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Specificity of Durum and Soft Winter Wheat Organogenesis Stages, Growth Phases and Development, Productivity and Quality in Forest-Steppe Conditions of the Voronezh Region

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***Abstract*—Two types of winter wheat were studied in forest-steppe conditions of the Voronezh region: durum (grade Donchanka) and soft (grade Bezenchukskaya 380). The purpose of the given study is to introduce the winter durum wheat into the Central Chernozem region. This requires the study of biological features of the corresponding grades for further development of adaptive cultivation technologies in unusual soil climatic conditions. The field and laboratory experiments covered the study of particularities of organogenesis stages, growth phases and development, productivity and quality regarding two wheat species. The differences in plant development were detectable in the forest-steppe conditions of the Central Chernozem region. Unlike the soft wheat, the durum winter wheat moves to the third stage of organogenesis in pre-winter conditions. The active growth and development of the growing-point is observed. At subsequent stages of organogenesis the durum winter wheat also surpasses the soft winter wheat cultivars in development. It speeds through interphases, and its vegetation period is 4 days longer. However, the durum wheat yields 6.32 tons ha-1 less than the soft species, its grain quality is better: 1000-kernel weight is 1.04 g higher, protein content is 1% higher, and gluten content is 1.9 % more. Gluten quality of solid wheat is 10.3 higher.**

Keywords—winter durum wheat, winter soft wheat, stages of organogenesis, increase cone, interphase period, vegetative period, productivity, weight of 1000 grains, protein, gluten, gluten quality.

I. INTRODUCTION

The introduction of winter durum wheat in the forest-steppe of the Central Chernozem region is a long-standing problem that is being solved for over 70 years. However, until now the durum wheat grains have been supplied to the Voronezh region from other regions of the Russian Federation or have been imported from foreign countries thus leading to cost increase for food products made of high-quality durum wheat. Hence, it is advisable to introduce the winter durum wheat, which yield is 1.5-2 times higher compared to the spring durum wheat and similar grains, in the Central Chernozem region. Due to successful development of domestic selection, there are many grades, which, according to their winter hardiness and productivity, are able to compete with winter soft grades and meet the requirements of successful production in the Central Chernozem region. The purpose of the study also includes the analysis of biological features and the development of adaptive cultivation technology of the winter durum wheat in forest-steppe conditions of the Voronezh region (1-6).

II. MATERIALS AND METHODS

The object of the study concerned the species of winter wheat: durum (grade Donchanka) and soft (grade Bezenchukskaya 380).

The field experiments were carried out in 2005-2010 (Experimental Station of Voronezh State Agrarian University, Voronezh region) using the cultivation technology typical for the Central Chernozem region.

The laboratory tests were carried out at the Department of Crop Science, Forage Production and Agricultural Technologies of the Voronezh State Agrarian University according to the corresponding state requirements (7-10).

During the study of the growing-point dynamics, the objects were microscoped and photographed via MBS-10 microscope for 25 plants selected from two non-adjacent repetitions at different stages of organogenesis (11, 12).

III. RESULTS AND DISCUSSION

The most objective way to identify the difference in growth, development and formation of winter durum and soft wheat grains is the method of plant biological control, which includes observations over the development and growth of the growing point (11, 13, 14).

F.M. Kuperman established 12 main stages of plant development within their life cycle (Tab. 1).

TABLE I. PHENOLOGICAL PHASES AND SUBPHASES, STAGES AND PROCESSES OF ORGANOGENESIS, PRODUCTIVITY ELEMENTS OF SPIKED GRAINS (15)

International phenological scale (Zadoxs, etc.)		**Organogenesis according to F.M. Kuperman**		
Phase	**Phase and subphase**	**Stage**	**Lead process**	**Resulting productivity element**
1	*2*	*3*	*4*	*5*
0 – germination	00-09	I	Differentiation and growth of infancy organs	Plant population, pcs/m2
1 – seedling	10 – coleoptile release from soil			
	11 – subphase of the first leaf			
	12-13 – 2-3 subphases of leaves	I-II		
	14-19 – 4-9 subphases of leaves			
2 – tillering	20 – leading shoot developed, lateral stem is in leaf sheath	II	Differentiation of the growing point into germinative nodes, internodes and stem leaves	Plant height (culm), number of leaves
	21-24 – beginning and further development of tillering, main and 1-4 lateral stems are developed			
	25 – main tillering, main and five lateral stems are developed			
	26-29 – final tillering, main and 6-9 (or more) lateral stems are developed	III	Differentiation of ear and bract axes	Number of rachis internodes, ear length
3 – booting	30 – beginning of booting, main and lateral stems are elongated alongside with leaf sheath	IV	Formation of spike buds	Number of buds in a ear
	31 – 1st node appears above soil on the main stem	V	Formation of floral elements	Number of flowers in an ear
	32 – 2nd node appears above soil on the main stem			
	33-36 – 2-6 nodes appear on the main stem	VI	Formation of flowers and ear, gametophytogenesis, growth of nurse organs, elongation of rachis internode	
	37-38 – flag leaves the leaf sheath	VI-VII		
	39 – flag tongue appears	VII		Head density, flower fertility
4 – swelling of the upper leaf sheath	40-44 – beginning of leaf sheath swelling	VII		
	45-46 – imbibed leaf sheath			
	47-48 – leaf sheath breaks			
	49 – ear rachis appears from the leaf sheath			
5 – earing	51-52 – beginning, first ear appears	VIII	Completion of formation of flower heads and flowers	Flower fertility
	53-54 – ¼ of the ear appears			
	55-56 – ½ of the ear appears			
	57-58 – ¾ of the ear appears			
	59 – the entire ear appears			
6 – blooming	60-63 – beginning, first anther appears in the ear middle	IX	Fertilization and zygote formation	Number of grains in an ear
	64-65 – complete blooming, majority of ears have mature anthers			
	66-69 – end of blooming – majority of ears shed its blossoms, single dry anthers are hanging			
7 – weevil formation and filling	70-71 – first grains reached their final size having jelly-like and liquid state	X	Weevil growth	Formation of grain size
	72-73 – early milky state	XI	Accumulation of nutrients in a weevil, its moisture content 50-40 %	Quality indicators and grain fineness
	74-75 – medium milky state			
	76-77 – late milky state			
	78-79 – dough state (squeezed out when endosperm is pressed)			

TABLE I. PART 2

8 – weevil yellowing	80-83 – beginning (early wax ripeness). Endosperm is not squeezed out	XI	Reduction of grain moisture from 40 to 35-25% – in the middle and up to 24-21% – at the end of the phase	Transformation of weevil nutrients into storage organs
	84-86 – medium stage (grain content is soft and plastic)			
	87-89 – end (grains are elastic, dense, dimple is formed when pressed with nail, grains can be broken)	XII		
9 – complete ripeness	90-99 – beginning (weevil is hard, moisture content 20-18%)	XII	Formation of buds is completed in a weevil	Gradually increasing the germination index reaches its maximum

Characteristic productivity elements are formed at each stage. At the same time the need of plants for heat, light, moisture, nutrition is changing throughout the organogenesis stages (11, 15).

The new international phenological scale (Zadoxs, etc.) representing a decimal code of grass development is globally accepted. Ten main phases numbered from 0 to 9 are identified in the life cycle of plants. In turn, each phase is divided into 10 subphases (1) (Tab. 1).

The beginning and duration of organogenesis stages for durum and soft wheat is not always the same.

At the I stage of organogenesis (seedling and sprout phases, 00-19 subphases), characterized by the apical part of meristem of the growing point of the rachis and plumule formation, no differences between winter wheat species were identified (Fig. 1). According to its appearance during this period the growing point represents a cone with a wide basis, up to 1.5 mm. At this stage such productivity elements as effective germination and plant thickness are formed. For wheat, this stage corresponds to grain germination, one shoot phase.

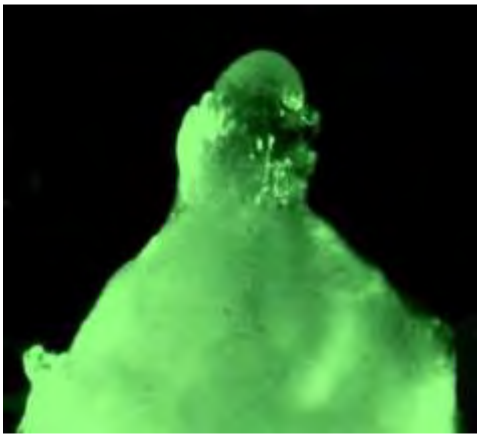

Fig. 1. Growing point of winter wheat at the I stage of organogenesis [10]

According to the experiments, 11.8 days passed on average from planting to seedlings, and no differences between the studied species of winter wheat were revealed (Tab. 2). In many respects, the duration of planting to seedling period depended on the moisture of the seed layer. In droughty weather it was difficult to get even and full sprouts, and the planting to seedling period extended to 14 days, and under favorable conditions its duration was 10-11 days.

TABLE II. EXPERIMENTS RESULTS, 11.8 DAYS PASSED ON AVERAGE FROM PLANTING TO SEEDLINGS

Interstage period	**Type of winter wheat**	
	durum	**soft**
Planting – full seedlings	11.8	11.8
Full seedlings – tillering	18.4	18.4
Tillering – spring vegetation	177.4	177.4
Spring vegetation – booting	27.6	29.2
Booting – earing	17.0	18.0
Earing – blooming	7.8	7.8
Blooming – jelly-like and liquid state of weevils	8.3	8.4
Jelly-like and liquid – milky state of weevils	11.2	8.6
Milky state – beginning of wax ripeness	17.0	14.6
Beginning of wax ripeness – complete ripeness	15.0	13.2
Vegetation period	298.6	294.8

The II stage of organogenesis (phase of autumn tillering, 20-25 subphases) is characterized by the formation of vegetative mass (culm nodes with leaf sprouts and internodes) during autumn tillering. At this stage not only the number of shoot nodes and internodes in adult plant states, but also the degree and nature of branching of the main axis and lateral shoots are defined. Hence, at the II stage of organogenesis the basis of the vegetative plant sphere is formed.

During autumn growth and development (II stage of organogenesis) no considerable differences in differentiation degree and the growing point increase between two species of winter wheat were revealed (Tab. 3).

In the conditions of long warm weather of 2006 autumn period, the growing point of the winter soft wheat steadily remained at the II stage of organogenesis (Fig. 2). This contributed to the growth and formation of additional plumula stem nodes, and later – to the increase in the number of nodal leaves.

TABLE III. GROWING POINT INCREASE FOR DIFFERENT TYPES OF WHEAT (2005-2007 AUTUMN PERIODS AND 2006-2008 SPRING PERIODS)

Type of winter wheat	Year	Size of the growing point at organogenesis stages, mm		
		autumn period (II-III stage)	autumn period (II-III stage)	autumn period (II-III stage)
Durum	2005/2006	0.33544	0.35056	1.22808
	2006/2007	0.36344	0.37296	1.23256
	2007/2008	0.33656	0.34832	1.23088
	Среднее	0.34510	0.35728	1.23046
Soft	2005/2006	0.33628	0.34776	1.07632
	2006/2007	0.34468	0.36736	1.09256
	2007/2008	0.33642	0.34552	1.09424
	Среднее	0.33908	0.35350	1.08766
LSD_{05}	2005-2006	0.00112	0.00196	0.03682
	2006-2007	0.00714	0.00322	0.04074
	2007-2008	0.00098	0.00252	0.04228

a. Sample of a Table footnote. *(Table footnote)*

Fig. 2. Growing point of winter soft wheat at the II stage of organogenesis before wintering, 2006-2007.

The durum wheat had a bigger elongation and segmentation of the growing point (plumula ear axis), earlier transition of 20-30% of plants to the III stage of organogenesis (Fig. 3).

The degree of the growing point development during the autumn period influences the winter hardiness of winter wheat. Usually the plants of the II stage of organogenesis are more frost- and winter-resistant. Winter hardiness (resistance to wintering) is one of the key properties characterizing the advantages of winter wheat species. The increase in winter hardiness of the winter durum wheat in the Central Chernozem region is a determining factor of its successful cultivation in the region. Hence, relatively late planting is more preferable for this type of wheat so that the growing points are wintered at the II stage of organogenesis.

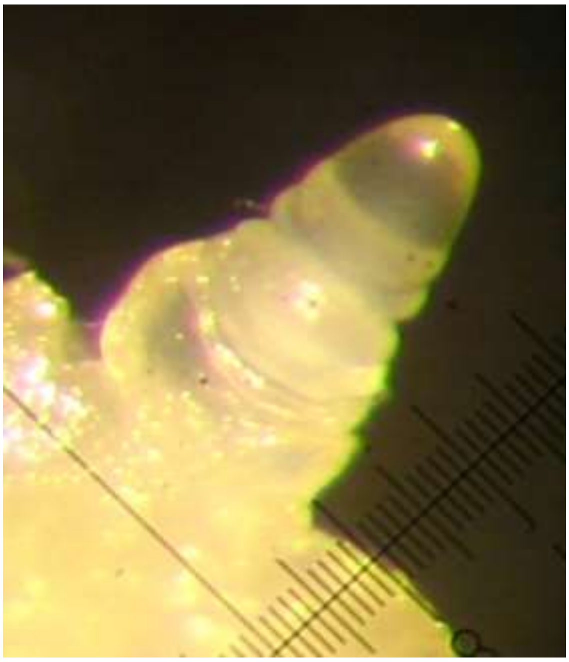

Fig. 3. Growing point of winter durum wheat at the III stage of organogenesis before wintering, 2006-2007.

At the second stage of organogenesis the plant habit (height, number of leaves), the tillering ratio and winter hardiness are formed. For wheat, this stage coincides with the phase of autumn tillering.

It is known that the soil moisture, nutrition, heat and duration of autumn vegetation influence the intensity of autumn tillering.

The experiments showed that the duration of the interphase shoot-tillering period significantly depends on weather conditions of the second half of September and the beginning of October. During the years of experiments, the agricultural and meteorological conditions of this period were not quite favorable due to increased temperature, and the tillering phase began on the 18-19th day almost simultaneously after shoots of both types of wheat.

The III stage of organogenesis (spring tillering, 26-29 subphases) is characterized by differentiation of the main axis of a rudimentary ear and bracts (rudimentary covering leaves of floral bracts and bractlets). With the transition to the III stage of organogenesis the peduncle formation is accompanied by the seizure of the real stem leaves formed in the upper shoot growing point and the formation of upper leaves reduced leaf blades on the lowest part of a peduncle. The productivity elements formed at the III stage of organogenesis represent the number of rachis internodes. This stage phenologically corresponds to spring tillering of wheat plants. Early-spring nitric nutrition improves tillering, culm growth and formation of ears (number of cones, and then flowers).

The IV stage of organogenesis (30th subphase) is characterized by the appearance of primordial leaf blades or glumal buds (growing points of the second order) on a germinative head axis. Phenological features of this stage of organogenesis include the beginning of the booting phase (appearance of the first stem node). During this period, some cones are formed in an ear alongside with the development of drought resistance of plants (16, 17).

The nutrition of plants at the beginning of booting improves the formation of ear spikes, and hence the number of grains in it, ensures the survival of synchronously developed spiciferous tillering stems thus considerably increasing the productivity of plants.

The experiments showed that after the vegetation renewal in spring at the III-IV stages of organogenesis when the potential ear productivity is formed, the growing point of the winter durum wheat during five years of study was on average bigger in size and is more varied, had more glumal buds along the entire length of rachis internode (Fig. 4). The differentiation of glumal buds (formation of flowers) was very intensive in the 3-4th segments (from the basis). Then the formation goes up and down along the ear axis. It indicates the advanced development of the durum wheat at the IV-V stages of organogenesis in comparison with the soft wheat.

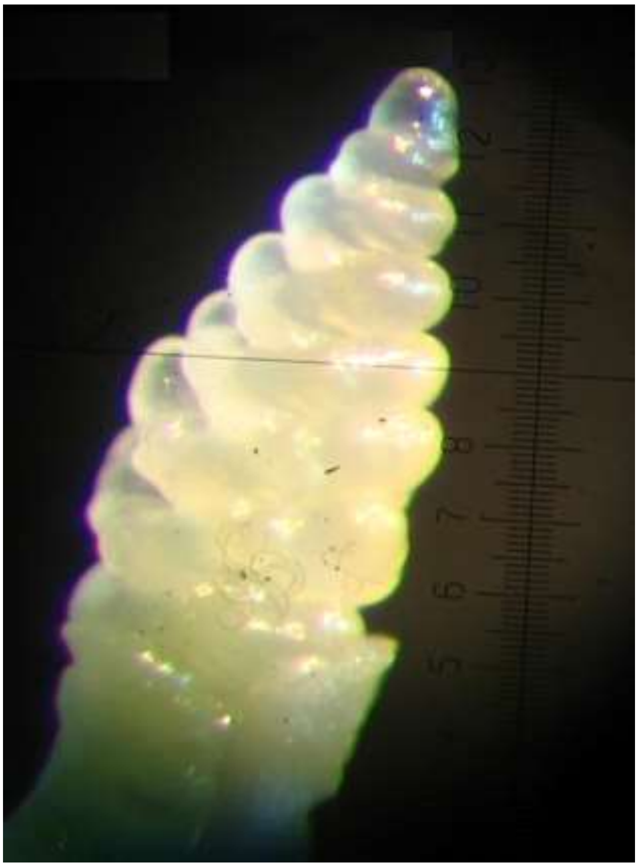

Fig. 4. Growing point of durum winter wheat after spring renewal of vegetation, 2007

Fig. 5. Growing point of soft winter wheat (b) after spring renewal of vegetation, 2007

The V stage of organogenesis (31-32 subphases) is characterized by the beginning of formation and differentiation of flowers – qualitatively new organs. At the beginning of this stage, there is the increased differentiation of cover organs. At the bottom of a glumal bud two beads are formed thus forming the bowl-shaped glume bases. At this stage, stamens and a pestle are formed, a pestle is more expressed for the winter durum wheat (Fig. 5). Phenological features of the V stage include the appearance of the second stem node. The ear, namely the number of future flowers in an ear is strenuously formed. It is desirable that the planting structure at this stage of organogenesis satisfied one-two synchronously developed shoots on a plant (16, 18).

Fig. 6. Growing point of durum winter wheat at the V stage of organogenesis, 2008-2009.

At the IV-V stages of organogenesis when the number of cones and flowers in an ear is formed alongside with the features defining drought resistance of plants, the winter durum wheat surpasses the winter soft wheat in its development.

At the VI stage of organogenesis (33-37 subphases) macro- and microsporogenesis take place in parent cells. The last flag leaf is rolled in a tube and an ear – in its axil film.

Unlike previous five stages (which may detain the development in the absence of certain conditions), the VI stage is characterized by its short duration and intensive processes which may be delayed. Therefore, the lack of the necessary conditions for the formation of pollen grain, at least within 10-15 hours, will lead to the deformation of sporogenous tissues in nucellus anthers. This period requires the satisfaction of plant needs in light of a certain intensity, in water and nutrients, especially in phosphorus (18).

The VII stage of organogenesis (38-49 subphases) is characterized by the preparation for the formation of the main groups of specialized pollen cells and an ovary of female gametophyte. The main phenological features of this stage include the lining of a uvula (ligula) of the last leaf and strongly grown leaf sheath and ear swelling (15, 16). The IV-VII stages of organogenesis occur within the culm growth, i.e. within the booting phase.

The experiments showed that 27.6 days pass on average during five years from the beginning of the renewal of spring vegetation to the beginning of booting for durum wheat, and for soft wheat – 29.2 days, i.e. 1.6 days more. The development of the winter wheat considerably depends on the time of renewal of spring vegetation and weather conditions. Early emergence from under snow in March (2008), high temperature and plentiful rainfall in April extended the spring tillering in comparison with later renewal of spring vegetation, warm and droughty April (2006, 2007, 2009, 2010) by 9-14 days. The duration of spring tillering of winter wheat also depends on the day length (light period). The booting phase of the winter wheat begins when the photoperiod reaches 14.5-15.5 hours, and the average daily temperature makes 10-12°C. The booting phase began 1-2 days earlier for the durum wheat than for the soft one.

At the VII stage of organogenesis (51-59 subphases), the formation of all bodies of an ear (glumes and flowers) is finished. Phenological features of this stage include earing. The VI-VIII stages form the number of fertile (fruiting) flowers in each glume and in the entire ear, its density and heat resistance of plants. For wheat, this stage coincides with earing.

The duration of the interphase booting-earing period during five years made on average 17 days for the durum wheat, and 18 days – for the soft one.

At the VII-VIII stages of organogenesis it is necessary to ensure timely nitric nutrition to increase number, fineness and quality (protein, gluten) of future plant grains in each ear.

The IX stage of organogenesis (60-69 subphases) is characterized by blossoming, fertilization (zygote formation) and germ formation. This stage is initial for the formation of a new affiliated organism on a parent plant. At this stage of organogenesis the ear grain content of winter wheat is formed. The top stops growing at the beginning of the stage. According to phenological features, the stage corresponds to full blossoming of winter wheat ears.

On the X stage of organogenesis (70-71 subphases), the weevil of winter wheat is formed and is growing. Quite intense organ-forming processes are typical for this stage. The productivity element of this stage is the size (length) of a weevil (16).

It should be noted that at this stage of weevil formation the germ becomes autonomous, i.e. independent of a parent organism. From this stage, the germ may be taken from a weevil and planted *in vitro*. In such simple hormone-free environment it will undergo all further processes, will form other structures resulting in the normal sprout (19).

The XI stage of organogenesis (72-86 subphases) is characterized by the overflow of nutrients in a grain. The endosperm structure is passing through complex transformations: synthesis of proteins, fats and carbohydrates. This stage coincides with filling (milky and jelly-like state) and wax ripeness of grains. The content of nutritious (dry) substances in grains increases, and the amount of moisture decreases thus forming the mass and quality of a weevil, plant resistance against hot dry winds.

At the XII stage of organogenesis (87-99 subphases), grain nutrients turn into reserve food material. The weevil growth is almost stopped. The formation of germs is completed, germination capacity reaches its maximum. This leads to complete ripeness of grains, parent plants die off (16, 17).

The weather conditions in June and July strongly affect the duration of formation, filling and maturing of winter wheat grains. The duration of these stages considerably varied depending on weather conditions. High temperatures and lack of soil moisture reduced the grain maturity, while warm and rainy weather extended it. Hot, dry weather and deficiency of moisture in a meter soil layer accelerated this period for about 6-8 days, and warm weather and sufficient moisture prolonged it. The period of formation, filling and maturing of the durum wheat weevil made 43 days, and of the soft wheat weevil – 36 days. The durum wheat was slightly different in a longer period of filling and maturing of grains. In general, the vegetative period of the durum winter wheat made on average 299, and of the soft winter wheat – 295 days (Tab. 1).

The productivity also depended on the type of wheat. On average in five years of study, the best productivity was demonstrated by the winter soft wheat (Tab. 4), which is likely caused by its bigger adaptability to the conditions of the Voronezh region. The winter durum wheat stood down by 6.3 c/hectare. The productivity of both species of winter wheat strongly varied throughout years and depended on the average daily temperature and the amount of rainfall during the vegetation period.

TABLE IV. PRODUCTIVITY OF WINTER DURUM AND SOFT WHEAT IN 2006-2010.

Type /grade of winter wheat	2006	2007	2008	2009	2010	Average for 5 years
Durum / grade Donchanka	14.6	39.6	69.1	43.7	23.4	38.1
Soft / grade Bezenchukskaya 380	25.9	42.6	71.8	52.3	29.4	44.4
LSD_{05}	1.12	0.95	3.64	4.03	3.60	-

The quality of wheat grains is a complex phenomenon. It includes over two dozens of interconnected features. From a large variety of quality indicators, our attention was mainly drawn to the following: 1000-kernel weight, protein and gluten, gluten deformation (Tab. 5).

TABLE V. AVERAGE QUALITY OF WINTER DURUM AND SOFT WHEAT FOR 2006-2010

Type /grade of winter wheat	1000-kernel weight, g	Protein, %	Gluten, %	Gluten deformation ratio
Durum / grade Donchanka	42.22	15.9	30.9	91.9
Soft / grade Bezenchukskaya 380	41.18	14.9	29.0	81.6

The 1000-kernel weight shows rich conditions, plumpness, and fineness of received grains. The study showed that during five years the durum wheat on average had the best 1000-kernel weight (42.2 g) than the soft one, which was 1.04 g less.

The protein content is a critical indicator of grain quality, which defines its technological properties.

On average during 2006-2010, the durum wheat grains contained more protein than the soft winter wheat (1.0% less).

According to E.P. Popova, the protein content in farinaceous grain of soft wheat, especially its central part, does not form a solid monolith with starch grains. At the same time, many pockets are formed in cells, while the proteinaceous matrix of the durum wheat grain takes all intervals between starched grains and covers them with a solid layer (20).

It should be noted that in 2008 and 2009 the protein content of the winter durum wheat was higher and made 16.9%. These indicators are considered optimum since the protein content shall not exceed 18%. First, grains with high protein content may often be shrinked, which reduces the middlings extraction. Second, the macaroni dough from such middlings is hyperextensible thus leading to difficulties in the macaroni process (20-22).

The second important biochemical indicator is the gluten content. It accounts for dough ability to maintain fermenting carbon dioxide. High gluten content improves the quality of macaroni and cereal products developed from the durum wheat grains.

According to experiments, during five years the best gluten content was recorded for the winter durum wheat (30.9%), which was higher compared to the winter soft wheat by 1.9%.

The gluten quality as well as its quantity, is also very important. It is caused by a number of properties: firmness, elasticity, extensibility, viscosity, connectivity and color of gluten. The gluten deformation indicators for durum and soft wheat during five years on average did not exceed 100 units and the gluten quality corresponded to the second group (satisfactory, weak).

Thus, the study revealed the differences in plant development between winter durum and soft wheat in forest-steppe conditions of the Central Chernozem region. Starting from the III stage of organogenesis, the durum wheat is marked by the strengthening of its growing point in comparison with the soft wheat. At subsequent stages of organogenesis the winter durum wheat also exceeds the winter soft wheat and quicker passes through the interphase periods up to the filling stage. The vegetative period of the winter durum wheat is 4 days more, which provides for earlier harvesting. According to productivity, the durum wheat ranks below the soft one (by 6.32 c/hectare, or 14.2%), but exceeds the latter one in grain quality. The 1000-kernel weight of the winter durum wheat is more by 1.04 g, protein content – by 1%, gluten – by 1.9% than the winter soft wheat.

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