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SUITABILITY OF POTATO VARIETIES FOR FRENCH FRY PROCESSING UNDER CLIMATIC STRESS

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Abstract

To evaluate the influence of climatic factors on the technological quality of potato tubers during the 2024 and 2025 agricultural years, six potato varieties - Asinaria, Azaria, Castrum, Cezarina, Cosiana, and Darilena - were studied for their suitability for French fry processing. Tubers were analyzed for technological quality parameters, including specific gravity, determined using a PW-2050 digital weigher; dry matter content, assessed by the oven-drying method; and reducing sugar content, measured semi-quantitatively using Quantofix test strips. Frying suitability was evaluated by calculating the frying index, determining the percentage of French fries with brown ends, and assessing the number of colour classes assigned to the fried samples based on comparison with the Munsell USDA Frozen French Fry Color Standard. The frying index ranged from 0.3 to 4.5 among the six varieties, while specific gravity values varied between 1.072 and 1.094.

Key words*: potato varieties, processing, climatic stress.*

INTRODUCTION

Potato (*Solanum tuberosum* L.), widely cultivated for both fresh consumption and industrial processing, is one of the most important food crops worldwide. French fries and chips are the most important products obtained by frying. The quality of the raw material intended for processing is a very important factor in ensuring the obtaining of products with appropriate technological properties (Singh and Kaur, 2016).

The suitability for frying processing is determined by the technological parameters of potato tubers: specific gravity, dry matter, starch and reducing sugars content. The high dry matter and starch content allows the obtaining of products with low oil absorption, and the low concentrations of reducing sugars lead to the obtaining of light and uniform colour of fried products (Islam et al., 2022; Stark et al., 2003).

From a processing perspective, tubers with higher dry matter content and lower concentrations of reducing sugars are preferred for French fries production, as they ensure better frying performance and a lighter color of the fried product. Therefore, the climatic conditions recorded during the growing season may partially explain possible variations in the technological parameters of the potato varieties, including dry matter content, reducing sugars, and frying quality indices (Hamouz et al., 2005). The period of heat stress with high temperatures during tuber development leads to an increase in the content of reducing sugars, a decrease in the content of dry matter, which leads to colour defects during roasting (Busse et al., 2018).

The suitability for frying processing is influenced by the genetic characteristics of the potato varieties. Technological characteristics that can influence the quality of fried products, dry matter content, starch content, reducing sugars are influenced by genotype (Feltran et al., 2004). Therefore, the selection of varieties suitable for processing is an important objective in breeding programs (Bethke et al., 2019; Seid and Tessema, 2024). Some varieties show high stability of technological characteristics, which makes them more suitable for industrial processing, especially for French fries production.

Genotype × environment interactions shape potato quality traits, making their targeted selection essential for breeding cultivars with

multiple desirable traits under variable conditions (Zhou et al., 2025).

Studies on the influence of climatic factors on tuber quality parameters are important for selecting varieties suitable for the processing industry. Especially for the production of French fries, it is necessary to identify varieties with high dry matter content, low levels of reducing sugars and high stability of these characteristics under different climatic conditions (Islam et al., 2022).

The present study aims to analyze the influence of climatic conditions during the growing season and the variety on the suitability of potato tubers for processing as French fries, by evaluating relevant technological parameters, such as dry matter content, specific gravity, reducing sugar content and color of fried products.

MATERIALS AND METHODS

In order to study the influence of climatic factors on the technological quality of potato tubers in the agricultural years 2024 and 2025, six potato varieties were studied regarding their suitability for processing as French fry. Thus, a bifactorial experiment was undertaken: factor A - crop year with 2 levels: 2024 and 2025 (with 2025 considered the control) and factor B - variety with 6 levels: Asinaria, Azaria, Castrum, Cezarina, Cosiana, Darilena, and the control was represented by the average of the six varieties for each parameter studied. The technological quality parameters of potato tubers were determined before processing: specific gravity, dry matter content, reducing sugars.

After frying, observations were made on the technological parameters of the obtained fried potato strips: frying index, percentage of brown ends, colour class number. Specific gravity was determined by weighing the tuber samples in air and water, using the PW-2050 Weigher digital scale. This device operates using a load cell that converts the applied force (weight) into a proportional electrical signal, which is electronically processed and digitally displayed (Bărăscu and Ștefan, 2025). The dry matter content of the potato tubers was determined using the oven drying method. Reducing carbohydrates can influence the colour, taste and texture of the processed products. The reducing sugar content of potato tubers was determined using QUANTOFIX® test strips, which were read with a QUANTOFIX® Relax digital reader device; this is a semi-quantitative method based on colour reactions.

To determine the suitability of potato samples for French fries, 20 potato sticks, with a section of 1 x 1 cm, taken from the central area of 20 potato tubers, are heat-treated by frying in a standardized manner (4 minutes at 175ºC). Each fried potato stick is classified into the predominant colour category (000, 00, 0, 1, 2, 3, 4), compared to a reference scale (USDA Munsell Color Chart for French Fried Potatoes), then the frying index and the number of fries with a browned end are calculated. The suitability of potatoes for frying is designated by:

- The frying index (Ip) which represents the colour of the fries: the lower it is, the lighter the fries are in colour (light yellow); the higher it is, the darker the French fries are (brown). The index value shows the level of suitability of the potato sample for frying (Ip) as follows: Ip ≤ 2.5 = excellent; Ip between 2.5 and 3.0 = good; Ip between 3.0 and 3.5 = medium; Ip between 3.5 and 4.0 = poor; Ip > 4.0 = very poor.
- The number of French fries with a browned ends, with a brown or black colour at one (or both) ends, between 0.5 and 1.5 cm.
- The number of colour classes reflects the homogeneity of the French fries colour. The method used to determine the colour of French fries classifies each of the 20 French fries in the sample into a colour class, ranging from very light (class "000") to very dark (class "4"). The higher the number of classes, the more heterogeneous the French fries colour.

RESULTS AND DISCUSSIONS

The climatic conditions during the growing season shows that the year 2025 was characterized by lower average temperatures during the growing season (15.9°C) compared to 2024 (17.8°C), but with a higher total amount of precipitation (372 mm versus 306.8 mm) (Figure 1).

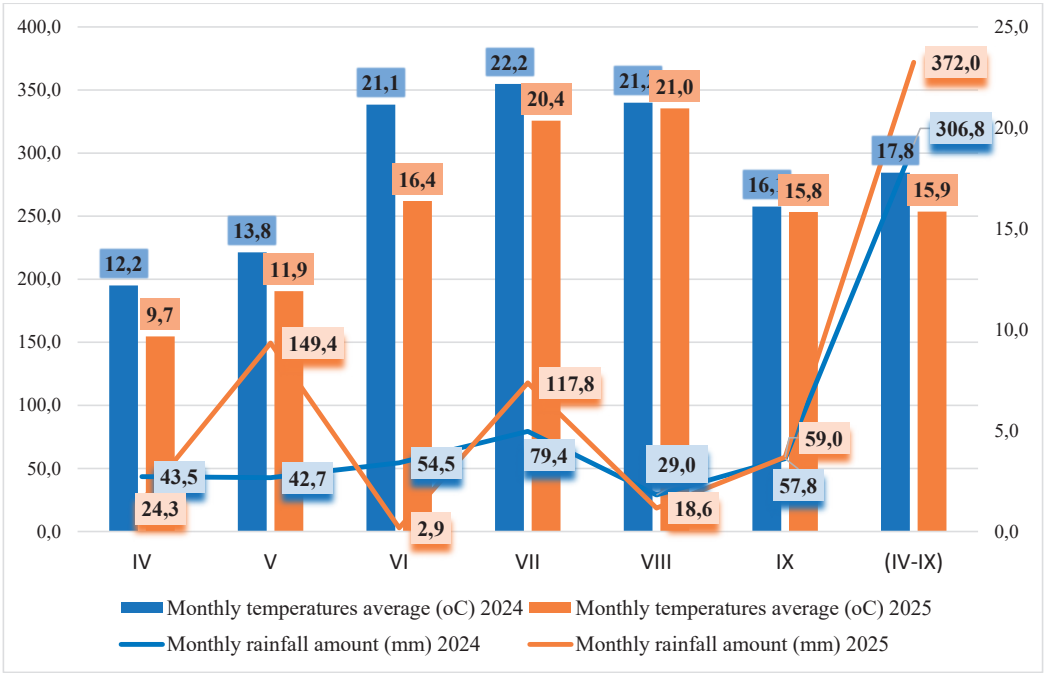

Figure 1. Monthly temperatures average and rainfall amount during the potato growing season (April-September, 2024-2025, Brașov)

During the tuber bulking period (June-August), temperatures in 2024 ranged between 21.1 and 22.2°C, above the optimal range for starch accumulation in potato tubers, potentially affecting dry matter content. In contrast, the cooler conditions recorded in 2025, particularly in June (16.4°C), may have a positive influence on dry matter accumulation.

Stress conditions caused by high temperature or water availability may stimulate the conversion of starch into simple sugars, increasing the concentration of reducing sugars in tubers.

Analyzing the influence of the climatic conditions of the crop year on the technological parameters of fresh potatoes and French fry potatoes obtained by processing them, it was found that in 2024, compared to 2025, climatic conditions had a negative influence on the dry matter content of potato tubers (%), determining a significant difference (-2.02%). For the other parameters taken into study, no statistically significant differences were recorded (Table 1).

Following the analysis of the influence of the variety on the technological parameters taken into consideration, according to Table 2, the specific gravity values were between 1.0782 (Cezarina variety) and 1.0877 (Azaria variety). For this parameter there were no statistically significant differences compared to the average of all varieties, considered as a control.

Regarding the dry matter content, the Azaria variety recorded a significantly positive difference of 1.18 (%), compared to the average of the varieties. The Cezarina variety had the lowest accumulation of dry matter in tubers (20.07%).

While the Cezarina variety, with the highest value of reducing sugars content (0.40 mg/g), presented a distinctly significant difference (0.1172 mg/g), the Azaria variety recorded the lowest value of reducing sugars (0.19 mg/g) which led, compared to the average values of all varieties, to a significantly negative difference (-0.0936 mg/g).

The Azaria variety recorded the lowest value of the frying index (1.15), determining the obtaining of a distinctly significant negative difference (1.51), and the Cezarina variety achieved the highest value (4.22) and a very significantly positive difference (1.56). Also, the Castrum variety showed influence on frying, obtaining a significantly positive difference

(1.01). Regarding brown ends, the Cezarina variety surpassed the control with a very significant positive difference (60.14%), while Azaria and Cosiana recorded significant negative differences (24.03%) and distinctly significant (24.86%).
The color class number had values between 2.3 (Azaria) and 4.5 (Cosiana). The Azaria variety stands out with a significant negative difference (1.3), compared to the control. The low value of this parameter indicates the uniformity of the colour during roasting of this variety, a positive characteristic for processing. For the other varieties, no statistically significant differences were obtained.

Table 1. The influence of culture year on technological quality parameters

Year (a)	Specific gravity	Diff. /Sign.	Dry matter (%)	Diff. (%) /Sign.	Reducing sugars (mg/g)	Diff. (mg/g) /Sign.	Frying index	Diff. /Sign.	Brown ends (%)	Diff. (%) /Sign	Color class number	Diff. /Sign
2024 (a_1)	1.0798	-0.0068 ns	20.09	-2.02 o	0.32	0.06 ns	2.76	0.19 ns	31.39	-0.28 ns	3.4	-0.4 ns
2025 (a_2) (Ct)	1.0867	-	22.12	-	0.25	-	2.56	-	31.67	-	3.9	-
		DL 5% = 0.0068; DL 1% = 0.0158; DL 0.1% = 0.0502.		DL 5% = 1.25; DL 1% = 2.89; DL 0.1% = 9.19.		DL 5% = 0.07; DL 1% = 0.17; DL 0.1% = 0.55.		DL 5% = 0.69; DL 1% = 1.60; DL 0.1% = 5.10.		DL 5% = 8.61; DL 1% = 19.89; DL 0.1% = 63.30.		DL 5% = 0.9; DL 1% = 2.0; DL 0.1% = 6.3.

Table 2. The influence of variety on technological quality parameters

Variety (b)	Specific gravity	Diff. /Sign.	Dry matter (%)	Diff. (%) /Sign.	Reducing sugars (mg/g)	Diff. (mg/g) /Sign.	Frying index	Diff. /Sign.	Brown ends (%)	Diff. (%) /Sign	Color class number	Diff. /Sign
Asinaria (b_1)	1.0813	-0.0019 ns	20.66	-0.45 ns	0.24	-0.0478 ns	2.48	-0.18 ns	20.83	-10.69 ns	3.2	-0.5 ns
Azaria (b_2)	1.0877	0.0044 ns	22.29	1.18 *	0.19	-0.0936 o	1.15	-1.51 oo	7.50	-24.03 o	2.3	-1.3 o
Castrum (b_3)	1.0833	0.0001 ns	20.99	-0.12 ns	0.34	0.0557 ns	3.67	1.01 *	46.67	15.14 ns	4.0	0.3 ns
Cezarina (b_4)	1.0782	-0.0051 ns	20.07	-1.03 ns	0.40	0.1172 **	4.22	1.56 ***	91.67	60.14 ***	3.8	0.2 ns
Cosiana (b_5)	1.0858	0.0026 ns	21.51	0.40 ns	0.28	-0.0090 ns	1.92	-0.74 ns	6.67	-24.86 oo	4.5	0.8 ns
Darilena (b_6)	1.0832	-0.0001 ns	21.12	-0.02 ns	0.26	-0.0224 ns	2.52	-0.14 ns	15.83	-15.69 ns	4.2	0.5 ns
Mean (Ct)	1.0833	-	21.11	-	0.28	-	2.66	-	31.53	-	3.7	-
		DL 5% = 0.0053; DL 1% = 0.0071; DL 0.1% = 0.0097.		DL 5% = 1.01; DL 1% = 1.38; DL 0.1% = 1.87.		DL 5% = 0.07; DL 1% = 0.10; DL 0.1% = 0.14.		DL 5% = 0.84; DL 1% = 1.14; DL 0.1% = 1.54.		DL 5% = 18.16; DL 1% = 24.67; DL 0.1% = 33.45.		DL 5% = 1.1; DL 1% = 1.4; DL 0.1% = 2.0.

The comparison of the two crop years shows an increase in specific gravity in 2025 compared to 2024, but the positive difference of 0.0068 is statistically insignificant. The largest differences between years were recorded for the varieties Cezarina (0.0097) and Cosiana (0.0090), these differences being significantly negative (Table 3).
From the analysis of the influence of the variety on the dry matter content, the Azaria variety stood out with a statistically significant positive difference (1.54%) compared to the control in 2024, indicating a superior capacity of this variety to accumulate dry matter. In 2025, for the 6 varieties analyzed, there were no significant differences compared to the control (Table 4).
The comparison of the two crop years highlights a significant increase in dry matter content in 2025 (22.12%) compared to 2024 (20.09%), the average difference between 2024 and 2025 being significantly negative (2.02%).

Table 3. The combined influence of culture year and variety on specific weight

Year(a)/Variety (b)	Specific gravity		Specific gravity		Diff./Sign. (a_1-a_2)
	2024 (a_1)	Diff./Sign.	2025 (a_2) (Ct)	Diff./Sign.	
Asinaria (b_1)	1.0793	-0.0005 ns	1.0833	-0.0033 ns	-0.0040 ns
Azaria (b_2)	1.0853	0.0055 ns	1.0900	0.0033 ns	-0.0047 ns
Castrum (b_3)	1.0793	-0.0005 ns	1.0873	0.0007 ns	-0.0080 ns
Cezarina (b_4)	1.0733	-0.0065 ns	1.0830	-0.0037 ns	-0.0097 o
Cosiana (b_5)	1.0813	0.0015 ns	1.0903	0.0037 ns	-0.0090 o
Darilena(b_6)	1.0803	0.0005 ns	1.0860	-0.0007 ns	-0.0057 ns
Mean (Ct)	1.0798	-	1.0867	-	0.0068 ns
			DL 5% = 0.0074; DL 1% = 0.0101; DL 0.1% = 0.0137.		DL 5% = 0.0087; DL 1% = 0.0145; DL 0.1% = 0.0317.

The Castrum variety obtained the largest negative difference of 2.79%, being a distinctly significant difference. Also, the varieties Cezarina, Cosiana and Asinaria obtained significant negative differences between the two years of cultivation (2.44%; 2.48% and 1.68%).

Table 4. The combined influence of culture year and variety on dry matter (%)

Year(a)/Variety (b)	Dry matter (%)		Dry matter (%)		Diff. (%)/Sign. (a_1-a_2)
	2024 (a_1)	Diff./Sign.	2025 (a_2) (Ct)	Diff./Sign.	
Asinaria (b_1)	19.81	-0.28 ns	21.50	-0.62 ns	-1.68 o
Azaria (b_2)	21.63	1.54 *	22.95	0.83 ns	-1.32 ns
Castrum (b_3)	19.59	-0.50 ns	22.38	0.26 ns	-2.79 oo
Cezarina (b_4)	18.85	-1.24 ns	21.29	-0.83 ns	-2.44 o
Cosiana (b_5)	20.27	0.17 ns	22.75	0.63 ns	-2.48 o
Darilena(b_6)	20.41	0.32 ns	21.83	-0.28 ns	-1.42 ns
Mean (Ct)	20.09	-	22.12	-	-2.02 o
			DL 5% = 1.43; DL 1% = 1.95; DL 0.1% = 2.64.		DL 5% = 1.63; DL 1% = 2.70; DL 0.1% = 5.78.

From the analysis of the influence of the crop year and the variety on the content of reducing sugars in potato tubers (Table 5) it appears that in 2024, the Cezarina variety had the highest value of reducing sugars (0.4332 mg/g) and a significant positive difference (0.1155 mg/g) compared to the control.

In 2025, the Castrum and Cezarina varieties recorded statistically significant positive differences (0.1144 and 0.1188 mg/g), compared to the control, while Azaria presented a distinctly significant negative difference (0.1440 mg/g), having a reduced content of reducing sugars.

In 2025 compared to 2024, at the variety level, Azaria presented a significant positive difference, with a reduction in the content of reducing sugars of 0.1636 mg/g. The other varieties showed statistically insignificant differences between the study years.

Table 5. The combined influence of culture year and variety on reducing sugars (mg/g)

Year(a)/Variety (b)	Reducing sugars (mg/g)		Reducing sugars (mg/g)		Diff. (mg/g)/Sign. (a_1-a_2)
	2024 (a_1)	Diff./Sign.	2025 (a_2) (Ct)	Diff./Sign.	
Asinaria (b_1)	0.2915	-0.0262 ns	0.1855	-0.0694 ns	0.1060 ns
Azaria (b_2)	0.2745	-0.0432 ns	0.1110	-0.1440 oo	0.1636 *
Castrum (b_3)	0.3147	-0.0030 ns	0.3693	0.1144 *	-0.0546 ns
Cezarina (b_4)	0.4332	0.1155 *	0.3738	0.1188 *	0.0595 ns
Cosiana (b_5)	0.3320	0.0143 ns	0.2226	-0.0324 ns	0.1094 ns
Darilena(b_6)	0.2602	-0.0575 ns	0.2677	0.0127 ns	-0.0075 ns
Mean (Ct)	0.3177	-	0.2550	-	0.0627 ns
		DL 5% = 0.1049; DL 1% = 0.1426; DL 0.1% = 0.1933.			DL 5% = 0.1124; DL 1% = 0.1771; DL 0.1% = 0.3486.

Regarding the frying index (Table 6), in 2024, the Cezarina variety recorded the highest value (4.23) and a significant positive difference (1.48).

Table 6. The combined influence of culture year and variety on frying index

Year(a) / Variety(b)	Frying index		Frying index		Diff. /Sign. (a_1-a_2)
	2024 (a_1)	Diff. /Sign.	2025 (a_2) (Ct)	Diff. /Sign.	
Asinaria (b_1)	2.80	0.04 ns	2.17	-0.39 ns	0.63 ns
Azaria (b_2)	1.97	-0.79 ns	0.33	-2.23 ooo	1.63 *
Castrum (b_3)	3.13	0.38 ns	4.20	1.64 **	-1.07 ns
Cezarina (b_4)	4.23	1.48 *	4.20	1.64 **	0.03 ns
Cosiana (b_5)	2.07	-0.69 ns	1.77	-0.79 ns	0.30 ns
Darilena(b_6)	2.33	-0.42 ns	2.70	0.14 ns	-0.37 ns
Mean (Ct)	2.76	-	2.56	-	0.19 ns
		DL 5% = 1.18; DL 1% = 1.61; DL 0.1% = 2.18.		DL 5% = 1.21; DL 1% = 1.84; DL 0.1% = 3.34.	

In 2025, the Castrum and Cezarina varieties presented equal values (4.20) of the frying index and a distinctly significant positive difference (1.64). The very high values of the frying index for the two varieties, in the two years of study, indicate that these varieties are not suitable for processing as French fries. The Azaria variety, with a significantly positive difference between crop years, with a reduction in the frying index of 1.63 in 2025, ranks first in terms of suitability for processing as French fries. The Cosiana variety, with fryng index values of 2.07 in 2024 and 1.77 in 2025, is also suitable for this type of processing.

From the analysis of the influence of the crop year and the variety on the percentage of brown ends observed in French fries stiks (Table 7.), in 2024 the Cezarina variety recorded a statistically very significant increase compared to the control (65.28%), in the brown ends, indicating a very low suitability for processing as French fries. In contrast, the Darilena variety showed a significant negative difference (26.39%), and the other varieties did not show statistically significant differences compared to the control. Also, in 2025 the Cezarina variety showed a very significant difference in the percentage of brown heads (55.00%), compared to the control, and the Azaria and Cosiana varieties recorded significant negative differences (31.67 and 26.67%) compared to the control, indicating their suitability for processing as French fries.

In 2024 compared to 2025, the Asinaria variety recorded a significant increase in the percentage of brown ends (25.00%), and the Castrum variety showed a significant reduction (33.33%) of this parameter in 2024 compared to 2025. The other varieties did not show significant differences between crop years.

Table 7. The combined influence of culture year and variety on brown ends (%)

Year (a) Variety (b)	Brown ends (%)		Brown ends (%)		Diff. (%) /Sign. (a_1-a_2)
	2024 (a_1)	Diff. /Sign.	2025 (a_2) (Ct)	Diff. /Sign.	
Asinaria (b_1)	33.33	1.94 ns	8.33	-23.33 ns	25.00 *
Azaria (b_2)	15.00	-16.39 ns	0.00	-31.67 o	15.00 ns
Castrum (b_3)	30.00	-1.39 ns	63.33	31.67 *	-33.33 o
Cezarina (b_4)	96.67	65.28 ***	86.67	55.00 ***	10.00 ns
Cosiana (b_5)	8.33	-23.06 ns	5.00	-26.67 o	3.33 ns
Darilena(b_6)	5.00	-26.39 o	26.67	-5.00 ns	-21.67 ns
Mean (Ct)	31.39	-	31.67	-	-0.28 ns
	DL 5% = 25.68; DL 1% = 34.89; DL 0.1% = 47.30.		DL 5% = 24.40; DL 1% = 34.58; DL 0.1% = 53.22.		

Regarding colour class number, the differences between varieties and the control were statistically insignificant, indicating a reduced influence of the variety on this parameter under the conditions of 2024 (Table 8).

Table 8. The combined influence of culture year and variety on color class number

Year (a) /Variety (b)	Color class number		Color class number		Diff. /Sign. (a_1-a_2)
	2024 (a_1)	Diff. /Sign.	2025 (a_2) (Ct)	Diff. /Sign.	
Asinaria (b_1)	2.7	-0.8 ns	3.7	-0.2 ns	-1.0 ns
Azaria (b_2)	2.7	-0.8 ns	2.0	-1.9 o	0.7 ns
Castrum (b_3)	3.3	-0.1 ns	4.7	0.8 ns	-1.3 ns
Cezarina (b_4)	3.3	-0.1 ns	4.3	0.4 ns	-1.0 ns
Cosiana (b_5)	4.7	1.2 ns	4.3	0.4 ns	0.3 ns
Darilena(b_6)	4.0	0.6 ns	4.3	0.4 ns	-0.3 ns
Mean (Ct)	3.4	-	3.9		-0.4 ns
			DL 5% = 1.5; DL 1% = 2.0; DL 0.1% = 2.8.	DL 5% = 1.5; DL 1% = 2.3; DL 0.1% = 4.2.	

In 2025, the Azaria variety presented a significantly negative influence (1.9), compared to the control.

At the variety level, the differences between crop years were statistically insignificant.

The correlation matrix highlights several relationships between potato tuber quality traits and climatic factors during the growing season (April–September) in 2024–2025. Specific gravity showed a strong positive correlation with dry matter content (r=0.87), while both parameters were negatively correlated with reducing sugars (r=−0.63 and r=−0.66). Reducing sugars exhibited the strongest positive correlation with the frying index (r=0.91), confirming their major influence on frying quality and color development. Average temperature during the growing season was negatively correlated with specific gravity and dry matter content (r = −0.74 and r = −0.88) and positively associated with reducing sugars (r = 0.36), suggesting that higher temperatures may reduce dry matter accumulation while promoting sugar formation in tubers. In contrast, total precipitation during the same period showed only weak correlations with the analyzed quality traits.

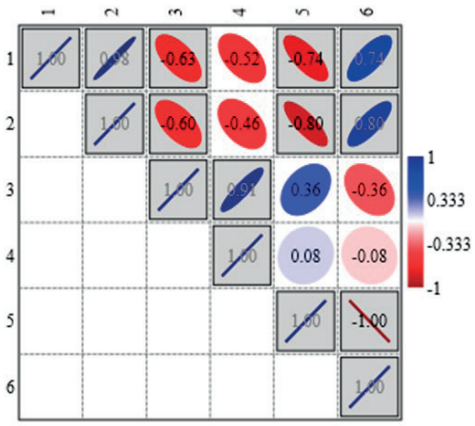

Figure 2. Correlation matrix between potato tuber quality parameters: 1 - Specific gravity, 2 - Dry matter (%), 3 - Reducing sugars, 4 - Frying index, and climatic variables 5 - Temperature, 6 - rainfall (2024-2025)

CONCLUSIONS

The climatic conditions recorded during the potato growing season (April–September) differed between the two studied years (2024, 2025), both in terms of thermal regime and rainfall distribution. Meteorological data revealed that 2024 was characterized by higher temperatures and reduced rainfall during the April-September period, which negatively impacted potato tubers

dry matter accumulation. In contrast, 2025 presented more favourable climatic conditions, for this technological parameter.

The Azaria variety, on average over the two years studied, having the highest dry matter content (22.29%), the lowest reducing sugar content (0.19 mg/g), the lowest frying index (1.15), the very low percentage of brown ends (7.5%) and the lowest number of color classes (2.3), can be considered a variety with high suitability for processing as French fries.

The Cezarina and Castrum varieties are not suitable for processing as French fries because, in the two years of observations, they recorded low dry matter content (20.07% and 20.99%), high reducing sugar content (0.40 mg/g and 0.34 mg/g), high frying index (4.22 and 3.67) and a very high percentage of brown ends (91.67% and 46.67%).

Frying quality is mainly determined by the content of reducing sugars, which is influenced by the genetic characteristics of the potato varieties.

Therefore, the selection of varieties with low levels of reducing sugars and high dry matter content is an essential factor for obtaining high-quality French fries.

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