International Journal of Botany Studies
www.botanyjournals.com
ISSN: 2455-541X
Received: 04-04-2022, Accepted: 20-04-2022, Published: 06-05-2022
Volume 7, Issue 5, 2022, Page No. 19-31

The effect of pyrimidine and pyridine derivatives on the growth and productivity of Sorghum

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Abstract

The effect of derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur and Kamethur) and N-oxide-2,6-dimethylpyridine (Ivin) on growth and productivity of various cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) and sweet sorghum (*Sorghum saccharatum* (L.) Moench) was studied. It was found that soaking seeds with water solutions of Methyur, Kamethur and Ivin used at a concentration of 10^{-7}M before sowing them into the soil contributed to improve the growth of sorghum and increase their productivity. The obtained results testify to the cultivar-dependent action of chemical compounds derivatives of pyrimidine and pyridine. The possibility of practical application of Methyur, Kamethur and Ivin as new effective regulators of sorghum growth is discussed.

Keywords: sorghum, pyrimidine, pyridine, growth, productivity

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the important cereal food, fodder and technical crops grown in many countries around the world [1, 2]. Sorghum ranks fifth in the world after wheat, rice, corn and barley. Currently, sorghum is grown on almost all continents, over the past 50 years, the sorghum sown areas in the world amount to almost 44 million hectares [2].

Sorghum is one of the crops that, at relatively low cost, brings farmers a steady income. Grain sorghum ranks fourth after wheat, rice and corn in world production. The main producers of grain sorghum are China, Pakistan, India, Korea, Thailand, United States of America, Mexico, Argentina, Nicaragua, Peru, Uruguay, Honduras, Brasil, Colombia, El Salvador, Guatemala, Haiti, Venezuela, France, Italy, Spain, Romania, Albania, Israel, Jordan, Australia, Southern Ukraine [2, 3].

As a food plant, sorghum is in third place after wheat and rice. Sorghum grain is processed into cereals, flour and starch [4, 5]. The fraction of sorghum grain endosperm is rich in protein (80%), starch (94%) and B-complex vitamins (50 to 75%), and the germ fraction of sorghum contains more than 68% of the total mineral matter, 75% oil, 15% protein and B-complex vitamins [5]. Sorghum does not contain gluten, so to improve the quality of baking, wheat flour is added to sorghum. Sorghum flour is used to make porridge, cakes, drinks, and is added to the first and second courses.

Sorghum is also valued for its high feed quality, sorghum grain contains about 92.50 % dry matter, 3270.00 kcal/kg metabolizable energy, 9.50 % crude protein, 2.55 % ether extract, 2.70 % crude fiber, 1.25 % ash and 76.60 % nitrogen free extract (NFE) [6]. Its protein is slightly higher than maize but as with most cereals it is deficient in lysine and tryptophan [6].

Sweet sorghum (*Sorghum saccharatum* (L.) Moench), enriched with stem sugar, belongs to the subspecies of sorghum (*Sorghum bicolor* (L.) Moench), which is used for the production of sugar, syrups, molasses and honey [7-9].

Sorghum, along with corn, is the main crop for bioethanol production [3, 10-12]. It is estimated that 650-700 kg of starch or 300-350 liters of alcohol can be obtained from 1 ton of sorghum grain, which is 35 liters more than from 1 ton of corn [10]. Sweet sorghum, due to its biomass yield and high concentration of easily fermentable sugars in juice and bagasse, is also used for ethanol production [7]. Residues of sorghum after juice removal and after harvesting can be used as an alternative source for the production of solid biofuels (biobutanol, biogas, fuel pellets, etc.), as the productivity of sorghum on biomass reaches 20-25 tons of dry weight per hectare [3, 10-14]. At a humidity of 15-20%, the energy value during the combustion of sorghum residues is 10-12 MJ/kg. The use of granulation and briquetting technologies allows improving the energy performance of biomass residues.

The main advantage of sorghum is its high drought tolerance and unpretentiousness to soils, which makes this crop especially important in the context of global climate change [15]. However, there are problems with growing sorghum under adverse environmental conditons; for this purpose, plant growth regulators are used to improve growth and increase productivity of sorghum [16, 17].

In recent decades, new effective plant growth regulators based on synthetic low molecular weight heterocyclic compounds belonging to azoles, azines and their condensed derivatives have been developed in the V.P. Kukchar Institute of Bioorganic Chemistry and Petrochemistry, NAS of Ukraine [18-21].

Among these classes of chemical compounds, the most promising for practical use are synthetic derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur and Kamethur) and N-oxide-2, 6-dimethylpyridine (Ivin). Our studies of these compounds in the laboratory and in the field conditions showed their high phytohormone-like regulatory activity on major crops (corn, barley, oats, sorghum, beets, lettuce) [22-24].

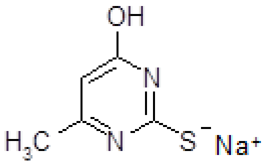
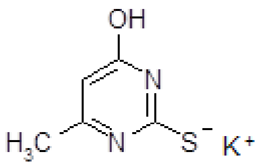
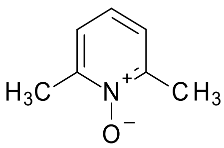
The purpose of this work is to study the effect of derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur and Kamethur) and N-oxide-2,6-dimethylpyridine (Ivin) on growth and productivity of various cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) and sweet sorghum (*Sorghum saccharatum* (L.) Moench) grown in the field conditions.

Materials and methods

Chemical compounds studied in the experiment

Chemical compounds derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur and Kamethur) and N-oxide-2,6-dimethylpyridine (Ivin) were synthesized in the Department for Chemistry of Bioactive Nitrogen-Containing Heterocyclic Compounds, V. P. Kukchar Institute of Bioorganic Chemistry and Petrochemistry of the National Academy of Sciences of Ukraine (Table 1).

Table 1: Chemical name, structure and relative molecular mass of chemical compounds

Chemical compounds №	Chemical structure	Chemical name and relative molecular weight
1		Sodium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur) MW=165.17
2		Potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Kamethur) MW=181.28
3		N-oxide-2,6-dimethylpyridine (Ivin) MW=125.17

Plant material

Seeds of grain sorghum (*Sorghum bicolor* (L.) cultivars Steppe, Yarona, and sweet sorghum (*Sorghum saccharatum* (L.) Moench) cultivars Favorite, Medster, Dovista, Silosne 42 were obtained from Mykolayiv National Agrarian University (MNAU), Ukraine.

Plant growth conditions

Experiments were conducted in the field of the Mykolayiv National Agrarian University (MNAU), Ukraine. Sorghum seeds were superficially sterilized with 1 % KMnO4 solution for 3 min, then sterilized with 96 % ethanol solution for 1 min, after which they were washed three times with sterile distilled water. After this procedure, the seeds were soaked in distilled water (control) or water solutions of any compound: Methyur, Kamethur or Ivin at the concentration of 10^{-7}M (experiment) for 24 hours.

Then the treated seeds were dried and planted in the soil. Field experiments were conducted in accordance with the methodology described in the manual [25]. Comparative analysis of growth parameters: the average length of root (in mm) and the average fresh weight of plant (in gram) of sorghum grown for 2 month in the field, and productivity parameters: the average panicle length (in cm) and the average fresh weight of grain (in gram) of sorghum grown for 4 month in the field was carried out according to the guidelines [26].

Statistical Analysis. All experiments were performed in three replicates. Statistical analysis of the data was performed using dispersive Student's-t test with the level of significance at $P \leq 0.05$, the values are mean ± SD [27].

Results

Effect of Methyur, Kamethur and Ivin on growth of sorghum

The results of field studies showed that the growth parameters of various cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) and sweet sorghum (*Sorghum saccharatum* (L.) Moench) (the average length of root (in mm), the average fresh weight of plant (in gram)) obtained from seeds soaked in water solutions of any compound Methyur, Kamethur or Ivin at a concentration of 10^{-7}M, exceeded that of control plants obtained from seeds soaked in distilled water as follows: the average length of root increased by 12-87%, and the average fresh weight of plant increased by 7-67%, compared to the control (Fig. 1 – Fig. 6).

It was found that the growth parameters of experimental grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Steppe exceeded that of control plants (Fig. 1, A , B and C). The average length of root increased as follows: by 87% - in plants obtained from seeds soaked in Kamethur, by 56% - in plants obtained from seeds soaked in Methyur, by 37% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of plant increased as follows: by 49% - in plants obtained from seeds soaked in Kamethur, by 51% - in plants obtained from seeds soaked in Methyur, by 30% - in plants obtained from seeds soaked in Ivin, compared to the control.

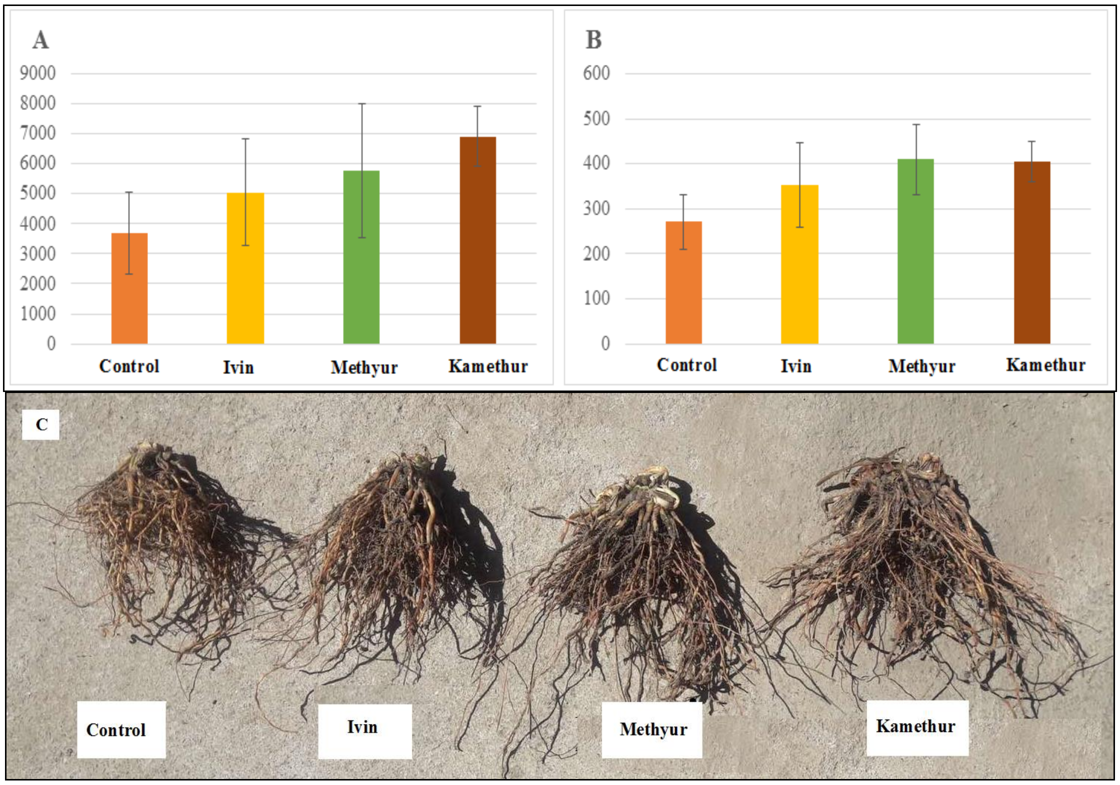


Fig 1: The growth parameters of grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Steppe grown for 2 month in the field: A - the average length of root (in mm), B - the average fresh weight of plant (in gram), C – sorghum roots

The growth parameters of experimental grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Yarona exceeded that of control plants (Fig. 2, A, B and C). The average length of root increased as follows: by 15% - in plants obtained from seeds soaked in Kamethur, by 14% - in plants obtained from seeds soaked in Methyur, by 29% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of plant increased as follows: by 67% - in plants obtained from seeds soaked in Kamethur, by 53% - in plants obtained from seeds soaked in Methyur, by 21% - in plants obtained from seeds soaked in Ivin, compared to the control.

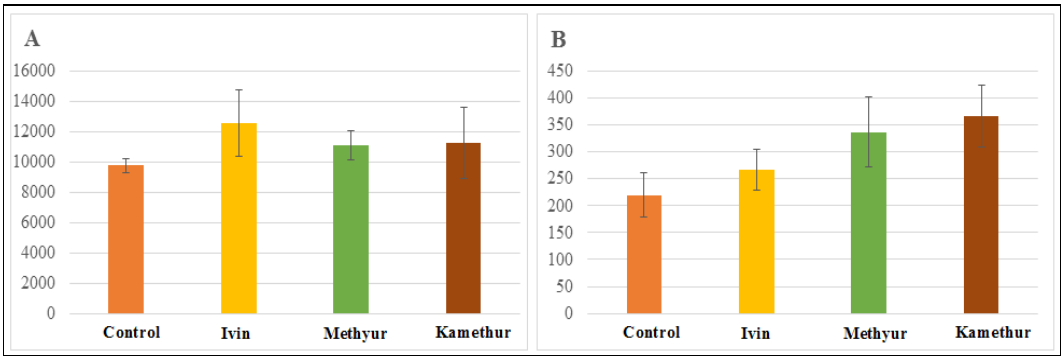


Fig 2: The growth parameters of grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Yarona grown for 2 month in the field: A - the average length of root (in mm), B - the average fresh weight of plant (in gram), C – sorghum roots

The growth parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Favorite exceeded that of control plants (Fig. 3, A, B and C).

The average length of root increased as follows: by 20% - in plants obtained from seeds soaked in Kamethur, by 40% - in plants obtained from seeds soaked in Methyur, by 25% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of plant increased as follows: by 7% - in plants obtained from seeds soaked in Kamethur, by 57% - in plants obtained from seeds soaked in Methyur, by 30% - in plants obtained from seeds soaked in Ivin, compared to the control.

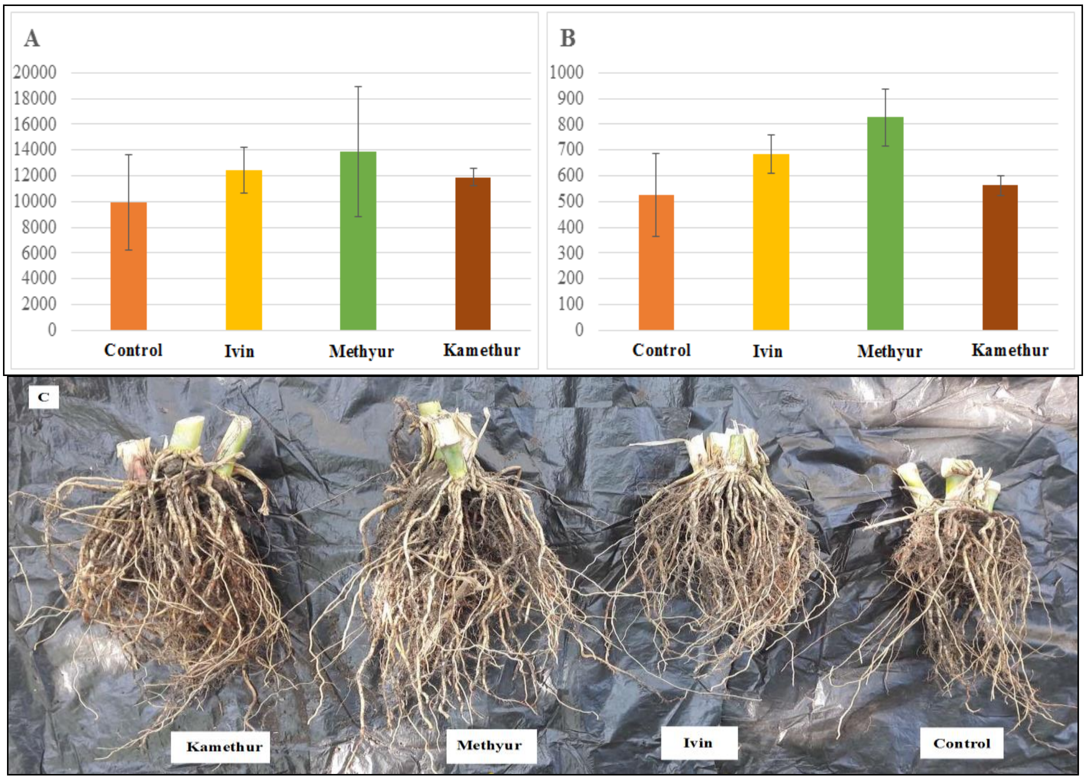


Fig 3: The growth parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Favorite grown for 2 month in the field: A - the average length of root (in mm), B - the average fresh weight of plant (in gram), C – sorghum roots

The growth parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Medster exceeded that of control plants (Fig. 4, A, B and C). The average length of root increased as follows: by 12% - in plants obtained from seeds soaked in Kamethur, by 28% - in plants obtained from seeds soaked in Methyur, by 24% - in plants obtained from seeds soaked in Ivin, compared to the control.

The average fresh weight of plant increased as follows: by 60% - in plants obtained from seeds soaked in Kamethur, by 67% - in plants obtained from seeds soaked in Methyur, by 46% - in plants obtained from seeds soaked in Ivin, compared to the control.

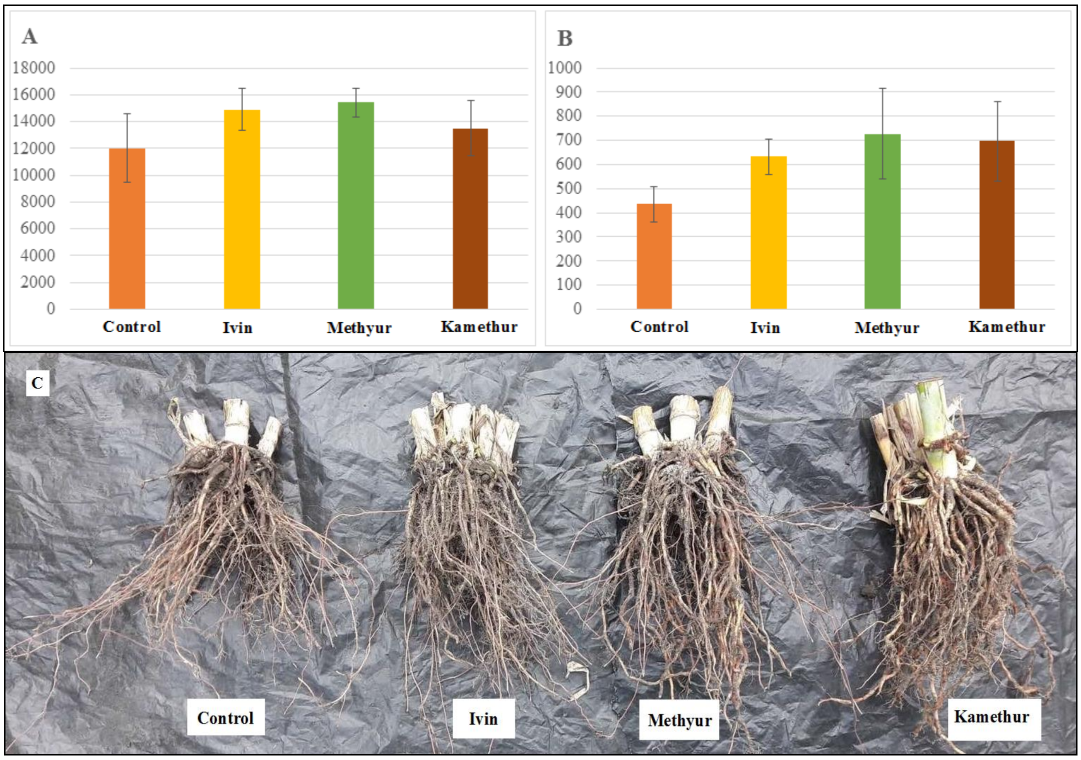


Fig 4: The growth parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Medster grown for 2 month in the field: A - the average length of root (in mm), B - the average fresh weight of plant (in gram), C – sorghum roots

The growth parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Dovista exceeded that of control plants (Fig. 5, A, B and C). The average length of root increased as follows: by 22% - in plants obtained from seeds soaked in Kamethur, by 14% - in plants obtained from seeds soaked in Methyur, by 19% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of plant increased as follows: by 30% - in plants obtained from seeds soaked in Kamethur, by 34% - in plants obtained from seeds soaked in Methyur, by 30% - in plants obtained from seeds soaked in Ivin, compared to the control.

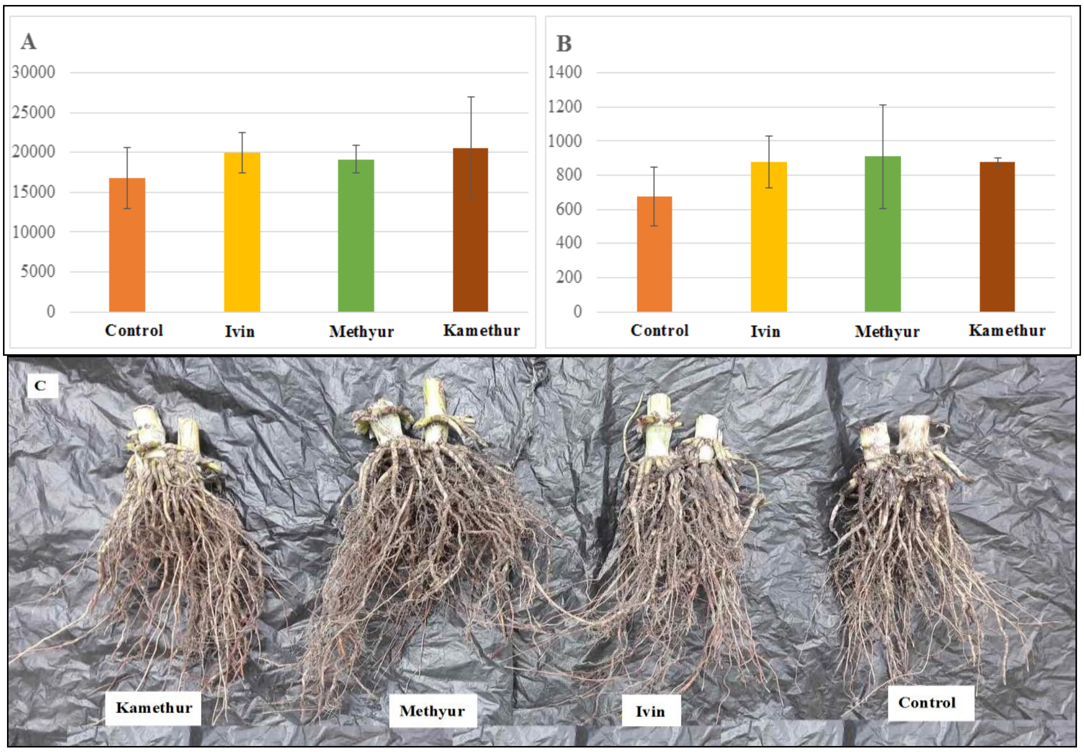


Fig 5: The growth parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Dovista grown for 2 month in the field: A - the average length of root (in mm), B - the average fresh weight of plant (in gram), C – sorghum roots

The growth parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Silosne 42 exceeded that of control plants (Fig. 6, A, B and C). The average length of root increased as follows: by 25% - in plants obtained from seeds soaked in Kamethur, by 61% - in plants obtained from seeds soaked in Methyur, by 24% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of plant increased as follows: by 21% - in plants obtained from seeds soaked in Kamethur, by 35% - in plants obtained from seeds soaked in Methyur, by 22% - in plants obtained from seeds soaked in Ivin, compared to the control.

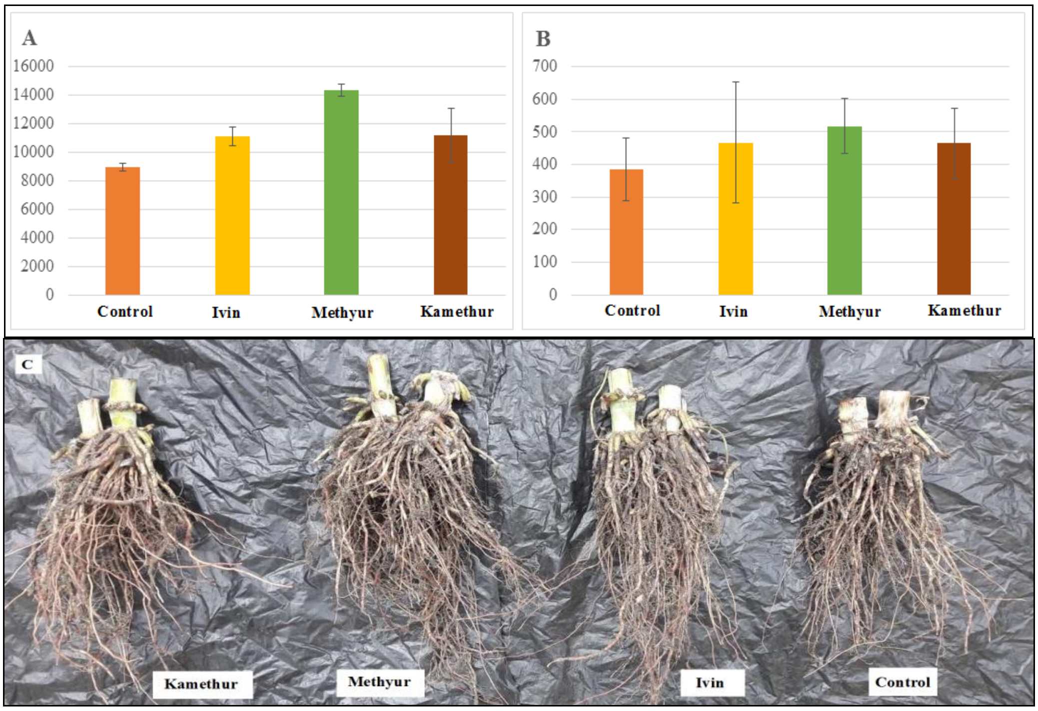


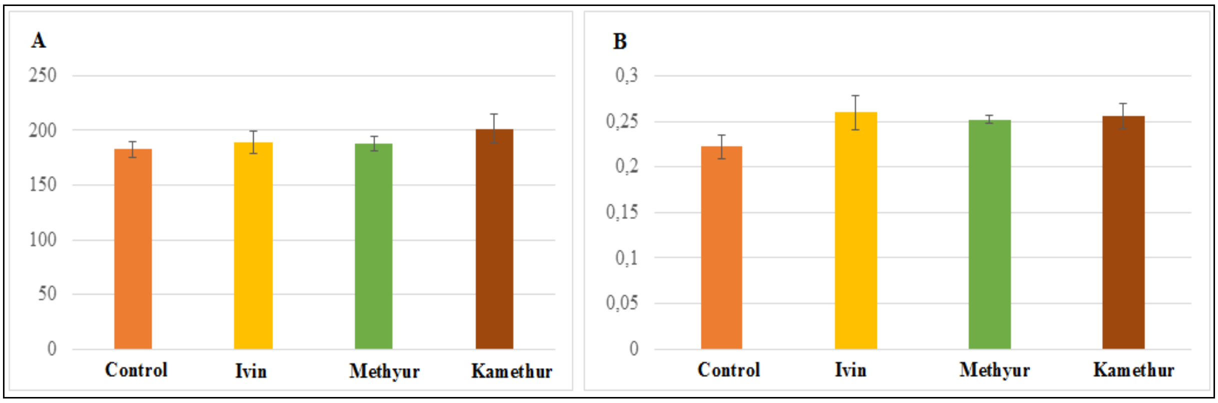
Fig 6: The growth parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Silosne 42 grown for 2 month in the field: A - the average length of root (in mm), B - the average fresh weight of plant (in gram), C – sorghum roots

Effect of Methyur, Kamethur and Ivin on productivity of sorghum

The results of field studies showed that the productivity parameters of various cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) and sweet sorghum (*Sorghum saccharatum* (L.) Moench) (panicle length (in cm), fresh weight of grain (in gram)) obtained from seeds soaked in water solutions of any compound Methyur, Kamethur or Ivin at a concentration of 10^{-7}M, exceeded that of control plants obtained from seeds soaked in distilled water as follows: the average panicle length increased by 3-50 %, the average fresh weight of grain increased by 8–38 %, compared to the control (Fig. 7 - Fig. 12).

The productivity parameters of experimental grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Steppe exceeded that of control plants (Fig. 7, A, B and C).

The average length of the panicle increased as follows: by 10% - in plants obtained from seeds soaked in Kamethur, by 3% - in plants obtained from seeds soaked in Methyur, by 3% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of grain increased as follows: by 15% - in plants obtained from seeds soaked in Kamethur, by 14% - in plants obtained from seeds soaked in Methyur, by 17% - in plants obtained from seeds soaked in Ivin, compared to the control.



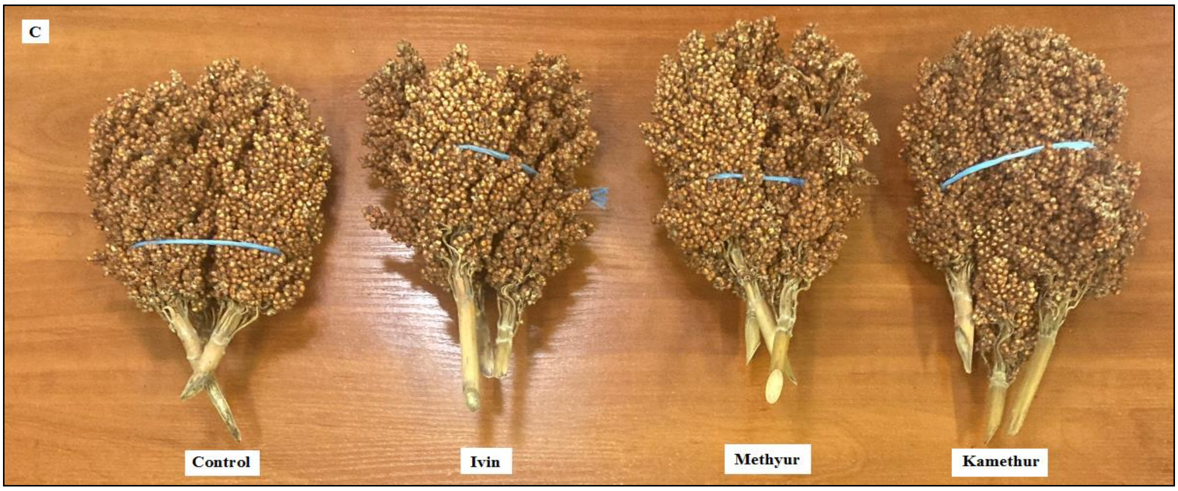


Fig 7: The productivity parameters of grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Steppe grown for 4 month in the field: A - panicle length (in cm), B - fresh weight of grain (in gram), C – panicles with sorghum grains

The productivity parameters of experimental grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Yarona exceeded that of control plants (Fig. 8, A, B and C). The average length of the panicle increased as follows: by 7% - in plants obtained from seeds soaked in Kamethur, by 20% - in plants obtained from seeds soaked in Methyur, by 17% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of grain increased as follows: by 22% - in plants obtained from seeds soaked in Kamethur, by 26% - in plants obtained from seeds soaked in Methyur, by 13% - in plants obtained from seeds soaked in Ivin, compared to the control. The productivity parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Favorite exceeded that of control plants (Fig. 9, A, B and C). The average length of the panicle increased as follows: by 36% - in plants obtained from seeds soaked in Kamethur, by 37% - in plants obtained from seeds soaked in Methyur, by 25% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of grain increased as follows: by 24% - in plants obtained from seeds soaked in Kamethur, by 38% - in plants obtained from seeds soaked in Methyur, by 35% - in plants obtained from seeds soaked in Ivin, compared to the control.

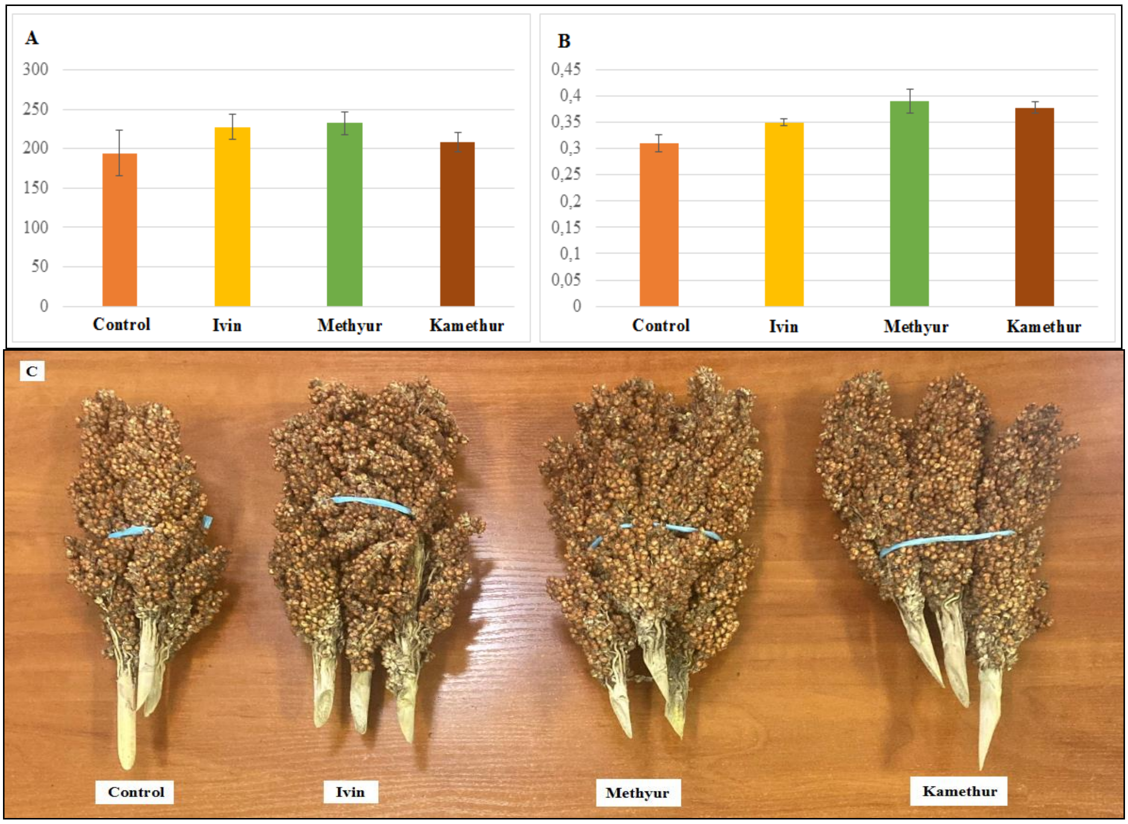


Fig 8: The productivity parameters of grain sorghum (*Sorghum bicolor* (L.) Moench) cv. Yarona grown for 4 month in the field: A – the average panicle length (in cm), B - the average fresh weight of grain (in gram), C – panicles with sorghum grains

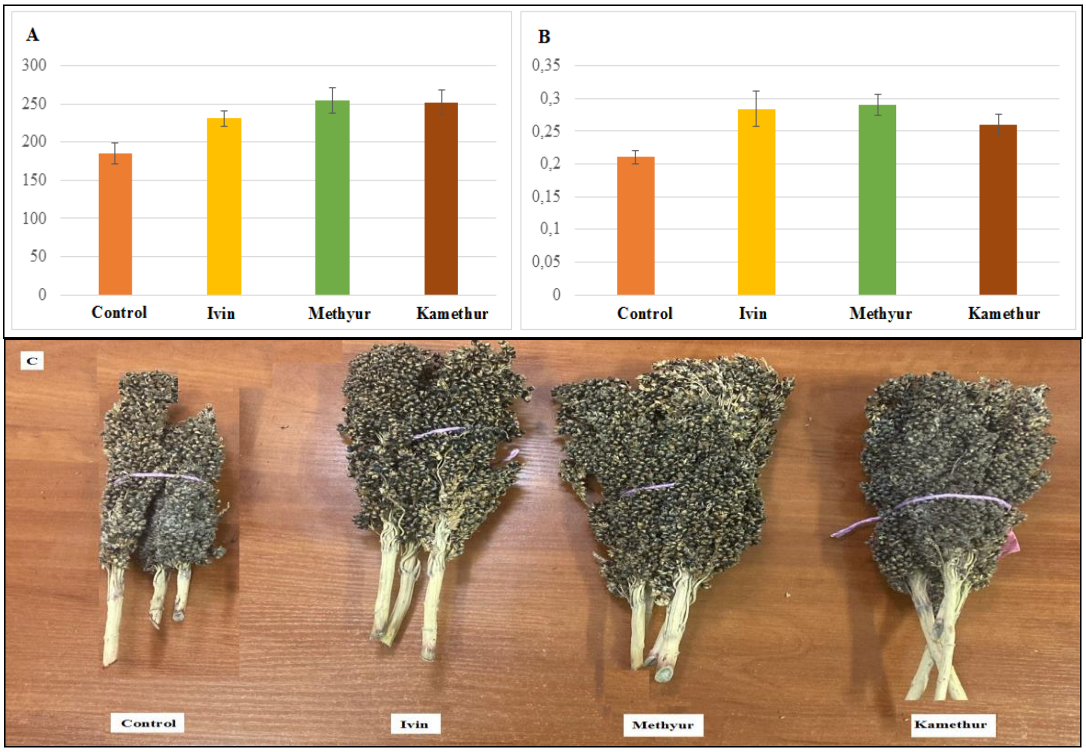


Fig 9: The productivity parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Favorite grown for 4 month in the field: A – the average panicle length (in cm), B – the average fresh weight of grain (in gram), C – panicles with sorghum grains

The productivity parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Medster exceeded that of control plants (Fig. 10, A, B and C). The average length of the panicle increased as follows: by 12% - in plants obtained from seeds soaked in Kamethur, by 21% - in plants obtained from seeds soaked in Methyur, by 25% - in plants obtained from seeds soaked in Ivin, compared to the control. The average fresh weight of grain increased as follows: by 17% - in plants obtained from seeds soaked in Kamethur, by 11% - in plants obtained from seeds soaked in Methyur, by 12% - in plants obtained from seeds soaked in Ivin, compared to the control.

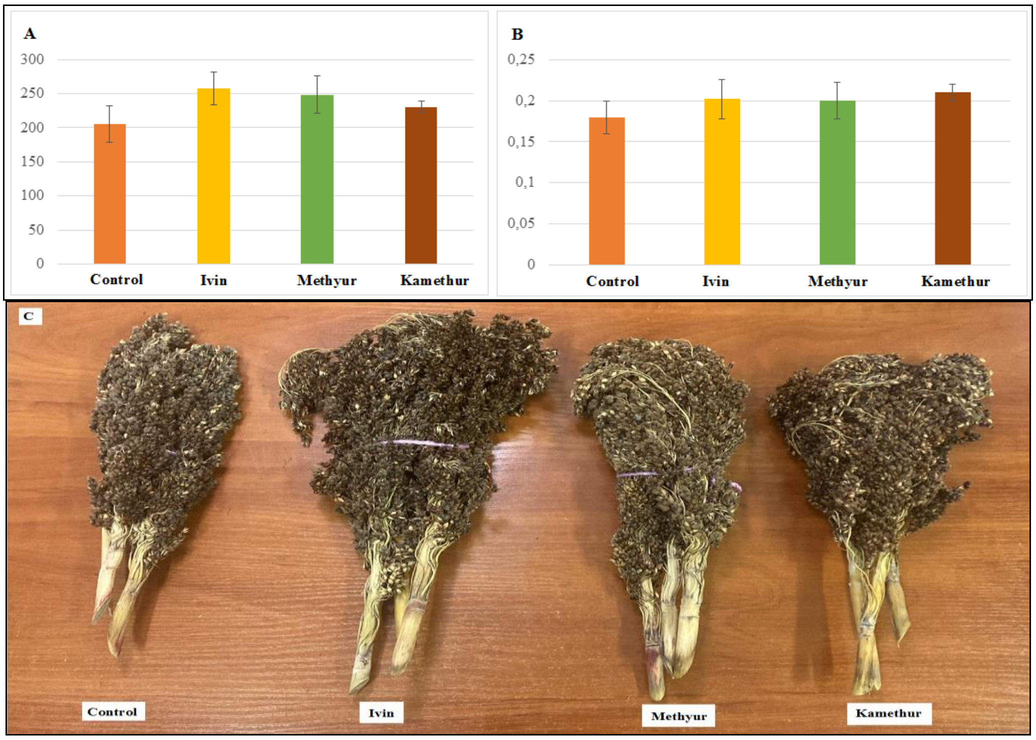


Fig 10: The productivity parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Medster grown for 4 month in the field: A – the average panicle length (in cm), B – the average fresh weight of grain (in gram), C – panicles with sorghum grains

The productivity parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Dovista exceeded that of control plants (Fig. 11, A, B and C).

The average length of the panicle increased as follows: by 50% - in plants obtained from seeds soaked in Kamethur, by 38% - in plants obtained from seeds soaked in Methyur, by 12% - in plants obtained from seeds soaked in Ivin, compared to the control.

The average fresh weight of grain increased as follows: by 19% - in plants obtained from seeds soaked in Kamethur, by 16% - in plants obtained from seeds soaked in Methyur, by 15% - in plants obtained from seeds soaked in Ivin, compared to the control.

The productivity parameters of experimental sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Silosne 42 exceeded that of control plants (Fig. 12, A, B and C).

The average length of the panicle in plants obtained from seeds soaked in Methyur increased by 13%, compared to the control. The average fresh weight of grain increased as follows: by 22% - in plants obtained from seeds soaked in Kamethur, by 8% - in plants obtained from seeds soaked in Methyur, by 15% - in plants obtained from seeds soaked in Ivin, compared to the control.

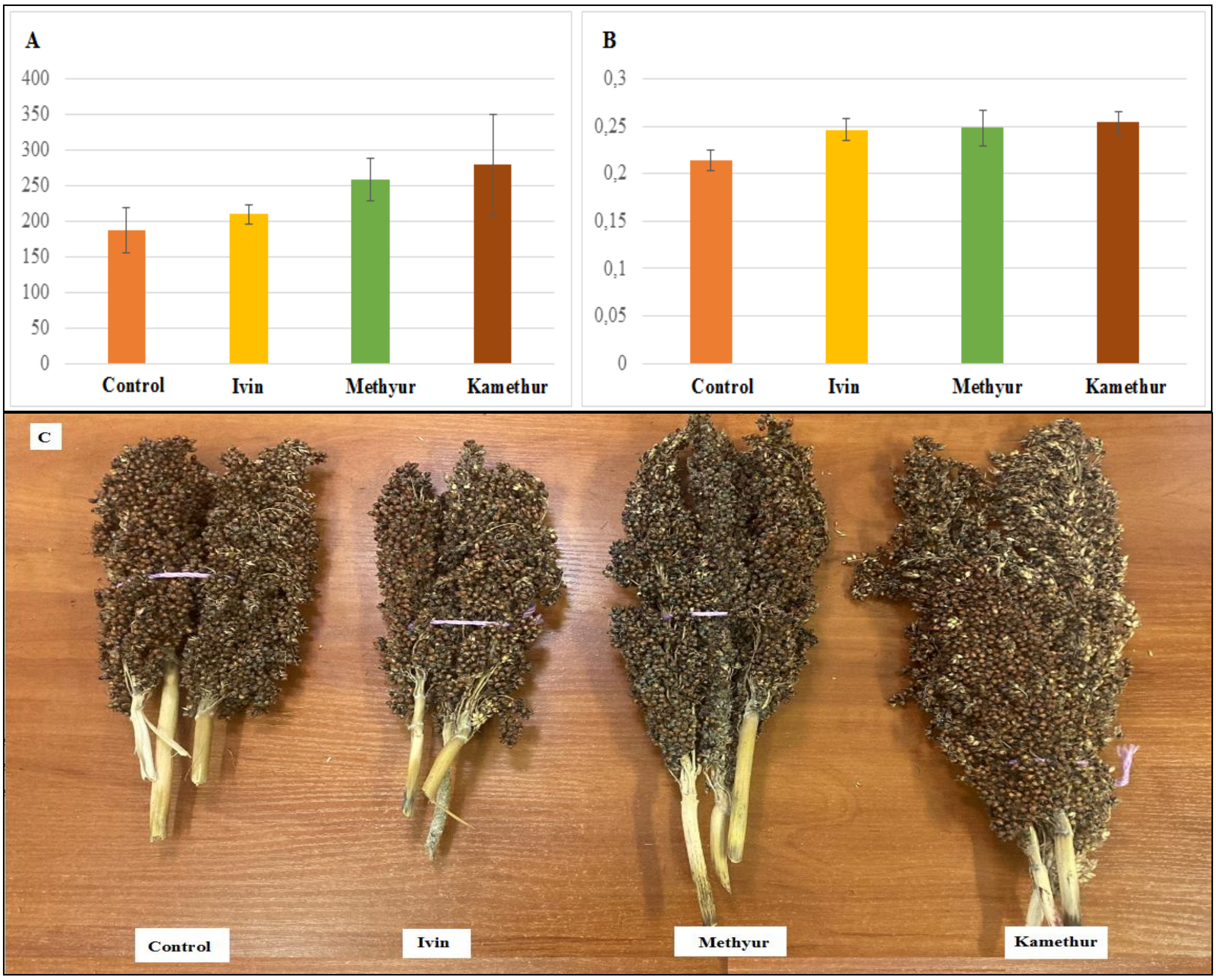
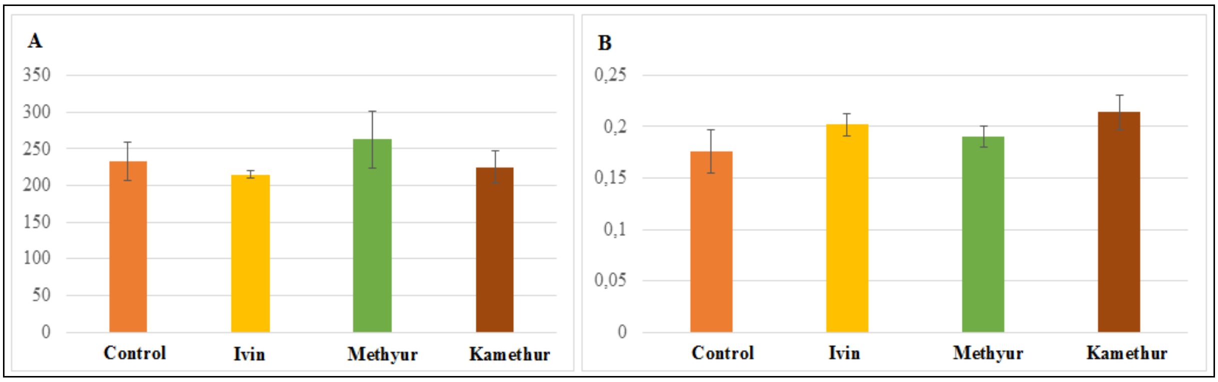


Fig 11: The productivity parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Dovista grown for 4 month in the field: A – the average panicle length (in cm), B – the average fresh weight of grain (in gram), C – panicles with sorghum grains



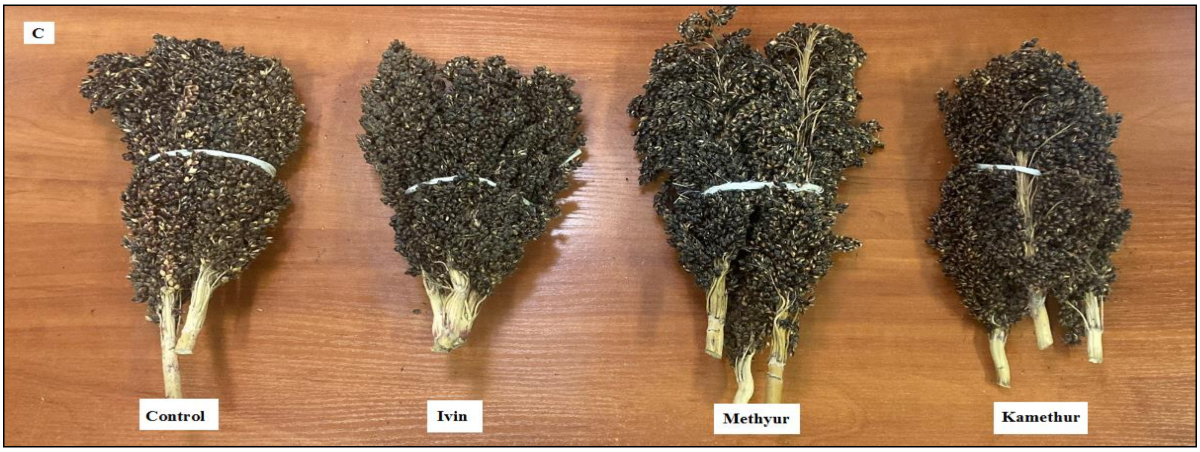


Fig 12: The productivity parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench) cv. Silosne 42 grown for 4 month in the field: A – the average panicle length (in cm), B – the average fresh weight of grain (in gram), C – panicles with sorghum grains

Discussion

Global climate change and chemical pollution of the environment with toxic waste from industrial and agricultural production are the two most important elements affecting the growth and development of plants, which leads to a decrease in product quality and plant resistance to abiotic and biotic stresses [28-30]. The relevance of the problem of developing a technology for growing crops to increase productivity and enhance plant adaptation to abiotic and biotic stresses is currently very significant.

Among the approaches used, one of the potential methods is the use of phytohormones or their chemical analogues for the treatment of plant seeds before planting, as well as plants during the growing season. In addition to the conventional plant growth regulators used, low molecular weight synthetic heterocyclic compounds related to pyridine and pyrimidine derivatives have recently been proposed as new plant growth regulating substances, herbicides and fungicides [31-35]. The advantage of using these classes of chemical compounds for plant treatment is their high efficiency at low concentrations (10^{-6}M–10^{-9}M) and the absence of a toxic effects on the cells of eukaryotic organisms, i.e. environmental safety. The use of synthetic low molecular weight heterocyclic compounds in low environmentally friendly concentrations of 10^{-6}M-10^{-9}M reduces the negative effects of toxic to humans and animals chemical pesticides and conventional growth regulators, the excess of which accumulates in soils and crops that are products of human and animal consumption [36-38].

New effective plant growth regulators based on synthetic low molecular weight heterocyclic compounds include derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur and Kamethur) and N-oxide-2, 6-dimethylpyridine (Ivin). The results of our works [22-24] and works of other authors [39] indicate that pyrimidine derivatives Methyur and Kamethur, and pyridine derivative Ivin show similar activity to plant hormones auxins and cytokinins on the processes of cell elongation and division, activation of photosynthetic processes, increasing of protein biosynthesis and activity of antioxidant enzymes in plant cells. Field studies have shown that the chemical compounds Methyur, Kamethur and Ivin significantly improve the growth and development of major crops (corn, barley, oats, sorghum, beets, lettuce) during their ontogenesis, increase plant productivity and improve their adaptation to abiotic stressors such as salinity and water deficiency [22-24, 39].

Our studies of the molecular mechanisms of action of the chemical compounds Methyur and Ivin showed their stimulating effect on changes in gene expression at the level of transcription and translation of genetic information, due to which the time of plant ontogenesis is reduced by almost half [40]. Our studies have shown that the pyrimidine derivative Methyur has a stimulating effect on the biosynthesis of the protein component of the secondary cell wall – extensin, which plays an important role in plant resistance to abiotic stressors [40]. We also found that the chemical compounds Methyur and Ivin can affect plant growth indirectly, through the endogenous pool of phytohormones in plant cells [41]. We suggested that the regulatory action of chemical compounds Methyur, Kamethur and Ivin may be related to their auxin and cytokinin-like effects on cell elongation, cell division and cell differentiation, which are the main processes of formation and development of shoot and root meristems in plants [42, 43].

Based on the above, the development of new effective plant growth regulators based on pyrimidine derivatives Methyur and Kamethur, and pyridine derivative Ivin to improve the growth and productivity of sorghum is a very important issue.

Conclusions

The results of the present work showed that under conditions of sorghum seed treatment before planting in the soil with water solutions of chemical compounds Methyur, Kamethur and Ivin, there was an improvement in the growth and productivity of sorghum. The cultivar-dependent action of chemical compounds derivatives of pyrimidine and pyridine was observed.

The growth parameters of various cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) and sweet sorghum (*Sorghum saccharatum* (L.) Moench) obtained from seeds soaked in water solutions of any compound Methyur, Kamethur or Ivin at a concentration of 10^{-7}M, exceeded that of control plants as follows: the average length of root increased by 12-87%, and the average fresh weight of plant increased by 7-67%, compared to the control.
The productivity parameters of various cultivars of grain sorghum (*Sorghum bicolor* (L.) Moench) and sweet sorghum (*Sorghum saccharatum* (L.) Moench) obtained from seeds soaked in water solutions of any compound Methyur, Kamethur or Ivin at a concentration of 10^{-7}M, exceeded that of control plants as follows: the average panicle length increased by 3-50 %, and the average fresh weight of grain increased by 8–38 %, compared to the control.
The obtained results confirmed the possibility of practical application of Methyur, Kamethur and Ivin as new effective regulators of sorghum growth.

Acknowledgment
We are thankful to the Mykolayiv National Agrarian University (MNAU) for providing sorghum seeds and agricultural equipment for field experiments.

Conflicts of Interest
The authors declare no conflict of interest.

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