

TECHNOLOGICAL AND BIOCHEMICAL PARAMETERS OF *Triticum durum* INFLUENCED BY NPK FERTILIZATION

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Abstract

The aim of the study was to track the change in the values of some technological and biochemical parameters under the influence of prolonged application of synthetic nitrogen, phosphorus and potassium. The experiment was conducted in the experimental field of the Field Crops Institute-Chirpan, Bulgaria. The study showed data from 2020/2024. The results of the study showed that meteorological conditions strongly influenced the biochemical traits and to a small extent on the technological parameters. Nitrogen fertilization had a major impact on the technological and biochemical traits of durum wheat compared to phosphorus and potassium fertilizers. High nitrogen rates strongly influenced biochemical traits, while moderate fertilization was more effective for technological parameters. Average for the test period, fertilization with N₈₀P₁₂₀ increased thousand kernel weight (47.1 g) to the greatest extent. Combined fertilization with N₄₀P₄₀ had the strongest effect on test weight (78.5 kg/ha). Grain vitreousness and protein content were highest under the influence of N₁₆₀ (75.6% and 15.2%). Gluten content was maximized by fertilization with N₁₆₀P₄₀ (32.3%).

Key words: biochemical traits, nitrogen, phosphorus, potassium, technological traits, *triticum durum*.

INTRODUCTION

Globally, durum wheat ranks second in cultivation after bread wheat. It is one of the few cereals intended exclusively for human consumption (Samson et al., 2023). In many regions around the world, it is of paramount importance for feeding the population. In the Western world, durum wheat is used to make pasta, while in the East it is used to make couscous, bulgur and freekeh. Due to the higher yields per unit area, durum wheat was inferior in production to bread wheat. Of the total wheat production areas in the world, durum wheat accounts for only 8% (Mariam et al., 2024). Despite the advantages, nitrogen fertilizers has a high financial cost, and its synthesis, transport, and application in the field demand a considerable amount of energy derived from fossil fuels (Dragov, Taneva and Bozhanova, 2021).

The three most commonly required and widely used nutrients in agriculture are nitrogen (N), phosphorus (P), and potassium (K) (Dhillon et al., 2019). Farmers invariably resort to the use of traditional nitrogen, phosphorus, and potassium fertilizers (NPK fertilizers) worldwide to achieve high crop yields

(Amoakwah et al., 2024). Conventional fertilizer use efficiency have not improved significantly over the years, with N, P and K efficiencies hardly exceeding 30-35%, 18-20%, and 35-40%, respectively (Kumar et al., 2023). The N, P and K fertilizer application rates need to be optimized to reduce the nitrate residue in the soil while maintaining a high wheat yield (He et al., 2024). Phosphorus is one of the most widely occurring nutrients for development and growth of wheat (Boukhalfa-Deraoui et al., 2020). Phosphorus plays many key functions in plant life especially in the storage and transfer of energy, photosynthesis, respiration, cell division, and enlargement (Shafi et al., 2020). Without adequate amount application of P, a plant cannot reach its maximum yield potential (Desta, 2022). However, in recent decades, the excessive application of phosphate fertilizer in the soil in pursuit of higher crop yields has raised some environmental problems (Liu et al., 2024). For this reason, improvement in phosphorus management is of high priority (Kominko, Gorazda and Wzorek, 2019). Potassium promotes diseases resistance, regulates water balance, strengthens stalks, build proteins, regulates respiration, stretches water, and acts as a disease retarder, but it is

ineffective without nutrients like nitrogen and phosphorus (Kumar et al., 2024).

The most important traits for the milling industry are the vitreous body of the grain and the protein and gluten content of the grain. Basically, the protein content in the grain primarily depends on the nitrogen content in the soil (Lalevic et al., 2022). Nitrogen is material basis for the synthesis of wheat protein (Noor et al., 2023). Nitrogen fertilizers have a significant effect on the protein content of wheat grain and as a consequence, on wheat prices (Klikocka and Szczepaniak, 2023). White endosperm is typically found in starchy kernels with low protein content (Lachutta and Jankowski, 2024). N fertilization improves grain filling (by reducing empty spaces and decreasing the content of α -amylase), delays ripening, and prolongs grain dormancy (Dargie, Wogi and Kidanu, 2020). It is a key component of enzymes and structural proteins, nucleic acid, pigments and a wide range of secondary metabolites (Ivanova-Kovacheva et al., 2024). Variation in quantity and quality of the gluten-forming proteins has been shown to greatly affect wheat end-use quality (Rathan et al., 2020). Therefore, intensive production technologies based on the extensive use of fertilizers (Sulek et al., 2023). Despite the advantages, nitrogen fertilizers have a high financial cost, and its synthesis, transport, and application in the field demand a considerable amount of energy derived from fossil fuels (Monteiro et al., 2024). Nitrogen fertilization has become one of the main criticisms of modern agriculture in society (Neuweiler et al., 2021).

For the evolution of grain yield, thousand kernel weight (TKW) is an important parameter, being used in research as a measurement indicator (Temneanu and Marghitas, 2019). It is strongly influenced by environmental conditions and food supplies (Mohsin et al., 2014). On the other hand, the key features of grains that strongly influence yield are the good kernel size, high test weight (TW) and high percentage of hard vitreous kernels (Sissons, 2022). For these reasons, increasing TKW and TW are main targets in wheat breeding, in addition to total yield (Desiderio et al., 2019).

As the population grows, farmers are expected to increase their final output, while at the same time requiring higher quality of produce. To

achieve this increase, farmers have been applying unnecessarily large amounts of synthetic fertilizers for years. The forecasts currently do not look optimistic but at the same time, a reduction of fertilizer use by at least 20% is expected by 2030 (Orsini et al., 2023).

This study aimed to track the change in the values of some technological and biochemical parameters under the influence of prolonged application of synthetic nitrogen, phosphorus and potassium.

MATERIALS AND METHODS

The experiment was conducted in the experimental field of the Field Crops Institute-Chirpan, Bulgaria (42°11'58"N, 25°19'27"E). The experiment represented a sample of a multi-year fertilizer experiment that began in 1966. This study showed data from 2020/2024. Sowing of durum wheat was carried out in November with the *Saya* variety.

Four rates of nitrogen and phosphorus fertilizer were tested – 40, 80, 120 and 160 kg/ha and one rate of potassium fertilizer – 80 kg/ha. N, P and K fertilizers were applied individually in the appropriate doses and in combinations: N40P40, N80P40, N120P40, N160P40, N40P80, N80P80, N120P80, N160P80, N40P120, N80P120, N120P120, N160P120, N40P160, N80P160, N120P160, N160P160, N₁₂₀P₁₂₀K₈₀, respectively. A variant without fertilization was adopted as the control. P (triple superphosphate), K (potassium sulfate) and 1/3 of N (ammonium nitrate) were incorporated before sowing, and of 2/3 of N in the spring – in the tillering phase.

For a period of 5 years, the 1000-grain weight (TKW), test weight (TW), grain vitreous (GV), protein content (PC) and gluten content (GC) in the grain were monitored.

To establish reliable differences between the variants (at a probability level of $P \leq 0.01$), the data were subjected to analysis of variance (ANOVA) for each year separately and the average value of the years of the study.

Table 1 showed the sum of temperature and precipitation over the vegetative period of durum wheat and multi-year period. The observed growing seasons were significantly higher than the multi-year period in terms of temperatures. The period 2023/24 had the

largest sum of temperature – 2815.3°C, with the difference with the multi-year period being 805.6°C. The lowest accumulated sum of

temperature was 2021/22 - 2226.0°C. For the Chirpan region, the wheat requirement is around 1865°C.

Table 1. Sum of temperature (°C) and precipitation (mm) over the vegetative period of durum wheat and multi-year period (1928/2013)

Years/mounts	XI	XII	I	II	III	IV	V	VI	sum
Sum of temperature, °C									
2019/20	335.5	110.9	44.6	154.0	256.9	314.0	515.9	614.9	2346.7
2020/21	197.4	181.1	99.3	125.7	161.7	309.4	524.4	616.4	2215.4
2021/22	237.2	120.4	57.1	117.6	130.4	367.3	537.0	659.0	2226.0
2022/23	304.1	165.5	169.5	184.3	262.4	332.8	474.6	627.9	2521.1
2023/24	278.7	120.3	80.0	303.4	306.0	463.8	496.0	767.1	2815.3
1928/2013	215.9	61.1	-6.2	49.4	188.9	357.9	511.5	630.7	2009.7
Precipitation, mm									
2019/20	82.4	21.6	1.5	55.5	67.4	62.2	50.3	62.6	403.5
2020/21	7.4	70.4	108.6	25.8	39.1	84.0	34.9	42.8	413.0
2021/22	14.2	108.8	21.4	40.1	22.4	36.0	29.4	80.5	352.8
2022/23	46.9	44.4	120.0	0.2	34.4	68.2	54.8	69.5	438.4
2023/24	45.2	75.1	44.8	5.2	31.4	51.4	59.7	24.8	337.6
1928/2013	47.3	54.0	44.3	37.7	37.0	45.2	64.1	65.4	395.0

In this respect, the closest was the period 2021/22. The higher temperatures had provided the plants with good conditions for entering the winter period with well-tillering plants. In the ripening phase, temperature sums above 500-600°C help accumulated a greater amount of dry matter in the grain. Precipitation for the study period was close to that of the multi-year period, but unevenly distributed. The exception was 2023/24, where precipitation was significantly lower (337.6 mm). During this period, the wheat had passed the ripening phase with extremely insufficient soil moisture (24.8 mm). However, the 5 observed years met the soil moisture requirement during the growing season for about 280-380 mm.

RESULTS AND DISCUSSIONS

Table 2 showed TKW for each of test years and average for the test period. TKW varied between 41.7-50.4 g in different years and 44.7-47.1 g on average for the period. Higher values were observed in 2021, where the highest TKW (50.4 g) was recorded from fertilization with N₈₀P₁₂₀. However, the difference with N₈₀P₈₀ was only 0.2 g. In 2020, N₁₆₀P₁₂₀ had the strongest effect (48.9 g), 2022 - N₁₂₀P₁₂₀ (47.1 g), 2023 - N₈₀P₁₆₀ (48.6 g) и 2024 -K₈₀ (49.5 g). The application of N and P alone showed a moderate increase. The implementation of K in 2024 was impressive. This year, the K₈₀ variant was the only one with a confirmed impact by ANOVA. NPK

fertilization did not have a strong impact in two of the years studied (2020 and 2021) and on average for the study. Moderate fertilization with NP fertilizers showed the best results. Mussarat et al. (2021) reported that increasing the rate of independently applied nitrogen and phosphorus fertilizers leads to a decrease in values. The authors reported that N₄₀ had a TKW of 37.36 g, while N₁₆₀ had a TKW of 33.12 g, and P₆₀ had a TKW of 38.16 g and P₉₀ had a TKW of 36.37 g. In a study by Chetan et al. (2024), it was reported that NP fertilization significantly increased TKW by increasing N rate – N₃₆P₉₂ – 32.89 g; N₁₀₈P₉₂ – 33.98 g (ns) and N₁₄₁P₉₂ – 34.63 g (*) in spring wheat. A study by Obaid et al. (2019) reported the positive influence of P on TKW in bread wheat. Increasing the norm to P₉₀ shows the highest value, and with the next increase (P₁₀₅) TKW decreases.

Table 3 showed TW for each of test years and average for the test period. TW varied between 65.4-81.7 kg/hl in different years and 75.6-78.6 kg/hl on average for the period. Only in 2020 did mineral fertilization have a significant effect and all variants have a confirmed effect. In 2024, all values were lower than the unfertilized control. A similar trend was observed by Allende-Montalban et al. (2024). The authors reported the highest TW from the unfertilized control (80.6 kg/hl). Under the influence of N fertilizer, the values decreased – N₂₇ – 79.3 kg/hl and N₅₄ – 78.7 kg/hl, respectively.

Table 2. Thousand kernel weight (g) for each of test years and average for the test period

Fertilization	2020	2021	2022	2023	2024	Average
N ₀ P ₀ K ₀	43.0	45.7	41.7	44.2	48.7	44.7
N ₄₀	44.6***	47.7***	42.6*	46.4***	46.1 ^{ns}	45.5 ^{ns}
N ₈₀	46.3***	46.0 ^{ns}	42.6*	45.9***	47.2 ^{ns}	45.6 ^{ns}
N ₁₂₀	45.3***	46.4 ^{ns}	43.7***	44.1 ^{ns}	44.9 ^{ns}	44.9 ^{ns}
N ₁₆₀	46.8***	46.6 ^{ns}	43.4***	45.0**	43.4 ^{ns}	45.0 ^{ns}
P ₄₀	43.0 ^{ns}	44.6 ^{ns}	41.8 ^{ns}	46.5***	48.9 ^{ns}	45.0 ^{ns}
P ₈₀	43.6 ^{ns}	45.2 ^{ns}	42.1 ^{ns}	45.2**	47.5 ^{ns}	44.7 ^{ns}
P ₁₂₀	43.9*	48.8***	42.4 ^{ns}	43.7 ^{ns}	47.1 ^{ns}	45.2 ^{ns}
P ₁₆₀	48.7***	46.0 ^{ns}	42.2 ^{ns}	44.3 ^{ns}	48.8 ^{ns}	46.0 ^{ns}
N ₄₀ P ₄₀	46.7***	47.6***	43.0**	46.9***	45.7 ^{ns}	46.0 ^{ns}
N ₈₀ P ₄₀	45.6***	48.4***	43.1**	45.8***	45.7 ^{ns}	45.7 ^{ns}
N ₁₂₀ P ₄₀	46.3***	45.4 ^{ns}	44.1***	43.6 ^{ns}	46.1 ^{ns}	45.1 ^{ns}
N ₁₆₀ P ₄₀	44.2**	46.0 ^{ns}	44.7***	44.1 ^{ns}	44.9 ^{ns}	44.8 ^{ns}
N ₄₀ P ₈₀	47.8***	48.5***	43.0**	47.6***	47.0 ^{ns}	46.8*
N ₈₀ P ₈₀	47.5***	50.2***	43.6***	46.3***	45.4 ^{ns}	46.6 ^{ns}
N ₁₂₀ P ₈₀	44.7***	46.6*	45.2***	45.1**	44.0 ^{ns}	45.1 ^{ns}
N ₁₆₀ P ₈₀	44.4***	45.2 ^{ns}	45.0***	44.4 ^{ns}	44.7 ^{ns}	44.7 ^{ns}
N ₄₀ P ₁₂₀	45.9***	48.8***	44.4***	45.5***	45.9 ^{ns}	46.1 ^{ns}
N ₈₀ P ₁₂₀	44.6***	50.4***	46.3***	46.9***	45.3 ^{ns}	46.7*
N ₁₂₀ P ₁₂₀	44.2***	47.1***	47.1***	44.1 ^{ns}	45.2 ^{ns}	45.5 ^{ns}
N ₁₆₀ P ₁₂₀	48.9***	46.1 ^{ns}	46.5***	43.8 ^{ns}	43.5 ^{ns}	45.8 ^{ns}
N ₄₀ P ₁₆₀	48.4***	49.3***	44.4***	45.9***	46.8 ^{ns}	47.0*
N ₈₀ P ₁₆₀	48.4***	47.8***	45.9***	48.6***	45.0 ^{ns}	47.1*
N ₁₂₀ P ₁₆₀	44.4***	47.5***	45.3***	45.9***	46.3 ^{ns}	45.9 ^{ns}
N ₁₆₀ P ₁₆₀	45.0***	46.6*	45.4***	43.5 ^{ns}	46.4 ^{ns}	45.4 ^{ns}
K ₈₀	44.1**	44.4 ^{ns}	42.5*	45.7***	49.5*	45.2 ^{ns}
N ₁₂₀ P ₁₂₀ K ₈₀	48.3***	47.2***	46.8***	44.2 ^{ns}	44.5 ^{ns}	46.2 ^{ns}
LSD	5%	0.8	0.8	0.6	0.8	2.0
	1%	1.1	1.1	1.1	1.1	2.7
	0,1%	1.4	1.4	1.5	1.4	3.4

ns: no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

Table 3. Test weight (kg/hl) for each of test years and average for the test period

Fertilization	2020	2021	2022	2023	2024	Average
N ₀ P ₀ K ₀	74.8	76.0	79.1	78.8	81.7	78.1
N ₄₀	75.5***	75.9 ^{ns}	80.0***	78.8 ^{ns}	80.0 ^{ns}	78.0 ^{ns}
N ₈₀	77.3***	76.7***	77.9 ^{ns}	80.0***	79.5 ^{ns}	78.3 ^{ns}
N ₁₂₀	77.6***	75.4 ^{ns}	78.0 ^{ns}	78.3 ^{ns}	78.5 ^{ns}	77.6 ^{ns}
N ₁₆₀	77.3***	74.7 ^{ns}	76.7 ^{ns}	76.5 ^{ns}	78.3 ^{ns}	76.7 ^{ns}
P ₄₀	77.4***	76.4***	79.8**	78.5 ^{ns}	80.9 ^{ns}	78.6 ^{ns}
P ₈₀	76.6***	75.4 ^{ns}	79.5 ^{ns}	78.7 ^{ns}	80.4 ^{ns}	78.2 ^{ns}
P ₁₂₀	76.9***	75.1 ^{ns}	79.1 ^{ns}	78.5 ^{ns}	80.2 ^{ns}	78.0 ^{ns}
P ₁₆₀	76.7***	75.8 ^{ns}	79.6*	78.8 ^{ns}	81.0 ^{ns}	78.4 ^{ns}
N ₄₀ P ₄₀	78.8***	75.6 ^{ns}	79.2 ^{ns}	78.5 ^{ns}	80.2 ^{ns}	78.5 ^{ns}
N ₈₀ P ₄₀	77.2***	75.6 ^{ns}	78.5 ^{ns}	78.8 ^{ns}	79.8 ^{ns}	78.0 ^{ns}
N ₁₂₀ P ₄₀	76.1***	75.3 ^{ns}	79.2 ^{ns}	78.0 ^{ns}	78.9 ^{ns}	77.5 ^{ns}
N ₁₆₀ P ₄₀	76.1***	74.5 ^{ns}	77.7 ^{ns}	77.0 ^{ns}	78.6 ^{ns}	76.8 ^{ns}
N ₄₀ P ₈₀	78.0***	75.6 ^{ns}	78.9 ^{ns}	78.8 ^{ns}	79.9 ^{ns}	78.2 ^{ns}
N ₈₀ P ₈₀	77.5***	76.0 ^{ns}	78.7 ^{ns}	78.8 ^{ns}	78.3 ^{ns}	77.9 ^{ns}
N ₁₂₀ P ₈₀	76.7***	74.7 ^{ns}	78.8 ^{ns}	78.3 ^{ns}	78.1 ^{ns}	77.3 ^{ns}
N ₁₆₀ P ₈₀	75.9***	73.9 ^{ns}	78.2 ^{ns}	76.0 ^{ns}	78.5 ^{ns}	76.5 ^{ns}
N ₄₀ P ₁₂₀	78.1***	75.8 ^{ns}	79.1 ^{ns}	78.8 ^{ns}	79.1 ^{ns}	78.2 ^{ns}
N ₈₀ P ₁₂₀	76.4***	75.9 ^{ns}	79.0 ^{ns}	78.8 ^{ns}	79.3 ^{ns}	77.9 ^{ns}
N ₁₂₀ P ₁₂₀	77.0***	75.7 ^{ns}	78.7 ^{ns}	78.3 ^{ns}	79.5 ^{ns}	77.8 ^{ns}
N ₁₆₀ P ₁₂₀	76.0***	75.0 ^{ns}	78.3 ^{ns}	77.0 ^{ns}	77.2 ^{ns}	76.7 ^{ns}

Fertilization	2020	2021	2022	2023	2024	Average
N ₄₀ P ₁₆₀	78.1***	75.3 ^{ns}	79.4 ^{ns}	79.0 ^{ns}	79.3 ^{ns}	78.2 ^{ns}
N ₈₀ P ₁₆₀	77.5***	75.9 ^{ns}	79.6*	79.0 ^{ns}	79.6 ^{ns}	78.3 ^{ns}
N ₁₂₀ P ₁₆₀	76.7***	75.1 ^{ns}	78.2 ^{ns}	78.5 ^{ns}	79.3 ^{ns}	77.6 ^{ns}
N ₁₆₀ P ₁₆₀	76.4***	75.3 ^{ns}	78.5 ^{ns}	77.5 ^{ns}	78.8 ^{ns}	77.3 ^{ns}
K ₈₀	77.1***	75.9 ^{ns}	65.4 ^{ns}	79.3***	80.5 ^{ns}	75.6 ^{ns}
N ₁₂₀ P ₁₂₀ K ₈₀	78.0***	75.6 ^{ns}	77.9 ^{ns}	78.3 ^{ns}	79.3 ^{ns}	77.8 ^{ns}
LSD	5%	0.3	0.11	0.5	0.3	1.7
	1%	0.4	0.14	0.6	0.4	2.3
	0.1%	0.5	0.19	0.8	0.5	3.0

ns: no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

Over the years of the study, a trend towards a stronger influence of low N-P rates in the range of 40-80 kg/ha was observed. In three of the years studied (2021, 2022, 2023), nitrogen application alone showed the best results, N₈₀ – 76.7 kg/hl, N₄₀ – 80.0 kg/hl и N₈₀ – 81.7 kg/hl, respectively. The results in this study confirmed the results of De Santis et al. (2024), who published data from two locations on the impact of N fertilization on TW. The authors reported that in both locations the rate of 80 kg N ha⁻¹ had the strongest effect compared to N₉₀ and the unfertilized control, but the differences were small. Eshetu and Tafes (2025) observed the response of TW to increasing N rates from 0 to 115 and reported little difference between the variants, while Chadda et al. (2025) reported the highest values from the unfertilized control (80.7 kg/hl).

A large variation in GV was observed over the years of the study (Table 4). Which showed that GV was determined by environmental growth conditions (Lullien-Pellerin, 2020). The data ranged between 18.2-96.2%. 2021 had the lowest values, which can be explained by the lower sum of temperatures compared to other years. 2024 had values typical for Bulgarian durum wheat varieties. The highest sum of temperatures and low rainfall during grain ripening this year resulted in vitreousness above 80% of all variants, reaching 96.2% of N₁₆₀P₈₀. Overall, all variants were influenced by the higher fertilization rate 160 kg N ha⁻¹. This trend was also maintained in the average values. A similar pattern was reported by Bozek et al. (2022). In a study by Bogole et al. (2017), a gradual increase in GV was observed with increasing N rate, with the highest rate (N₁₇₅) having the highest value– 89.9%. Compared to N, the action of P alone had no effect on the values. This result was in contradiction with the claim of Panayotova et al. (2017) that increasing

P by 80 and 160 kg ha⁻¹ led to an increase in durum wheat vitreousness by 5.4% and 13.6%, respectively.

Regarding protein content, the values over the years varied between 9.0-16.4% (Table 5). The P and K application had little or no effect. Although PC is a varietal characteristic, nitrogen fertilization had a confirmed influence. The rate of 160 kg/ha had the strongest effect on the values, both alone and with NP and NPK fertilization. A number of authors have reported the positive impact of nitrogen (Ayadi et al., 2022; Pop et al., 2024). For example, Pop et al. (2024) reported that the unfertilized control was 10.63%, and the highest PC was the highest rate - N₁₂₀ - 15.40%. The results of phosphorus fertilization also matched. The authors reported a weakly demonstrated increase with P₈₀ fertilization (13.68%). Other authors, such as Chen et al. (2022), reported minimal increases under the influence of N fertilizer. The authors reported a PC of 16.3% when fertilizing with N₆₅ and an increase of only 0.5% (16.8%) when fertilizing with N₁₃₅.

Over the years of the study, GC varied widely – 15.0-36.2% (Table 6). Gluten, as the main protein component, was mainly affected by nitrogen fertilization and less by P and K, which confirmed the results of Jastrebska et al. (2024) that phosphorus had no significant effect on GC. Increasing the N rate led to an increase in the values, whether in combination or alone. The dose of N₁₆₀ affected GC the most. During the years of the study, the variant with the highest value was the N₁₆₀P₄₀ (2020) with a GC of 36.2%, and on average for the tested period – 32.3% of the same variant. A similar trend was reported by Kizilgeci et al. (2021) and Liu et al. (2021).

Conversely, Abera et al. (2020) reported that GC increases to the norm from N₁₂₂, with values decreasing as it increases to N₁₈₃.

Table 4. Grain vitreous (%) for each of test years and average for the test period

Fertilization	2020	2021	2022	2023	2024	Average
N ₀ P ₀ K ₀	58.8	18.2	50.2	39.2	85.8	50.4
N ₄₀	61.2	28.6	67.2	38.8	91.6	57.5 ^{ns}
N ₈₀	68.0	43.4	77.0	52.6	94.4	67.1 ^{**}
N ₁₂₀	74.8	52.6	77.8	65.2	93.2	72.7 ^{***}
N ₁₆₀	66.8	70.2	80.2	66.0	95.0	75.6^{***}
P ₄₀	52.0	20.8	51.0	42.4	84.6	50.2 ^{ns}
P ₈₀	69.0	25.0	47.2	35.6	81.8	51.7 ^{ns}
P ₁₂₀	56.2	29.0	46.8	35.0	83.2	50.0 ^{ns}
P ₁₆₀	53.8	23.8	45.6	40.2	86.8	50.0 ^{ns}
N ₄₀ P ₄₀	54.2	35.6	69.8	34.0	93.2	57.4 ^{ns}
N ₈₀ P ₄₀	70.2	50.8	74.2	52.8	93.0	68.2 ^{***}
N ₁₂₀ P ₄₀	73.2	57.6	75.8	59.8	90.2	63.3 ^{**}
N ₁₆₀ P ₄₀	80.2	57.2	77.6	70.0	92.4	75.5^{***}
N ₄₀ P ₈₀	54.0	26.2	60.6	38.2	88.8	53.6 ^{ns}
N ₈₀ P ₈₀	65.8	40.6	72.8	47.0	94.2	64.1 ^{**}
N ₁₂₀ P ₈₀	70.8	52.8	77.0	62.0	93.8	71.3 ^{***}
N ₁₆₀ P ₈₀	68.2	56.8	80.6	62.8	96.2	72.9^{***}
N ₄₀ P ₁₂₀	57.0	29.0	64.0	37.6	91.6	55.8 ^{ns}
N ₈₀ P ₁₂₀	60.2	30.8	69.6	43.6	91.4	59.1 ^{ns}
N ₁₂₀ P ₁₂₀	73.4	49.0	72.6	62.8	94.4	70.4 ^{***}
N ₁₆₀ P ₁₂₀	78.0	56.0	76.4	68.2	92.4	74.2 ^{***}
N ₄₀ P ₁₆₀	58.2	31.2	59.2	38.4	92.8	56.0 ^{ns}
N ₈₀ P ₁₆₀	61.0	39.8	71.0	46.8	93.8	62.5 [*]
N ₁₂₀ P ₁₆₀	73.2	44.4	76.2	63.4	94.6	70.4 ^{***}
N ₁₆₀ P ₁₆₀	74.2	52.6	78.8	65.0	94.0	72.9 ^{***}
K ₈₀	55.0	34.0	48.0	38.8	82.8	51.7 ^{ns}
N ₁₂₀ P ₁₂₀ K ₈₀	76.8	54.2	81.6	60.6	93.0	73.2 ^{***}
LSD	5%					9.2
	1%					12.2
	0,1%					15.8

ns: no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

Table 5. Protein content (%) for each of test years and average for the test period

Fertilization	2020	2021	2022	2023	2024	Average
N ₀ P ₀ K ₀	10.9	10.4	11.6	9.7 ^{ns}	11.6	10.8
N ₄₀	13.9 ^{***}	11.0 ^{***}	12.8 ^{***}	9.5 ^{ns}	13.1 ^{***}	12.1 ^{**}
N ₈₀	13.7 ^{***}	12.8 ^{***}	15.0 ^{***}	11.7 ^{***}	15.3 ^{***}	13.7 ^{***}
N ₁₂₀	15.1 ^{***}	13.2 ^{***}	16.0 ^{***}	12.9 ^{***}	16.2 ^{***}	14.7 ^{***}
N ₁₆₀	14.0 ^{***}	14.7^{***}	16.3 ^{***}	14.7^{***}	16.3^{***}	15.2^{***}
P ₄₀	11.6 ^{***}	9.9 ^{ns}	11.5 ^{ns}	10.0 [*]	11.6 ^{ns}	10.9 ^{ns}
P ₈₀	11.7 ^{***}	10.5 ^{ns}	10.9 ^{ns}	9.7 ^{ns}	10.6 ^{ns}	10.7 ^{ns}
P ₁₂₀	11.5 ^{**}	11.1 ^{***}	11.1 ^{ns}	9.0 ^{ns}	12.6 ^{***}	11.1 ^{ns}
P ₁₆₀	11.2 ^{ns}	10.4 ^{ns}	11.1 ^{ns}	9.4 ^{ns}	11.3 ^{ns}	10.7 ^{ns}
N ₄₀ P ₄₀	11.1 ^{ns}	11.4 ^{***}	13.1 ^{***}	8.9 ^{ns}	13.6 ^{***}	11.6 [*]
N ₈₀ P ₄₀	13.0 ^{***}	12.5 ^{***}	14.6 ^{***}	10.6 ^{***}	14.9 ^{***}	13.1 ^{***}
N ₁₂₀ P ₄₀	14.8 ^{***}	13.6 ^{***}	16.0 ^{***}	13.0 ^{***}	15.1 ^{***}	14.5 ^{***}
N ₁₆₀ P ₄₀	14.2 ^{***}	13.9 ^{***}	16.4^{***}	13.9 ^{***}	15.1 ^{***}	14.7 ^{***}
N ₄₀ P ₈₀	11.1 ^{ns}	10.3 ^{ns}	12.5 ^{***}	9.2 ^{ns}	13.3 ^{***}	11.3 ^{ns}
N ₈₀ P ₈₀	12.7 ^{***}	12.3 ^{***}	14.4 ^{***}	10.3 ^{***}	14.9 ^{***}	12.9 ^{***}
N ₁₂₀ P ₈₀	14.7 ^{***}	12.8 ^{***}	15.3 ^{***}	12.5 ^{***}	15.7 ^{***}	14.2 ^{***}

Fertilization	2020	2021	2022	2023	2024	Average
N ₁₆₀ P ₈₀	15.9***	13.7***	16.0***	13.4***	15.6***	14.9***
N ₄₀ P ₁₂₀	11.3*	10.6*	12.9***	9.8 ^{ns}	13.9***	11.7*
N ₈₀ P ₁₂₀	12.1***	10.5 ^{ns}	13.8***	10.4***	14.8***	12.3***
N ₁₂₀ P ₁₂₀	14.9***	12.4***	14.7***	12.5***	15.1***	13.9***
N ₁₆₀ P ₁₂₀	16.0***	13.3***	16.3***	13.3***	15.9***	15.0***
N ₄₀ P ₁₆₀	11.4**	10.9***	12.6***	9.5 ^{ns}	13.5***	11.6*
N ₈₀ P ₁₆₀	12.2***	10.7**	13.8***	10.5***	14.6***	12.3***
N ₁₂₀ P ₁₆₀	15.0***	11.8***	15.2***	12.1***	14.7***	13.8***
N ₁₆₀ P ₁₆₀	15.3***	13.0***	15.5***	13.2***	14.9***	14.4***
K ₈₀	11.2 ^{ns}	10.6*	11.1 ^{ns}	9.7 ^{ns}	11.3 ^{ns}	10.8 ^{ns}
N ₁₂₀ P ₁₂₀ K ₈₀	14.9***	12.9***	14.9***	11.9***	15.4***	14.0***
LSD	5%	0.4	0.2	0.3	0.1	0.8
	1%	0.5	0.3	0.3	0.2	1.1
	0,1%	0.7	0.4	0.4	0.3	1.4

ns: no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

Table 6. Gluten content (%) for each of test years and average for the test period

Fertilization	2020	2021	2022	2023	2024	Average
N ₀ P ₀ K ₀	22.4	19.6	22.3	17.2	22.1	20.7
N ₄₀	23.3 ^{ns}	21.5***	25.6***	16.5 ^{ns}	26.9***	22.8 ^{ns}
N ₈₀	29.6***	26.6***	31.3***	22.0***	30.3***	28.0***
N ₁₂₀	34.2***	27.8***	34.5***	26.2***	32.6***	31.1***
N ₁₆₀	30.3***	30.0***	35.8***	31.1***	32.5***	31.9***
P ₄₀	23.2 ^{ns}	20.2 ^{ns}	20.8 ^{ns}	17.9*	22.9***	21.0 ^{ns}
P ₈₀	30.1***	21.4***	20.2 ^{ns}	16.6 ^{ns}	20.0 ^{ns}	21.8 ^{ns}
P ₁₂₀	22.1 ^{ns}	22.5***	20.7 ^{ns}	15.0 ^{ns}	24.3***	20.9 ^{ns}
P ₁₆₀	21.7 ^{ns}	22.2***	20.7 ^{ns}	16.2 ^{ns}	21.7 ^{ns}	20.5 ^{ns}
N ₄₀ P ₄₀	21.4 ^{ns}	22.8***	26.6***	14.4 ^{ns}	26.2***	22.3 ^{ns}
N ₈₀ P ₄₀	27.1***	20.8***	31.0***	19.4***	30.1***	26.6***
N ₁₂₀ P ₄₀	33.4***	21.1***	34.0***	25.8***	30.6***	30.4***
N ₁₆₀ P ₄₀	36.2***	21.7***	35.8***	29.1***	30.5***	32.3***
N ₄₀ P ₈₀	21.2 ^{ns}	25.4***	25.0***	15.3 ^{ns}	26.5***	21.8 ^{ns}
N ₈₀ P ₈₀	26.1***	25.1***	29.9***	18.4***	30.6***	26.0***
N ₁₂₀ P ₈₀	32.7***	21.3***	32.5***	24.3***	31.3***	29.5***
N ₁₆₀ P ₈₀	31.5***	21.6***	34.7***	27.5***	31.6***	30.9***
N ₄₀ P ₁₂₀	21.8 ^{ns}	28.2***	25.7***	17.1 ^{ns}	27.4***	22.6 ^{ns}
N ₈₀ P ₁₂₀	22.4 ^{ns}	26.9***	28.2***	18.8***	29.6***	24.1*
N ₁₂₀ P ₁₂₀	33.1***	25.3***	31.3***	24.9***	30.2***	29.0***
N ₁₆₀ P ₁₂₀	36.2***	23.4***	35.2***	27.7***	31.7***	31.8***
N ₄₀ P ₁₆₀	20.5 ^{ns}	29.8***	24.2***	15.3 ^{ns}	26.4***	21.6 ^{ns}
N ₈₀ P ₁₆₀	24.6***	29.2***	28.6***	18.7***	29.8***	24.7***
N ₁₂₀ P ₁₆₀	33.9***	28.0***	32.2***	24.3***	29.9***	28.4***
N ₁₆₀ P ₁₆₀	34.7***	26.3***	33.1***	27.3***	30.5***	30.4***
K ₈₀	21.0 ^{ns}	21.3***	20.8 ^{ns}	17.1 ^{ns}	22.2 ^{ns}	20.5 ^{ns}
N ₁₂₀ P ₁₂₀ K ₈₀	33.1***	26.5***	31.5***	23.2***	30.4***	28.9***
LSD	5%	1.2	0.7	0.6	0.3	2.7
	1%	1.6	0.9	0.8	0.4	3.6
	0,1%	2.1	1.2	1.0	0.6	4.6

ns: no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

CONCLUSIONS

The results of the study showed that meteorological conditions strongly influenced the biochemical indicators (protein and gluten content in the grain and vitreousness of the grain) and to a small extent on the technological parameters – thousand kernel weight and test weight. Nitrogen fertilization had a major impact on the technological and biochemical traits of durum wheat compared to phosphorus and potassium fertilizers. High nitrogen rates strongly influenced biochemical traits, while moderate fertilization was more effective for technological parameters. Fertilization with N₈₀P₁₂₀ increased thousand kernel weight (47.1 g) to the greatest extent. Combined fertilization N₄₀P₄₀ had the strongest effect on test weight (78.5 kg/hl). Grain vitreousness and protein content were highest under the influence of N₁₆₀ (75.6% and 15.2%, respective). Gluten content was maximized by fertilization with N₁₆₀P₄₀ (32.3%).

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