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EFFICIENCY OF USING THE IDENTIFICATION SCALES FOR GROWTH AND DEVELOPMENT STAGES OF SORGHUM PLANTS

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ABSTRACT

Aim of this study was to determine the efficiency of developing and forming the productivity elements of sorghum crops, selected in Ukraine, with the purpose of optimizing their productivity. Field studies were conducted in the soil and climatic conditions of the Central Forest-Steppe zone of Ukraine in 2012–2018 within the DPDH Salyvinkivske and at the Bila Tserkva Research and Selection Station of the Institute of Bioenergy Crops and Sugar Beet of the National Academy of Agricultural Sciences of Ukraine. Sorghum varieties of domestic breeding were used for the studies: common sorghum (bicolor): Odeskyi 205, Lan 59 and sweet sorghum: Huliver, Dovista. The following experimental factors were investigated: *Factor A*: Hybrid. *Factor B*: The phase of foliar fertilization: growth and development scales for sorghum plants according to BBCH 21-24, 31 and 37, according to Kuperman III, IV and VI-VII. *Factor B*: Treating the plants with Vympel 2 growth stimulator (0.5 l/ha). The differences between the investigated scales and common features were determined via the comparison of phenological phases and organogenesis stages based on the specificities of organ formation of sorghum plants and using the results of morphophysiological analysis.

The results of the comparison of growth and development scales for sorghum crops demonstrated that Feekes scale and the scale of Keller & Baggiolini are derivatives of the unified extended growth and development scale (BBCH) and describe the growth and development of sorghum plants in a less detailed way. Thus, the experimental studies were conducted with the consideration of BBCH and Kuperman scales which uniformly highlight the main growth and development stages of plants. It was also determined that from I to VII stage of organogenesis Kuperman scale classifies growth and development stages of sorghum crops based on the state of the apical dome and the initiation of vegetative and reproductive organs of the plant on it. Thus, it is difficult to determine early stages accurately without the morphophysiological analysis. Foliar application of Vympel 2 growth stimulator on microstages 21-24 by the unified extended BBCH scale promoted faster growth and development of grain sorghum plants and the formation of higher grain productivity. For instance, Odeskyi 205 variety produced the yield of 5.26 t/ha, and the yield of Lan 59 was 5.70 t/ha. The introduction of a growth stimulator at the third stage of organogenesis according to Kuperman also contributed to the increase in comparison with the control variants, but the yield for the studied varieties was 5.10 and 5.56 t/ha. Similar introduction of the growth stimulator on the fields of sweet sorghum hybrids contributed to better productivity indices and quality of the received produce in comparison with the control variants. For instance, in case of applying Vympel 2 growth stimulator to Huliver hybrid, its biomass yield on microstages 21-24 was 93.5 t/ha, the dry matter harvest was 18.9 t/ha and the overall sugar content in the stem juice was 14.9 %, while these indices for Dovista hybrid amounted to 98.8 t/ha, 19.8 t/ha and 15.7 % respectively. After the introduction of a growth stimulator on the third stage of organogenesis according to Kuperman, the biomass yield of Huliver hybrid was 92.1 t/ha, the dry matter harvest – 18.4 t/ha and the overall sugar content in the stem juice – 14.8 %, while those of Dovista hybrid were 97.3 t/ha, 19.3 t/ha and 15.6 % respectively.

The results of comparing growth and development scales for sorghum crops demonstrated the suitability of BBCH and Kuperman scales to describe the state of plants and good agreement between them. However, the identification according to the scale of F.M. Kuperman on early stages of sorghum growth and development is too complicated in practice, requiring specific skills and morphophysiological analysis. Such scales as Keller & Baggiolini and Feekes are derivatives of BBCH scale with the specification of some phases of plant growth and development. To stimulate growth processes, foliar fertilization on early stages of sorghum growth and development should be done based on the data of plant growth and development microstages. For instance, after the introduction of Vympel 2 growth stimulator on microstages 21-24 according to BBCH, the increase in the yield of grain sorghum, compared to its application on the third stage of organogenesis, was by 0.14–0.16 t/ha, and the increase in the biomass yield of sweet sorghum was 1.6 t/ha respectively. Foliar fertilization on later stages of growth and development of grain sorghum and sweet sorghum, aimed at forming higher quality of the produce, does not require accurate identification of microstages of plant growth and development; thus, it is possible to determine the time of applying stimulators efficiently both based on the data of BBCH scale and on the scale, developed by F.M. Kuperman.

***Keywords*:** unified extended BBCH scale, Feekes scale, Kuperman scale, Keller & Baggiolini scale, identification of plant development stage, organogenesis stages, foliar fertilization.

INTRODUCTION

The identification of phenological stages of sweet sorghum growth and development is relevant from the standpoint of optimizing its cultivation technology, especially with consideration of climate change. Achieving high yield of plants requires proper use of industrial resources and management methods on the corresponding stage of crop development (Thapa *et al.*, 2017; Maw *et al.*, 2017; Chapke, 2019; Maiti and Singh, 2019; Sory *et al.*, 2017; Cuevas and Prom, 2020; Reddy *et al.*, 2014).

A series of BBCH-scales was developed for different species of mono- and dicotyledonous plants. The scale envisages the use of the decimal code system, divided into macro- and microstages.

The name of BBCH scale officially comes from the names of Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie. However, there is an unofficial opinion that the abbreviation of the scale stands for the initial letters of the names of four companies, which initially sponsored the studies on the unification and distribution of the scale: Bayer, BASF, Ciba-Geigy and Hoechst (Thomas WTB, 2014; Meier, 1997; Hess *et al.*, 1997).

The phenological macro- and microstages of plant development according to BBCH scale are used to identify the stage of plant development and to determine the terms of applying fertilizers, pesticides and conducting other agrotechnological procedures.

In 1962, a scale covering 12 organogenesis stages for cereals and other agricultural crops was developed under the leadership of F.M. Kuperman (Kuperman, 1984). Each stage is characterized by a specific state of the apical dome and the formation of new organs or a change in their development. It is suggested to divide the whole life cycle of an annual plant into three periods: a) embryonic period and youth (I-IV stages); b) maturing and reproduction (V-VIII stages); c) senescence (IX-XII stages).

Feekes scale was introduced by the Dutch agronomist Willem Feekes (1907–1979) in 1941. It is more widely used in the United States of America than similar scales, such as Zadoks scale of BBCH (Large, 1954).

Zadoks scale is a cereal development scale, introduced by the Dutch phytopathologist Jan C. Zadoks (Zadoks *et al.*, 1974). It presupposes the knowledge of critical plant development stages only. For instance, in some countries the application of nitrogen and herbicides should be completed during tillering. In France the recommendation on the first application of nitrogen is 6 weeks before Z30 and the second one – on Z30, and growth stimulators are usually applied at Z30. Disease control is most relevant at stage Z31, Z32, Z35, in particular, as soon as the flag leaf is out (Z37) (Zadoks *et al.*, 1974).

Keller & Baggiolini scale, developed in Switzerland, is in fact an extended Feekes scale, in which growth stages are coded with letters (Thomas, 2014).

Feekes scale is considered to be traditional and most common in global practice. It indicates sorghum development stages from 1 to 11, where stage 1 represents shoots and stage 11 – the process of grain ripening. Feekes scale is especially efficient between stages 6 and 10.5 which corresponds to the period from the emergence of the first node at the beginning of stem extension (stage 6) until the completion of flowering (stage 10.5). Stem extension is divided into five stages (stages 6–10), they are taken into account when it is relevant to know the critical time for fungicide application.

According to Haun scale, cereal development is divided into 16 stages – from 1 to 16. Stage 1 represents the emergence of the first leaf through coleoptile, and stage 16 – kernel hardening. Haun scale is based on unfolding of leaves on the main stem and is useful in terms of dividing the vegetative growth stages. According to Haun scale, stages 1–9 or higher represent complete unfolding of the first, second, third and the following leaves (L1, L2, L3 etc.) on the main stem. The method of classifying sorghum development according to Haun is constant only during vegetative stages of growth, but it does not give any numerical indication of the stages of kernel ripening. As leaves begin unfolding after the emergence of shoots in a proper and expected way, Haun scale indicates which shoots have been formed (or should be formed) on the plant. The advantage of Haun scale lies in the possibility of computerizing sorghum development stages (Thomas, 2014).

According to Zadoks scale, both stages are under consideration – vegetative and reproductive. This scale is also easier computerized than Feekes scale. The development of a plant is divided into 10 initial stages (10, 20, 30 etc.), each of which, in its turn, is divided into 10 secondary stages (11, 12, 13 etc.; 21, 22, 23 etc.) till the total number of 100 stages. Thus, Zadoks scale allows using more than one code for plant description (Zadoks *et al.*, 1974).

At present, seven crops of Sorghum genus are presented in Ukraine, namely, common sorghum (bicolor), soryz, sweet sorghum, Sorghum-Sudan grass hybrid, broom sorghum, perennial sorghum and grass sorghum (State register of plant varieties suitable for dissemination in Ukraine in 2020), but the most common ones are common sorghum (bicolor) and sweet sorghum (Fedorchuk *et al.*, 2017).

On early stages of growth and development, sorghum plants are characterized by rather slow growth of the stem and formation of a leaf apparatus. As plants grow slowly, have relatively small size and area of the leaves, they cannot compete with weeds. In addition, the shortage of mobile forms of nutrients in soil or air drought can also decrease the level of potential yield of this crop (Kraig *et al.*, 2019; Marinov-Serafimov *et al.*, 2018).

From the agrotechnical standpoint, it is important to find working ways of correcting the total duration of the vegetation period and the activation of some phenophases of sorghum growth and development. Timely application of plant growth stimulators contributes to the acceleration or prolongation of some stages of growth and development. These agrotechnical measures may help avoid the stress for plants from inadequate environmental factors during critical stages of growth and development (Reddy *et al.*, 2014).

The issue of accurate application of plant growth stimulators is closely associated with the knowledge and identification of plant growth and development phases. Similarly to other cereals, sorghum comes through phenological phases of growth and development during its

ontogenesis. Traditionally in global practice the determination of growth and development phases of sorghum crops is done according to the scales, which are somewhat related. The main scales are BBCH, Keller & Baggiolini, Feekes, Zadoks, Haun (Lambright, 2019; Zadoks *et al.*, 1974; Thomas, 2014; Large, 1954; Meier, 1997; Vanderlip and Reeves, 1972; Hess *et al.*, 1997).

It is common for domestic practice to use the scale, developed by F.M. Kuperman. According to this scale, 12 stages of organogenesis can be identified for sorghum. However, the phases according to Keller & Baggiolini and Feekes can be set equal to the data according to Kuperman, whereas BBCH scale, built on more precise knowledge of plant development physiology, is hardly compared to simpler scales (Lambright, 2019; Kuperman, 1984; Reddy, 2017). Taking into consideration the fact that BBCHis one of the most complete, internationally recognized and common scales, the aim of this work was to determine the efficiency of practical application of scales of growth and development of sorghum crops, which are notable for adaptivity to increased temperature, a decrease in precipitation, tolerance to long drought periods, resistance to lying down, diseases, pests under conditions of climate changes using the example of studies on sorghum varieties of domestic selection with the purpose of optimizing their productivity.

MATERIALS AND METHODS

In 2012–2018 the phenological phases of growth and development of sorghum crops were determined in field experiments, conducted within DPDH Salyvinkivske (the village of Ksaverivkadruha, Vasylkiv district, Kyiv region) and at the Bila Tserkva Research and Selection Station of the Institute of Bioenergy Crops and Sugar Beet of NAAS. Both locations of investigations are in the Central Forest-Steppe of Ukraine, in the zone of unstable irrigation, where climate is moderately continental.

The soil of the experimental field of DPDH Salyvinkivske is podzolic chernozem, notable for the following fertility parameters: content of humus according to Turin–3.21 %, alkaline hydrolyzed nitrogen by Kornfeld's method–156 mg/kg of soil, mobile phosphorus and potassium according to Chirikov – 77 and 89 mg/kg of soil respectively, saline pH – 6.4 (Rozhkov *et al.*., 2016).

The soil of the experiment field at Bila Tserkva ESS is typical low-humus chernozem, notable for the following fertility parameters: content of humus according to Turin – 3.50 %, alkaline hydrolyzed nitrogen by Kornfeld's method – 134 mg/kg of soil, mobile phosphorus and potassium according to Chirikov – 76 and 98 mg/kg of soil respectively, saline pH – 6.2 (Rozhkov *et al*., 2016).

Ground water in the experimental fields is at the depth of 5–8 m, so the water regime was largely formed by precipitation. In the low places of the experiments, conducted at DPDHSalyvinkivske, ground waters were close to the surface or at the depth of 2.6–4.3 m. Water regime of these soils was formed by atmospheric and soil irrigation.

The analysis of weather conditions and the level of their variability during 2012–2018 compared to the average perennial indices was conducted based on the criteria of significance coefficient for the deviations of agrometeorological regime elements of each investigated year from the average perennial values (Rozhkov *et al*., 2016).

It was determined that the most significant deviations in terms of precipitation were observed in 2012, 2015, 2016, 2017 and 2018. In 2015 and 2017, all the months of the vegetation period for sorghum had negative values of the deviation significance coefficient, which corresponded to insufficient precipitation.

The years of 2012 and 2018 were critical in terms of parameters of the average daily air temperature, when the vegetation periods had from 3 (April, May, July) to 4 months (May, June, July, August) of almost extreme conditions. In general, one can note stable exceeding of average daily temperature of the vegetation period in all the years of studies, except for June of 2013 and 2014.

However, according to the physiological needs of sorghum crops, weather conditions of the vegetation periods in 2012–2018 can be characterized as favorable ones – high sum of active temperatures, exceeding average annual air temperatures by 1.2–3.1 °C above the norm. In addition, during the studies there was partial compensation of precipitation moisture shortage at the expense of close ground water. The exception may be found only in 2017 when the systematic lack of total precipitation in 2015–2016 resulted both in moisture shortage as of the beginning of vegetation in 2017, and to sharp decrease in the level of ground water. Therefore, the level of productivity, including sorghum crops in the Kyiv region, was rather low in 2017. Although in 2018 there were also extreme conditions, but there was no sharp decrease in the productivity, observed by us. First of all, this was ensured by the increase in moisture reserves, available for plants in soil due to a considerable amount of precipitation in autumn-winter, and a sufficient amount of precipitation in May-June 2018 – in the critical month for growth and development of sorghum.

Field experiments were conducted with the most common crops of Sorghum genus: common sorghum (bicolor) and sweet sorghum.

Field experiment of cultivating common sorghum (bicolor) hybrids (DPDHSalyvinkivske, 2012–2015) was conducted according to the following scheme: *Factor A*: Hybrid: Odeskyi 205, Lan 59. *Factor B*: The phase of foliar fertilization: according to BBCH 21-24, 31 and 37, according to Kuperman III, IV and VI-VII. *Factor B*: Treating the plants with a growth stimulator: control – the plants were treated with water, Vympel 2 (0.5 l/ha).

The area of the plot for sowing was 35 sq.m., the area under registration – 25 sq.m. The experiment was randomized for factors A and B, systematized for factor B, and repeated four times.

Field experiment of cultivating sweet sorghum hybrids (*Sorghum saccuratum* Jakuschev.) (Bila Tserkva ESS, 2016–2018) was conducted by the following scheme: *Factor A*: Hybrid: Huliver, Dovista. *Factor B*: The phase of foliar fertilization: according to BBCH 21-24, 31 and 37, according to Kuperman III, IV and VI-VII. *Factor B*: Treating the plants with the growth stimulator. Control – the plants were treated with water, Vympel 2 (0.5 l/ha).

The area of the plot for sowing was 35 sq.m., the area under registration – 25 sq.m. The experiment was

randomized for factors A and B, systematized for factor B, and repeated four times.

Prior to the treatment with the growth stimulator, the elementary plot of 70 sq.m. was divided in half into the control variant and the variant of applying the growth stimulator Vympel 2. In case of randomized location of Factors A and B, systematic variants of locating elementary plots of Factor B were allocated in each of them. Therefore, during further comparison of the study results, the data of control variants were not averaged to one figure, but compared against the algorithm of the closest neighbor instead (Jivani *et al.*, 2016).

The agro-technology of cultivating grain sorghum and sweet sorghum was recommended for the Right-Bank part of the Forest-Steppe of Ukraine, except for the investigated elements.

Mineral fertilizer was used as the main fertilizer, introduced in the ratio of $N_{45}P_{60}K_{60}$. Phosphate-potassium fertilizer was introduced prior to tillage, and nitrogen fertilizer – prior to pre-sowing grubbing. The level of mineral nutrition was determined according to the needs of sorghum plants and depending on the provision of nutrients for the soil of experimental plots (Rozhkov *et al.*, 2016; Fedorchuk *et al.,* 2017).

The seeds were sown at soil temperature over 12°C, the depth of covering seeds was 2–4 cm. Grain sorghum was sown in wide rows with the row spacing of 70 cm and with the consideration of the density which would allow leaving 160–180 thousand of plants per hectare at the time of harvesting. Wide rows with row spacing of 45 cm were used to sow sweet sorghum. The norm of sowing was 10–12 seeds/m of the row line, the density of plants as of the time of harvesting was 190–230 thousand of plants per hectare.

To ensure efficient control of weeds, prior to sowing the seeds were treated with the antidote Concept 3, which allowed for pre-emergence and post-emergence introduction of preparations based on S-metolachlor (PrimextraTZ Gold 500 SC, Primextra Gold 720 SC, Dual Gold 960 EC). Dicotyledonous weeds were controlled by postemergent herbicides of 2.4 D group till the phase of 5 sorghum leaves (Fedorchuk *et al.,* 2017).

Grain sorghum was harvested at grain humidity of not more than 22 ℃. Sweet sorghum was harvested in the phase of middle dough using silo-harvesters (Fedorchuk *et al.,* 2017).

Vympel 2 (DOLYNA-TSENTR LLC, Ukraine) – a complex natural-synthetic preparation of contact systemic action for the treatment of seeds and vegetating plants was used in the studies. The preparation contained polyatomic alcohols (at least 300 g/l), humic acids (up to 30 g/l), carbonic acids (3.0 g/l), natural stimulators-adaptogens. It was selected for the studies due to its adaptogenic, thermoprotective and antistress properties. The preparation accelerated the growth and development of plants, promoted the activation of consuming nutrients and leaf surface formation (Storozhyk and Muzyka, 2017).

The following scales were used for observation of the growth and development of cereals: BBCH, Keller & Baggiolini, Feekes, Zadoks, Haun, Kuperman. To determine the differences between the investigated scales and to find common traits, we compared phenological phases and stages of organogenesis, finding common traits based on the specificities of organ formation of sorghum plants on the embryonic level (Kuperman, 1984; Zadoks *et al.*, 1974; Thomas, 2014; Large, 1954; Meier, 1997; Vanderlip and Reeves, 1972; Hess *et al.*, 1997).

The experimental fields were planned according to the method of experiments in agronomy and in compliance with the method of state variety testing of agricultural crops (Rozhkov *et al.*, 2016; Tkachyk, 2015) with randomized location in four repeats.

The statistical processing of the study results was done by ANOVA method with Bonferroni correction using Statistica6.0 package (Wegman, 2012).

RESULTS

There are many variants of describing the phenological development of plants using the scales of their growth and development, however, regardless of their universal elements, they differ rather considerably in some respects. The comparative study on determining the course of phases, organogenesis stages, microstages of growth and development of plants and forming the productivity elements of sorghum crops according to Keller & Baggiolini, Feekes, BBCH and Kuperman demonstrated similarities and differences between these scales (Table 1).

The analysis of phases, stages of organogenesis and microstages should start with comparing the accuracy of describing growth and development of sorghum crops according to the information from different scales (Table 1). BBCH scale is considered to be the most complete as it contains 99 stages, whereas Keller & Baggiolini scale – 21, Kuperman – 12, and Feekes – 11 (with some substages). Thus, we shall compare the remaining scales according to the increase in macro- and microstages by BBCH scale.

The macrostage of seed germination is highlighted in detail only in BBCH scale, though the knowledge of the specificities of sorghum seed germination is relevant not only from the standpoint of the speed of plant development, but also obtaining sufficient field germination.

The macrostage of sorghum leaves development is registered in all the scales under our investigation, but only in BBCH and Feekes scales the emergence from the first to the fourth and following leaves is described. Keller & Baggiolini scale controls only the emergence of the first three leaves, and according to Kuperman the identification of sorghum plant growth is considered from the standpoint of the formation of plant organs on the embryonic level: the formation and differentiation of the apical dome. The second stage of organogenesis according to Kuperman actually starts in the phase of the third leaf and continues at the beginning of tillering. It is impossible to identify the emergence of this stage of organogenesis without deep analysis of the state of the apical dome.

Table 1 : The comparative ratio of the course of phases, organogenesis stages, microstages of plant growth and development and the formation of productivity elements of sorghum crops (composed using the data of field studies in 2012–2018)

Phenological phase	According to Keller & Baggiolini	According to Feekes	International scale BBCH, microstage	Organogenesis stages according to Kuperman		Which productivity elements may be changed	Which agrotechnical measures could enhance plant productivity
				No. of the stage	organ formation of the embryonic level		
1	2	3	4	5	6	7	8
Macrostage: Germination			**00-10**			Field germination should be at least 70 %, sowing should be done with the consideration of germination in laboratory conditions	Predecessor, soil preparation, method of sowing, depth of sowing, norm of sowing, fertilizers, etc.
Dry seed			00				
Radicle emerged			05				
Coleoptile emerged			07				
Macrostage: Leaf development			**10-19**	**I**	Formation of the apical dome, which is still non-differentiated.	Field germination, development of the root system, simultaneity of germination and conditions for commonuniform growth of plants.	High quality pre-sowing treatment of soil, covering the seeds at one depth
Coleoptile emerges on the soil surface	A	1	10				
First leaf phase	B	1.1	11				
Second leaf phase	C	1.2	12				
Third leaf phase	D	1.3	13	**II**	Beginning of intense differentiation in the apical dome. Initiation of primordial stem nodes and internodes, the leaves are in the form of rollers.	Height of plants, number of leaves, tillering coefficient	Predecessor, terms of sowing, norm of sowing, sufficient reserves of P_2O5 and K_2O in soil. Tillering coefficient may be increased using growth regulators
Phase of the fourth and following leaves		1.4-1.9	14-19				
Macrostage: Tillering			**20-29**				
Side tiller in the leaf sheath			20				
Start of tillering, plants have one side tiller	E	2	21				
End of tillering, up to six tillers are developed	F	3	25	**III**	Differentiation of the main axis of the primordial inflorescence into primordial spikelets	Number of tillers, spikelets, length of the panicle	Fertilization with nitrogen fertilizers increases the number of segments of panicle
End of tillering. Side tillers continue their fast development	C	4	29				
Macrostage: Stem elongation			**30-49**	**IV**	Formation of apical domes of the second order, formation of spikelet heads. Branching of the panicle.	Number of spikelets in the panicle, formation of more stems. After stage IV, it is almost impossible to increase the length of the panicle and the number of spikelets.	Nitrogen introduction can double the number of kernels in the panicle. If needed, the preparations against lying down, herbicides and fungicides should be used.
Start of stem elongation	H	5	30				
First node appears	I	6	31				
Second node appears, tillering starts	J	7	32	**V**	Initiation of perianth organs of the flower, stamens, ovary and stigmas	The number of flowers in spikelets may increase from 2–3 to 4–5.	High level of nitrogen provision
Third-sixth nodes emerge, tillering		7	33-36	**VI**	End of differentiation of all the panicle parts. Formation of anthers (microsporogenesis) and stigmas (megasporogenesis)	Fertility of flowers (their ability of pollination)	High level of provision with nutrients, especially phosphorus
Flag leaf emerges	K	8	37	**VI-VII**	Intensive growth of the panicle length, perianth organs of spikelets and flowers. Gametophytogenesis, formation of ovules and pollen grains	Fertility of flowers. Panicle density (in sunny weather the panicle is denser, in cloudy weather – not so dense)	Adherence to the whole complex of technological requirements. Treatment with fungicides increased the yield by 20–30 %
Ligula of flag leaf is visible		9	39	**VII**			
Upper leaf sheath is swollen	M	10.1	45				
Sheath breaks open, the panicle emerges		10.1	47-49				

Macrostage: Panicle emergence			**51-59**	**VIII**	Gametogenesis, completion of the processes of forming the organs of the panicle and flower. The largest upper internode continues to grow	Fertility of flowers	Timely nitrogen fertilization ensures the formation of the full kernel with high content of protein and fiber. Treatment with fungicides
Start of spikelet formation, the first spikelet of the panicle is visible	N	10.2	51				
Half of the panicle has spikelets		10.3	55				
The panicle is completely visible	O	10.5	59				
Macrostage: Anthesis			**61-69**	**IX**	Flowering, fertilization, a couple cell formation	The panicle has kernels. Termination of vegetative mass accumulation, the plant goes from vegetative to reproductive development	Adherence to all the requirements of the technology. Good phytosanitary state of the fields. Optimal area of the leaf surface.
Anthesis starts, first anthers emerge in the beginning of the panicle	P	10.5.1	61				
Full blossoming, most spikelets have mature anthers		10.5.2	65				
End of anthesis, most spikelets have completed flowering, anthers are dry	O	10.5.3	69				
Kernel formation. Grains are watery			70	**X**	Growth and formation of kernels, embryo and endosperm enlarge	Kernel sizes	Powerful individual development of each barley plant in the agrobiocenosis
Milky ripeness	**R**	**10.5.4**	**71-77**	**XI**	Accumulation of nutrients in the kernel. Kernels enlarge in their thickness and width. Grain content is milky	Weight of 1,000 grains. Grain unit	Prolongation of the active period of photosynthetic apparatus due to adaptive technology of cultivation
Early milky ripeness			73				
Medium milky ripeness	S	11.1	75				
Late milky ripeness			77				
Macrostage: Ripening			**83-90**	**XII**	At the beginning of stage XII, the accumulation of plastic substances in grain continues	Weight of grain	Adaptive technology ensures high productivity and quality of grain
Early wax ripeness			83				
Wax ripeness	T	11.2	85				
Yellow ripeness	U-V	11.3	87				
Macrostage: Full ripeness. Plant is dead.			**91-99**				
The grain is hard, the plant dies, dries out completely	V		91		The transformation of plastic substances into reserves	Weight of grain. Germination of seeds	To obtain grain with high germination level, the technology for seed plots should be applied
Dead ripeness			92				
Grain dormancy			95				
Grain germination of 50 %			96				
Grain comes out of dormancy			97				
The second dormancy period starts			98				
The second dormancy period is lost			99				

The macrostages of tillering and stem elongation are fully described by BBCH scale, Feekes scale and Keller &Baggiolini scale, except for microstage 20. Keller & Baggiolini scale does not identify the emergence of the third-sixth nodes of the stem, and Feekes scale presents microstages 32–36 as a unified stage. If the correspondence from stage III to VI by Kuperman is analyzed, they are identical to macrostages by BBCH stage from full tillering (25) to the emergence of third-sixth node and stem elongation (33–36). However, only the last stage can be

visually identified, the others require morphophysiological methods of analysis.

The macrostages from the emergence of the flag leaf (37) to breaking the sheath of the upper leaf (49) correspond to stages VI-VII of organogenesis by Kuperman. Besides BBCH scale, these stages may be identified most accurately according to Feekes scale, while Keller &Baggiolini scale determines only some stages of growth and development of sorghum plants.

Besides BBCH scale, the macrostages of panicle emergence and anthesis can be maximally identified by Feekes scale, and by Kuperman, organogenesis stages coincide with macrostages, have their visual manifestation and do not require morphophysiological methods of analysis. In fact, organogenesis stages VIII, IX, X, XI and XII by Kuperman are easily identified in field conditions similarly to identification of macro- and microstages by BBCH scale. It is noteworthy that for later macrostages of plant growth and development, namely, milky ripeness and full ripeness of grain, Keller & Baggiolini and Feekes scales ensure only episodic identification of the condition of plants. Macrostages 92–99 by BBCH are not described by other scales under our investigation at all.

Thus, it was determined that such scales as Feekes scale and Keller & Baggiolini scale are derivatives from BBCH and present fewer details about growth and development of sorghum plants. Therefore, further experimental studies were conducted with the consideration of unified extended scale – BBCH and Kuperman scale. However, from organogenesis stages I to VII, Kuperman scale classifies growth and development stages based on the condition of the apical dome and the initiation of vegetative and reproductive organs of the plant on it. Thus, accurate identification of early stages of development by this scale is impossible without morphophysiological analysis.

The study of the correspondence of phases, organogenesis stages, microstages of growth and development of plants and formation of productivity elements for sorghum crops was conducted on the background of perennial studies of different terms of applying foliar fertilization as the method of intensifying growth and development of plants at the beginning of their vegetation. There is a commonly known fact about slow growth of the vegetative (upper) part of sorghum plants during the first 40–50 days after germination which has negative impact on their adaptation to unfavorable conditions of cultivation and control of free ecological niches in the agrocenosis of a sorghum field (Reddy, 2017; Marinov-Serafimov *et al.,* 2018).

In case of foliar fertilization, it is extremely important to choose a phase of plant growth and development when a growth stimulator is applied. We have no possibility of using foliar fertilization or a growth stimulator “for future use” as it is often done during the introduction into soil, since everything we introduce penetrates plants very fast. Therefore, it is very important not only to understand when critical periods of supplying some nutrients start, but also to consider the specificities of growth and development of sorghum plants for their efficient consumption of growth stimulators and microfertilizers during foliar fertilization.

The specificities of the impact of growth stimulators on the productivity of common sorghum (bicolor) varieties *Sorghum bicolor* L. of domestic selection are presented in Table 2.

Table 2 : The impact of growth stimulators on the productivity of common sorghum (bicolor) *Sorghum bicolor L.* (average for 2012-2015)

Variety	The phase of foliar fertilization	Growth stimulator	Duration of vegetation period, days	Yield of grain, tons/ha	Protein content, %	Starch content, %
Odeskyi 205	Microstage 21–24 by BBCH	Control	110	4.70	10.8	73.5
		Vympel 2	102	5.26	10.9	73.8
	Stage III of organogenesis by Kuperman	Control	110	4.73	10.9	73.5
		Vympel 2	103	5.10	10.8	73.6
	Microstage 31 by BBCH	Control	110	4.68	10.8	73.6
		Vympel 2	104	5.05	11.0	73.9
	Stage IV of organogenesis by Kuperman	Control	110	4.71	10.7	73.5
		Vympel 2	104	5.01	11.0	73.9
	Microstage 37 by BBCH	Control	110	4.74	10.8	73.2
		Vympel 2	107	4.92	11.2	74.1
	Stage VI-VII of organogenesis by Kuperman	Control	110	4.70	10.9	73.3
		Vympel 2	108	4.90	11.3	74.2
Lan 59	Microstage 21–24 by BBCH	Control	110	5.22	11.0	75.1
		Vympel 2	103	5.70	11.2	75.3
	Stage III of organogenesis by Kuperman	Control	110	5.20	11.1	75.0
		Vympel 2	104	5.56	11.1	75.2
	Microstage 31 by BBCH	Control	110	5.25	11.0	74.8
		Vympel 2	105	5.50	11.4	75.2
	Stage IV of organogenesis by Kuperman	Control	110	5.18	10.9	74.9
		Vympel 2	105	5.44	11.5	75.3
	Microstage 37 by BBCH	Control	110	5.17	11.2	75.0
		Vympel 2	108	5.35	11.6	75.7
	Stage VI-VII of organogenesis by Kuperman	Control	110	5.22	11.1	75.1
		Vympel 2	109	5.32	11.6	75.9
ANOVA Bonferroni			2	0.13	0.4	0.9

The duration of the vegetation period for grain sorghum Odeskyi 205 and Lan 59 in control variants was 110 days on average during the years of studies. The introduction of the growth stimulator Vympel 2 on early stages of plant growth and development promoted the activation of growth processes and the reduction in the total vegetation period by 1–8 days.

It should be noted that the application of the growth stimulator Vympel 2 at microstage 21–24 by the unified extended BBCH scale allowed the plants of Odeskyi 205 variety to accelerate their growth and development by 8 days, and those of Lan 59 – by 7 days respectively. At the same time, the introduction of the growth stimulator on stage III of organogenesis by Kuperman promoted the decrease in the total duration of the vegetation period in the investigated sorghum varieties by 7 and 6 days respectively.

Later application of the growth stimulator on microstage 31 by BBCH and on stage IV of organogenesis by Kuperman were identical in the specificities of the impact of growth-stimulating substances on plants due to the correspondence of these stages from the physiological standpoint. The duration of the vegetation period for grain sorghum varieties Odeskyi 205 and Lan 59 in the experimental variants was 104 and 105 days respectively.

When growth stimulator Vympel 2 was applied on later stages of growth and development of grain sorghum plants, the impact of this preparation on the duration of the vegetation period was neutralized. In general, the differences between these varieties and control variants after the introduction of the stimulator on microstage 37 by BBCH and on stage VI-VII of organogenesis by Kuperman were 2–3 days for Odeskyi variety and 1–2 days for Lan 59 respectively. Actually the application of the growth stimulator on later stages of growth and development of grain sorghum plants cannot change the total duration of the vegetation period considerably.

On average during the years of studies, grain yield of Odesky 205 grain sorghum in control variants of the experiment was on the level of 4.68–4.74 t/ha, and that for Lan 59 – 5.18–5.25 t/ha respectively. The content of protein and starch in grain of Odeskyi 205 variety was 10.7–10.9 % and 73.2–73.6 %, whereas for Lan 59 variety it was 10.9–11.2 % and 74.8–75.1 %.

Foliar application of Vympel 2 growth stimulator on microstages 21-24 by the unified extended BBCH scale promoted faster growth and development of grain sorghum plants and as a result – the formation of higher grain productivity. For instance, Odeskyi 205 variety formed its productivity on the level of 5.26 t/ha which is 0.56 t/ha above the control, and in Lan 59 variety the productivity level was 5.70 t/ha which is 0.48 t/ha above the control variant respectively. At the same time, the introduction of a growth stimulator at the third stage of organogenesis according to Kuperman also contributed to the increase in comparison with the control variants, but the yield for the varieties under our investigation was 0.37 and 0.36 t/ha. The differences in the content of protein and starch in the investigated variants were of situational character and the deviations observed in these indices were within the experimental error.

Similar to the duration of the vegetation period, it is possible to state that the impact on the productivity levels of Odeskyi 205 and Lan 59 varieties of grain sorghum in case of later application of the growth stimulator on microstage 31 by BBCH and stage IV of organogenesis by Kuperman was identical. For instance, the increase in the yield in Odeskyi 205 variety in case of applying the growth stimulator by BBCH was 0.37 t/ha, and by Kuperman – 0.30 t/ha, while for Lan 59 it was 0.25 and 0.26 t/ha respectively. Actually the deviations obtained had reliable differences compared to the control variants, but while comparing the data between the variants of growth stimulator application they were within the experimental error.

The application of Vympel 2 growth stimulator on later stages of growth and development of grain sorghum is interesting from the standpoint of the change in quality indices of the yield obtained. For instance, in case of foliar fertilization on microstage 31 by BBCH and on stage IV of organogenesis by Kuperman, the content of protein in Odeskyi 205 sorghum grain was 0.2–0.33 % above the control variant, and in Lan 59 variety it was 0.4–0.6 % higher, similarly the content of starch was 0.3–0.4 and 0.4–0.4 % higher.

In case of foliar fertilization of grain sorghum plants with Vympel 2 on microstage 37 by BBCH and stage VI-VII of organogenesis by Kuperman, the yield of Odeskyi 205 variety was 0.18 and 0.20 t/ha above the control, and that of Lan 59 – 0.18 and 0.10 t/ha which slightly exceeded the indices of the experimental error. However, quality indices of sorghum yield increased considerably compared to earlier application of the growth stimulator. For instance, the fertilization on microstage 31 by BBCH promoted the formation of protein of 11.2 % and starch – 74.1 % in Odeskyi 205 sorghum grain, and as for Lan 59 variety – 11.6 and 75.7 %. The fertilization of stage IV of organogenesis by Kuperman promoted obtaining higher content of protein in the investigated sorghum variety by 0.4 and 0.5 % and in starch by 0.9 and 0.8 % respectively.

The impact of growth stimulators on the productivity of sweet sorghum hybrids *Sorghum saccharatum (L.) Moench* of domestic selection is presented in Table 3.

The results of the studies in determining the duration of the vegetation period of sweet sorghum hybrids Huliver and Dovista demonstrate that the application of the growth stimulator Vympel 2 on early stages of their growth and development promoted the decrease in the duration of the vegetation period by 1–9 days.

In case of foliar application of Vympel 2 growth stimulator on microstage 21–24 by BBCH, Huliver hybrid plants demonstrated a decrease in the vegetation period duration by 9 days and those of Dovista hybrid – by 7 days respectively, and the introduction of the growth stimulator on stage III of organogenesis by Kuperman promoted the vegetation period by 7 and 6 days respectively.

After the application of the growth stimulator on microstage 31 by BBCH and on stage IV of organogenesis by Kuperman, we received identical results of its impact on sweet sorghum plants. The vegetation period of sweet sorghum hybrids Huliver and Dovista lasted 108 and 132 days respectively.

After the introduction of the growth stimulator Vympel 2 on microstage 37 by BBCH and stage VI-VII of organogenesis by Kuperman, the vegetation period of Huliver hybrid was 1–2 days shorter and that of Dovista 2–3 shorter compared to the control. This is another proof of low efficiency of the introduction of the growth stimulator on

later stages of sweet sorghum growth and development in terms of correcting the total duration of the vegetation period.

In the control variants of the experiment, sweet sorghum plants of Huliver hybrid formed biomass yield of 88.4–88.9 t/ha, dry matter harvest – 17.6–17.8 t/ha and the overall sugar content in stem juice – 14.5–14.6 %, while in Dovista hybrid similar indices were as follows: 92.6–93.3 t/ha, 18.4–18.7 t/ha and 15.0–15.1 %. Thus, the deviation in productivity indices and sweet sorghum quality was within the experimental error which demonstrated the uniformity of cultivation conditions and comparability of the control variant indices in the experiment.

Table 3 : The impact of growth stimulators on the productivity of sweet sorghum *Sorghumsaccharatum (L.) Moench* (average for 2016–2018)

Hybrid	The phase of foliar fertilization	Growth stimulator	Duration of vegetation period, days	Biomass productivity, t/ha	Harvest of dry matter, t/ha	Content of overall sugar, %
Huliver	Microstage 21–24 by BBCH	Control	114	88.5	17.6	14.5
		Vympel 2	105	93.5	18.9	14.9
	Stage III of organogenesis by Kuperman	Control	114	88.7	17.8	14.6
		Vympel 2	107	92.1	18.4	14.8
	Microstage 31 by BBCH	Control	114	88.4	17.8	14.5
		Vympel 2	108	90.8	18.0	15.1
	Stage IV of organogenesis by Kuperman	Control	114	88.9	17.8	14.5
		Vympel 2	108	90.9	18.2	15.0
	Microstage 37 by BBCH	Control	114	88.6	17.7	14.5
		Vympel 2	112	89.9	18.2	15.3
	Stage VI-VII of organogenesis by Kuperman	Control	114	88.5	17.6	14.6
		Vympel 2	113	89.7	18.0	15.2
Dovista	Microstage 21–24 by BBCH	Control	136	92.9	18.5	15.1
		Vympel 2	129	98.8	19.8	15.7
	Stage III of organogenesis by Kuperman	Control	136	93.0	18.7	15.0
		Vympel 2	130	97.3	19.3	15.6
	Microstage 31 by BBCH	Control	136	92.6	18.6	15.0
		Vympel 2	132	96.5	19.3	15.8
	Stage IV of organogenesis by Kuperman	Control	136	92.9	18.4	15.1
		Vympel 2	132	96.4	19.2	16.0
	Microstage 37 by BBCH	Control	136	93.2	18.5	15.0
		Vympel 2	133	95.2	19.1	16.5
	Stage VI-VII of organogenesis by Kuperman	Control	136	93.3	18.6	15.1
		Vympel 2	134	94.8	18.9	16.4
ANOVA Bonferroni			2	1.4	0.6	0.4

Foliar application of Vympel 2 growth stimulator on microstage 21–24 by BBCH promoted the formation of better indices of productivity and quality of the obtained products in the investigated hybrids of sweet sorghum. For instance, in plants of Huliver hybrid, the biomass yield was 93.5 t/ha, the dry matter harvest was 18.9 t/ha and the overall sugar content in the stem juice was 14.9 %, while these indices for Dovista hybrid amounted to 98.8 t/ha, 19.8 t/ha and 15.7 % respectively. After the introduction of a growth stimulator on the third stage of organogenesis according to Kuperman, the biomass yield of Huliver hybrid was 92.1 t/ha, the dry matter harvest – 18.4 t/ha and the content of the overall sugar in the stem juice – 14.8 %, while those of Dovista hybrid were 97.3 t/ha, 19.3 t/ha and 15.6 % respectively.

Thus, the application of the growth stimulator on microstage 21–24 by BBCH was found to be efficient both in terms of improving the general state of sweet sorghum hybrid plants under investigation, and in their formation of reliable gains in biomass yield and dry matter harvest. The application of the growth stimulator on stage III of organogenesis by Kuperman was found to be less efficient compared to the first term of introduction, though the obtained increase in biomass yield and dry matter harvest reliably exceeded ANOVA indices with Bonferonni correction. After early application of plant growth stimulators, the parameters of overall sugar in stem juice of sweet sorghum hybrid plants under investigation had no reliable differences from the control variants.

After the introduction of Vympel 2 growth stimulator on microstage 31 by BBCH, the increase in biomass yield for Huliver hybrid was 2.4 t/ha and that in dry matter harvest – 0.2 t/ha, while 0.6 % more sugar was accumulated in stem juice compared to the control, and in Dovista hybrid the increase was 3.9 t/ha, 0.7 t/ha and 0.8 % respectively. On applying the growth stimulator in the phase, corresponding to stage IV of organogenesis by Kuperman, we obtained similar indices of yield gain and better produce quality which confirmed the statement about the identical data.

When the growth stimulator was applied later, on microstage 37 by BBCH and stage VII of organogenesis by Kuperman, the biomass gain in sweet sorghum of Huliver hybrid was 1.3 and 1.2 t/ha, and Dovista – 2.0 and 1.5 t/ha respectively. Therefore, only the increase in biomass yield in Dovista hybrid exceeded HIP indices, whereas the values of

Huliver hybrid were within the experimental error. Thus, the application of complex growth stimulators on later stages of sweet sorghum growth and development is less efficient in terms of their forming high productivity level.

Contrary to productivity, quality indices of sweet sorghum plants differed considerably from the control variants in case of foliar fertilization on microstage 37 by BBCH and stage VI-VII of organogenesis by Kuperman. It was determined that the overall sugar content in stem juice in Huliver hybrid was 0.8 and 0.6 % above the control, and that of Dovista hybrid – 1.5 and 1.3 % higher.

Therefore, the application of foliar treatment with growth stimulators in the period of active growth and development of sweet sorghum plants can improve the quality of the obtained produce considerably due to enhancing the general physiological state of plants and activation of growth processes. No considerable impact on the biomass formation was observed, which is related both to the specificities of the impact of growth stimulators on sorghum plants and by the fact that usually prior to anthesis the plants accumulate up to 50 % of their whole biomass on average (Lambright, 2019; Kraig *et al.*, 2019).

DISCUSSION

The main differences between the scales, analyzed by us, lie not only in the specificities of growth and development stage classification for sorghum crops but also in the methods of determining them. For instance, Kuperman scale has 12 stages of organogenesis, each of them is characterized by the state of the apical dome, while BBCH scale consists nine phenological macro- and 99 microstages. Feekes scale indicates sorghum development stages from 1 to 11, while Keller and Baggiolini scale is in fact the extended Feekes scale, but development stages in it are coded with letters (Thomas, 2014; Meier, 1997; Hess *et al.*, 1997; Kuperman, 1984; Zadoks *et al.*, 1974).

As the first half of Kuperman scale (stages I–VII of organogenesis) classifies growth and development stages of sorghum crops based on the state of the apical dome, domestic scientific literature has many examples of using only its part without sufficient detailing of early stages of growth and development. Accurate determination of early stages by this scale is complicated without the morphophysiological analysis (Fedorchuk *et al.*, 2017).

At present there are many articles on the issues of studying the specificities of growth and development of sorghum crops (Hill and Li, 2016; Olugbemi and Ababyomi, 2016), but the data on comparing the efficiency and convenience of using different scales are absent.

Initial slow and long growth of the vegetative part of a plant for the first 30–41 days since germination leads to acute response of sorghum to compliance with all the requirements of the cultivation technology in this very period. Currently scientists conduct active studies of both the issue of specificities of growth and development of sorghum crops and the ways of enhancing the efficiency of their cultivation via optimization of agrotechnical procedures according to the physiological needs of plants in different phases of their growth and development (Masaka *et al.*, 2019; Saadat and Homaee, 2015; Calvino and Messing, 2012).

The application of growth stimulators is an efficient agrotechnical procedure for reliable enhancing of growth and development and thus the level of productivity and quality of the obtained yield of sorghum crops. The articles of other scientists also highlight the fact that growth stimulators impact both the rate of photosynthesis processes and growth and development of plants, and their total resistance to unfavorable cultivation conditions (moisture deficiency, high air temperature, etc) (Stipešević *et al.*, 2018; Sebrina *et al.*, 2020; Narayanan *et al.*, 2013; Sharma *et al.*, 2004). Our studies confirmed high efficiency of applying Vympel 2 growth stimulator on growth and development, and formation of sorghum productivity. The application of the growth stimulator as a component of cultivation technology on early stages of sorghum plant development is more efficient based on the data of BBCH scale, which does not require morphophysiological analysis to identify the state of plants.

CONCLUSIONS

Timely and accurate identification of the correspondence between physical and biological time of plant development is a decisive factor in elaborating the strategy of managing the productivity of sorghum crops. The knowledge of specificities of the course of stages and microstages of development for plants is of utmost relevance in creating efficient technological maps of cultivating, applying agrotechnologies, which allow avoiding or minimizing stress conditions in plants, and using additional agromeasure of enhancing the productivity level efficiently.

The application of foliar fertilization on early stages of sorghum growth and development to stimulate growth processes in crops requires accurate identification of organogenesis stages or microstages of growth and development of plants. The application of the scale, developed by F.M. Kuperman, on early stages of sorghum growth and development does not always allow for accurate determination of organogenesis stages, as the identification method is too complicated in practice and requires morphophysiological analysis. It was determined that after foliar application of Vympel 2 growth stimulator in the phase of stage III of organogenesis by Kuperman, grain sorghum plants formed an increase in grain yield within 0.36–0.37 t/ha compared to the control. In case of introducing the stimulator on microstage 21–24 by BBCH the obtained gain was 0.48–0.56 t/ha compared to the control. Similarly, the increase in the biomass yield of sweet sorghum was 3.4–4.3 t/ha in the first case, and 5.0–5.9 t/ha in the second one, respectively. Thus, on early stages of growth and development of sorghum crops, it is better to use the data about microstages by BBCH scale to plan agrotechnical procedures of introducing growth stimulators.

Foliar fertilization on later stages of growth and development of sorghum crops, aimed at forming higher quality of the produce, does not require accurate identification of microstages of plant growth and development; thus, it is possible to determine the time of applying stimulators efficiently both based on the data of BBCH scale, and on the scale, developed by F.M. Kuperman. It was determined that after the application of Vympel 2 growth stimulator on microstage 37 by BBCH and stage VI-VII of organogenesis by Kuperman, the protein contentin grain sorghum kernel increased by 0.4–0.5 %, and that of starch – by 0.7–0.9 %. In a similar way, the application of the

growth stimulator to treat the fields of sweet sorghum promoted the increase in overall sugar in stem juice by 0.6–1.5 %.

Adherence to ethical principles. The investigations, highlighted in this article, did not involve humans or animals.

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