Response of stressed seeds of grain crops to changing conditions and duration of their storage

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Abstract. The article investigates the dynamics of the formation of an adaptive response in stressed seeds of spring wheat and barley, depending on the duration and storage conditions. Species differences in seeds on the impact of stress factors of abiotic and biotic nature were studied according to the criteria - morphological characteristics of seedlings, speed, germination energy and laboratory germination of seeds. The leading role of air exchange in blocking the development of stress reactions in seeds has been established. The effect of volatile secretions of saprophytic mold fungi and hyperthermia on the morphometric parameters of initial growth processes in seedlings is shown.

1 Introduction

The study of the properties of plant seeds, as a self-regulating biological system endowed with a reproductive ability, is not only theoretical, but also of no less important practical importance. This is evidenced by the overwhelming majority of experimental works related to the development of innovative agricultural technologies in various sectors of crop production and the improvement of methods for improving the sowing qualities of seeds during harvesting and in the post-harvest period [1-3]. Meanwhile, to date, there are a number of unresolved problems in crop production and seed science of grain crops, which include imperfect technology for harvesting and storing seeds. In the first case, this is mechanized harvesting, accompanied by inevitable macro- and microtrauma of grains, especially under adverse weather conditions and violation of technical regulations for harvesting [4-6]. During the subsequent cleaning, sorting and drying of the grain mass, the number of damage to the seeds increases. To violations of the integrity of the grains react with protective and adaptive reactions, a state of stress is formed in them. The functional activity of seeds decreases, the resources of reliability and stability are depleted, growth weakens, sowing qualities deteriorate sharply [7-9].

In this regard, the use of a phenomenon little known in the scientific literature, which consists in the ability of stressed air-dry and germinating seeds to remotely induce physiological modifications in intact (intact, intact), can be a significant scientific and

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practical contribution that forms the basis for improving the technologies for post-harvest storage of seeds [10].

Based on the foregoing, the purpose of this study was to study the adaptive response of seeds of two types of grain crops to the impact of stress factors of abiotic and biotic nature, depending on the conditions and duration of their storage. The task of the study included experimental substantiation, changes in the morphometric parameters of seedlings, speed, germination energy and laboratory germination in stressed seeds under various modes of post-harvest storage.

2 Materials and methods

Experiments were carried out with two types of seeds of grain crops - soft spring wheat (Triticumaestivum L.) variety Daria, barley (Nordeumdistichum) variety Vladimir. Seeds for sowing qualities met the requirements of GOST R52325-2005, the duration of their storage in the experiment was 24 months. Before storage, the seeds were exposed to abiotic and biotic stress factors. In the first case, the state of stress in air-dry caryopses was generated by shock mechanical effects, as a result of which scratches, cracks, dents appeared in 35-50% of caryopses, i.e. simulated a typical state of seed damage during combine harvesting of grain crops. The influence of the second abiotic stress factor was provided by hyperthermic exposure of seeds to air at temperatures up to 60-70°C for 1-2 hours.

Volatile secretions of saprophytic mold fungi (Penicillium, Aspergillus) were used as a damaging factor of biotic nature, in the gaseous environment of which the seeds were exposed for up to 10 days before storage. Seeds under stress were divided into two parts with their subsequent placement in bags of woven material and containers (metal weighing bottles), where, respectively, air exchange and its absence (hypoxia) are ensured. The subsequent storage of seeds with a moisture content of 13-14% was carried out in laboratory conditions at a temperature of +16 to +20°C and in granaries at a temperature ranging from negative to positive values.

Seeds that were not exposed to stress factors (intact, intact, without damage) were the control. The mass of samples of intact and damaged seeds was 500-1000 grams. The response of seeds under stress was evaluated in dynamics according to the following criteria: speed, germination energy, laboratory germination, morphological traits of seedlings, including the length and weight of primary roots, length and weight of sprouts. Experiments on seed germination were carried out in four repetitions, using 100 seeds in each repetition. Laboratory seed germination was determined according to GOST 12038-84, growth force according to GOST 10340-84.

Statistical processing of experimental data was performed using the Statistica 6.0 software package. The significance of differences in the studied parameters was assessed by Student's t-test. Differences were considered statistically significant at $P<0.05$. Results are presented as mean and standard error of the mean.

3 Results

The results of the studies show that the chronic state of stress in air-dry seeds of spring wheat, induced by damaging effects of various nature, was accompanied by a dynamic increase in the inhibition of morphometric parameters of seedlings and their weight, already after 6 months of storage (Table 1). The strongest inhibition of seedling growth was caused by the exposure of seeds to volatile secretions of mold fungi. Thus, at 12-month storage of seeds, the length of the sprout and the largest primary root, in this variant, compared to the control level, was 19% and 31%, respectively, while in the variants with mechanical injury and hyperthermia, these indicators compared to the control were 57% and 72%, respectively; 53% and 75%. The linear parameters of the sprout were suppressed more strongly in comparison with the primary root, while their number in all experimental variants differed slightly from the control.

Table 1. Response of Stressed Spring Wheat Seeds to Abiotic and Biotic Stress Factors (Laboratory Storage).

Stress factor	Seed storage time, months	Morphometric parameters of three-day-old seedlings			Weight of air-dry seedlings, g/100 pcs	
		Root length, mm	The length of the largest primary spine, mm	Number of primary roots, pcs.	Sprouts	Roots
Control	1	15.9±1.4	22.3±1.5	3.34	0.68±0.07	0.71±0.07
	6	20.1±2.3	30.8±2.4	3.39	0.71±0.08	0.69±0.05
	12	17.6±2.1	25.4±1.3	3.40	0.70±0.06	0.73±0.07
Mechanical injury	1	$\frac{18.4}{116}$±1.2*	$\frac{23.6}{106}$±1.5	3.41	$\frac{0.79}{104}$±0.09	$\frac{0.75}{106}$±0.08
	6	$\frac{15.67}{78}$±1.5*	$\frac{28.9}{94}$±1.1	3.32	$\frac{0.59}{83}$±006*	$\frac{0.64}{93}$±0.04
	12	$\frac{10.1}{57}$±1.4*	$\frac{18.4}{72}$±1.2*	3.35	$\frac{0.50}{71}$±0.04*	$\frac{0.58}{79}$±0.05*
An increase in temperature (hyperthermia)	1	$\frac{17.8}{112}$±1.1*	$\frac{23.8}{107}$±0.09	3.39	$\frac{0.70}{103}$±0.08	$\frac{0.74}{104}$±0.09
	6	$\frac{11.5}{67}$±1.3*	$\frac{19.3}{84}$±1.1*	3.37	$\frac{0.61}{86}$±0.04*	$\frac{0.68}{95}$±0.06
	12	$\frac{9.3}{53}$±1.5*	$\frac{19.1}{75}$±1.8*	3.34	$\frac{0.47}{67}$±0.05*	$\frac{0.51}{70}$±0.07*
Volatile secretions of fungi	1	$\frac{17.3}{108.8}$±1.1*	$\frac{24}{105.4}$±1.7	3.40	$\frac{0.74}{108.9}$±0.08*	$\frac{0.77}{105.4}$±0.06
	6	$\frac{8.7}{43}$±1.5*	$\frac{18.2}{59}$±1.4*	3.35	$\frac{0.41}{58}$±0.07*	$\frac{0.52}{75}$±0.07*
	12	$\frac{3.4}{19}$±0.6*	$\frac{7.6}{31}$±1.0*	3.33	$\frac{0.28}{41}$±0.03*	$\frac{0.32}{45}$±0.04*

*differences with control are statistically significant at P<0.5; numerator - absolute indicator; denominator - percentage of control.

Inhibition of the growth of the sprout and primary root in stressed seeds caused a decrease in their weight. The lowest value of these indicators was in the variant with volatile secretions of mold fungi, where the weight of the sprout and root by 12 months of storage, respectively, was 41% and 45% compared to the control, in other experimental variants these indicators were in the range of 67-79%.

However, the adaptive reaction in seedlings of damaged seeds was accompanied not only by growth inhibition, but with a storage period of 1 month, in all experimental variants it manifested itself in the form of stimulation of sprout growth with an excess of control by 8.8-16.0%.

In the practice of growing grain crops, the most typical stress factors that cause a state of stress in seeds during harvesting are mechanical injuries of grains. On stressed seeds of spring wheat and barley, the dynamics of changes in sowing qualities under laboratory storage conditions was traced (Table 2). With an increase in the duration of storage of seeds, significant species differences in stress resistance were noted. Thus, by 6 months of storage, the germination energy of seeds of spring wheat decreased by 15% compared to the control, while in barley this difference was 4%. By 24 months of storage, this indicator for spring wheat seeds was lower than the control by 28%, for barley by 11.5%.

Table 2. Dynamics of sowing qualities and growth force of seeds of grain crops under stress induced by mechanical injuries.

Seed storage time, months	Experience Variant	Germination energy, %	Laboratory germination, %	Strength of Growth	
				Number of sprouts, %	Weight 100pcs/g
6	Control - wheat	90.1±2.2	97.0±1.4	91.3±2.0	5.03
	Stressed - wheat	75.4±2.7*	92.3±3.1	86.0±1.9	$\frac{4.75}{94.4}$
	Control - barley	72.8±1.5	94.7±1.7	89.1±1.6	5.11
	Stressed - barley	68.7±2.1	92.5±1.8	85.8±2.2	$\frac{5.01}{98.0}$
12	Control - wheat	89.3±1.9	95.8±2.4	90.1±1.4	4.68
	Stressed - wheat	63.6±2.2*	83.5±1.8*	74.3±2.3	$\frac{3.61}{77.1}$*
	Control - barley	74.5±1.6	93.4±2.3	87.5±1.8	5.19
	Stressed - barley	70.1±1.1	90.7±1.6	82.0±1.3	$\frac{4.82}{92.8}$
24	Control - wheat	80.3±1.9	92.7±2.0	88.1±2.0	4.12
	Stressed - wheat	63.6±2.2*	76.2±3.3*	58±2.9*	$\frac{0.98}{23.7}$*
	Control - barley	74.5±1.6	92.3±1.5	75.0±1.3*	4.40
	Stressed - barley	70.1±1.1	80.4±1.2*	65±1.9	$\frac{2.75}{62.5}$*

* denominator - percentage of control.

A significant decrease in laboratory germination in spring wheat seeds was observed by 12 months of storage, where the differences with the control reached 10%, in barley seeds only 4%. The laboratory germination of stressed barley seeds significantly decreased only after 24 months of storage and was lower than the control by 8%, in seeds of spring wheat, respectively, by 16%.

That is, wheat seeds in terms of germination by 12 months of storage did not meet the requirements of the standard for sowing quality, while in barley seeds this indicator fell below the standard by 24 months. The deterioration of the sowing qualities of seeds caused a significant decrease in the growth rate of spring wheat and barley, most pronounced in the former. After 24 months of storage, the number of sprouts in stressed seeds was 30% less than the control, and their weight was 23.7% of the control.

On seeds of two species with an initial germination rate of 95%, an analysis was made of changes in the intensity of initial growth processes and sowing qualities of seeds subjected to hyperthermic exposure in (table 3). Storage of stressed spring wheat seeds in fabric bags (air-permeable) was accompanied by a pronounced decrease in the speed, germination energy and laboratory germination compared to storage in air- and light-tight containers by 25%, respectively; 17% and 10%.

Table 3. Influence of storage conditions and temperature conditions on the intensity of initial growth processes and sowing qualities of stressed seeds (12 months storage in a granary).

Seeds	Seed storage conditions	Temperature regime (+ positive + - variable)	Seed germination rate, %			Germination energy, %	Laboratory germination, %
			1st day	2nd day	3rd day		
Spring wheat	Fabric bags	+	11.4±1.3*	35.1±1.2*	72.2±2.4*	56.5±3.4*	82.6±2.4*
		+-	25.6±1.8*	57.9±1.7*	79.6±2.2	64.3±2.3*	87.5±1.7
	Container	+	38.4±1.8*	65.2±1.2*	83.2±1.7*	73.8±2.3*	92.9±0.9*
		+-	37.9±2.1*	70.1±2.3*	83.5±1.8	74.1±1.6*	93.0±1.8
Barley	Fabric bags	+	16.0±0.9*	41.2±1.4*	80.3±2.7*	73.2±1.9*	88.6±1.4*
		+-	19.6±1.3*	50.9±1.7*	82.6±0.9	79.4±1.3	90.3±0.9
	Container	+	20.3±1.1*	62.6±2.2*	90.7±1.4*	81.7±2.2*	94.5±1.1*
		+-	28.1±1.3*	59.8±1.8*	91.0±1.0	80.1±2.4	93.7±1.6

*differences that are intraspecifically significant between seeds stored in containers and tissue bags.

A similar dependence on the decrease in these indicators was observed in barley seeds, but in absolute terms, these differences were more than 2 times smaller than in spring wheat, respectively, did not exceed 12%, 6% and 3%. The positive temperature during storage of seeds in fabric bags caused the most severe inhibition compared to the variable temperature regime.

Container storage of stressed seeds for 12 months, regardless of the temperature regime, contributed to the preservation of laboratory germination in seeds of spring wheat and barley, respectively, at the level of 93 and 94%, i.e. sowing qualities of seeds corresponded to the requirements of GOST R52325-2005. The laboratory germination of seeds stored in cloth bags was below standard values.

4 Discussion

The state of stress in air-dry seeds of grain crops is caused by stress factors of both physical and biological nature. Seeds react to the damaging effect with adaptive reactions, accompanied by inhibition of seed germination, linear parameters of the sprout, primary roots, a decrease in germination energy and laboratory seed germination. In stressed seeds, complex metabolic processes occur associated with the inhibition of the most stress-sensitive physiological process - growth and the depletion of reliability resources. The suppression of linear indicators in seedlings indicates an imbalance between phytohormones that inhibit and stimulate growth processes.

Limitation of air exchange in stressed seeds, due to storage in containers, significantly reduces the inhibition of seedling growth, prolongs the sowing qualities of seeds. A higher degree of resistance of barley seeds to stress compared to spring wheat seeds, with a high degree of probability, is due to the presence of flower scales in barley caryopses, which reduces oxygen access (hypoxia) to the embryo, in contrast to naked spring wheat seeds. Container storage of seeds limits the access of active oxygen to the grain mass, reduces the activity of metabolic processes, stabilizes the initial level of intensity of the initial growth processes, blocks stress reactions, and prolongs the laboratory seed germination at the level of sowing standards.

The strongest inhibition of stressed seeds under the influence of hyperthermia and volatile secretions of mold fungi is associated with their effect on all vital cell structures, including the embryo, while mechanical injuries cause damage not to the entire grain, but only to individual parts.

5 Conclusion

Depending on the conditions and duration of storage of stressed seeds of grain crops, the nature of the response in 3-day-old seedlings was accompanied by a mild stimulation of the growth of sprouts and primary roots, depending on the variant of the experiment (the excess compared to the control was 5.4-16.0%), which was replaced by a sharp increase in the inhibition of these indicators (no more than 50-80% of the control) with an increase in storage time up to 6-12 months.

Container storage of stressed seeds contributes to the protection of seeds from the development of stress reactions. At the same time, in stressed seeds, the speed, germination energy and laboratory germination exceeded these indicators for seeds stored in breathable fabric bags, depending on the variant of the experiment, respectively, by 12-30%; 8-18% and 3-9%.

The isolation of the grain mass from active contact with atmospheric air ensured the prolongation of sowing qualities during 12 months of storage according to the germination criterion for seeds of spring wheat and barley, respectively, 93% and 94%.

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