Article

Evaluation of the yield and quality of maize hybrids (Zea mays L.) with different genotypes

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Abstract: The nutritional values of maize – protein, starch and oil content – play a decisive role in its use in industry, animal feed and the food industry. The development of these nutritional characteristics is influenced by numerous factors, including genetic background, crop year, agronomic factors and the ecological environment. By selecting the appropriate hybrid and applying appropriate cultivation techniques, these nutritional parameters can be tailored to different objectives, thereby ensuring economical and sustainable use. Precision technologies enable sustainable, climate-responsive farming and help farmers make faster, real-time, data-driven decisions. In these long-term field trials, smart machinery and tools are used and smart irrigation management ensures an optimal water supply, whilst sensor data supports the reliability of smart decisions. The analyses were aimed at reliably assessing the yield and yield quality of maize hybrids with different genotypes and growth periods (FAO 300, 400, 480) across two different growing seasons. In 2024 and 2025, in an experiment designed to assess field yield potential, the maize hybrids achieved varying but outstanding yields. Based on an analysis of the effects of the growing seasons, it was found that the average yield achieved in the more favourable year of 2024 (19.96 t/ha) significantly exceeded the yield achieved in 2025 (18.44 t/ha) by 1.52 tonnes per hectare. The genotypes studied achieved different yield and nutritional composition results in the years under investigation (2024, 2025). The greatest difference was observed in the FAO 300 hybrid, where, in the favourable growing season (2024), the yield was reliably 3.27 tonnes per hectare higher. The FAO 400 hybrid demonstrates good adaptability; its yield was reliably 1.07 tonnes per hectare higher in 2024 compared with the 2025 result. The FAO 480 hybrid produced an excellent yield, but this did not differ significantly between the two years studied. From a feed perspective, the nutritional values of maize kernels are very important. The starch content of the maize hybrids of different genotypes and maturity stages under investigation was very stable across the two crop years examined (62.18–63.42%). In the favourable growing season (2024), the starch content of the FAO 480 hybrid was favourable (63.15%), but did not differ significantly from that of the shorter-maturing hybrids. In the more favourable growing season (2025), a significant difference was observed only between the starch content of the FAO 300 and FAO 480 hybrids. The starch content of the FAO 300 hybrid was 1.24% higher than that of the FAO 480 hybrid. Protein content is a key characteristic of maize genotypes, and crop years also have a significant effect on it. Analysing the values for the two different crop years examined, it was found that the crop year has a significant effect on the protein content of maize kernels. The oil content of maize kernels is important in animal feed, but

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is of particular value in industrial processing. The oil content, averaged across the maize hybrids, showed a significant difference between the two crop years.

Keywords: maize, FAO number, starch, protein, oil, grain moisture

1. Introduction

The nutritional values of maize – its protein, starch and oil content – play a decisive role in its use in industry, animal feed and the food industry. These nutritional characteristics are influenced by numerous factors, including genetic background, crop year, agronomic factors and the ecological environment (1,6,15). The maize grain consists predominantly of starch, which accounts for between 65 and 75 % of the dry matter (19). The importance of the starch content is further enhanced by the fact that it serves as the raw material for industrial processing (e.g. starch production, isoglucose production) (4). The protein content of maize generally ranges between 7–10 %, which partially meets the protein requirements of compound feed. The biological value of the protein is determined by its amino acid composition. Glutamic acid is the dominant amino acid (15.7 mg %), but essential amino acids such as lysine and tryptophan are present only in small quantities. It is therefore essential to supplement these in the feed (10). The amino acid content is closely related to the crude protein content; as the protein content increases, the proportion of non-essential amino acids rises, whilst the proportion of essential amino acids decreases. The quality and nutritional parameters of maize are significantly influenced by genetic background, sowing time and site-specific conditions (13,15). Hard-grain hybrids have better protein content and milling properties, whilst soft-grain hybrids have a higher starch content. By optimising agronomic factors and selecting the appropriate sowing time, these internal quality parameters can be further improved (15,16,17). Moisture content also has a significant effect on the quality parameters of maize. Mechanical properties, such as hardness and the apparent modulus of elasticity, are sensitive to changes in moisture content (21). Furthermore, it is important for the processing industry that the quality of the maize hybrids meets specific end-use requirements, particularly in the production of feed mixes, starch or isoglucose (4). Irrigation and an adequate water supply to arable land play a particularly important role (11, 23). In Hungary, the majority of maize is used as animal feed, but the food and bio-industries are playing an increasingly significant role (24). Sweet maize, for example, is grown both for fresh consumption and as a raw material for the canning industry. Its nutritional value is, incidentally, excellent: 1 kg of sweet maize contains 3.35 g of protein, 10 g of fat and 221 g of carbohydrates (9). The favourable yields achieved in maize cultivation are attributable not only to agronomic practices but, above all, to favourable growing conditions. Variations between growing seasons carry a high degree of risk; they fundamentally influence the quantity and quality of yield, and thus also the income of growers (8,18). In dry years, a plant density of 50,000 plants per hectare is considered appropriate, whilst in average years, a density of 65–73,000 plants per hectare is deemed appropriate (8). Nutrient supply plays a key role in the implementation of precision farming (5,7,12,25). When assessing the effects of climate change on crops, maize is the most affected (26). Maize yield, grain moisture content at harvest, nutritional values, quality and industrial use are closely linked to genetic, ecological and agrotechnical factors (3, 12, 22). By selecting the appropriate hybrid and applying appropriate cultivation techniques, nutritional parameters can be tailored to different objectives, thereby ensuring economical and sustainable utilisation.

2. Materials and Methods

The protein, starch and oil parameters were measured by the Perten DA 7250 NIR analyser.

Climatic conditions

Located approximately 10 km west of Debrecen, the site of the performed meteorological measurements is the Field Crop Research Station of the Faculty of Agricultural and Food Sciences and Environmental Management of the University of Debrecen (N 47°33′, E 21°27′, 120 m above sea level). The climate and soil characteristics of the area are typical of one of Hungary's most important maize-growing regions, the Hajdúság loess ridge. The soil belongs to the calcareous chernozem type; it is flat and level, and can be classified as loam. Based on soil analysis results, it is characterised by a near-neutral pH and moderate humus and lime content. Its potassium content is 240 mg/kg and its phosphorus content is 133 mg/kg. An automatic weather station operates near the experimental arable plots, which is of great assistance in assessing weather conditions, particularly in terms of the accurate measurement of both temperature and precipitation. Climate data from 1981 to 2010 from the Debrecen Airport station of HungaroMet Hungarian Meteorological Service Non-profit Ltd. served as a reference for analysing deviations from the long-term average (28, 29, 30, 31).

Weather characteristics of the 2024 growing season (Debrecen-Látókép)

It is favourable for maize cultivation if the deeper soil layers are saturated with water during the winter half-year preceding the growing season. Otherwise (as was the case in 2022, for example), the risk of drought increases significantly. During the 2023/24 winter half-year, 283 mm of rainfall was recorded over a six-month period, significantly exceeding the average. The assessment of this period is somewhat qualified by the fact that most of the rainfall fell before the end of December, after which the weather was generally dry and mild. February was exceptionally mild, with by far the highest average temperature recorded since measurements began. The average for the winter half-year also showed an anomaly of +2.3°C (Table 1). The drying out of the topsoil began as early as February. The weather did not hinder the completion of spring soil preparation work.

Table 1. Monthly and half-yearly characteristics of temperature, precipitation (Debrecen-Látókép) and sunshine duration (Debrecen, OMSZ) in 2024

Period	Average temperature	Precipitation (mm)	Sunshine (hours)
Winter half-year (October–March)	6.5 (+2.3)	**283 (+69)**	686 (+29)
summer term (IV–IX)	19.9 (+2.4)	312 (-34)	1,602 (+128)
April	13.6 (+2.4)	38 (-15)	233 (+25)
May	17.5 (+0.9)	76 (+12)	266 (+25)
June	21.2 (+1.9)	66 (0)	258 (-4)
July	24.2 (+2.9)	**29 (-37)**	**330 (+51)**
August	**24.2 (+3.4)**	33 (-16)	321 (+39)
September	18.4 (+2.2)	70 (+22)	194 (-8)

The weather remained very mild until mid-April, after which temperatures fell back to near average (Figure 2). Unlike in previous years, the average temperature in April was higher (+2.4°C) than usual. A total of 38 mm of rain fell, the even distribution of which ensured that the sown maize germinated. May began with warm, dry weather, followed by significant rainfall, particularly during the last ten days of the month. This month was slightly warmer (17.5°C) and wetter (76 mm) than average, meaning that weather conditions were favourable during the early growth stage of maize.

Unusually, the average daily soil temperature consistently reached around 20°C as early as the first half of April (in the maize seedbed, at a depth of 5 cm), and even after the prolonged cooling period that began in mid-April, it remained consistently above the base temperature of maize (10°C), typically ranging between 11 and 15°C (Figure 1). From the end of April, the soil warmed towards 20°C, at which point the germination process was already proceeding rapidly. The air temperature remained below the soil temperature every day; the soil temperature surplus during this period is clear.

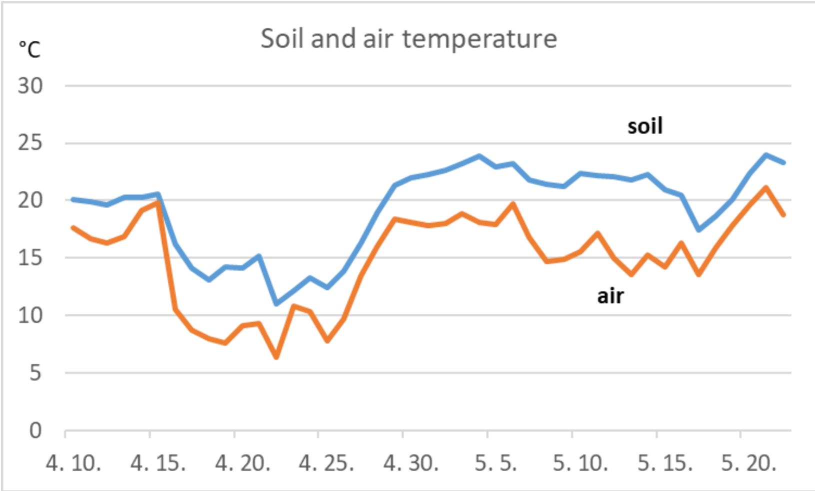
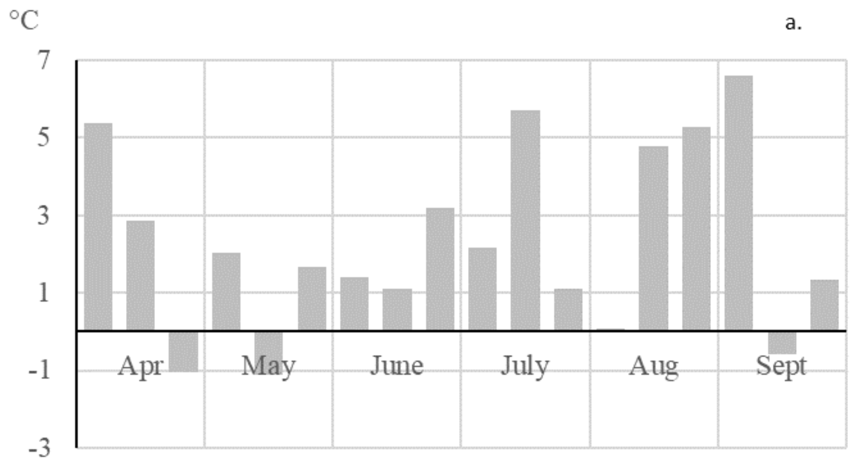


Figure 1. Trends in soil temperature (5 cm, ploughing) and air temperature (2 m) at Debrecen-Látókép, 10 April – 22 May 2024.

The warm June weather (21.9°C) was favourable for maize, as there was no extreme heat, and the average amount of rainfall (66 mm), combined with soil moisture in the deeper layers, ensured a good water supply. The heat intensified as the season progressed. Average temperatures in both July and August were close to record levels (24.2°C). One of the peaks of the heatwave occurred in mid-July, which in many places coincided with the flowering and kernel-setting phenophase – the stage at which maize is most sensitive to heat stress. The exceptionally hot weather in August (in the middle and at the end of the month) caused the ripening phase to be shortened. The number of hours of sunshine was also particularly high during the last two months of summer, with generally clear skies. Rainfall in July (29 mm) was less than half the long-term average, and August was also dry (33 mm). Total summer rainfall was 128 mm, a figure significantly lower than that recorded in recent years (e.g. 2021: 72 mm, 2022: 56 mm). The yield depression in the 2024 growing season was primarily due to the prolonged, extremely hot weather during the summer. Combined with below-average rainfall, this led to significant soil drought. It is likely that the damaging effects of atmospheric drought and high air temperatures also played a significant role in yield reduction. The number of hot days (max ≥ 30°C) during the summer period was very high (51) (Figure 2).



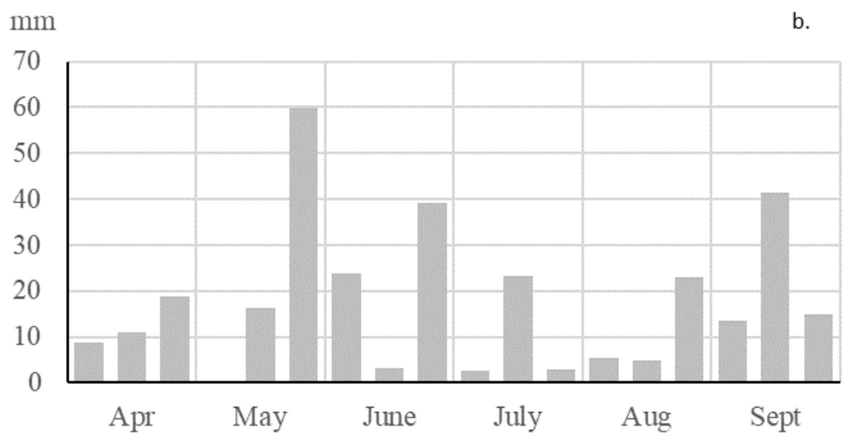


Figure 2. Deviations of decadal mean temperatures from the multi-year average (a) and total precipitation (b) during the 2024 growing season in Debrecen-Látókép

At the beginning of September, the unusually warm weather for the season continued, with the first decade showing a positive anomaly of nearly 7°C. A cooling trend set in mid-month, accompanied by significant rainfall. The dry, warm weather did not return for the remainder of the month. The physiological maturity of the maize, combined with rapid water loss and drying, enabled an early harvest. However, in the middle of the month, the rainy weather temporarily hampered harvesting work for a prolonged period.

Weather characteristics of the 2025 growing season (Debrecen-Látókép)

The average temperature (4.4 °C) and total precipitation (216 mm) for the 2024/25 winter half-year were both in line with the long-term average. However, the number of hours of sunshine significantly exceeded the usual level (by nearly 100 hours) (Table 2), which increased evaporation. It is important to note that, within this period, March was particularly wet, which directly affected and hindered any early seedbed preparation work. By the start of the growing season, the upper soil layers were saturated with water, but slightly less water than usual had seeped down into the deeper layers.

Table 2. Monthly and half-yearly characteristics of temperature, precipitation (Debrecen-Látókép) and sunshine duration (Debrecen, OMSZ) in 2025

Period	Average temperature	Precipitation (mm)	Sunshine (hours)
Winter half-year (October–March)	4.4 (+0.2)	216 (+2)	752 (+95)
summer term (IV–IX)	18.6 (+1.0)	239 (-107)	1,589 (+115)
April	12.9 (+1.7)	13 (-40)	236 (+28)
May	**14.2 (-2.4)**	34 (-30)	**201 (-40)**
June	**22.2 (+2.9)**	**10 (-56)**	**362 (+99)**
July	22.0 (+0.7)	86 (+20)	280 (+2)
August	21.6 (+0.8)	25 (-24)	303 (+21)
September	18.4 (+2.2)	**71 (+23)**	207 (+5)

Following the cooler days at the start of April, the rest of the month was characterised by distinctly warm, sunny weather. Overall, there was a positive temperature anomaly of nearly 2 °C. There was very little rainfall (13 mm), which, following a wet March, proved favourable for soil preparation and sowing. Due to the sharp drop in temperature during the first ten days of the month, the soil temperature fell below the maize base temperature (10 °C), but from the 12th onwards it remained consistently above this level (the daily mean). From the middle of the month onwards, daily average temperatures above 15 °C were recorded at a depth of 5 cm in the maize seedbed, which is favourable for emergence and early development (Figure 3).

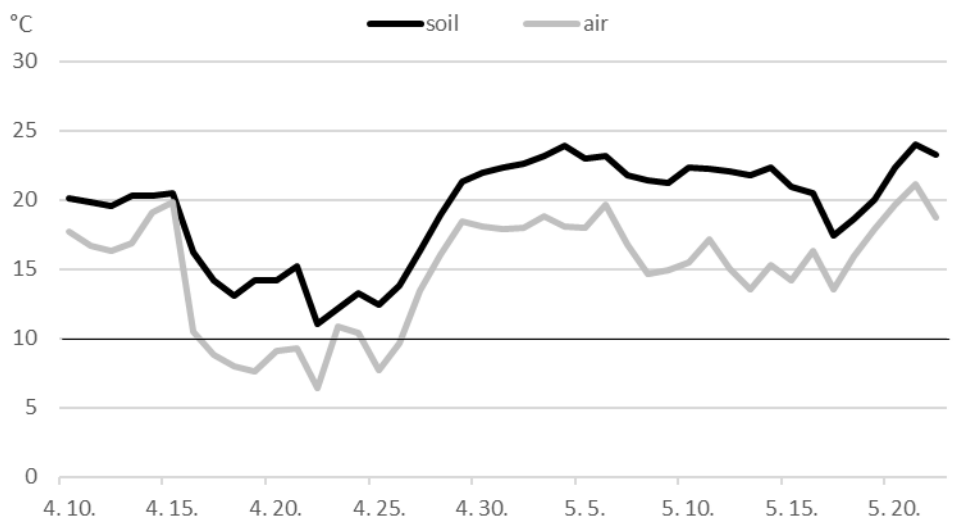


Figure 3. Trends in soil temperature (5 cm, ploughing) and air temperature (2 m) (Debrecen-Látókép, 1 April–31 May 2025)

The average temperature in May (14.2 °C) was significantly below the long-term average. The middle of the month was particularly cool, which caused plant growth to slow down considerably. Between 5 and 25 May, the daily mean temperature typically ranged between 10 and 13 °C, barely exceeding the base temperature. Dry weather, however, persisted for most of the month. Monthly rainfall (34 mm) was half the long-term average, concentrated mainly in the last ten days of the month. June brought very warm weather. The monthly mean temperature of 22.2 °C was 2.9 °C above average. There was no significant rainfall to contribute to maize water supply; a total of 10 mm fell in several rainfall. The very high duration of sunshine clearly illustrates the sunny nature of the weather. The sun shone for a total of 362 hours, an average of around 12 hours per day. During the growing season, this was the warmest, driest and sunniest month. In the second half of the month, signs of water stress on the maize were already visible to the naked eye (plant height, leaf condition), due to increasing soil drought and atmospheric drought occurring regularly during daylight hours. In July (from the 7th), there was a favourable change in the weather. Significant rainfall, totalling 86 mm and exceeding the long-term average, fell during the month, largely concentrated in the periods from the 7th to the 11th and from the 25th to the 28th. The increased cloud cover (with sunshine duration close to average) and the moderately warm weather (a positive anomaly of 0.7 °C) also helped to ensure that no significant heat or water stress developed during the period critical for maize yield (flowering and kernel set).

The average temperature for August was 22.0 °C, slightly above average but not unacceptably high. The warmest day of the year occurred during this month (a maximum of 36.8 °C on the 10th), though no prolonged heatwave developed. Total rainfall (25 mm) was only half the usual amount. Overall, this month – the crop development period – was characterised by moderate drought. Total summer rainfall was 121 mm, which differs only slightly from the 2024 summer figure; however, significantly lower figures have been recorded in recent years (e.g. 2021: 72 mm, 2022: 56 mm).

September was warmer (+2.2 °C) and wetter (71 mm) than average, though this did not affect crop yields. Temperatures dropped significantly from the summer-like values at the beginning of the month by the end of the month; after the 25th, daily maximum temperatures typically hovered around just 15 °C (Figure 4). The cool weather continued into the first ten days of October, with little rainfall. Grain drying proceeded at a moderate rate following physiological ripening; the harvest date was slightly later than in previous years, but the harvest operations were not substantially hindered by the weather (31).

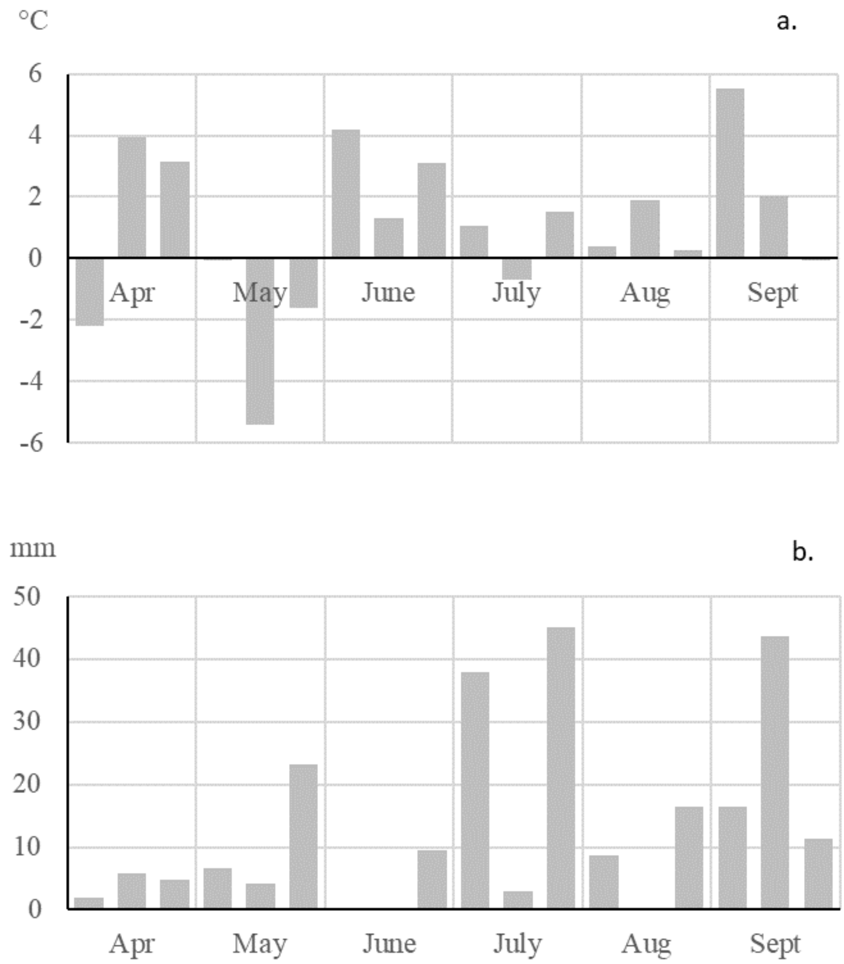


Figure 4. Deviation of decadal mean temperatures from the long-term average (a) and precipitation totals (b) during the growing season (Debrecen-Látókép, 2025)

Agrotechnical data 2024

Harvest of previous crop: 28 September 2023
Soil preparation – nutrient application:
3 October 2023 Fertiliser application: 300 kg/ha, NPK 4-24-24
11 October 2023 Ploughing
22 February 2024: Ploughing completed + Combinator
9 April 2024: Fertiliser application + cultivator, 500 kg/ha CAN (39%; 27-7-5)
Sowing: 11 April 2024
Emergence: 21 April – 3 May 2024
Weed control: 7 May 2024
Inter-row cultivation: 13 May 2024
Irrigation: 17 June 2024 – 13 August 2024 (14 times)
Total rainfall during the growing season: 254.86 mm
Fertiliser application: 20 June 2024, Megasol orange (25 kg of fertiliser)
NPK 3-5-40 (8kg N, 13 kg P_2O_5, 107 kg K_2O)
Harvest: 26 September 2024

Agrotechnical data 2025

Harvest of previous crop: 26 September 2024
Soil preparation – nutrient replenishment:
2 October 2024: fertiliser application at 300 kg/ha, NPK 4-24-24,
11 October 2024: ploughing,
4 March 2025: final ploughing + cultivator,

16 April 2025: fertiliser application + cultivator, 500 kg/ha CAN (39%; 27-7-5).
Sowing: 23 April 2025
Emergence: 30 April – 4 May 2025
Weed control: 17 May 2025 – Principal Forte Piton package.
Inter-row cultivation: 3 June 2025
Irrigation: 11 June 2025–2 September 2025
Total water applied during the growing season: 254.69 mm.
Fertiliser application: 31 July 2025. Megasol orange (50 kg of fertiliser) NPK 3-5-40 (1.75 kg N, 2.5 kg P_2O_5, 20 kg K_2O) applied.
Harvest: 10 October 2025

3. Results

The development and application of precision farming technologies increase crop production efficiency. Above all, the efficiency of water, fertiliser and plant protection product use can be improved through smart technological solutions. The timely detection of plant diseases and pests is crucial. Precision technologies enable sustainable, climate-responsive farming and help farmers make faster, real-time, data-driven decisions. In the performed long-term field trials, smart machinery and tools were used. Smart irrigation management ensures an optimal water supply, whilst sensor data supports the reliability of smart decisions.

The performed analyses were aimed at reliably assessing the yield and yield quality of maize hybrids of different genotypes and growth stages (FAO 300, 400, 480) across two different crop years. In 2024 and 2025, in an experiment designed to assess field yield potential, the maize hybrids achieved varying but outstanding yields. Based on an analysis of the effects of the growing seasons, it was found that the average yield achieved in the more favourable year of 2024 (19.96 t/ha) significantly exceeded the yield achieved in 2025 (18.44 t/ha) by 1.52 tonnes per hectare.

The analysed genotypes achieved different yield and nutritional composition results in the examined years (2024, 2025). The greatest difference was observed in the FAO 300 hybrid, where, in the favourable growing year (2024), the yield was reliably 3.27 tonnes per hectare higher. The FAO 400 hybrid demonstrates good adaptability; its yield was reliably 1.07 tonnes per hectare higher in 2024, compared with the 2025 result. The FAO 480 hybrid produced an excellent yield, but this did not differ significantly between the two years under study (Figure 5).

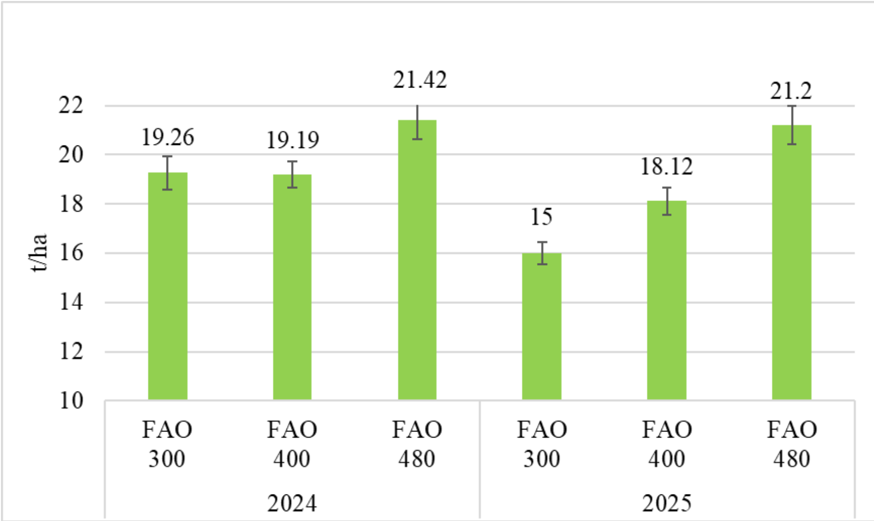


Figure 5. Yields (t/ha) of maize hybrids of different genotypes, 2024–2025

Of the parameters examined for the maize hybrids, grain moisture at harvest showed the greatest, statistically significant difference due to the effect of the growing year. In the more favourable growing year (2024), grain moisture was significantly (4.5%) lower than in 2025. This result had a significant impact on profitability due to lower drying costs. In 2024, there was no significant difference in grain moisture content between the three hybrids with different maturity dates under investigation, which clearly illustrates the strong effect of the growing season. In 2025, the grain moisture content of the FAO 300 hybrid (16.92%) was lower than that of the FAO 400 hybrid (17.67%), but the difference was not significant. The grain moisture content of the FAO 480 hybrid (18.57%) was reliably 1.65% higher than that of the FAO 300 (Figure 6).

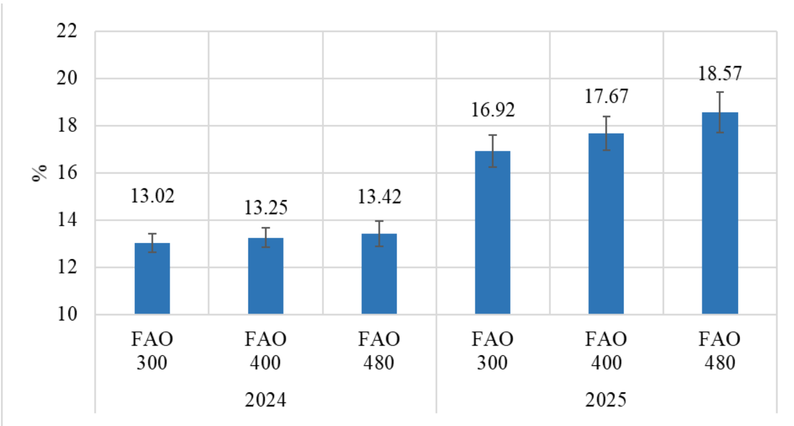


Figure 6. Kernel moisture content (%) of maize hybrids of different genotypes, 2024–2025

The nutritional values of maize kernels are very important from a feed perspective. The starch content of the maize hybrids of different genotypes and maturity stages examined was very stable across the two crop years studied (62.18–63.42%). In the favourable growing season (2024), the starch content of the FAO 480 hybrid was favourable (63.15%), but did not differ significantly from that of the hybrids with shorter growing seasons. In the more favourable growing season (2025), a significant difference was observed only between the starch contents of the FAO 300 and FAO 480 hybrids. The starch content of the FAO 300 hybrid was 1.24% higher than that of the FAO 480 hybrid (Figure 7).

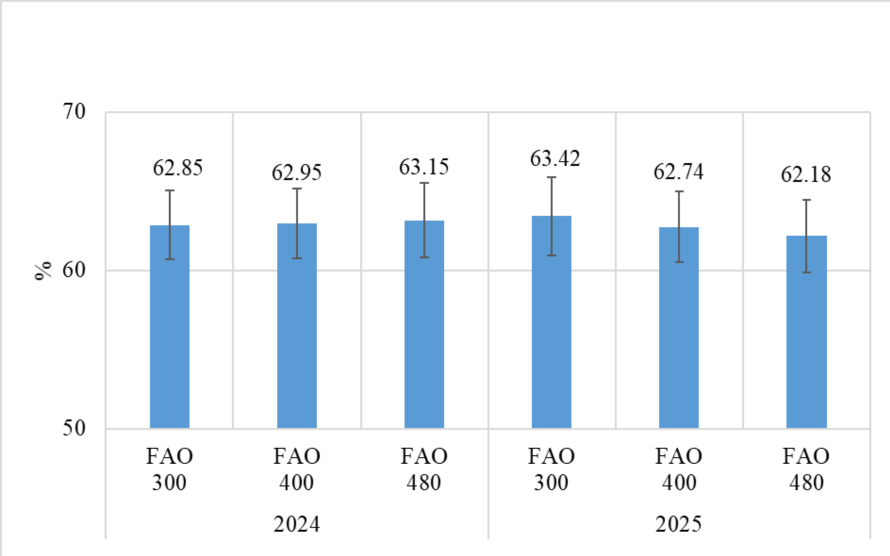


Figure 7. Starch content (%) of maize hybrids of different genotypes, 2024–2025

One of the most important quality parameters of maize yield is the protein content of the maize kernels. Protein content is a strong characteristic of maize genotypes and is also significantly influenced by the growing season. Analysing the values for the two different growing seasons examined, it was found that the growing season has a significant effect on the protein content of maize kernels. On average across maize hybrids, the protein content in favourable growing seasons is significantly higher (by 16 %) than in 2025. In 2024, compared with the results for the FAO 480 hybrid, the FAO 300 hybrid contained 0.88% more protein and the FAO 400 hybrid contained 0.38% more protein, with these differences being statistically significant. In 2025, in the most favourable growing season, the protein content of the maize hybrids studied did not differ significantly (Figure 8).

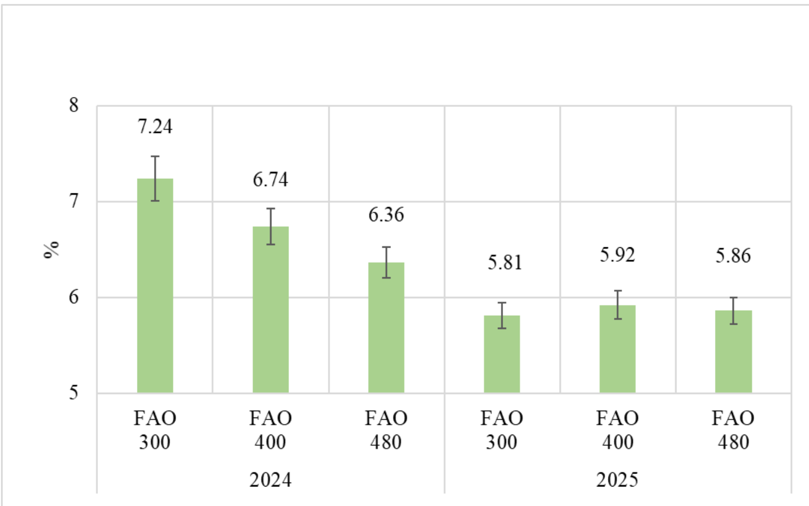


Figure 8. Protein content (%) of maize hybrids of different genotypes, 2024–2025

The oil content of maize kernels is important in animal feed, but is of particular value in industrial processing. On average across the maize hybrids, the oil content showed a significant difference between the two growing seasons, with a higher value in 2024 (+0.5%). In both 2024 and 2025, the oil content of the FAO 480 hybrid was reliably lower (0.48–0.49%) than that of the FAO 300 hybrid, with the difference being nearly identical. There was no significant difference in oil content between the FAO 400 hybrid and the FAO 480 hybrid in the two examined years (Figure 9).

Figure 9. Oil content (%) of maize hybrids of different genotypes, 2024–2025

Based on the results of field trials, the H 300 maize hybrid matures at the beginning of the FAO 300 group. In terms of yield, it is a high-yielding hybrid, with an average plant height of 225 cm. The cob emerges from the stalk at a height of 88 cm. It possesses good root and stalk characteristics, with an average stalk diameter of 20 mm. Its agronomic characteristics are favourable, with good germination vigour, early development and stalk strength. The thousand kernel weight was 428 grams. The average cob length was 17 cm, the average cob diameter 45 mm, and the average cob weight 188 grams. The average kernel weight was 167 grams. Number of rows: 16. Kernels per cob: 390. The hybrid's nutritional values are as follows: protein content 5.81–7.24 %, oil content 3.21–3.73 %, starch content 62.8–63.4 %.

The H 400 maize hybrid matures at the beginning of the FAO 400 group; it is a stable hybrid with good phenotypic characteristics. Average plant height is 225 cm, with the cob emerging from the stalk at a height of 91 cm. It has good root and stem characteristics, with an average stem diameter of 25 mm. Its agronomic characteristics are favourable, with good germination vigour, early development and stem strength. The thousand-seed weight was 475 grams. The average cob length was 17 cm, and the average cob diameter was 47 mm. The average cob weight was 230 grams, and the average kernel weight was 205 grams.

Number of rows: 16. Kernels per pod: 423. The hybrid's nutritional values are as follows: protein content 5.92–6.74 %, oil content 2.96–3.44 %, starch content 62.7–62.9 %.

Researchers widely use the number of days since emergence to analyse phenophases. The performed long-term field trials with maize made it possible to record the plants' phenophases throughout the entire growing season. According to the performed analyses, more accurate data was obtained, particularly during the generative stage, when taking effective heat sum (HU) calculations into account. For the FAO 300 hybrid, 66 days elapsed from emergence to silking, utilising a heat sum of 568 HU. It took 104 days and 1003 HU from emergence to wax ripeness (R4). It took 140 days from emergence to physiological maturity, requiring 1399 HU, which is typical for this genotype. This phenological stage is the most important in terms of yield, as the rate of dry matter accumulation is a key performance indicator for the hybrid. It took 161 days and 1507 HU from emergence to harvest. For the FAO 400 hybrid, 69 days elapsed from emergence to silking, utilising a heat sum of 607 HU. From emergence to wax ripeness (R4), 104 days and 1003 HU were required. The most significant correlations during the phenological stage from wax ripeness to the onset of physiological ripening was identified. The period from emergence to physiological ripening lasted 145 days and required 1,446 HU; and 162 days and 1507 HU were required until harvest.

The FAO 480 maize hybrid matures at the upper end of the FAO 400 group. It is a hybrid with a stable structure and a compact phenotype. Its average plant height is 318 cm. The cob emerges from the stalk at a height of 128 cm, and the thousand-kernel weight was 420 grams. It possesses good root and stem characteristics, with an average stem diameter of 20 mm. Its agronomic characteristics are favourable, with good early development and stem strength. The average pod length is 19 cm, and the average pod diameter is 48 mm. The average pod weight is 249 grams, and the average seed weight is 234 grams. Number of rows: 12. Seeds per pod: 532. The hybrid's nutritional values are as follows: protein content: 5.86–6.36%, oil content: 2.72–3.25%, starch content: 62.18–63.15%. For the FAO 480 hybrid, 60 days elapsed from emergence to silking, utilising a heat sum of 545 HU. It took 92 days and 967 HU from emergence to wax ripeness (R4). It took 117 days from emergence to physiological maturity, requiring 1277 HU. It took 150 days from emergence to harvest, requiring 1621 HU.

4. Discussion

The obtained research findings have demonstrated that growing seasons significantly influence the yield and protein, starch and oil contents of maize hybrids. It has been confirmed that nutritional values are important indicators for the wide-ranging use of maize crops. According to Nagy (17), alongside its use as animal feed, the use of maize in the food industry is increasing year on year. There is also significant demand for bioenergy production, and the use of by-products is growing. Csapó et al. (10) also emphasise the importance of the protein content and amino acid composition of feed. In their view, it is advisable to take nutritional values into account when selecting a hybrid, particularly if the farm is growing maize for direct use as feed. Paplógó (13) also emphasises the importance of genetic background in relation to nutritional values. Széles and Nagy (24) also note a close correlation between crop yields and climatic conditions. The research findings of Tebaldi and Lobell (26) demonstrate the significant impact of crop year. Several research groups have investigated and demonstrated, in line with their own findings, the effects of genetic, ecological and cultivation practices on the quantity and quality of maize grain yield (2, 22, 3).

5. Conclusions

The obtained research findings confirm that the nutritional values of maize – specifically its protein, starch and oil content – play a decisive role in the efficiency and profitability of maize production. The effect of the growing season on the yield of the maize hybrids under investigation has been quantified, which have different genetic backgrounds.

It was demonstrated that selecting the hybrids best suited to the growing site and applying professional crop management techniques ensure economical and sustainable maize production. In the performed trials, optimal water supply was ensured through smart irrigation management and smart machinery and equipment was used to implement these crop management techniques. The reliability of the experimental results was enhanced by the use of data from the long-term field trial and available smart sensors. The experimental results demonstrated the correlations between the yield, grain moisture content at harvest, and the protein, oil and starch content of the maize kernels of the different maize hybrid genotypes under investigation across two different growing seasons

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