ISSN: 04532198
Volume 62, Issue 06, July, 2020

Effect of Growth Regulators on Seed Quality and Grain Productivity of Hard Wheat (*Triticum durum*) in Non-Irrigated Conditions

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Abstract—The paper presents the results of the research examining the effect of seed treatment with plant growth regulators and seeding rates on the productivity of hard winter wheat varieties. The research was conducted during 2016-2019 in the southern black soil. The research scheme included the following factors and their variants: the varieties Dnipriana, Kassiopeia and Kreiser; the seed treatment with a plant growth regulator – without using it (water seed treatment), Kvadrostym and Nertus PlantaPeh; the seeding rate – 3, 4, 5 and 6 million seeds per hectare. The experimental data were processed by the standard ANOVA procedure within MS Excel software. In order to obtain the grain yield of hard winter wheat at the level of 4.72–4.86 t/ha with high indexes of growth capacity, laboratory and field germination capacity in non-irrigated conditions of the Southern Steppe of Ukraine it is recommended that the varieties Kassiopeia and Kreiser should be grown with the seeding rate of 5 million seeds per hectare and the seed treatment with the plant growth regulator Kvadrostym at the rate of 0.5 kg/t.

Keywords— plant growth regulator, productivity, quality, seeding rate, Triticum durum, variety

1. Introduction

Hard winter wheat is an important crop in the world and in Europe in particular [12], [22], [28], [30], [32], [34]. Hard wheat, or English wheat (*Triticum durum* or *Triticum turgidum* subsp. *durum*), is known for its special grain hardness, high protein content, intense yellow color, pleasant smell and also good bread-making properties. That makes it suitable for producing manna groats, alimentary paste and less suitable for flour. Hard wheat contains 27% of wet gluten that is 3% higher than that of common wheat (*Triticum aestivum L.*). Examination of genetic derivatives of basic quality indexes allows scientists to investigate the potential for further improvement of new varieties [2], [15], [18], [19], [31]. In Ukraine soft winter wheat (*Triticum aestivum L.*) is a traditional grain crop. The gross grain yield is a criterion for evaluation of the efficiency of its cultivation. In spite of unfavorable weather conditions for some years, the areas under this crop increase annually. For instance, in Ukraine this crop occupied 6.45 million hectares for the yield of 2019 that is 2.8% higher than the analogous index of the previous year [1]. Winter wheat may be re-sown up to 3 million hectares (in 2003 – more than 5 million hectares) because of unfavorable climate conditions and the crop damage. The rest of the area produces the yield of 3.0-3.5 t/ha. It is sufficient to grow soft winter wheat in the area of 5-6 million hectares for the domestic demand. The rest of the area occupied by this crop should be used for sowing other crops including hard wheat. The advantages of hard wheat in comparison to soft wheat are the following characteristics: it does not shed much grain, it is more resistant to diseases and pests and more lodging resistant. When grown on fertile soils with appropriate agro-technical measures it produces high and steady yields. However, it produces lower yields on the lands with medium fertility. This factor is one of the main reasons that make *Triticum durum* unpopular in Ukraine, and, as a result, alimentary paste is mostly made of soft wheat flour and imported hard wheat. All over the world the areas under hard wheat has increased over the past years and they make 18 million hectares being about 7% of the world total wheat sown areas. The main producers of hard wheat are the EU countries, making 28-36% of the world hard winter production, Italy being the largest producer – 4.0 million tons. The indexes of the gross yield in other countries are as follows: Spain – 1.8, France – 1.5 and Greece – 1.5 million tons. Canada makes 4.4 million tons of the gross production, Turkey – 3.0, Syria – 2.6, the USA – 2.4, Mexico – 1.4, the countries of Northern Africa: Egypt, Libya, Morocco and Tunis – 4.4, and Australia – 0.5 million tons [23].

In Ukraine the gross production of hard wheat varieties is 1.5-2.3 million tons, and the actual total harvested area is within 0.5 million hectares. Taking into account a considerable shortage of hard wheat at the European and world markets, it is necessary to expand the areas under this crop in Ukraine. Much attention should be paid to improving the technologies of growing hard winter wheat by means of innovative scientific research that will contribute to an increase in productivity and higher grain quality. One of the main directions in scientific search is optimization of varietal composition of winter wheat for a particular region and certain growing conditions and optimization of seeding rates affecting the productivity of the plant stand. Productive efficiency of hard wheat varieties is caused by not only achievements in plant breeding, but also agro-technological conditions. The research conducted in the wet Mediterranean conditions showed that the use of pyraclostrobin in the cultivation technology contributed to an increase in the yield not due to the effect of "plant health", but owing to inhibiting leaf diseases (the pathogenic agents *Blumeria graminis f. sp. tritici* та *Zymoseptoria tritici*) that prolonged the photosynthetic period of wheat flag leaves [29]. This method is also appropriate for fight against leaf mildew [33]. An important aspect of insuring high productivity is weeding in the areas under hard wheat. For instance, according to the research data obtained in the semi-arid Mediterranean conditions of Central Greece, the herbicide florasulam + 2,4-D was safe and did not cause any damage when applied individually or in combination with fungicides, while bromoxynil + 2,4-D in the mixture with azoxystrobin or trifloxystrobin + prothiokonazolw caused leaf damage [13]. The topical problem of the modern agricultural production is to develop technologies that contribute to crop productivity and are environment-friendly and safe for human health. Therefore, to study the interaction of these factors in growing hard winter wheat is a topical task, and the solution to this problem will contribute to an increase in the productivity and higher grain quality, and, consequently, to the expansion of the areas under the crop and an increase in the gross yield.

2. Materials and methods

The experiments were conducted at the experimental plots of the farm "Traven" in Kakhovka district of Kherson region. The experimental plots are located at the 46°36′01 Nw. 33°57′26″ Ed., the average height above sea level is 37 m.

The following factors and their variants were included in the research scheme:

- A –wheat durum variety: A1 - Dnipriana; A2 - Kassiopeia; A3 - Kreiser;
- B – the seed treatment with a plant growth regulator: B1 – without a plant growth regulator (water seed treatment); B2 – treatment with the preparation Kvadrostym, a water-soluble concentrate (the reactant: lignogumat of potassium (sodium) – 3.3 g/l, succinic acid – 0.5 g/l, arachidonic acid – 1.44 mg/l, polietilenglicol – 1500-510 g/l, polietilenglicol – 400-260 g/l, drinking water) at the rate of 0.5 kg/t of seeds; B3 – treatment with the prepatation Nertus PlantaPeg, the liquid (the reactant: polietilenglicol – 400 g/l and polietilenglicol – 1500-800 g/l, fulvic acids and salts of humic acids – 4 g/l) at the rate of 0.25 l/t;
- C – the seeding rate: C1 – 3 million seeds/ha, C2 – 4 million seeds/ha, C3 – 5 million seeds/ha, C4 – 6 million seeds/ha.

The research was conducted in the southern black soil with the content of mobile nitrogen – 3.88, mobile phosphorus – 17.0 and exchangeable potassium – 107.0 mg-eq. per 100 g of soil in the 0-30 cm soil layer. The growing technology of wheat durum (*Triticum durum*) was generally accepted for the conditions of Ukraine. Bare fallow was a predecessor of winter wheat. Caring for the predecessor included: the application of mineral fertilizers at the rate of $N_{42}S_{48}$ (ammonium sulphate with 21% of nitrogen content and 24% of sulphur content were used as a nitrogenous fertilizer), tillage at the depth of 25–27 cm was carried out. In spring nitrogen at the rate of N_{30} (ammonium nitrate with 34.4% of nitrogen content as a nitrogenous fertilizer) was applied to frozen melting soil. 2-3 cultivations were carried out prior to sowing depending on the year of the research. Pre-sowing cultivation was carried out at the seed sowing depth of 5-7 cm. The description of the varieties under study: Dnipriana – belongs to short-stem varieties (70.5-80.4 cm), resistant to lodging. Medium-early. The leaves are dark-green, narrow and medium-long. They are covered with wax bloom at the stage of tillering. The variant hordeinforme (the glume and beard are red, and the grain is white). The ear is conical, compact and medium-long (7.5-8.0 cm). The beards are coarse, long (11-13 cm) and serrated. The glume is elongated-oval, with medium nervation. The tooth of the glume is short and acute. The shoulder is sloping; the keel is pronounced. The grain is big, elongated-oval, white and vitreous. Short-stem. The resistance to fungal diseases is complex and high; frost resistance and cold tolerance are high, drought resistant. Grain protein content is 14.5-15.0%, the content of wet gluten is more than 32.8%. Kassiopeia is a variant hordeinforme. The ear is 6-7 cm long. The beards are serrated, of a red color. The caryopsis is white. Medium-early. Short-stem (71-80 cm). It is distinguished by complex resistance to different fungal diseases. Frost resistance, cold tolerance and drought resistance are high. It does not shed grain. The grain-unit is 810 g/l. Gluten content is 40.3%, grain protein content is 14.5%. Kreiser is a variant hordeinforme. The variety of an intense type. Highly productive. It has a large ear with many grains. The ear is bearded, not downy, of a bright red color, dense, cylindrical. The beards are long (11-12 cm), serrated, elastic, of a light-brown color. The glume is elongated. The tooth of the glume is medium; the shoulder is a little elevated. The caryopsis is semi-elongated, of a white color. It belongs to the steppe and forest-steppe eco-group. Medium-early. Medium-tall (105-110 cm), good lodging resistance. Frost resistance and cold tolerance are medium (5-7 points). The variety is distinguished by a medium need for vernalization (23-25 days) and also by medium photoperiod sensitivity. Drought resistance is medium (5-7 points). It is highly resistant to grain shedding and medium-resistant to grain sprouting. It is characterized by a complex resistance to widespread diseases, such as winter wheat leaf blotch and different types of smut, brown stem rust and powdery mildew. It has a medium grain (40.4-45.0 g) with the grain-unit of 785-827 g/l. Gluten content is 28.7-34.0%, protein content is 14.1-16.2%.

Pre-sowing seed treatment was done 1–2 days before sowing by the method of incrustation with 10 l of the solution per ton of seeds. During the crop vegetation period the plants were treated with the herbicide Alfa-Star (the reactant is tribenuron-methyl, 750 g/kg) at the rate of 0.02 kg/ha at the stage of booting against annual and perennial dicotyledonous weeds; with the fungicide of systemic action Unikal (tebuconazole, 500 g/kg) at the rate of 0.5 l/ha against powdery mildew, rust and leaf and ear blotch, ear fusariose; with the insecticides Karate Zeon 050 CS (the reactant is lambda-cygalotrine, 50 g/l) at the rate of 0.15 l/ha and Antikolorad (the reactant is imidakloprid, 150 g/l, lambda-cygalotrine, 50 g/l) at the rate of 0.25 l/ha against the sunn pest, thrips, cereal chafers and leeches. The grain yield of hard winter wheat was calculated by means of harvesting from the total experimental plot. After harvest, the seed yield was converted to basic humidity (14%). The experimental data of wheat durum (*Triticum durum*) were processed by the standard procedure of ANOVA within MS Excel software. The significance of the differences was proved for the reliability level of 95% (LSD_{05}). Growth capacity, germination energy, laboratory and field germination capacity were determined in hard winter wheat grain in the laboratory conditions. There are standards of the time of germination energy accounting for all agricultural crops. Seeds germinating quickly and simultaneously have high germination energy. Seeds with high germination energy sprout simultaneously, and the sprouts are less inhibited by weeds and more resistant to unfavorable conditions. Germination capacity is the most important index of seed quality. It is determined by the number of normal seedlings, emerging in 7 days of germination (for wheat spelt). Seed quality depends on its germination capacity [9], [25]. Germination capacity and germination energy were calculated as the percent of the total number of seeds for germination, as the average of four samples. In order to determine these indexes four samples of 100 seeds were chosen in succession from a pure seed fraction to germinate them in petri dishes between the filter paper. The petri dishes were placed in thermostats with the temperature of 20°C. The seed germination was observed daily during 7 days. The germination capacity was calculated as the percent of the germinated seeds of the total number of the sown seeds. Germination energy was determined after 3 days of germination and laboratory germination capacity was determined after 7 days [9], [25]. The weather conditions in the years of the research (2016-2019) thoroughly reflected the meteorological characteristic of the Southern Steppe of Ukraine that made it possible to obtain reliable experimental data, draw conclusions and offer recommendations for agricultural production in the given conditions (Table 1). During the vegetation period of hard winter wheat in 2016-2017 the air temperature was 10.1ºC that is 0.3ºC higher than the average data for many years in the area of cultivation. It should be mentioned that there was moisture scarcity in that year. The precipitation amount was 246.6 mm that was 153.4 mm less than the indexes for many years (the standard index is 400 mm). That index had an impact on the relative humidity in air being 73.5% for the period under study, the norm being 74.6%. The meteorological indexes of the vegetation period in 2017-2018 were characterized by a hot climate. The average annual air temperature was 12.7ºC being 2.9ºC higher than the indexes for many years. The precipitation amount was extremely low for that period – 129.5 mm (32.4% of the norm) against the background of high temperature. The relative humidity in air was the least for the years of the research – 70.9%. The best time for growth, development and yield formation was the vegetation period of 2018-2019 when the air temperature was 11.5ºC (the norm is 9.8ºC) on average for the year. The precipitation exceeded the indexes for many years 1.8 times being 714.6 mm, the relative humidity in air being 73.5%.

Table 1. Meteorological indexes during the period of *Triticum durum* vegetation in the field experiments (the weather station Askania-Nova in Chaplynka district of Kherson region)

2016			2017			2018			2019			Months
AT, ºC	PA, mm	RH, %	AT, ºC	PA, mm	RH, %	AT, ºC	PA, mm	RH, %	AT, ºC	PA, mm	RH, %	
-	-	-	-3.5	14.4	84	-0.4	17.6	85	0.0	21.2	96	January
-	-	-	0.6	22.0	82	-0.5	17.0	84	0.8	3.0	87	February
-	-	-	6.7	10.2	75	5.8	40.3	82	5.3	6.0	69	March
-	-	-	8.5	81.8	73	12.8	3.6	61	10.3	63.0	64	April
-	-	-	15.9	25.8	62	18.8	14.0	60	17.7	97.6	74	May
-	-	-	22.0	8.0	54	22.4	4.0	54	22.9	213.8	70	June
-	-	-	23.4	7.0	56	24.2	3.6	64	21.6	160.4	70	July
21.5	26	86	25.3	2.4	48	25.0	0.2	44	-	-	-	August
16.1	9.4	68	19.4	0.6	63	18.7	38.4	60	-	-	-	September
7.6	2.2	73	13.6	1.2	77	13.0	20.2	68	-	-	-	October
3.9	27.6	83	5.3	12.8	86	2.7	43.2	86	-	-	-	November
-1.8	12.2	86	5.7	12.4	87	0.5	47.6	94	-	-	-	December

Note: AT - air temperature. PA - precipitation amounts. RH - relative humidity.

3. Results and discussions

Currently the main direction in hard wheat breeding is creating varieties with high adaptiveness to changing conditions of the environment and high indexes of grain quality: the content of protein and gluten, vitreousity, the weight of 1000 seeds, grain-unit [6], [11], [19], [26]. Appropriate selection of varieties allows obtaining higher grain yields, using moisture, nutrients and light efficiently [5], [14]. The formation of optimum leaf surface area allows enhancing grain quality indexes [20]. The effect of abiotic and biotic factors on wheat growth and development is emphasized by many scientists highlighting that it causes a shorter vegetation period, intensifies vegetative development and grain maturation and also increases productivity [7], [10], [16], [17], [21]. The research conducted in 2014-2016 at the Institute of Field crops (Bulgaria) made it possible to determine that the crop productivity increases due to long-term photosynthesis of flag leaves [26]. The scientific research carried out in Poland proved that the yield mainly depends on a genotype and growing conditions. Growing wheat under optimum soil conditions changed the number of leaves, and under unfavorable climate conditions the application of nitrogenous fertilizers affected the number of grains per ear [11]. The results of the three-year research (2016-2019) prove that the varieties of hard winter wheat examined in the research were characterized by sufficiently high productivity (Table 2). For instance, the grain productivity of the variety Kassiopeia was 3.60–4.72 t/ha on average for three years of the research depending on the seeding rate and the seed treatment with a plant growth regulator. The variety Dnipriana (A1) formed the grain productivity lower by 2.6-5.3% depending on the factors under study in comparison to the variety Kassiopeia (A2). The variety Kreiser (A3) had the highest grain productivity – 3.65-4.86 t/ha depending on the seed treatment with a plant growth regulator and the seeding rates that is higher by 0.05-0.14 t/ha than that of the variety Kassiopeia (A2) and higher by 0.23-0.26 t/ha than that of the variety Dnipriana (A1).

Table 2. The grain productivity of hard winter wheat depending on a varietal composition, seeding rates and seed treatment with a plant growth regulator, t/ha (the average for 2017-2019)

Wheat durum variety (A)	Seed treatment with a plant growth regulator (B)	Seeding rate (C)			
		C1	C2	C3	C4
A1	B1	3.42	3.74	3.97	3.62
	B2	3.96	4.31	4.60	4.17
	B3	3.72	4.13	4.41	3.98
A2	B1	3.60	3.78	4.10	3.73
	B2	4.06	4.36	4.72	4.26
	B3	3.94	4.16	4.54	4.12
A3	B1	3.65	3.84	4.19	3.75
	B2	4.18	4.07	4.86	4.31
	B3	4.01	4.27	4.65	4.13
LSD_{05}	A	0.16			
	B	0.19			
	C	0.16			

Table 3. Effect of plant growth regulators on seed quality of hard winter wheat varieties (the average for 2017-2019)

Wheat durum variety (A)	Seed treatment with a plant growth regulator (B)	Growth capacity		Germination energy, %	Laboratory germination capacity, %	Field germination capacity, %
		Length of sprouts, cm	Weight of 100 sprouts, g			
A1	B1	2.6	4.4	82	89	82.4
	B2	3.2	6.1	90	95	89.7
	B3	2.9	5.7	85	93	88.5
A2	B1	3.2	5.9	85	92	85.6
	B2	3.6	6.6	90	95	89.9
	B3	3.4	6.3	88	93	88.6
A3	B1	3.2	6.0	92	93	87.1

	B2	3.8	6.9	95	96	91.4
	B3	3.6	6.7	93	94	90.0
LSD_{05}	A	0.12	0.19	1.20	1.22	1.18
	B	0.12	0.19	1.20	1.22	1.18

The scientists established that it is possible to obtain yields at the level of 3.275-4.900 t/ha under sowing density of 4-6 million seeds per hectare under relatively favorable conditions with long and warm autumn and insufficient moistening of a seedbed. Under unfavorable conditions the maximum level of the crop yield was 0.746-1.157 t/ha at the seeding rate of 5-6 million seeds per hectare [4]. The experimental data prove that the highest grain yield of hard winter wheat varieties was obtained with the seeding rate of 5 million seeds per hectare and made 3.97–4.60 t/ha in the variety Dnipriana (A1), 4.10–4.72 t/ha in the variety Kassiopeia (A2), 4.19–4.86 t/ha in the variety Kreiser (A3) on average for three years depending on the effect of a plant growth regulator. The was a decrease in the yield of the variety Dnipriana (A1) by 0.23–0.29 t/ha, the variety Kassiopeia (A2) – by 0.32–0.38 t/ha and the variety Kreiser (A3) – by 0.35–0.79 t/ha with the seeding rate of 4 million seeds per hectare, and with the seeding rate of 6 million seeds per hectare – by 0.35–0.43, 0.37–0.46 and 0.44–0.55 t/ha respectively. The lowest yield of hard winter wheat was obtained with the seeding rate of 3 million seeds per hectare. The seed treatment with the plant growth regulator Kvadrostym contributed to an increase in the yield of hard winter wheat in comparison to the control sample: by 15.2–15.9% in the variety Dnipriana (A1), by 12.8-15.3% in the variety Kassiopeia (A2) and by 6.0-16.0% in the variety Kreiser (A3), the seed treatment with the plant growth regulator Nertus PlantaPeg (B3) – by 8.8-11.1%, 9.4-10.7%, 9.9-11.2% respectively on average for three years. The effect of the plant growth regulator Kvadrostym was more considerable. Seed quality is affected by the amount of mineral fertilizers, especially nitrogenous fertilizers. The research conducted in Gravina in Apulia (Apulia, southern Italy) proved the efficiency of applying N_{90}, distributed by three main stages of growth and development. It had a considerable effect on the yield and grain protein content [27]. This is proved by the studies of other scientists [3], [24]. An important resource for increasing crop productivity and improving product quality is applying plant growth regulators ensuring the results that cannot be achieved with other agricultural measures. They are capable of not only increasing crop productivity and improving product quality, but also enhancing crop resistance to diseases and stress factors and reducing pesticide application rates. The experimental research allows maintaining that the use of the tank mixture Amalgerol premium + TEC (micro-elements) and the subsequent foliar feeding with Vertex high-H34, High-phos, TEC and the stimulator Amalgerol premium cause more plant resistance to the external environment [8].

The data of our research made it possible to determine that the seed treatment with plant growth regulators had a different effect on the sowing seed quality (Table 3). For instance, the use of plant growth regulators for the seed treatment contributed to an increase of the indexes of growth capacity of hard winter wheat seeds. When Kvadrostym was applied, the length of seedlings increased by 23.1% in the variety Dnipriana (A1), by 12.5% in the variety Kassiopeia (A2), and by 18.8% in the variety Kreiser (A3) in comparison to the control sample, and when the seeds were treated with Nertus PlantaPeg (B3) the length of seedlings increased by 11.5%, 6.3% and 12.5% respectively. The effect of the plant growth regulator Kvadrostym was more considerable. The weight of 100 seedlings increased by 1.7g, 0.7g, 0.9g i 1.3g, 0.4g and 0.7g respectively. The research proves that seed treatment with plant growth regulators has an effect on an increase in germination energy, laboratory and field germination capacity of seeds. For instance, the index of germination energy increased by 3-8 percentage points in the variety Dnipriana (A1), by 3-5 percentage points in the variety Kassiopeia (A2) and by 1-3 percentage points in the variety Kreiser (A3) when plant growth regulators were applied. When the seeds were treated with plant growth regulators, the laboratory germination capacity increased from 89 to 93-95% in the variety Dnipriana (A1), from 92 to 93-95% in the variety Kassiopeia (A2) and from 93 to 94-96% in the variety Kreiser (A3) when compared to the control sample. The plant growth regulator Kvadrostym had a more considerable effect on this index. The field germination capacity of the seeds also increased when plant growth regulators were applied. For instance, the seed treatment with the plant growth regulator Nertus PlantaPeg (B3) increased the field germination capacity by 7.4 relative percent in the variety Dnipriana (A1), by 3.5 relative percent in the variety Kassiopeia (A2) and by 3.3 relative percent in the variety Kreiser (A3), and with the plant growth regulator Kvadrostym – by 8.9, 5.0, 4.9 relative percent respectively in comparison to the control sample (B1).

4. Conclusions

In order to obtain the grain yield of hard winter wheat with high indexes of growth capacity, laboratory and field germination capacity at the level of 4.72–4.86 t/ha in non-irrigated conditions of the Southern Steppe of Ukraine it is recommended that the varieties Kassiopeia and Kreiser should be grown with the seeding rate of 5 million seeds per hectare and the seed treatment with the plant growth regulator Kvadrostym at the rate of 0.5 kg/t.

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