], Sosnogorsk forestry (Komi Republic, Russia) and the Morshanskiy Leskhoz, Parlinskiy production area (Tambov region, Russia), respectively, Figure 1 and Table 1. The seeds were extracted from the cones, dewinged, dried to a moisture content of 8%, and prepared on a gravity separator [42]. Next, the seeds were stored in sealed glass jars at −5 °C and 6–8% humidity. Immediately before the experiment, seeds were removed from storage and held for at least 24 h at room temperature (t = 18 °C, humidity = 45%).



Figure 1. The provenance of Scots pine seeds used in study.

Table 1. Distances between provenance where Scots pine seeds were collected for the study, km.

	Lisino	Tambov	Komi
Lisino, 30.70590° E 59.43476° N, 65 m a.s.l.	—	~1700	~2700
Tambov, 41.96639° E 53.56359° N, 119 m a.s.l.	~1700	—	~2500
Komi, 53.72314° E 63.51939° N, 118 m a.s.l.	~2700	~2500	—

2.2. Lab Experiment

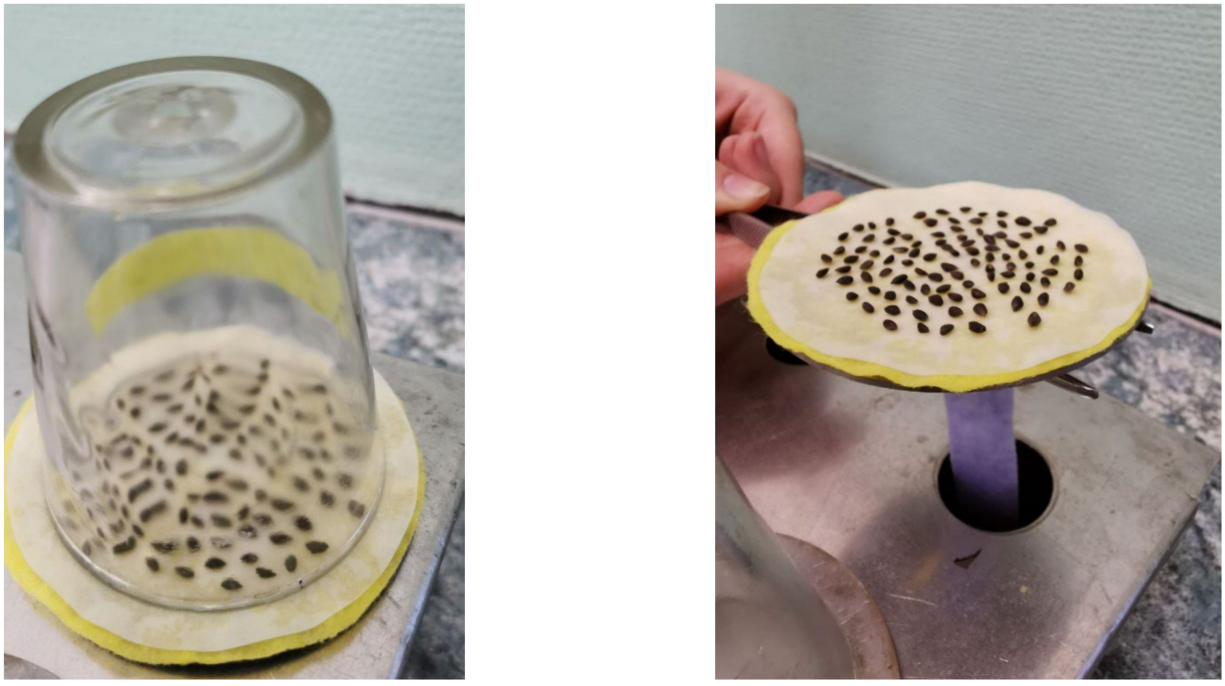
Experiments were carried out at the Department of Forest Cultures, St. Petersburg State Forest Technical University, from 1 October 2021 to 15 October 2021. Four samples of seeds were selected from the batch (Lisino, Tambov, Komi), and each sample was reduced to 25 g by quartering. Seeds were sorted on a 2.4/20 mm, 2.0/20 mm, 1.7/20 mm, 1.5/20 mm, 1.2/20 mm, and 1 mm diameter round hole sieve set for 5 min. Each fraction was weighed,

then manually sorted into three colours (black, brown, and white) and weighed again on scales of the second accuracy class BCT-600/10; the received data were entered in Table 2, and Figures A2–A4 from Appendix A.

Table 2. Distribution in percentage of seed samples of Scots pine by size and seed coat colour.

Colour/Size	Lisino's Seedlot				Tambov's Seedlot				Komi's Seedlot			
	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
White	19.54	8.24	8.48	8.55	15.87	15.96	14.80	8.48	11.43	14.79	11.08	12.95
Brown	18.94	55.05	58.73	47.86	65.33	69.24	76.25	58.73	38.40	63.88	38.67	34.38
Black	61.52	36.71	32.79	43.59	18.80	14.80	8.95	32.79	50.17	21.33	50.25	52.67
1	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2/20	41.90	0.04	0.04	0.08	0.37	0.08	0.04	0.04	0.21	0.25	0.38	0.24
1.5/20	49.09	38.07	37.42	38.58	24.69	23.44	34.95	37.42	35.41	36.38	44.27	43.72
1.7/20	6.20	52.15	51.30	51.10	45.68	57.50	54.13	51.30	49.79	47.39	44.40	46.35
2.0/20	0.32	8.94	10.62	9.32	23.95	17.82	10.50	10.62	13.52	14.70	10.62	9.58
2.4/20	0.00	0.81	0.62	0.92	5.32	1.16	0.39	0.62	1.07	1.27	0.33	0.12

Further experiments were conducted on the germination of samples of 100 seeds each, samples with a number of seeds less than 100 were laid, but due to the statistical uncertainty of the results, they are not listed. Seeds were spread in 100 pieces of each fraction and each colour. Seeds were placed on a special bed for germination (Figure 2). It consisted of a flannel lining with a wick sewn to the centre and filter paper. One hundred seeds spread on the bed were covered with a glass cap disinfected with 60% ethanol. The spread seeds were transferred to germination apparatuses filled with water so that the wick and filter paper would not dry out. The water level in the apparatuses was filled to a height of 2–3 cm below the seed bed. According to GOST 13056.6-97 [43], the beginning of seed germination is the day following the day of seed placement. Recording the results of germination in apparatuses is carried out separately for each hundred. The number of germinated seeds, as well as obviously rotten seeds, which are removed from the bed with tweezers, is counted during the counting days for each hundred.



(**a**) (**b**)

Figure 2. Germination bed–with glass cap (**a**) and without (**b**).

2.3. Field Experiment

Determination of soil germination in the experiment was carried out in two germination terms for seeds of Scots pine from Tambov and Komi. Seeds were not sorted by colour and fraction, only by region of origin. We took into account the appearance of hypocotyl on the surface and the unfolding of the needles.

2.3.1. First Planting Rotation

Sowing was performed on 8 May 2021, Gatchina District, Leningrad Region, Druzhnaya Gorka settlement. Each variant was sown into three Plantek 81F containers, the cells of which were filled with substrate based on milled upland peat diluted with dolomite flour to pH 5.5 and with the addition of N_{16} P_{16} K_{16}, then pressed with a cassette from above. Seeds were sown with 2 seeds per cell, then the cells were filled with a mixture of granite chips and peat [44]. The sown cassettes were placed in a greenhouse. Once every two weeks, they were watered with a solution of 2% potassium permanganate—regular watering, one time per day. Shoots appeared on 29 May 2021 (Tables A1–A18).

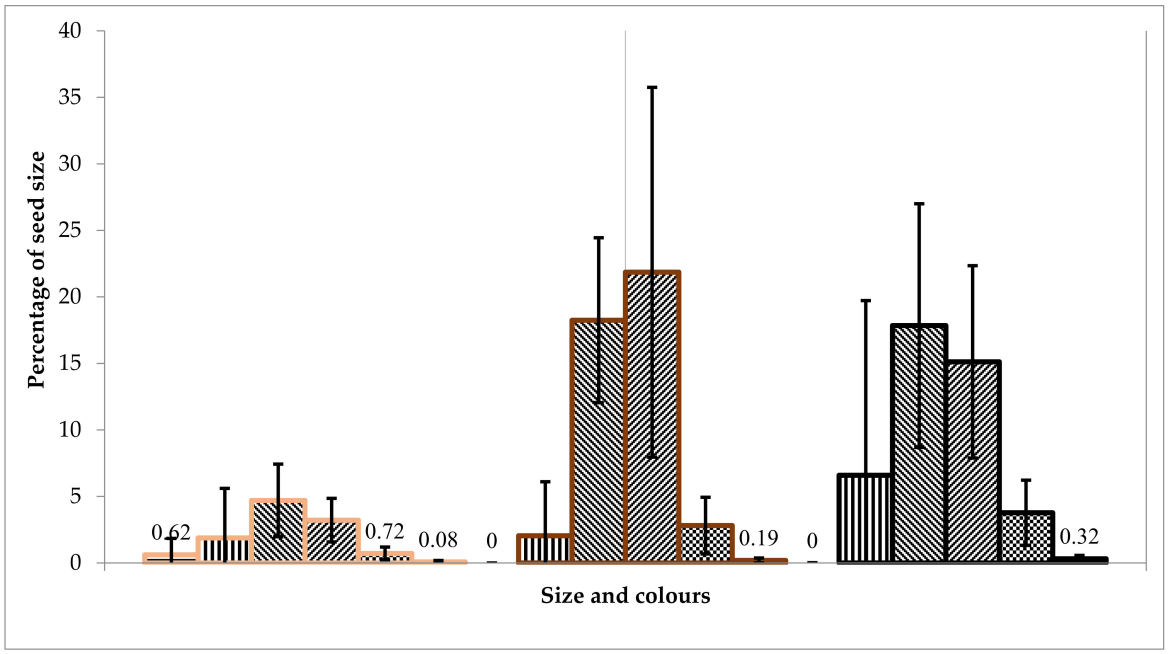
2.3.2. Second Planting Rotation

Sowing was carried out on 26 June 2021, Gatchina District, Leningrad Region, Druzhnaya Gorka settlement. The Tambov variant was seeded into 1 cassette of 12 × 7 and 1 cassette of 6 × 7 cells, the Komi variant into 2 cassettes of 12 × 7 cells. The cells, as in the first rotation, were filled with a peat-based substrate, pressed with a cassette from above, seeds were sown 4 seeds per cell, then the cells were filled with a mixture of granite chips and peat. The finished cassettes were placed in a greenhouse. Once every two weeks, they were watered with a solution of 2% potassium permanganate—regular watering, one time a day. Shoots appeared on 14 July 2021 (Tables A19–A26).

3. Results

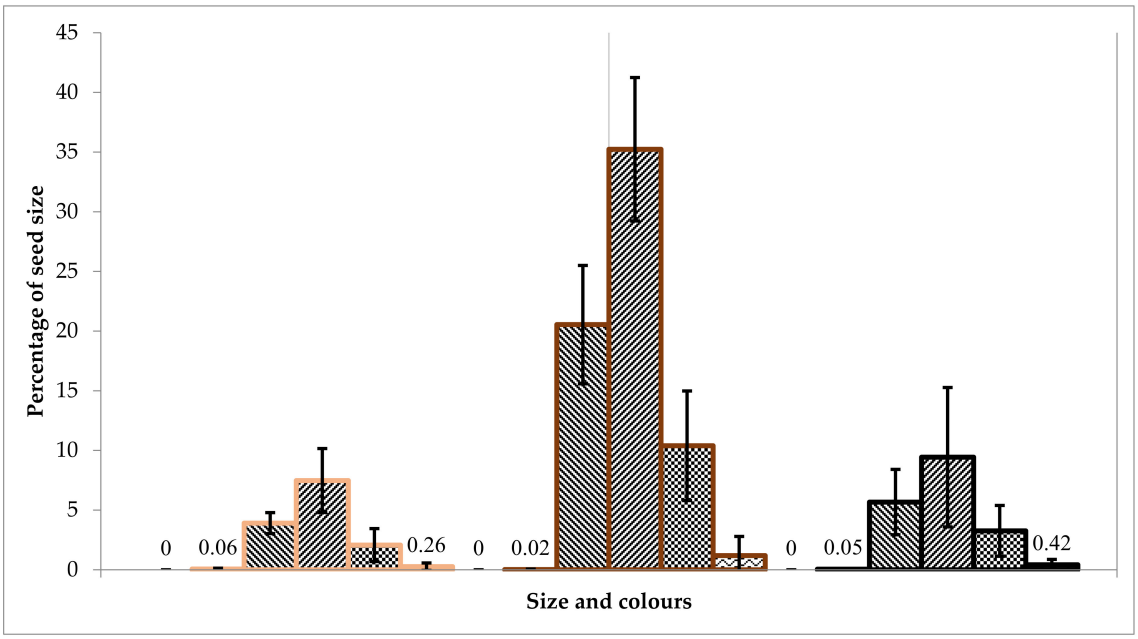
3.1. Lab Experiment

The distribution of Scots pine seeds (Table 2) from three faraway Lisino (Figure 3a), Tambov (Figure 3b), and Komi (Figure 3c) locations demonstrates a differentiated character.

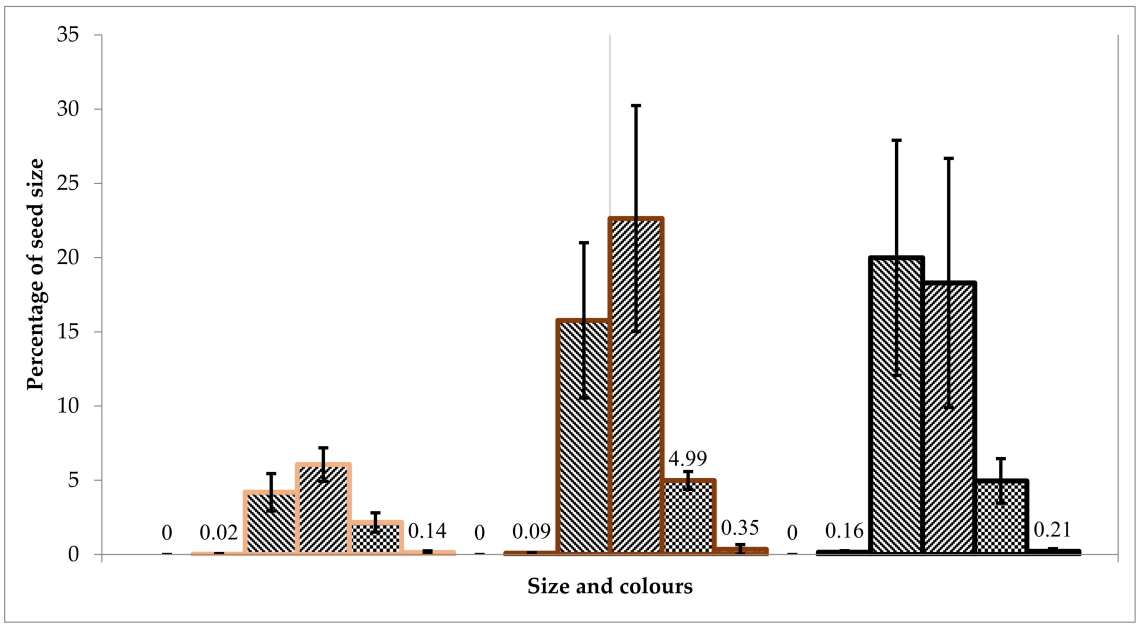


(**a**)

Figure 3. *Cont.*



(**b**)



(**c**)

Figure 3. Scots pine seed samples distribution by size and seed coat colour collected at the Lisino (**a**), Tambov (**b**), Komi (**c**) locations. A plot's group bounded by beige lines has a white seed fraction, brown–brown seed fraction and black lines–black seed fraction. In each colour group there are 6 subgroups graded by size (from left to right) by sieves of 1.0, 1.2, 1.5, 1.7, 2.0 and 2.4 mm round hole diameters. The plots' heights denote the average mean, and the whiskers ± SD.

The results for the studied locations are arranged in order of increasing seed size fractions: 1.2 (Table 3), 1.4 (Tables 4 and 5), 1.7 (Tables 6 and 7), 2.0 (Tables 8 and 9). The different nature of the relationship between seed colour and laboratory germination was revealed. For the more northern region (Lisino), the highest germination was observed in seeds with black colouring for small seeds and with brown colouring for large seeds (Tables 3, 4, 6 and 8). For the Tambov region, the highest germination was noted in seeds with brown colouring and larger sizes of the seeds themselves (Tables 5, 6 and 9). There were no small fraction of seeds.

Table 3. Germination results—Lisino.

Colour		**White**			**Brown**		
Size		**1.2/20**			**1.2/20**		
Sample		**Sample 1**	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**	**Sample 3**
Number of germinated seeds, pieces	08.10.2021	14	17	15	16	16	14
	12.10.2021	17	13	17	10	8	15
	15.10.2021	1	2	0	5	0	0
Number of ungrown seeds, pieces	08.10.2021	86	83	85	84	83	85
	12.10.2021	69	70	53	65	75	70
	15.10.2021	68	66	49	60	75	70
Number of rotted seeds, pieces	08.10.2021	0	0	0	0	1	0
	12.10.2021	0	0	15	8	0	0
	15.10.2021	0	2	4	0	0	0
Germination energy, %		14%	17%	15%	16%	16%	14%
Average germination energy, %			15%			15%	
Germination, %		32%	32%	32%	31%	24%	29%
Average germination, %			32%			28%	

Table 4. Germination results—Lisino.

Colour		**White**			**Brown**			**Black**		
Size		**1.5/20**			**1.5/20**			**1.5/20**		
Sample		**Sample 1**	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**	**Sample 3**
Number of germinated seeds, pieces	08.10.2021	43	48	45	39	40	49	27	35	25
	12.10.2021	10	6	6	8	7	13	15	10	7
	15.10.2021	1	1	1	3	4	5	8	3	1
Number of ungrown seeds, pieces	08.10.2021	57	51	55	61	60	51	73	65	75
	12.10.2021	47	45	49	53	53	38	51	21	30
	15.10.2021	46	42	48	46	38	24	41	17	29
Number of rotted seeds, pieces	08.10.2021	0	1	0	0	0	0	0	0	0
	12.10.2021	0	0	0	0	0	0	7	35	38
	15.10.2021	0	2	0	4	11	9	2	1	0
Germination energy, %		43%	48%	45%	39%	40%	49%	27%	35%	25%
Average germination energy, %			45%			43%			29%	
Germination, %		54%	55%	52%	50%	51%	67%	50%	48%	33%
Average germination, %			54%			56%			44%	

Table 5. Germination results—Tambov.

Colour		**White**		**Brown**		**Black**
Size		**1.5/20**		**1.5/20**		**1.5/20**
Sample		**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**	**Sample 1**
Number of germinated seeds, pieces	08.10.2021	58	50	57	61	52
	12.10.2021	7	15	6	2	5
	15.10.2021	0	2	0	2	0
Number of ungrown seeds, pieces	08.10.2021	43	49	43	39	48
	12.10.2021	31	41	34	34	43
	15.10.2021	31	34	30	28	40
Number of rotted seeds, pieces	08.10.2021	0	1	0	0	0
	12.10.2021	5	3	3	3	0
	15.10.2021	0	5	4	4	3
Germination energy, %		57%	50%	57%	61%	52%
Average germination energy, %		54%		59%		52%
Germination, %		64%	67%	63%	65%	57%
Average germination, %		66%		64%		57%

Table 6. Germination results—Lisino.

Colour		**White**			**Brown**			**Black**	
Size		**1.7/20**			**1.7/20**			**1.7/20**	
Sample		**Sample 1**	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**
Number of germinated seeds, pieces	08.10.2021	37	39	53	61	50	56	27	21
	12.10.2021	8	10	10	8	19	17	12	13
	15.10.2021	0	2	0	1	0	0	0	0
Number of ungrown seeds, pieces	08.10.2021	63	61	46	39	50	42	73	79
	12.10.2021	55	51	31	31	24	25	60	40
	15.10.2021	53	43	29	30	22	24	60	38
Number of rotted seeds, pieces	08.10.2021	0	0	1	0	0	1	0	0
	12.10.2021	0	0	6	0	2	0	1	26
	15.10.2021	2	6	2	0	2	1	0	2
Germination energy, %		37%	39%	53%	61%	50%	57%	27%	21%
Average germination energy, %			43%			56%		24%	
Germination, %		45%	51%	63%	70%	69%	74%	39%	34%
Average germination, %			53%			70%		37%	

Table 7. Germination results—Tambov.

Colour		**White**		**Brown**		**Black**
Size		**1.7/20**		**1.7/20**		**1.7/20**
Sample		**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**	**Sample 1**
Number of germinated seeds, pieces	08.10.2021	57	68	61	58	40
	12.10.2021	4	5	19	8	4
	15.10.2021	1	0	0	2	0
Number of ungrown seeds, pieces	08.10.2021	49	35	39	42	60
	12.10.2021	34	25	19	31	15
	15.10.2021	33	16	16	27	14
Number of rotted seeds, pieces	08.10.2021	0	0	0	0	0
	12.10.2021	11	5	1	3	45
	15.10.2021	0	9	3	2	1
Germination energy, %		54%	68%	61%	58%	40%
Average germination energy, %		61%		60%		40%
Germination, %		58%	73%	80%	68%	44%
Average germination, %		66%		74%		44%

Table 8. Germination results—Lisino.

Colour		**White**	**Brown**			**Black**		
Size		**2.0/20**	**2.0/20**			**2.0/20**		
Sample		**Sample 1**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 1**	**Sample 2**	**Sample 3**
Number of germinated seeds, pieces	08.10.2021	38	76	63	59	23	29	32
	12.10.2021	5	9	12	22	8	12	11
	15.10.2021	4	0	1	0	0	1	2
Number of ungrown seeds, pieces	08.10.2021	63	24	37	41	77	71	68
	12.10.2021	53	15	25	19	68	59	57
	15.10.2021	41	13	22	19	68	58	53
Number of rotted seeds, pieces	08.10.2021	0	0	0	0	0	0	0
	12.10.2021	5	0	0	0	1	0	0
	15.10.2021	8	2	2	0	0	0	2
Germination energy, %		38%	76%	63%	59%	23%	29%	32%
Average germination energy, %		38%		66%			28%	
Germination, %		47%	85%	76%	81%	31%	42%	45%
Average germination, %		47%		81%			39%	

Table 9. Germination results—Tambov.

Colour		White			Brown				Black		
Size		2.0/20			2.0/20				2.0/20		
Sample		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3
Number of germinated seeds, pieces	08.10.2021	53	30	57	56	60	71	74	38	59	45
	12.10.2021	11	5	8	11	8	3	8	21	8	16
	15.10.2021	1	1	0	2	0	0	0	3	2	0
Number of ungrown seeds, pieces	08.10.2021	41	48	43	40	38	29	26	62	42	49
	12.10.2021	27	30	22	8	11	26	13	24	14	9
	15.10.2021	24	29	22	6	10	26	10	21	11	9
Number of rotted seeds, pieces	08.10.2021	0	0	0	4	3	0	0	0	0	6
	12.10.2021	3	13	13	21	19	0	5	17	20	24
	15.10.2021	2	0	0	0	1	0	3	0	1	0
Germination energy, %		56%	38%	57%	56%	59%	71%	74%	38%	58%	45%
Average germination energy, %			51%			65%				28%	
Germination, %		69%	46%	65%	69%	67%	74%	82%	62%	68%	61%
Average germination, %			60%			73%				39%	

3.2. Field Experiment

To test the germination of seeds from different harvesting regions, sown without sorting by colour and size in cassettes and sprouted in a greenhouse, the results showed a difference both by region and by growing rotations (Tables 10 and 11). For the Komi region, the highest germination is shown in the second rotation. For Tambov, the greatest germination is observed in the first rotation. The average and median dimensions of the height of seedlings for Tambov are also larger than for Komi (Table 12).

Table 10. First planting rotation.

Parameters	Tambov				Komi			
	Container 1	Container 2	Container 3	Average	Container 1	Container 2	Container 3	Average
Cells, pcs.	81	81	81	81	81	81	81	81
Seeds per cell, pcs.	2	2	2	2	2	2	2	2
Total sown, pcs.	162	162	162	162	162	162	162	162
Seedlings, pcs.	51	36	37	41.3	24	22	14	20
Germination, %	31	22	23	26	15	14	9	12

Table 11. Second planting rotation.

Parameters	Tambov			Komi		
	Container 1	Container 2	Average	Container 1	Container 2	Average
Cells, pcs.	84	49	66.5	84	84	84
Seeds per cell, pcs.	4	4	4	4	4	4
Total sown, pcs.	336	196	162	336	336	336
Seedlings, pcs.	69	51	60	67	58	62.5
Germination, %	21	26	23	20	17	19

Table 12. Second planting rotation—seedling length, mm.

Parameters	Tambov			Komi		
	Container 1	Container 2	Both	Container 1	Container 2	Both
Min	27	25	25	15	18	15
Max	78	84	84	78	75	78
Average	53.68	51.19	52.6	46.51	48.40	47.4
Median	53	51.5	52	44	47	46
Mode	42	48	42	43	47	47
Variance	141.03	200.27	168.01	216.64	179.96	200.67
Deviation	11.88	14.15	12.96	14.72	13.41	14.17
Kurtosis	−0.77	-0.51	−0.55	−0.53	−0.65	−0.63
Skewness	0.17	0.11	0.09	0.31	−0.13	0.12

4. Discussion

Comparing the first and second rotation of Tambov seeds, we can conclude that the average ground germination is 25 ± 5%. The average ground germination of seeds from Komi is 15 ± 5%. It can be concluded that there is a difference between the sowing qualities of seeds from different regions, Table 13. However, is there a dependence on seed coat colour and seed size?

Table 13. Ranking of Scots pine seeds with different coat colours according to germination.

Size	Colour	Germination	Rank		
			Lisino	Tambov	Komi
1.2/20	White	Laboratory	32%	—	—
		Field	—	*25%	*15%
	Brown	Laboratory	28%	—	—
		Field	—	*25%	*15%
	Black	Laboratory	56%	—	—
		Field	—	*25%	*15%
1.5/20	White	Laboratory	54%	66%	—
		Field	—	*25%	*15%
	Brown	Laboratory	56%	64%	—
		Field	—	*25%	*15%
	Black	Laboratory	44%	57%	—
		Field	—	*25%	*15%
1.7/20	White	Laboratory	53%	66%	—
		Field	—	*25%	*15%
	Brown	Laboratory	71%	74%	—
		Field	—	*25%	*15%
	Black	Laboratory	37%	44%	—
		Field	—	*25%	*15%
2.0/20	White	Laboratory	46%	60%	—
		Field	—	*25%	*15%
	Brown	Laboratory	81%	73%	—
		Field	—	*25%	*15%
	Black	Laboratory	39%	64%	—
		Field	—	*25%	*15%

*—without sorting by colour and fraction, in a mixture.

The results obtained on the soil germination of seeds showed that it is more expedient to use unsorted seeds from the Komi region for growing in the first rotation. Seeds from the Tambov region can be grown according to a two-rotation scheme for the growing season.

A laboratory experiment showed that the seed size distribution corresponds to the Gaussian distribution. The fraction of 1.7 to 2.0 mm (medium-sized seeds) prevails in all cases and colours in 30–40%, except white for each batch. The overall low germination efficiency of seeds was recorded in all the collected seed batches.

The laboratory germination of the Tambov's seedlot is higher than the Lisino's seedlot, and its soil germination is higher than the soil germination in the batch of seeds from Komi, which is explained by the more southern region of seed origin. Since the Tambov's seedlot was stored for two years in the seed storage, and the Lisino's seedlot for four years, it can be assumed that the decrease in germination is due to the duration of the storage period. However, at the same time, the germination of medium and large seeds of the brown fraction decreases slightly, due to a larger supply of nutrients in the endosperm.

The colour of pine seeds may well have a certain breeding value. Thus, in Estonia, there was less ground germination in light seeds and worse growth of seedlings from black seeds [45]. In Ukraine, 40-year-old crops planted from 12 groups of seeds by colour were studied, and only cultures from light seeds were preserved significantly worse [46]. In the study of pine seeds from 93 points [47], light seeds were characterized by reduced germination energy, which was 75% versus 81% for black and variegated seeds. In Belarus,

in the Minsk region, there was less damage to the crops of shoots created from dark seeds of pine seedlings [48], and seedlings from dark seeds are also resistant to fusarium [49].

However, offspring from light seeds do not grow worse in all regions. In the northwest of Russia, seedlings from light seeds are equivalent and even surpass in height plants obtained from seeds of other colours [50].

Some researchers believe that the colour of the seeds is associated with the conditions of the place of growth and light tones are inherent in fresh and dry pine forests, and seeds with a predominance of dark shade are inherent in moist growing conditions [35]. In phenetic studies of pine, the study of the variability of the seed colour structures showed that they are determined by three layers and have a high degree of heritability, and the frequency of phenols of the third colour layer of seeds can serve as markers of pine populations [51]. In Rayevsky's dissertation [52], on the basis of a system of methods for isolating and evaluating phenes of Vidyakin's Scots pine, five phenotypes were isolated for the conditions of the Petrozavodsk forest seed plantation (Republic of Karelia, Russia) and it was found that clones with dark brown and brown seed colouration have the highest seed productivity.

Studies have shown that plantations with different proportions of dark and light-coloured seeds are represented within the boundaries of the area of Scots pine. At the same time, trees with dark-coloured seeds predominate in most plantings. A particularly large representation of pine trees with dark seeds is characteristic of rich and sufficiently moist ecotopes. Pine trees with light-coloured seeds are more common in the dry forests of the forest-steppe zone (southern regions), as well as in pessimal conditions characterized by a cold thermal regime and excessive moistening of plantings near the northern border of the range [51]. The productivity of such pine forests is usually estimated at no higher than the III class of yield. A significant proportion of trees with light seeds are characteristic of pine swamp habitats, while their number increases in "dystrophic areas" and decreases as the ecological situation improves in other areas of the ecotope. In a number of studies, the relationship between the colour of seeds and their weight has not been revealed [53]. However, most of the works devoted to the study of the variability of seed colouration emphasize the breeding significance of this trait and its connection with economically valuable forestry and breeding indicators of individual trees and plantings [54]. Thus, S. Kurdiani, when studying a pine plantation in the Kiev region, found various levels of damage mainly in trees producing light seeds [55].

In a some papers devoted to the study of the effect of seed colouration on the growth and stability of offspring, the advantage of seedlings grown from light seeds was noted [56,57]. Other authors, on the contrary, concluded that the best growth and stability are characteristic of seedlings grown from dark-coloured seeds. In the conditions of the Moscow region, there was an increased resistance to fusarium seedlings from black seeds [58].

Experiments to study the influence of the conditions of origin and cultivation on the growth and preservation of offspring from colour-seed forms of Scots pine were also conducted in the forest-steppe regions of Siberia. Thus, in the south of the Krasnoyarsk Territory, ecological cultures representing the offspring of populations differentiated by seed colour were studied in arid conditions [35,59]. As a result of the research, differences were found in the survival rate and growth of offspring of populations with the advantage of different colour-seed groups-with black, brown, and light grey shades of the seed peel.

During the study by M.V. Rogozin, pine seeds were divided into gradations: black, dark, variegated, brown and light. In all gradations, different frequencies of the best families with intrafamily selection of phenotypically best individuals were observed, but a stable advantage was shown by variegated seeds, in which in eight experiments out of 11 the frequency was 129–227% of the norm. The most variable offspring were from light seeds with a frequency of the best families from 0 to 400%. Seeds with a dark colour germinated more slowly than variegated and brown ones, and the germination time of light seeds in different years varied from the longest (2.4 days) to the shortest (1.13 days).

The author suggested that it is likely that trees with light seeds play the role of a mobile element in the gene pool and influence the adaptation of pine trees during its settlement to the south and north, which is confirmed by other studies [60].

Other researchers found that dark seeds germinate better than light ones [61–63], while others found no difference [64]. Baldwin [61] classified pine seeds (*Pinus sylvestris* L.) into four colour classes: light, brown, dark and variegated. A possible reason for the different colour of pine seeds used in forestry may be that they are subjected to abrasion during industrial extraction, the worn seeds are paler [65]. However, Steven et al. [62] noticed that pine seeds have a naturally variable colour. They estimated the percentage of different colour classes in all major local forests as 10.2% light, 49.1% brown, 36.7% dark and 4.0% variegated. Since colour variations are widespread, the question of how this affects germination remains important.

Mukassabi et al. did not find a significant relationship between the percentage of dark, full seeds and such characteristics as the length of the cone, the number of seeds per cone, the height of the tree [39]. However, it was found that the mass of dark seeds can be accurately predicted by the mass of random samples from 100 mixed seeds. Moreover, the number of dark seeds can be predicted by the average weight of 100 samples of dark seeds. These ratios are likely to be valid for other seed sources and are of direct practical importance for a rapid method of assessing seed germination. The study also shows that a large proportion of dark, viable seeds can be obtained from young trees.

In Russia, the following practice is legally fixed: in accordance with the order of the Ministry of Natural Resources of the Russian Federation No. 909 of 9 November 2020, zoned seeds harvested within the boundaries of the municipal district should be used for forest reproduction; in their absence, seeds of forest plants—the source of origin of which is located within the territory of the forestry—should be used. Forest-seeded areas are fixed by the order of the Ministry of Natural Resources of the Russian Federation, dated 8 October 2015. All the seeds studied belong to different forest-seed areas; therefore, the justification for the use of Tambov seed material in the Leningrad region will require the creation of geographical crops and further research.

In the context of climate change, the tendency to move forest seeds from south to north and the revision of the concept of functional zoning [66] may be necessary in the future. In 2022, it is planned to lay field experiments with Lisino's seeds and take into account seedlings from the provenances of Komi and Tambov based on the results of wintering under snow.

In future studies, it is planned to take into account the colour of the coating as an influence parameter when stored in containers, in a controlled substrate.

5. Conclusions

1. The composition of seeds in seedling sites from all sources by the colour of the seed coat according to P-P and Q-Q analysis is better described by the normal distribution, with a predominance of seeds with a brown colour of the seed coat. At the same time, the pine form with a predominance of black seeds is common for seeds in the northern regions taken within the framework of this study, and a form with a predominance of brown seeds is characteristic closer to the south.
2. Determination of germination energy and germination of Scots pine seeds by the colour of the covering scales seed colour according to the studied origins allows you to reduce the number of seeds of poor quality when sorting seeds. Thus, with mechanized seeding, you should reduce the consumption of seed material per one cell of the cassette, which allows you to optimize further care for seedlings and remove the operation of harvesting excess seedlings in manual mode.
3. Seed germination in laboratory conditions is higher in seeds with a dark colour of the seed coat.
4. Germination of seeds in containers within the framework of this study is higher for seeds from the southern provenance.

5. The determination of the colour of seeds with increased germination energy and germination at the level of the region of their collection allows us to further identify areas of plantings where seeds with colouring will prevail in pinecones.
6. Taking into account the colour of seeds during forest-seed zoning at the level of the normative legal framework in the field of reforestation, it will allow for the regulation of the growing of seedlings with a closed root system, taking into account the origin and colour of seeds, thereby avoiding unnecessary costs for the use of non-conditioned seed material.

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Data Availability Statement: *Pinus sylvestris* L. seeds were used in this study. The cones were collected in the following provenances: the natural forest stand of Lisinsky educational-and-experimental forestry farm (30.70590° E 59.43476° N, 65 m a.s.l., Leningrad region, Lisino-Korpus, Russia) in the fall of 2017; the Sosnogorsk natural forest stand, (53.72314° E 63.51939° N, 118 m a.s.l. Komi Republic, Russia) in the fall of 2019; and the Parlinskiy production area (41.96639° E 53.56359° N, 119 m a.s.l. Morshanskiy Leskhoz, Tambov region, Russia) in the fall of 2019.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Below are the Tables A1–A26 for two planting rotations with the results of counting seedlings and hypocotyls. The number means the number of seedlings. The number with "h" means the number of hypocotyls.

The distributions for each sample by colour and fraction are displayed below in Figures A2–A4 and the legend for figures is described in Figure A1. On the left is the smallest fraction (1 mm), on the right the largest is 2.4/20 mm.

Table A1. First planting rotation—Tambov—Container 1—29 May 2021.

№/№	1	2	3	4	5	6	7	8	9
1	1	1	1 h	0	0	0	0	0	0
2	0	2	1	1 h	1 h	2	2	1	1
3	0	1 h	2 h	0	2	1	1 h	1	1 h
4	0	0	1 h	1	1	1	1 + 1 h	2 h	1 h
5	0	1	1 + 1 h	1 h	2	1 + 2 h	0	1	0
6	1 h	1	0	0	0	1 h	1 h	1	1
7	2	2 h	2	2	1 h	2	0	1	1 h
8	0	1	0	0	1	0	1 h	0	2
9	2	1 h	2	1	1 + 1 h	0	1	1 h	0

Table A2. First planting rotation—Tambov—Container 1—6 June 2021.

№/№	1	2	3	4	5	6	7	8	9
1	1	1	2	0	1	0	2	1	0
2	1 h	1	2	1	1	1	2	1	1
3	0	2	2	0	2	1 + 1 h	1	1	2
4	0	0	0	1	1	1	1	2	1
5	0	1	1	1	1	0	1	1	0
6	1	1	0	0	0	2	1 h	1	0
7	2	2	2	2	1	2	0	1	1
8	0	0	0	0	1	0	1 h	0	2
9	2	1 h	0	1	2	2	2	0	0

Table A3. First planting rotation—Tambov—Container 1—14 July 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	1	2	0	2	0	2	2	1
2	0	0	1	1	1	1	2	1	1
3	0	1	0	0	1	1	1	0	1
4	0	0	0	1	0	1	1	1	0
5	0	0	0	1	1	0	1	1	0
6	1	1	0	0	0	0	0	0	0
7	2	1	1	1	1	2	0	1	1
8	0	0	0	0	1	0	0	0	1
9	2	0	0	0	2	0	2	0	0

Table A4. First planting rotation—Tambov—Container 2—29 May 2021.

№/№	1	2	3	4	5	6	7	8	9
1	1	0	0	0	0	1	2 h	0	0
2	0	0	0	0	0	0	2 h	1	0
3	2	0	0	0	2 h	1 h	2	2	1 + 1 h
4	0	0	0	0	0	0	0	1 + 1 h	2
5	0	0	0	0	0	0	0	0	1
6	1	1	0	1 + 1 h	1 + 1 h	2	1	0	0
7	0	0	0	0	1	2	2	1 + 1 h	1 + 1 h
8	2	1	1	1 h	1 h	1 h	0	0	0
9	0	0	0	0	0	0	0	0	1 + 1 h

Table A5. First planting rotation—Tambov—Container 2—6 June 2021.

№/№	1	2	3	4	5	6	7	8	9
1	1	0	0	0	1	1	2	1 h	1
2	0	0	0	0	0	0	1	1	1
3	1	0	0	0	2 h	0	2	2	1
4	0	0	0	0	0	0	0	1	1 + 1h
5	0	0	0	0	1	0	0	0	2
6	1	0	0	1	2	2	1	0	0
7	0	0	1	0	0	2	2	1	2
8	2	2	0	1	0	2	0	0	0
9	0	0	0	1	0	1	0	0	2

Table A6. First planting rotation—Tambov—Container 2—14 July 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	0	1	0	1	0	0
2	0	0	0	0	0	0	1	0	1
3	2	0	0	0	0	0	2	1	1
4	0	0	0	0	0	0	0	0	1
5	0	0	0	0	0	1	0	0	2
6	1	0	0	1	1	1	1	0	1
7	0	0	1	0	0	2	2	0	2
8	2	2	0	1	0	2	0	0	0
9	0	0	0	1	0	0	0	0	1

Table A7. First planting rotation—Tambov—Container 3—29 May 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	2	0	2	2 + 1 h	0	1	1	0
2	1	1	2	0	2	0	1 h	2	0
3	1	1	1	2	1 h	1	0	1 h	1
4	0	1	0	0	1	1	1 h	0	0
5	1	1	0	1	0	2	1	0	1 h
6	0	1	0	1 h	0	0	1	1 h	0
7	0	0	1 h	0	1 h	0	2	0	0
8	2	0	1 h	0	0	1 h	1	0	1
9	0	1 + 1 h	0	0	0	0	2 h	1 h	0

Table A8. First planting rotation—Tambov—Container 3—6 June 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	2	0	2	1 + 1 h	0	1	1	0
2	0	1	1	0	2	0	0	1	0
3	1	1	1	1	0	1	0	1	1 h
4	0	1	0	0	1	1	1 h	0	0
5	1	1	0	1	0	2	1	0	1
6	0	1	0	0	0	0	1	1 h	0
7	0	0	1	1	1	0	2	0	1
8	2	0	0	0	0	0	1	0	1
9	0	1 + 1 h	0	1	0	1	1 h	0	1

Table A9. First planting rotation—Tambov—Container 3—14 July 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	1 + 1 h	0	2	0	0	1	2	0
2	0	1	1	0	2	0	0	1	0
3	1	1	1	1	0	1	0	0	0
4	0	1	0	0	1	1	0	0	0
5	1	0	0	1	0	1	1	0	0
6	0	0	0	0	0	0	1	0	0
7	0	0	1	1	1	0	2	0	1
8	2	0	0	0	0	0	1	0	1
9	0	1	0	0	0	0	1	1	0

Table A10. First planting rotation—Komi—Container 1—29 May 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	1 h	2 h	2	1 h	0	0	2 h
2	1 h	0	0	1 h	1	0	3	1 h	0
3	0	1 h	0	2 h	0	1 h	1 h	1	0
4	0	0	0	0	2	2	1	2	0
5	0	0	0	0	2	2	1	0	0
6	0	0	2	2 h	1	2	1 h	1 h	0
7	0	1 h	1	1 h	1 h	1	1	1 h	1 h
8	0	0	1 + 1 h	1	1	0	2	2	0
9	0	0	0	2 h	1 h	0	1 + 1 h	2	0

Table A11. First planting rotation—Komi—Container 1—6 June 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	1 + 1 h
2	0	0	0	0	1	0	1	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	0	2	1	1
5	0	0	0	0	1 h	1	0	1	0
6	0	1	1	0	1	0	0	1	1
7	0	0	1	0	0	2	1	1	1
8	0	0	1	0	1	0	2	2	2
9	0	0	0	0	0	0	0	0	0

Table A12. First planting rotation—Komi—Container 1—14 July 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	1
2	0	0	0	0	1	1	1	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	1	0	1	1	1
5	0	0	0	0	0	1	0	1	0
6	0	1	1	0	1	0	0	1	1
7	0	0	1	0	0	2	1	1	0
8	0	0	1	0	1	0	2	0	0
9	0	0	0	0	0	0	0	0	0

Table A13. First planting rotation—Komi—Container 2—29 May 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	1 + 1 h	2 h	0	0	1 h	0
2	1 h	0	1 h	2	1 h	0	0	0	1 h
3	0	1 h	2	1	1 h	2	2	0	0
4	0	0	1	1 h	1 h	1 h	1	0	0
5	0	3	0	2	1 + 1 h	0	1 h	2	0
6	0	2 h	1 h	1	0	2	2	1 h	1 h
7	0	1 h	1 h	0	1 + 1 h	2	1	2	0
8	0	0	1	0	2 h	1 h	0	0	2
9	0	0	0	0	0	0	2 h	1 h	1 + 1 h

Table A14. First planting rotation—Komi—Container 2—6 June 2021.

№/№	1	2	3	4	5	6	7	8	9
1	1 h	0	0	2	2	0	0	0	0
2	1	0	1	2	1	0	0	0	0
3	0	0	2	0	1 h	2	2	0	0
4	0	0	1	0	0	0	1	0	0
5	0	0	0	0	2	0	0	1	0
6	0	0	0	1	0	1	2	1	0
7	0	0	0	0	0	0	1	2	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1

Table A15. First planting rotation—Komi—Container 2—14 July 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	1	2	0	0	0	0	0
3	0	0	2	0	1	2	2	0	0
4	0	0	1	0	0	0	1	0	0
5	0	0	0	2	0	0	0	1	0
6	0	0	0	1	0	1	1	0	0
7	0	0	0	0	0	0	2	2	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

Table A16. First planting rotation—Komi—Container 3—29 May 2021.

№/№	1	2	3	4	5	6	7	8	9
1	1 h	0	0	0	0	0	1	0	0
2	0	0	0	0	1 + 1 h	0	1 h	0	2 h
3	0	0	0	0	0	2	2	0	1 h
4	0	0	0	0	0	1 h	1 h	1 + 1 h	0
5	0	0	0	0	0	0	1	1	2 h
6	0	0	0	0	0	0	0	1 + 1 h	0
7	0	0	0	1	0	1	1 h	1	0
8	0	0	0	0	1 h	0	2	0	2 h
9	0	0	1 h	0	2 h	0	0	0	0

Table A17. First planting rotation—Komi—Container 3—6 June 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	1	0	0
2	0	0	0	0	1	0	1	0	1
3	0	0	0	0	0	1	1	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	1	0
6	0	0	0	0	0	1	0	1	1
7	0	0	0	0	0	1	1	1	0
8	0	0	0	0	0	0	1	0	1
9	0	0	0	0	0	0	0	0	1

Table A18. First planting rotation—Komi—Container 3—14 July 2021.

№/№	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	1
3	0	0	0	0	0	1	1	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	1	0
6	0	0	0	0	0	1	0	1	1
7	0	0	0	0	0	1	1	1	0
8	0	0	0	0	1	0	1	0	1
9	0	0	0	0	0	0	0	0	0

Table A19. Second planting rotation—Komi—Container 1—14 July 2021.

№/№	1	2	3	4	5	6	7
1	1	3	2	1	3	0	0
2	0	1	0	2	1	1	3
3	0	0	2	0	1	1	2
4	2	2	2	4	1	2	0
5	2	0	0	0	0	0	0
6	1	3	1	0	0	4	0
7	0	2	0	2	4	1	0
8	0	1	1	1	2	1	0
9	3	0	1	1	0	0	0
10	2	2	0	0	0	2	1
11	0	0	0	1	1	0	0
12	1	1	1	1	0	0	1

Table A20. Second planting rotation—Komi—Container 1—18 September 2021.

№/№	1	2	3	4	5	6	7
1	0	3	1	1	3	0	0
2	0	1	0	1	1	1	0
3	0	0	2	0	1	1	0
4	2	2	2	4	1	2	0
5	2	0	0	0	0	0	0
6	1	3	1	0	0	4	0
7	0	2	0	0	4	1	0
8	0	0	0	1	1	1	0
9	3	0	1	0	0	0	0
10	2	2	0	0	0	2	1
11	0	0	0	1	1	0	0
12	1	1	1	0	0	0	1

Table A21. Second planting rotation—Komi—Container 2—14 July 2021.

№/№	1	2	3	4	5	6	7
1	3	1	0	0	1	4	1 + 1 h
2	0	1	1	1	4	0	1
3	0	1	3	0	1	0	4
4	1	1	0	1	0	3	0
5	2	3	0	2	0	0	0
6	2	1	0	1	1	0	0
7	0	0	0	0	0	0	1
8	0	1	3	3	3	0	0
9	0	0	0	0	2	2	1
10	1	0	1	0	1	0	2
11	2	1	2	0	0	0	1
12	1	1	1	2	0	0	2

Table A22. Second planting rotation—Komi—Container 2—18 September 2021.

№/№	1	2	3	4	5	6	7
1	0	0	0	0	0	4	1
2	0	1	1	0	3	0	2
3	0	1	0	3	0	0	3
4	1	1	0	0	0	1	0
5	2	1	1	0	0	0	0
6	1	1	0	1	1	0	0
7	0	0	0	0	0	0	0
8	0	1	3	3	3	0	0
9	0	0	0	0	2	2	0
10	0	0	1	0	0	1	2
11	2	0	2	0	0	0	1
12	1	0	1	2	0	0	1

Table A23. Second planting rotation—Tambov—Container 1—14 July 2021.

№/№	1	2	3	4	5	6	7
1	1 h	3	3	1	1	1	0
2	2	2	0	0	1	1	3
3	0	2	1	0	0	3	0
4	1	1	0	0	0	0	1
5	4	1	1	1	1	1	0
6	3	0	0	0	1	1	0
7	2	1	0	0	0	3	2
8	1	2	1 h	1	0	0	0
9	1	2	2	0	2	1	0
10	4	1	1	1 h	0	0	2
11	1 + 1 h	0	1	0	1	1 + 1 h	2
12	1	0	1	0	0	2	2

Table A24. Second planting rotation—Tambov—Container 1—18 September 2021.

№/№	1	2	3	4	5	6	7
1	0	3	3	1	1	0	0
2	1	2	0	0	1	1	3
3	0	2	1	0	0	3	0
4	1	1	0	0	0	0	1
5	4	1	1	1	1	1	0
6	3	0	0	0	1	1	0
7	2	1	0	0	0	3	2
8	1	2	0	0	0	0	0
9	0	0	3	0	2	0	0
10	2	1	1	1	0	0	2
11	0	0	1	0	1	0	1
12	0	0	1	0	0	2	1

Table A25. Second planting rotation—Tambov—Container 2—14 July 2021.

№/№	1	2	3	4	5	6	7
1	4	3	3	0	0	0	0
2	2	2 h	0	5	0	1	0
3	3	3	0	0	2	2	0
4	0	1	2	3	3	2	1
5	0	0	0	2	2	1	3
6	0	0	0	0	0	1	2
7	0	0	0	0	3	1	0

Table A26. Second planting rotation—Tambov—Container 2—18 September 2021.

№/№	1	2	3	4	5	6	7
1	5	3	3	0	0	0	0
2	1	0	0	5	1	0	0
3	2	2	0	0	2	2	0
4	0	1	2	3	3	1	1
5	0	0	0	2	2	0	2
6	0	0	0	1	0	1	1
7	0	0	0	0	4	1	0

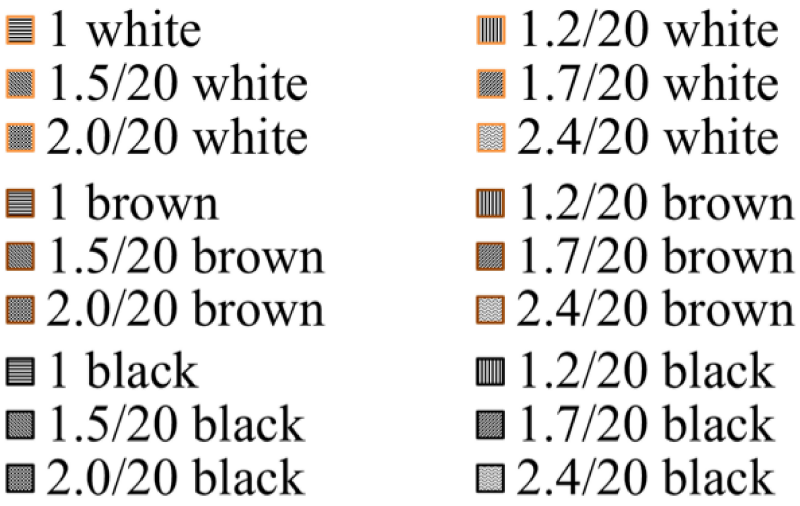
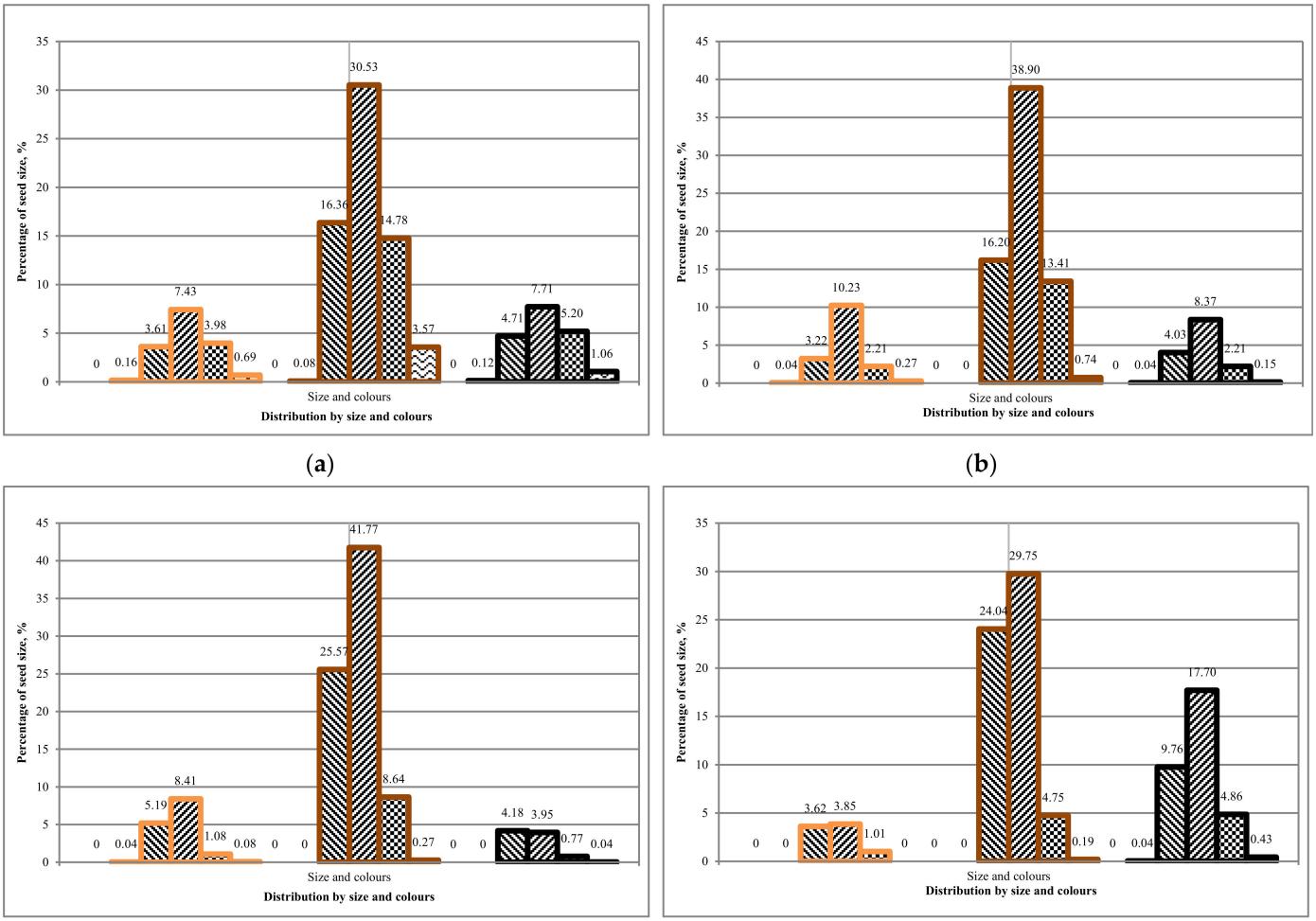


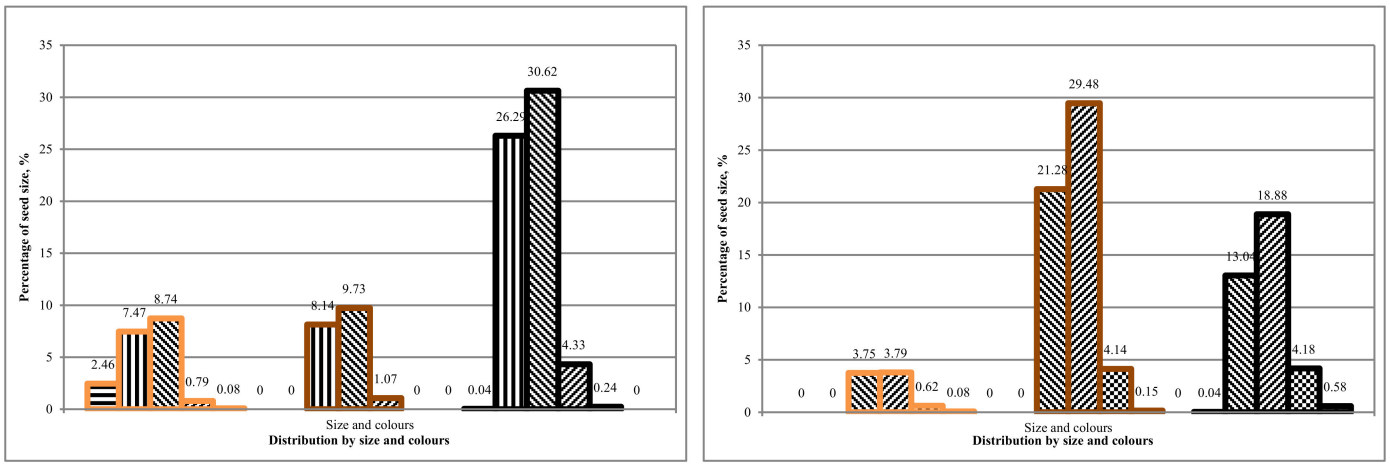
Figure A1. Legend for Figures A2–A4.



(**a**) (**b**)

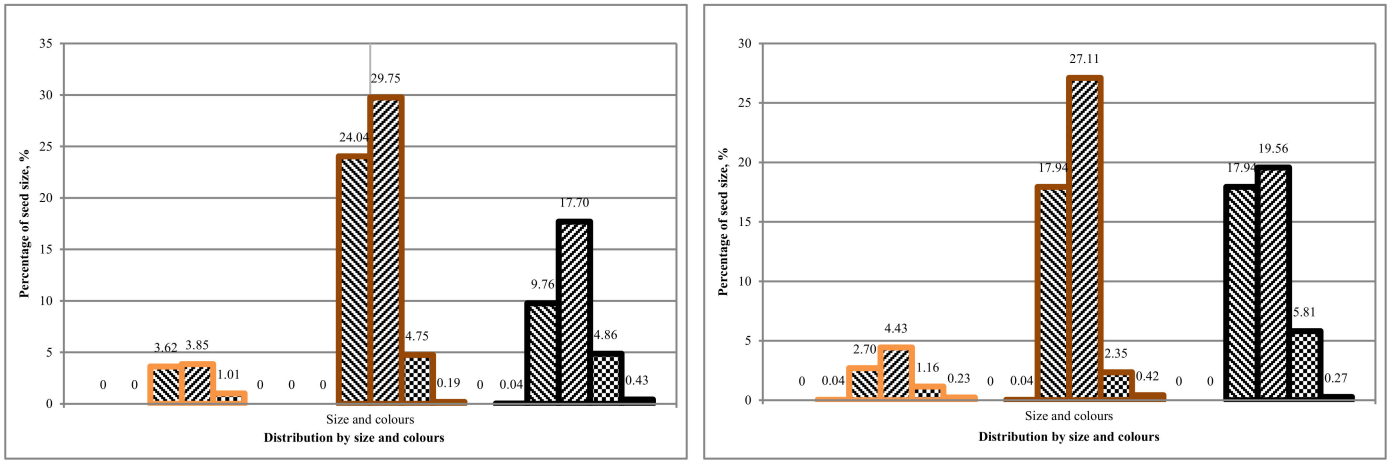
(**c**) (**d**)

Figure A2. Distribution of seeds of the Tambov batch by fractions and colours: (**a**) sample 1; (**b**) sample 2; (**c**) sample 3; (**d**) sample 4.



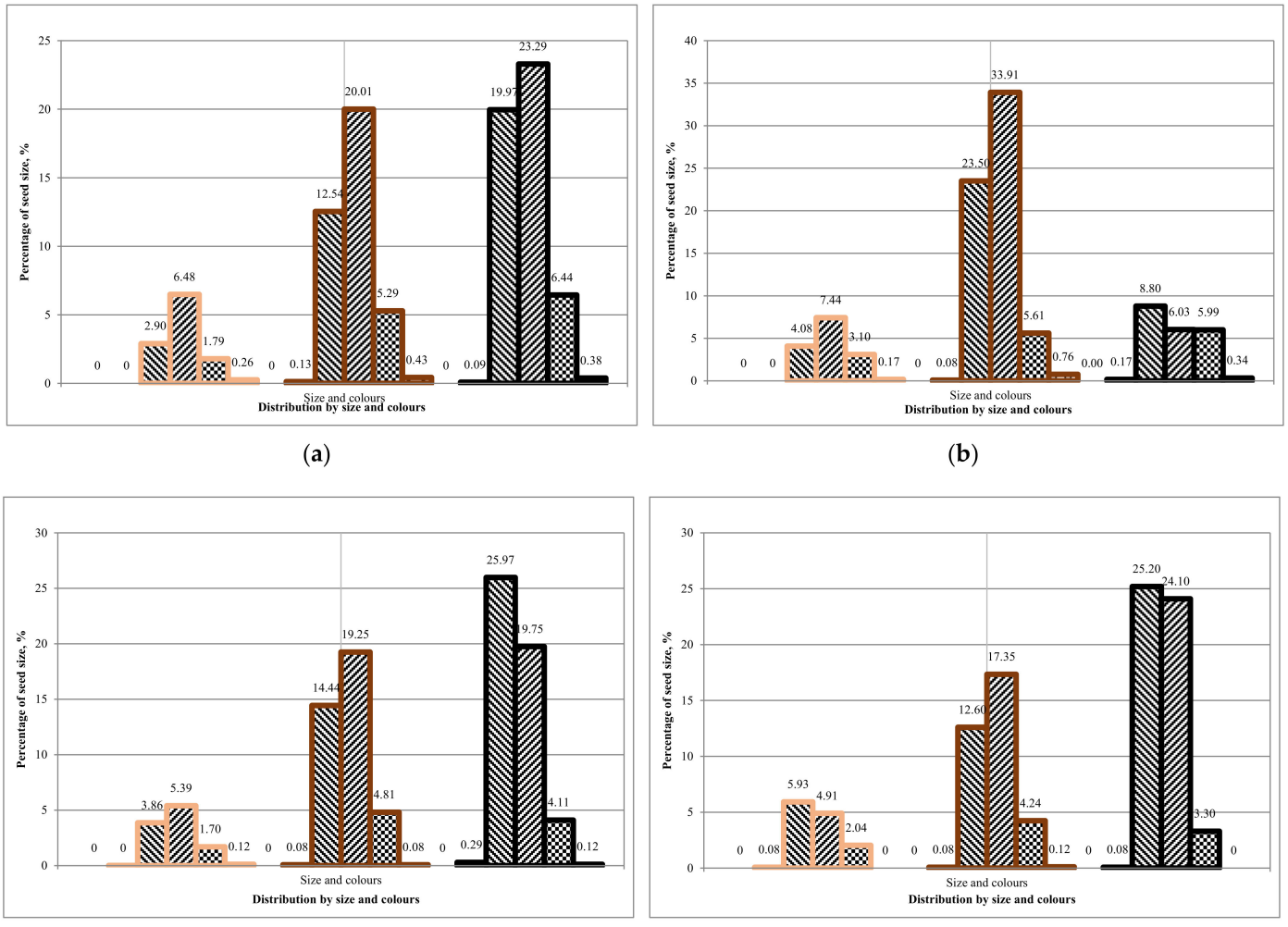
(**a**) (**b**)

Figure A3. *Cont.*



(**c**) (**d**)

Figure A3. Distribution of seeds of the Lisino batch by fractions and colours: (**a**) sample 1; (**b**) sample 2; (**c**) sample 3; (**d**) sample 4.



(**a**) (**b**)

(**c**) (**d**)

Figure A4. Distribution of seeds of the Komi batch by fractions and colours: (**a**) sample 1; (**b**) sample 2; (**c**) sample 3; (**d**) sample 4.

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