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# Physical characteristics of the grain of corn hybrid Knezha-435 depending on the system mineral fertilization

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**Abstract:** The experiment was conducted at the stationary field trail of DAI General Toshevo. Based on different fertilizer rates (0, 60, 120 and 180 N and respectively $P_2O_5$ kg/ha and potassium – 0, 60 and 120 $K_2O$ kg/ha) the dynamics of the physical characteristics of the corn grain (hybrid Knezha-435) for the period 2020-2023 was established. The research period is characterized by a very pronounced influence of meteorological conditions on the values of the physical characteristics of the grain at the tested rates and ratios between NPK in the fertilizer rate. The conditions of 2022 are particularly favorable for the formation of the largest grain - an average of 290.8 g/1000 grains in combination with the highest average values per hectoliter (79.6 kg). The year was characterized by increasing values of the 1000 grain as a result of nitrogen fertilization – alone and in combination with PK. In the group of combinations of $N_{180}$, an average value of 305.8 g was reached, and the maximum value (328.3 g) was established in the combination $N_{180}P_0K_{60}$. The combination of meteorological components of 2020 and especially 2023 lead to the formation of grain with lower average values - 243.3 g and 209.2 g, respectively. Increasing nitrogen rates are the reason for the decrease in the values of the index. In 2021, the differentiation in the values of grain size depending on the amount of nitrogen norm is significantly less pronounced compared to 2020 and 2022. The dynamics of hectoliter values are influenced more significantly by the conditions of the year and less by those of norms of fertilization. It has been established that in the absence of nitrogen fertilization or when applying lower nitrogen rates, hectoliter is higher compared to the annual use of aggressive nitrogen rates.

**Key words:** maize; long-term NPK fertilization; grain physical properties

## INTRODUCTION

We get information about the history and evolution of corn from Goodman and Galinat (1988), who in their review indicate that the culture was first domesticated 7000 - 10000 years ago in Mexico. Subsequently, it quickly spread to North America, and then throughout the world. However, its origin and early evolution are still controversial in scientific circles.

Maize is currently one of the most common field crops in the world. Rosegrant et al. (2008) predict that by 2050 in developing countries its demand and production will double. This crop has the highest genetic potential for yield among cereal crops and it is no coincidence that it is also known as the Queen of the Field. Increasing the yield and improving a number of nutritional and industrial properties of maize is an important combination for the modern production of this crop (Pollack and Scott, 2005; Osorno and Carena, 2008). Maize plays a very important role in human nutrition and in the production of animal feed (Olaniyan and Lukas, 2004; Enujeke, 2013). It is used for the production of various products, such as oil, flour, diet foods and biofuels. The nu-

tritional value of maize is extremely important and at the modern stage its improvement is impossible without the coordinated use of genetic methods and technologiesfor production (Has et al., 2004; Hegyi et al., 2007; Hegyi et al., 2008; Idikut et al., 2009).

The physical properties of corn are a result of the structure of the grain. The same are tied to its nutritional value, i.e. they also provide information on the chemical properties of the grain. Hectoliter mass and thousand grain weight are physical characteristics that determine the milling/ grinding properties of the grain. These indicators are decisive not only for the economic value of the grain, but also for the nutritional characteristics of the produced products, especially those in the field of dietary nutrition (Oniya et al., 2019). Cordova-Noboa et al. (2021) point out in their research that the physical characteristics of the corn kernel are essential for the development and production of the relevant machines - from those for harvesting to those related to food and feed processing.

By American standardsone of the important physical characteristics of the grain is the hectoliter - minimum 76 kg/hl (Abdala et al., 2018). It is not an accurate indicator of a specific quality feature of the grain. However, low hectoliter corn has a lower percentage of hard endosperm and therefore yields a lower yield of first-quality, large kernels at milling (Rutledge, 1978). Many factors influence hectoliter values. These include such indicators as size, density, shape and „slipperiness“ of the outer layer of the grain. These also include grain moisture content, plant stress effects caused by disease, insects, soil fertility and/or environmental conditions (drought, hail and premature frost). This means that anything that affects the movement of nutrients to the grain during the filling process, or degrades the integrity of the grain (eg cob rot and mold) after it has already been filled, reduces the TW of the grain (Nafziger, 2003; Hisks, 2004; Nielsen, 2009).

1000-grain weight is also a very important indicator of seed quality, which affects germination, seed potential, plant growth and productivity (Hossein Afshari et al., 2011). This quality depends on the size of the embryo and the preserved amount of nutrients used for germination and growth (Ebadi and Hisoriev, 2011; Cao et al., 2011). It is not by chance that this indicator is considered one of the most important, because is also directly related to the processing of corn grain in dry and wet milling technologies. Higher 1000-grain mass is a preferred characteristic for wet milling because it is associated with higher starch and protein yields and lower fiber yields (Milašinovic et al., 2007; Milašinovic et al., 2014).

The aim of the research is to expand our knowledge about the changes in the physical characteristics of the grain of hybrid Knezha-435 depending on the long-term mineral fertilization with different fertilizer combinations between nitrogen, phosphorus and potassium.

## MATERIAL AND METHODS

The beginning of agricultural research in Dobrudja began in 1941, when the Agricultural Research Station was established. Dobrudja Agricultural Institute was founded in 1951 in the black earth zone (Haplic Chernozems). Its location is 43°40’ northern latitude and 28°10’ eastern longitude. In the autumn of 1966, a stationary field fertilizer experiment was set up on the land of the Experimental Field with different norms and ratios of nitrogen, phosphorus and potassium input from mineral sources in a 2-field crop rotation (wheat-maize). It is part of the geographical network of this experiment in the country, as the experiments cover the main soil types in Northern and Southern Bulgaria of essential importance for field crops.The research was conducted at the Dobrudzha Agricultural Institute - General Toshevo during the period 2020-2023 in non-irrigated conditions. On the basis of different fertilizer rates (0, 60, 120 and 180 N and respectively $P_2O_5$ kg/ha and potassium - 0, 60 and 120 $K_2O$ kg/ha) the dynamics in the physical characteristics of the corn grain was determined. These include the mass of 1000 grains (g) and the hectoliter mass/weight of the grain (kg/ hl). The study was conducted with the hybrid

Knezha-435, which is a medium-early, simple-line hybrid from the FAO 400-500 group. Assays were performed in quadruplicate from randomized replicates. The LINEMA LITRE (Poids naturel du grain á l'hectolitre) device manufactured by Tripette&Renaud – France was used to determine the hectoliter weight of the grain.

The period under study is characterized by significant dynamics in the main meteorological components. The detailed characterization of meteorological conditions during the corn growing season is presented in Nankova et al. (2025). The comparison is made for the climate norm 1990-2020. Briefly for this material, we can summarize that the research period with the best opportunity for moisture supply of the crop is distinguished by 2020. The sum of autumn-winter precipitation is 218.4 mm and they exceed the climate norm by 37.6%. Vegetation precipitation also exceeds the climate norm by 18.80 mm (6.6%). The year is distinguished by heavy precipitation in June (162.7 mm) and severe drought in the months of August and September.

In 2021, autumn-winter precipitation is close to the climate norm, but vegetation precipitation is 35.8 mm lower. Severe drought occurs in July and August, and September is characterized by heavy precipitation.

The most critical year for the development of corn is 2023, in which the sum of autumn-winter precipitation is 64.1% of the climate norm, and for vegetation - respectively 55.1% of the same. The year is also distinguished by prolonged extreme temperatures, which greatly hindered the development of the crop. The average annual temperature is the highest since 1990 - 13.2 $^0$C and is 1.9$^0$C above the average for the period 1990-2020.

Statistical analysis was performed according to the analysis of variance (ANOVA) procedure, and the differences between variants were determined using the Wullar-Duncan test.

## RESULTS AND DISCUSSION

The analysis of the variances of the two indicators shows a well-expressed dynamics in the values both by year and depending on the size of the nitrogen rate within the same year (Table 1).

It is obvious that the physical characteristics of the corn grain are influenced to the maximum extent by the tested fertilizer rates and combinations between nitrogen, phosphorus and potassium in each of the studied years.

On average for the period, the results of the research show that at different levels of fertil-

**Table 1.** Analysis of variances of 1000 grain weight and hectoliter weight according to the main nitrogen soil fertilization with PK combinations by years of investigation

| Dependent Variable (df=11) | 2020 | | 2021 | | 2022 | | 2023 | |
|---|---|---|---|---|---|---|---|---|
| | F | Sig. | F | Sig. | F | Sig. | F | Sig. |
| $N_0$ | | | | | | | | |
| TGW | 15,776 | ,000 | 34,791 | ,000 | 10,626 | ,000 | 3,650 | ,004 |
| HW | 138,232 | ,000 | 16,560 | ,000 | 62,411 | ,000 | 28,766 | ,000 |
| $N_{60}$ | | | | | | | | |
| TGW | 68,668 | ,000 | 10,531 | ,000 | 26,804 | ,000 | 7,175 | ,000 |
| HW | 96,947 | ,000 | 16,564 | ,000 | 21,223 | ,000 | 11,125 | ,000 |
| $N_{120}$ | | | | | | | | |
| TGW | 12,182 | ,000 | 58,270 | ,000 | 21,148 | ,000 | 70,902 | ,000 |
| HW | 30,185 | ,000 | 9,881 | ,000 | 65,082 | ,000 | 1156,378 | ,000 |
| $N_{180}$ | | | | | | | | |
| TGW | 24,641 | ,000 | 32,927 | ,000 | 9,987 | ,000 | 28,574 | ,000 |
| HW | 75,399 | ,000 | 151,463 | ,000 | 23,355 | ,000 | 484,861 | ,000 |

ization, the changes in the values of the indicators have a high degree of statistical reliability (Table 2). They are most strongly influenced by the weather conditions of the growing season. In terms of mass per 1000 grains, the strength of this influence varies depending on the rate of nitrogen fertilization from 70.02% to 88.53%. In the conditions of nitrogen deficiency for ($N_0$ and $N_{60}$), the grain size is more strongly dependent on the meteorological factor compared to the variants with higher nitrogen fertilizer rates.

Combinations of nitrogen with PK also reliably affect the mass of 1000, but with a significantly weaker force. It is the same with the highest values for the fertilizer variants in the $N_{120}$+RK group, where an increase in the strength of interaction between the two factors was also found.

And for the hectoliter weight values, the meteorological factor remains the one with the greatest influence, but compared to its influence on the 1000 grain mass, the SS% values are lower. With this indicator, an increased influence of the impact of the RK fertilization factor in combination with optimal and high nitrogen rates ($N_{120}$ and $N_{180}$) is observed. Under similar conditions, the hectoliter mass of the corn grain is strongly influenced by the interaction between the tested factors. For the region of Shabla (Northeastern Bulgaria) Delibaltova et al. (2019) found that the productive capabilities of different corn hybrids, as well as the physical properties of the grain, to the greatest extent depend on the weather conditions of the years and mainly on the amount of precipitation. Kirchev (2014) in two radically different agro-ecological regions of Bulgaria (Dobrich and Chirpan) traces the changes in a number of culture indicators and points out that hybrids later than FAO 400 group are not suitable. According to the author‘s research, the chernozem soils in the region of Dobrich obtained better results compared to those at the smolnitsa in the region of Chirpan.

In his developments Halverson & Zeleny (1988) and Dorsey-Redding et al. (1991) point out that mass per thousand grains is not only a function of grain size and density. This metric provides important information about flour yield due to the fact that large and dense grains usually have a higher endosperm to bran ratio. Goranovska et al. (2022) from the Maize Institute in Knezha (Bulgaria) also track changes in productivity and a number of technological characteristics of maize depending on the applied agrotechnical practices in its cultivation.

A complete look at the grain size values obtained in each of the study years provides detailed information on the changes resulting from the different ratios of the three macronutrients (Table 3). Naturally, the option without nitrogen fertilization at first glance is not interesting for mass conventional production, but it gives us information in two directions. First, it reflects the influence of natural fertility on the values of this indicator, which is important for the biological production of the crop. By year, values ranged from 209.33 g to 278.00 g. The second direction in which we receive information is the influence of independent phosphorus or potassium fertilization. Dif-

**Table 2.** Analysis of variances of TKW and HW according to the main nitrogen soil fertilization with PK combinations and percent of the total variability explain by factors average for 2020-2023

| Dependent Variable | Source (Factor) | df | $N_0$ | | $N_{60}$ | | $N_{120}$ | | $N_{180}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *p-value* | SS, % | *p-value* | SS, % | p-value | SS, % | p-value | SS, % |
| TKW | Years (1) | 3 | ,000 | 88,53 | ,000 | 86,65 | ,000 | 70,02 | ,000 | 85,79 |
| | PK var. (2) | 11 | ,000 | 3,02 | ,000 | 4,87 | ,000 | 6,50 | ,000 | 1,70 |
| | 1 x 2 | 33 | ,000 | 8,45 | ,000 | 8,48 | ,000 | 23,48 | ,000 | 12,51 |
| HW | Years (1) | 3 | ,000 | 74,34 | ,000 | 73,71 | ,000 | 42,06 | ,000 | 46,47 |
| | PK var. (2) | 11 | ,000 | 9,44 | ,000 | 7,83 | ,000 | 18,14 | ,000 | 13,57 |
| | 1 x 2 | 33 | ,000 | 16,22 | ,000 | 18,46 | ,000 | 39,80 | ,000 | 39,96 |

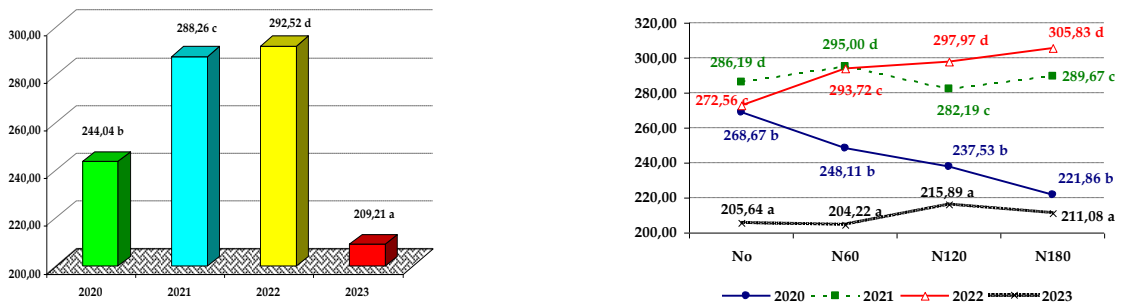
**Table 3.** Values of the mass of 1000 grains by year depending on the size of the nitrogen norms and its combination with phosphorus and potassium, g

| № | PK var. | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| | | $N_0$ | | | |
| 1 | $P_0K_0$ | 271,333 cd | 278,000 cd | 254,333 a | 209,333 bcd |
| 2 | $P_{60}K_0$ | 262,333 abc | 260,667 a | 259,667 ab | 201,000 abc |
| 3 | $P_{120}K_0$ | 285,333 e | 267,667 bc | 260,667 ab | 214,000 d |
| 4 | $P_{180}K_0$ | 286,333 e | 274,000 bc | 284,000 ef | 208,667 bcd |
| 5 | $P_0K_{60}$ | 256,000 a | 285,333 d | 265,667 bc | 212,000 cd |
| 6 | $P_0K_{120}$ | 256,333 a | 282,667 d | 268,000 bc | 204,000 bcd |
| 7 | $P_{60}K_{60}$ | 257,667 ab | 284,667 d | 275,333 cde | 212,667 d |
| 8 | $P_{60}K_{120}$ | 271,333 cd | 305,000 f | 272,000 cd | 200,667 abc |
| 9 | $P_{120}K_{60}$ | 271,667 cd | 284,000 d | 288,000 f | 210,333 bcd |
| 10 | $P_{120}K_{120}$ | 267,333 bc | 319,667 g | 284,333 ef | 200,333 ab |
| 11 | $P_{180}K_{60}$ | 279,333 de | 294,667 e | 279,667 def | 192,000 a |
| 12 | $P_{180}K_{120}$ | 259,000 ab | 298,000 ef | 279,000 def | 202,667 abcd |
| | | $N_{60}$ | | | |
| 1 | $P_0K_0$ | 236,333 c | 283,333 a | 277,000 ab | 194,000 a |
| 2 | $P_{60}K_0$ | 238,333 d | 286,000 ab | 294,000 c | 193,667 a |
| 3 | $P_{120}K_0$ | 291,667 e | 305,000 e | 300,000 cd | 206,667 abc |
| 4 | $P_{180}K_0$ | 233,667 bc | 296,667 cd | 284,333 b | 197,667 ab |
| 5 | $P_0K_{60}$ | 235,667 c | 286,333 ab | 274,000 a | 195,000 a |
| 6 | $P_0K_{120}$ | 228,000 b | 296,333 cd | 307,000 d | 219,000 cd |
| 7 | $P_{60}K_{60}$ | 278,333 d | 302,333 de | 292,667 c | 207,000 abc |
| 8 | $P_{60}K_{120}$ | 276,333 d | 295,000 cd | 295,667 c | 209,667 bc |
| 9 | $P_{120}K_{60}$ | 220,333 a | 287,333 ab | 298,667 c | 229,000 d |
| 10 | $P_{120}K_{120}$ | 274,000 d | 300,667 cde | 283,000 b | 201,000 ab |
| 11 | $P_{180}K_{60}$ | 227,000 ab | 293,333 bc | 300,333 cd | 194,667 a |
| 12 | $P_{180}K_{120}$ | 237,667 c | 307,667 e | 318,000 e | 203,333 ab |
| | | $N_{120}$ | | | |
| 1 | $P_0K_0$ | 280,000 e | 274,000 cd | 281,000 a | 209,333 c |
| 2 | $P_{60}K_0$ | 219,667 b | 271,000 bc | 302,333 e | 191,667 a |
| 3 | $P_{120}K_0$ | 218,667 b | 278,333 d | 285,000 ab | 212,667 c |
| 4 | $P_{180}K_0$ | 239,000 bc | 281,000 d | 294,000 cd | 242,667 d |
| 5 | $P_0K_{60}$ | 239,000 bc | 280,000 d | 289,333 bc | 192,667 a |
| 6 | $P_0K_{120}$ | 254,333 cd | 266,333 ab | 302,333 e | 192,333 a |
| 7 | $P_{60}K_{60}$ | 269,667 de | 262,000 a | 317,000 f | 259,000 e |
| 8 | $P_{60}K_{120}$ | 218,000 b | 276,667 cd | 314,667 f | 184,333 a |
| 9 | $P_{120}K_{60}$ | 220,667 b | 295,000 e | 291,000 bc | 291,000 f |
| 10 | $P_{120}K_{120}$ | 247,000 c | 303,000 f | 311,333 f | 213,333 c |
| 11 | $P_{180}K_{60}$ | 249,000 cd | 278,667 d | 286,667 abc | 195,667 ab |
| 12 | $P_{180}K_{120}$ | 195,333 a | 320,333 g | 301,000 de | 206,000 bc |
| | | $N_{180}$ | | | |
| 1 | $P_0K_0$ | 222,000 cde | 260,000 a | 296,000 a | 208,000 cd |
| 2 | $P_{60}K_0$ | 240,667 fg | 300,333 c | 308,333 bcd | 185,000 a |
| 3 | $P_{120}K_0$ | 187,667 a | 311,000 d | 298,667 ab | 221,667 ef |
| 4 | $P_{180}K_0$ | 212,000 cd | 285,333 b | 313,333 d | 199,333 bc |
| 5 | $P_0K_{60}$ | 212,000 cd | 259,667 a | 328,333 e | 230,333 fg |
| 6 | $P_0K_{120}$ | 256,000 h | 285,667 b | 314,000 d | 213,667 de |
| 7 | $P_{60}K_{60}$ | 219,000 cd | 297,333 c | 311,333 cd | 193,000 ab |
| 8 | $P_{60}K_{120}$ | 224,333 de | 278,333 b | 303,000 abc | 250,333 h |
| 9 | $P_{120}K_{60}$ | 246,333 gh | 313,667 d | 294,333 a | 199,667 bc |
| 10 | $P_{120}K_{120}$ | 233,667 ef | 285,333 b | 308,333 bcd | 200,000 bc |
| 11 | $P_{180}K_{60}$ | 199,000 b | 297,667 c | 299,667 ab | 240,667 gh |
| 12 | $P_{180}K_{120}$ | 209,667 bc | 301,667 c | 294,667 a | 191,333 ab |

ferent fertilizer rates and ratios between phosphorus and potassium have a maximally manifested positive effect on grain size under different conditions over the years.

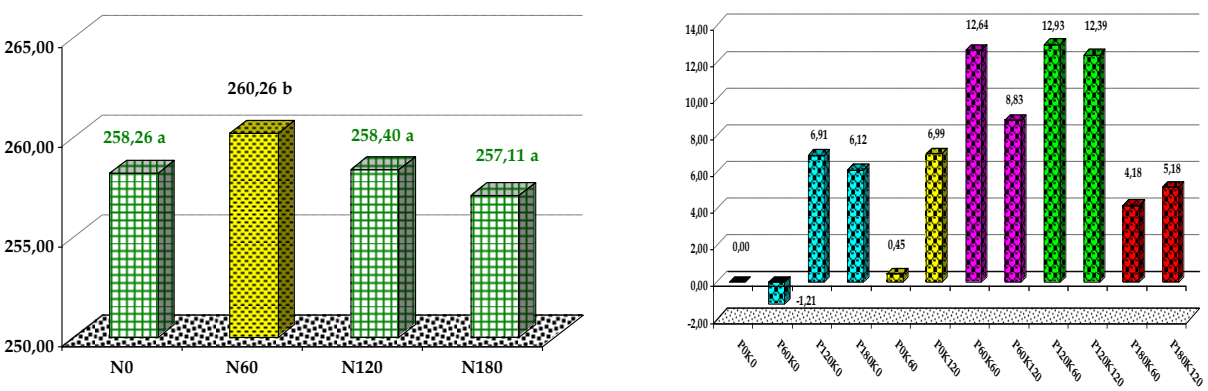
For example, in 2020, the mass of 1000 grains is the greatest with independent phosphorus fertilization with 120 and 180 kg/ha. For 2021, the grain was the largest in the variant $N_0P_{120}K_{120}$ - 319.67 g as well as in $N_0P_{60}K_{120}$ - 305.00 g, and in 2022 - the maximum in values was reached in the variants $N_0P_{120}K_{60}$ - 288.00 g and $N_0P_{120}K_{120}$ - 284.33 g. As extremely unfavorable during the study period is 2023. In the case of drastic droughts in critical phases of crop development, the largest grain was obtained in the variants $N_0P_0K_{60}$ - 212.00 g and $N_0P_{60}K_{60}$ - 202.67 g. These results show that phosphorus and potassium fertilization without the presence of nitrogen fertilization have a strong positive effect on the mass of 1000 grains.

On average, for 2021 and 2022, the corn grain has higher values for the tested fertilizer variants compared to the other years (Fig. 1). The differentiation both by year and by nitrogen fertilizer rates within each year is clearly expressed. The results in 2023 were unsatisfactory, when the lowest average value was obtained - 209.21 g. The decrease compared to 2022 is 83.31 g or the same is 71.51% of it. A gradual increase in grain size with an increase in the rate of nitrogen fertilization was found in 2022 – from 272.56 g ($N_0$) to 305.83 g ($N_{180}$). The complex of conditions in 2020 lead to the establishment of a completely opposite trend - a decrease in grain size with an increase in the rate of nitrogen fertilization.




By years By years and N norms

**Figure 1.** Weight of 1000 grains averaged by years and nitrogen fertilizer norms, g




By N norms By PK combinations

**Figure 2.** Weight of 1000 grains on average according to nitrogen fertilizer norms and difference compared to the control variant for the different PK combinations, g

Within the framework of the study, the grain obtained in the fertilizer combinations of the $N_{60}$+PK group is distinguished by greater size compared to all other nitrogen rates (Fig. 2). Observed differences in PK combinations in the $N_0$, $N_{120}$ and $N_{180}$ groups were insignificant.

On average, for the tested nitrogen standards, the greatest increase in grain size compared to the control variant - by more than 12 g, was found in the combinations including $P_{60}K_{60}$, $P_{120}K_{60}$ and $P_{120}K_{120}$. A phosphorus rate of 60 kg $P_2O_5$/ha (alone or in combination with nitrogen) had a negative effect on the indicator values, while at higher phosphorus normss the increase was just over 6 g. The trend is similar when applying 120 kg $K_2O$/ha.

The combination of nitrogen with high fertilizer rates of phosphorus and potassium resulted in obtaining a significantly smaller increase in the average values of the mass of 1000 grains compared to the control variant, as well as compared to the fertilizer combinations listed above.

In the research of Bódi & Pepó (2007) is specified the indicator for characterizing the density of corn. It is essentially the weight of a certain volume of grain. We also call it hectoliter mass/weight or simply hectoliter (kg/hl). This indicator is an important characteristic for the physical condition of the grain and plays an important role in storage and transport, as well as for the milling industry. Its values are influenced by a number of factors - moisture content in the grain, drought, rainfall, high temperatures, nutrition and other components of the overall agricultural technique, including the hybrid characteristics of the genotype. According to Zhang et al. (2020) the hectoliter mass is an indicator that directly reflectsthe quality of the corn grain. In addition, the hectoliter is an important trait in maize selection. Understanding the genetic mechanism of the indicator is important for effective crop selection. Ding et al. (2011) in their study identified quantitative trait loci (QTL) for hectoliter weight of maize. Research on this crop in the world and in our country shows that currently and in the future, large-scale research (hybrid testing, application of new agrotechnical elements) will be needed to understand the factors influencing this physical characteristic of the grain.

The results of the experiment show that in the absence of nitrogen fertilization in the absolute control ($N_0P_0K_0$) hectoliter weight values range from 71.03 kg/hl (2020) to 78.70 kg/hl (2022) (Table 4). These data support the strong influence of weather conditions on the values of the indicator. Fertilization with phosphorus and potassium in each of the years has a different effect compared to the control. In 2020, the largest number of variants exceed the values of the control by more than 5 kg/hl in PK combinations, regardless of their norms. The trend is similar in 2021 when the same hectoliter is over 77 kg/hl at 76.17 kg/hl for the control variant. Without nitrogen fertilization in 2022, a maximum was achieved in the values of the indicator (> 80 kg/hl) kg/hl in the combinations $N_0P_{180}K_0$, $N_0P_{60}K_{60}$ and $N_0P_{60}K_{120}$. The heaviest grain in the extremely unfavorable 2023 was found in the fertilizer variants $N_0P_0K_{120}$, $N_0P_{60}K_{120}$ and $N_0P_{180}K_{120}$.

The independent nitrogen fertilization with 60 kg N/ha in 2020 and 2022 the hectoliter mass slightly exceeds the absolute control ($N_0P_0K_0$), and in the other years it is around its values. Against this background, NP and NK combinations have a positive effect on the values of the indicator compared to nitrogen fertilization alone ($N_{60}P_0K_0$) in the research years. Practically all ratios between RK on this nitrogen background have a positive role in obtaining a heavier grain.

Independently fertilization with nitrogen (120 kg N/ha) definitely leads to an increase in hectoliter mass values compared to the $N_0P_0K_0$ and $N_{60}P_0K_0$ variants. This fact is most pronounced in 2020 and 2023. RK combinations of this nitrogen background increased the hectoliter weight values compared to nitrogen fertilization alone in 2022 for all tested variants in this nitrogen group. The values of the indicator for NK variants and $N_{120}P_{180}K_{120}$ stand out the most. In 2023, the combinations $N_{120}$+PK lead to a decrease in hectoliter mass compared to nitrogen fertilization alone.

The negative effect of self-introduction of high nitrogen rates ($N_{180}P_0K_0$) compared to absolute control was most pronounced in 2021 and 2023.

**Table 4.** Values of the hectoliter weight of grain by year depending on the size of the nitrogen norms and its combination with phosphorus and potassium, kg/hl

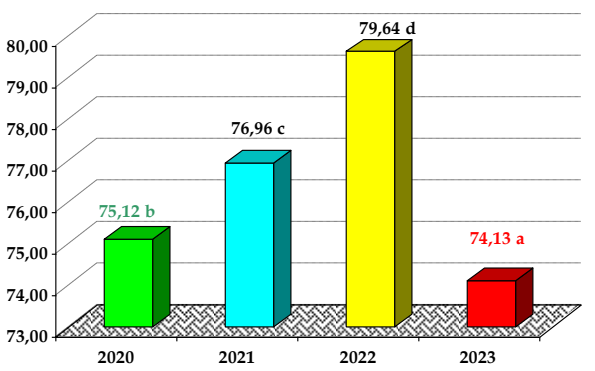
| № | PK var. | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| **$N_0$** | | | | | |
| 1 | $P_0K_0$ | 71,033 a | 77,233 c | 78,700 a | 75,833 c |
| 2 | $P_{60}K_0$ | 72,633 b | 76,067 a | 79,200 b | 76,333 de |
| 3 | $P_{120}K_0$ | 73,767 c | 76,800 bc | 79,200 b | 75,900 c |
| 4 | $P_{180}K_0$ | 74,533 d | 78,367 d | 80,467 g | 76,100 cde |
| 5 | $P_0K_{60}$ | 75,300 e | 77,267 c | 79,267 b | 74,800 a |
| 6 | $P_0K_{120}$ | 74,533 d | 76,367 ab | 79,500 cd | 75,067 ab |
| 7 | $P_{60}K_{60}$ | 76,533 gh | 78,233 d | 80,233 f | 75,867 c |
| 8 | $P_{60}K_{120}$ | 75,900 f | 77,333 c | 80,433 fg | 76,400 e |
| 9 | $P_{120}K_{60}$ | 76,767 h | 78,100 d | 79,267 b | 75,367 b |
| 10 | $P_{120}K_{120}$ | 76,367 gh | 76,300 ab | 79,700 de | 75,000 a |
| 11 | $P_{180}K_{60}$ | 76,533 gh | 76,233 ab | 79,333 bc | 76,000 cd |
| 12 | $P_{180}K_{120}$ | 76,167 fg | 77,233 c | 79,733 e | 76,900 f |
| **$N_{60}$** | | | | | |
| 1 | $P_0K_0$ | 74,267 a | 76,800 bcde | 79,400 ab | 75,233 b |
| 2 | $P_{60}K_0$ | 76,033 ef | 77,300 f | 79,600 bc | 76,367 cd |
| 3 | $P_{120}K_0$ | 76,467 f | 77,967 g | 80,167 f | 75,067 b |
| 4 | $P_{180}K_0$ | 75,433 cd | 76,500 abc | 79,833 cde | 76,267 c |
| 5 | $P_0K_{60}$ | 75,067 bc | 77,967 g | 79,600 bc | 76,467 cd |
| 6 | $P_0K_{120}$ | 76,300 ef | 76,167 a | 79,167 a | 77,367 de |
| 7 | $P_{60}K_{60}$ | 78,500 h | 77,200 ef | 79,600 bc | 77,900 e |
| 8 | $P_{60}K_{120}$ | 76,933 g | 76,400 ab | 79,800 cd | 73,733 a |
| 9 | $P_{120}K_{60}$ | 74,733 b | 76,900 cdef | 80,100 ef | 76,367 cd |
| 10 | $P_{120}K_{120}$ | 78,367 h | 77,033 def | 79,900 def | 76,267 c |
| 11 | $P_{180}K_{60}$ | 75,833 de | 77,300 f | 80,800 g | 76,667 cd |
| 12 | $P_{180}K_{120}$ | 77,100 g | 76,633 bcd | 80,000 def | 76,467 cd |
| | | $N_{120}$ | | | |
| 1 | $P_0K_0$ | 75,567 e | 76,167 ab | 78,867 a | 77,667 h |
| 2 | $P_{60}K_0$ | 73,967 ab | 76,400 abc | 79,100 b | 61,567 b |
| 3 | $P_{120}K_0$ | 73,733 a | 77,700 f | 79,167 b | 60,667 a |
| 4 | $P_{180}K_0$ | 74,067 ab | 76,633 bcd | 79,600 c | 65,167 c |
| 5 | $P_0K_{60}$ | 74,900 d | 77,300 ef | 80,000 e | 77,367 h |
| 6 | $P_0K_{120}$ | 75,967 e | 77,267 ef | 80,067 e | 75,667 f |
| 7 | $P_{60}K_{60}$ | 75,933 e | 77,167 def | 79,800 d | 72,600 e |
| 8 | $P_{60}K_{120}$ | 74,267 abc | 76,800 cde | 79,033 ab | 69,500 d |
| 9 | $P_{120}K_{60}$ | 74,733 cd | 77,700 f | 79,033 ab | 76,700 g |
| 10 | $P_{120}K_{120}$ | 77,300 f | 76,000 a | 79,567 c | 77,467 h |
| 11 | $P_{180}K_{60}$ | 75,567 e | 77,233 ef | 79,600 c | 76,667 g |
| 12 | $P_{180}K_{120}$ | 74,433 bcd | 76,300 abc | 80,500 f | 75,600 f |
| | | $N_{180}$ | | | |
| 1 | $P_0K_0$ | 73,733 c | 75,733 a | 78,567 a | 71,900 d |
| 2 | $P_{60}K_0$ | 75,367 f | 77,867 h | 79,433 c | 60,733 a |
| 3 | $P_{120}K_0$ | 71,667 a | 78,600 i | 79,067 b | 62,933 b |
| 4 | $P_{180}K_0$ | 72,900 b | 77,467 g | 79,433 c | 68,567 c |
| 5 | $P_0K_{60}$ | 74,300 de | 77,000 e | 80,100 fg | 75,267 e |
| 6 | $P_0K_{120}$ | 75,300 f | 77,233 f | 80,200 g | 76,167 f |
| 7 | $P_{60}K_{60}$ | 73,767 c | 76,600 d | 80,100 fg | 68,467 c |
| 8 | $P_{60}K_{120}$ | 76,600 g | 76,300 c | 79,700 cde | 78,567 h |
| 9 | $P_{120}K_{60}$ | 74,700 e | 76,533 d | 79,767 de | 75,100 e |
| 10 | $P_{120}K_{120}$ | 75,800 f | 76,000 b | 79,867 ef | 76,367 fg |
| 11 | $P_{180}K_{60}$ | 71,900 a | 76,233 c | 79,400 c | 76,700 fg |
| 12 | $P_{180}K_{120}$ | 74,100 cd | 76,200 bc | 79,500 cd | 77,167 g |

An effect in a positive direction was found from NP and NK combinations compared to NPK combinations in 2020. In 2022, the positive influence of NK combinations, as well as that of the fertilizer variant $N_{180}P_{60}K_{60}$.

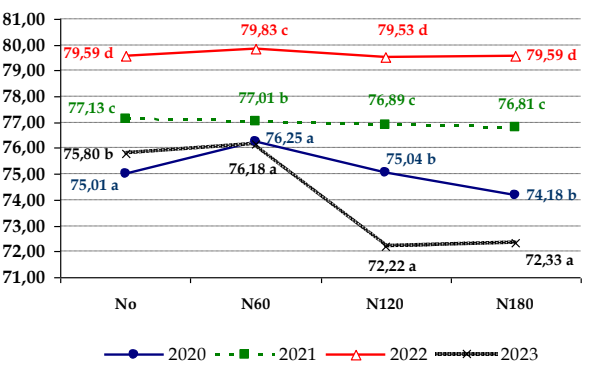
For the adverse conditions of 2023, all NP combinations resulted in the production of grain with a much lower hectoliter mass compared to the group control variant $N_{180}P_0K_0$. The same applies to the $N_{180}P_{60}K_{60}$ variant. For all other variants in this nitrogen group, a positive influence of NK and NPK combinations was found, but at high phosphorus rates.

As a result of the discussion so far, the fact that the years 2020 and especially 2023 are to varying degrees unfavorable for the development of the crop, which also affects the physical characteristics of the grain (Fig. 3). In 2022, the average value of the hectoliter mass of hybrid Knezha-435 exceeded the standard in different countries of the world, regardless of the wide variety of nutritional regimes in the soil on which it was grown.

The differences in hectoliter mass values were the least significant for corn grown under the experimental conditions in 2021, followed by 2023. Characteristic for 2020 and 2021, grain with higher hectoliter mass values was obtained in the $N_{60}$+PK group in comparison with other nitrogen fertilizer groups - 77.32 kg/hl (Fig. 4). Fertilizer combinations from the group $N_{120}$+PK and $N_{180}$+PK on average for the research period show a tendency towards a gradual decrease in the values of this indicator.

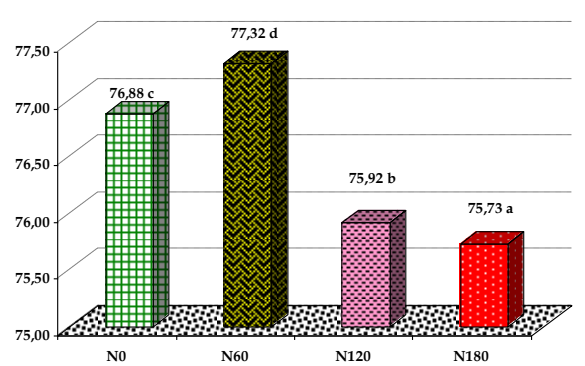



By years

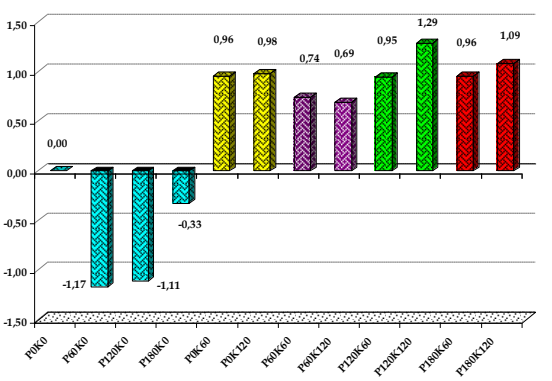



By years and N norms

**Figure 3.** Hectoliter weight of grain average by year and nitrogen fertilizer norms, kg/hl




By N norms




By PK combinations

**Figure 4.** Hectoliter weight of grain on average for 2020-2023 according to nitrogen fertilizer norms and difference compared to the control variant for the different PK combinations, kg/hl

**Table 5.** Correlation dependences between the mass per 1000 and the hectoliter weight by years and levels of nitrogen fertilization on average for the tested PK combinations (Pearson Correlation)

| **Years** | No | $N_{60}$ | $N_{120}$ | $N_{180}$ |
|---|---|---|---|---|
| 2020 (n=36) | -,112 | ,663(**) | ,596(**) | ,722(**) |
| 2021 (n=36) | -,071 | -,080 | -,292 | ,356(*) |
| 2022 (n=36) | ,460(**) | ,251 | ,194 | ,502(**) |
| 2023 (n=36) | -,218 | ,112 | ,075 | ,424(*) |
| **2020-2023** (n=576) | **,303(**)** | **0,609**** | **0,562**** | **0,710**** |
| **Average for the experiment** | **0,554**** | | | |

** Correlation is significant at the 0.05 level (2-tailed).*
*** Correlation is significant at the 0.01 level (2-tailed).*

Phosphorus fertilization with increasing rates on average for the tested levels of nitrogen fertilization leads to a decrease in the hectoliter mass of maize compared to the absolute control ($N_0P_0K_0$). In contrast, a well-expressed positive effect was found with NK combinations. The most significant increase in this indicator was found in the combinations of nitrogen with $P_{120}K_{120}$.

A number of Bulgarian researchers have concentrated their efforts in connection with establishing the influence of a number of agrotechnical factors on the elements of productivity and physical properties of the grain of corn hybrids in the conditions of different agro-ecological regions of Bulgaria (Nenova, 2010; Delibaltova, 2016; Delibaltova et al., 2019; Goranovska et al., 2022; Simeonova et al., 2023).

The obtained results for the interrelation between the two indicators, characterizing the physical properties of the grain, show their strongest correlation dependence at the highest nitrogen rate, regardless of the weather conditions of the year (Table 5). For the conditions of 2020, this relationship is statistically with a high level of confidence and for the fertilizer combinations against the background of 60 and 120 kg N/ha.

## CONCLUSIONS

It was established that the physical characteristics of the Knezha-435 hybrid corn grain are statistically reliably influenced by the growing conditions and the agrotechnical approach to plant nutrition. For both indicators, the meteorological factor has a determining role on their values. However, this role is more pronounced at the mass of 1000 grains. Different norms between phosphorus and potassium against the background of increasing rates of nitrogen fertilization have a reliable, but significantly less pronounced influence on the values of the indicators. The interaction between the meteorological factor and the nutritional regime has a more pronounced influence on the hectoliter weight of the grain compared to the mass of 1000 grains, especially at the intensive normes of nitrogen fertilization.

On average, for the research period, increasing rates of nitrogen fertilization lead to a decrease in the values of the indicators. The combination of nitrogen, regardless of its norm, is recommended to be with $P_{120}K_{60}$ or $P_{120}K_{120}$.

Regardless of the specifics of the years of research, the interrelationship between the two indicators at the aggressively high nitrogen rate is highly pronounced. On average for the period, it reaches higher correlation values (0.710**) compared to the other combinations of the tested nitrogen norms.

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