

THE USE OF SENSORY VEGETATION INDICES IN POTATO CLONAL SELECTION FOR THE IDENTIFICATION OF RESILIENT GENOTYPES

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Abstract

At NIRDPSB Brasov, in order to evaluate the response to the thermo-hydric stress of 2025, NDVI and SPAD vegetation indices were dynamically evaluated. Their quantification allowed obtaining a predictive image on the growth, development and adaptive capacity of plants, underpinning the efficient selection of the most valuable potato genotypes. Of the 28 genotypes evaluated in relation to the control variety Castrum, genotypes 1979/5, 2011/5 and 2018/1 maintained a high photosynthetic capacity until the end of the season (late maturity), unlike the genotype 2151/10 which, although it preserved a reasonable leaf cover (NDVI 0.89), manifested rapid cellular senescence through drastic pigment degradation (decrease to 38.8 SPAD units), standing out as a potential new early potato variety.

Key words: breeding, NDVI, SPAD, phenotypic selection.

INTRODUCTION

Among various crops, potato (*Solanum tuberosum* L.) stands out as both a staple food and a commercially valuable cash crop, feeding millions worldwide and supporting agro-industries (Biswal et al., 2025b).

Vegetation indices are extensively used to assess and monitor the vegetation and health status of the agricultural crops (Ivanovici et al., 2024). They can provide complementary information on vegetation physiology and ecology (Kulig et al., 2024; Yang et al., 2025), on leaf function, which is essential in capturing light and CO₂ needed for the growth of underground organs (Hermeziu et al., 2025). Good development of plants is indicative of their good nutrition, normal course of their life processes and, thus, optimum yielding and nutrient accumulation (Zarzecka et al., 2021). Adam (2025) showed that the dynamics of NDVI (Normalized Difference Vegetation Index) and SPAD (Soil Plant Analysis Development) indices values reveal substantial potential for employing these non-invasive metrics as robust tools for monitoring vegetation performance. From the agronomic point of view, accurate yield prediction is critical for sustainable potato production, NDVI being the best parameter to

use at the peak vegetative stage of potato (Lin et al., 2023; Biswal et al., 2025a), also based on the SPAD values, as revealed in the works of Dvořák and Král (2019), Trawczyński (2019) and Drăghici et al. (2024). For breeding purpose, these findings contribute to understanding the genetic mechanisms underlying potato tolerance to nitrogen deficiency stress, offering valuable insights for the development of future marker-assisted selection programs aimed at improving nitrogen use efficiency and stress resilience (Iribar et al., 2025). Rapid and non-destructive phenotyping approaches represent a pivotal advancement in optimizing the selection processes in potato breeding programs.

MATERIALS AND METHODS

The evaluated biological material comes from the breeding program of the National Institute of Research and Development for Potato and Sugar Beet (NIRDPSB) Brasov. The planting of potato genotypes took place in the third decade of April (April 22, 2025), respecting the scheme of establishing the breeding field and the specific cultivation technology. The process of creating new potato varieties is a long-term and highly complex effort, spanning a period of 12 years, from the first generative hybrid population to

comparative orientation and competition cultures, going through rigorous selection stages. In 2025, 28 breeding lines in the Vegetative Descendants stage were selected for phenotypic evaluation, compared to the Castrum control (medium-early potato variety created at NIRDPSB). To assess the response to thermohydric stress, the portable FieldScout CM 1000 NDVI Meter was used. This instrument served as a non-destructive and efficient screening method, facilitating real-time data acquisition. To obtain physiological data complementary to those obtained by NDVI, there was performed real-time monitoring of chlorophyll concentration in potato leaves using a SPAD 502 plus FieldScout Minolta chlorophyll meter. The SPAD index value is a direct indicator of the relative chlorophyll content, which reflects the photosynthetic capacity of the plant, while the NDVI index measures the density and overall health of the canopy, being a good indicator of green biomass. Whereas NDVI decreases as plants age and turn yellow, the SPAD value shows a precise decrease in pigment in individual leaves, thus confirming the state of cellular degradation and stress. The formulas underlying the evaluated indices are $NDVI = \frac{NIR-RED}{NIR+RED}$ and $N\ index = \frac{\text{readings average}}{\text{control average}} \times 100\%$ (for SPAD values), as described by Stefan et al. (2019). Data acquisition was done dynamically on two different calendar dates, June 23 and August 14, 2025. These dates correspond to the end of the vegetative development phase or, depending on the precocity of the genotypes, the beginning of flowering, respectively, the tuber filling stage and maturity, a critical period for the translocation of assimilates, in which the products of photosynthesis are directed from the leaf apparatus to the tubers, for the accumulation of dry matter. From 3 plants of each genotype, 3 measurements were taken from the upper half of the plants and the average was calculated per plant. To identify genetic variability and select superior breeding lines, the average values used as repetitions were processed by analysis of variance (ANOVA) and the Pearson correlation test, the results being complemented by the calculation of the standard deviation in the SPSS statistical program. The correlation analysis targeted the liaison between SPAD, respectively NDVI indices and the studied genotypes. To

enable the statistical procedure in SPSS, the genotype variable was treated as an ordinal variable and coded numerically (1 to 29), following their ranking from Tables 1 and 2. This numerical assignment permitted the evaluation of linear associations between the breeding lines and the physiological indicators. The climatic conditions of the agricultural year 2024-2025 were evaluated using climatic data provided by the local meteorological station Brasov-Ghimbay, belonging to the National Meteorological Administration.

RESULTS AND DISCUSSIONS

The 2024-2025 agricultural year was warmer than the multiannual average (MAT), especially during winter, and was marked by a significant water deficit during both winter and growing periods. This combination of high temperature and rainfall deficit indicated unfavourable agrometeorological conditions for achieving optimal potato crop yields, requiring stress mitigation solutions, such as the use of new climate-resilient genotypes in cultivation. During the growing season (April - September), an average temperature of 16.1°C was recorded, slightly warmer than the MAT (15.6°C), with a positive deviation of 0.5°C and a deficit in precipitation, with an amount of 361.9 mm compared to the MAT of 420.6 mm, resulting in a deficit of 58.7 mm. To measure the potential and resilience of potato breeding lines, we used dynamic measurement of NDVI and SPAD indices, thus gaining insight into the efficiency with which plants transform light energy into organic matter. Under optimal vegetation conditions, plants show maximum absorption of solar radiation for photosynthesis and high infrared reflectance. Measurements carried out in June revealed an average NDVI index value of 0.89 for the genotypes under selection, with a variation between 0.84 and 0.92. Since NDVI values close to +1.0 indicate maximum green leaf density and optimal photosynthetic vigor, these results confirm that the evaluated genetic material presented a good vegetative state at the time of data acquisition. All genotypes under selection manifested a health state and a photosynthetic vigor superior to the Castrum control (0.84) at the date of evaluation. Most genotypes fell within the range 0.89-0.90,

significantly exceeding the NDVI index value of the control. The highest values were achieved by the genotypes 2151/10, 25-1901/6, 1940/4 and 1901/12. Only two genotypes, 2008/5 and 2011/5 (0.86), although slightly higher than the control, were close to the control index value, but in general there were no genotypes clearly inferior in terms of NDVI index. At the August data acquisition, the average NDVI index was 0.88. The NDVI index ranged between 0.81 (genotype 1979/4) and 0.92 (genotype 2011/5). Although the values are still high, they were generally lower compared to June. The control Castrum recorded a value of 0.92, placing itself among the genotypes with the best vigor at this late date. Genotypes 2011/5 (0.92) and 25-1901/6, 1979/5, 1897/2 (0.91) showed the highest vigor, indicating later maturity. Genotypes such as 2008/5 and 1979/4 (both with NDVI index 0.81) recorded significantly lower values, implying more advanced senescence and susceptibility to the thermo-hydric stress factor characteristic of August. Compared to the June assessment, although some genotypes maintained or even slightly increased the value (such as the Castrum control), a large part of the genotypes that had very high values in June (>0.90) recorded a slight decrease or stagnation in August. This is normal, because in mid-August, the potato usually enters the senescence phase, where the leaves start to lose chlorophyll, decreasing the red absorption and implicitly the NDVI value. The genotype 2151/10, which was the leader in June (0.92), decreased to 0.89 in August, while genotypes such as 2011/5 took over the leading position. This dynamic denotes differences in the precocity of maturation and in the resistance of the genotypes to stress. The fact that the Castrum control increased from 0.84 to 0.92 is an unexpected result from the point of view of senescence, given its classification in the semi-early maturity group, but given the vegetation period of 110-120 days (Hermeziu et al., 2015), in June it was in an accelerated growth phase. In summary, the transition from June to August reflects a specific dynamic of the vegetation curve of each genotype, highlighting the genotypes that maintain an active green leaf surface, i.e. photosynthetic vigor for longer, an important character for the continuous accumulation of biomass.

SPAD index measurements, which indicate the relative chlorophyll content and thus the photosynthetic capacity, showed a good general vigor of the genotypes at the end of June 2025. Most genotypes showed SPAD values between 43.2 and 51.7, respectively an active chlorophyll content specific to the intensive growth phase. The highest chlorophyll concentrations were recorded by the genotypes 1979/4 (51.7), 2008/4 (51.6) and 2002/5 (50.3). These genotypes demonstrated a superior photosynthetic efficiency at this date. The Castrum control recorded a SPAD value of 47.9 units. There were genotypes that showed SPAD values below or equal to those of the control. The lowest values were observed at 2151/7 (43.2), 1927/3 (44.0) and 2165/2 (44.5), therefore a slower development compared to the NDVI index, which was high for most. When taking SPAD data in August, a high variability in chlorophyll content was observed comparable to the June records, reflecting differences in the rate of maturation and senescence. SPAD index values ranged between 38.8 (genotype 2151/10) and 54.3 (genotype 2018/1). The range is wider than in June, which led to the highlighting of genotypes that had already entered senescence from those that maintained a high chlorophyll concentration. The highest concentrations were shown by the genotypes 2018/1 (54.3), 1979/5 (53.4) and 2021/2 (52.9). These genotypes behave as later genotypes. The Castrum control recorded a SPAD value of 47.2, a value similar to the 47.9 SPAD units in June. Genotypes with values below 40.0 (2151/10 at 38.8, 2165/6 at 39.8, 2027/1 at 39.2) show advanced senescence at the cellular level.

Statistical interpretation of the results

In Tables 1 and 2 it is observed that the results of the analysis of variance (ANOVA) confirm that there are significant differences between the potato breeding lines studied for both indices (NDVI and SPAD).

Although both observation data provide statistically valid results ($p < 0.05$), the measurements performed in August provide a much greater discrimination power (higher F values), being the most relevant moment for the ranking and selection of genotypes according to vegetative vigor and chlorophyll content.

Table 1. Analysis of variance for SPAD index values

Breeding line	SPAD (23.06.2025)			SPAD (14.08.2025)		
	Value	Difference	Significance	Value	Difference	Significance
1979/4	51.66	3.76	*	52.69	5.51	*
2008/4	51.64	3.74	*	50.90	3.72	*
2002/5	50.32	2.42	*	40.10	-7.08	o
24-1895/4	50.23	2.33	*	47.46	0.28	*
2151/10	50.19	2.29	*	38.76	-8.42	oo
2008/5	49.46	1.56	*	45.27	-1.91	o
2011/4	49.20	1.30	*	50.41	3.23	*
2018/1	49.02	1.12	*	54.27	7.09	*
2027/1	48.83	0.93	*	39.16	-8.02	oo
25-1901/6	48.79	0.89	*	48.03	0.85	*
2021/3	48.64	0.74	*	52.62	5.44	*
2021/2	48.30	0.40	*	52.92	5.74	*
2008/3	47.94	0.04	*	48.56	1.38	*
1968/1	47.73	-0.17	o	47.00	-0.18	o
1979/5	47.69	-0.21	o	53.40	6.22	*
2011/5	47.57	-0.33	o	52.00	4.82	*
1940/4	47.41	-0.49	o	46.19	-0.99	o
1901/12	47.29	-0.61	o	44.84	-2.34	o
2008/2	47.26	-0.64	o	47.64	0.46	*
1901/11	46.91	-0.99	o	52.13	4.95	*
2008/1	45.87	-2.02	o	43.67	-3.51	o
2002/4	45.88	-2.02	o	41.38	-5.80	o
1930/3	45.71	-2.19	o	48.46	1.28	*
1897/2	45.13	-2.77	o	42.32	-4.86	o
2165/6	44.69	-3.21	o	39.76	-7.42	o
2165/2	44.54	-3.36	o	44.44	-2.74	o
1927/3	44.09	-3.81	o	41.04	-6.14	o
2151/7	43.23	-4.67	o	47.68	0.50	*
CASTRUM (Ct)	47.90			47.18		
DL 5%		0.28		DL 5%		0.37
DL 1%		5.95		DL 1%		7.84
DL 0,1%		7.69		DL 0,1%		10.12

Table 2. Analysis of variance for NDVI index values

Breeding line	NDVI (23.06.2025)			NDVI (14.08.2025)		
	Value	Difference	Significance	Value	Difference	Significance
1979/4	0.89	0.046	**	0.81	-0.112	ooo
2008/4	0.89	0.046	**	0.87	-0.050	oo
2002/5	0.90	0.063	***	0.90	-0.017	oo
24-1895/4	0.89	0.046	**	0.88	-0.040	oo
2151/10	0.92	0.076	***	0.89	-0.033	oo
2008/5	0.86	0.020	*	0.81	-0.111	ooo
2011/4	0.87	0.029	*	0.90	-0.016	oo
2018/1	0.90	0.062	***	0.85	-0.068	ooo
2027/1	0.90	0.059	***	0.88	-0.036	oo
25-1901/6	0.91	0.068	***	0.91	0.068	***
2021/3	0.89	0.051	**	0.87	-0.052	oo
2021/2	0.87	0.033	*	0.89	-0.032	oo
2008/3	0.88	0.044	**	0.89	-0.027	oo
1968/1	0.89	0.046	**	0.85	-0.069	ooo
1979/5	0.89	0.054	**	0.91	-0.010	oo
2011/5	0.86	0.016	*	0.92	-0.004	oo
1940/4	0.91	0.070	***	0.84	-0.083	ooo
1901/12	0.91	0.071	***	0.89	-0.028	oo
2008/2	0.88	0.043	*	0.87	-0.047	oo
1901/11	0.89	0.053	**	0.87	-0.048	oo
2008/1	0.89	0.054	**	0.85	-0.074	ooo
2002/4	0.90	0.062	***	0.87	-0.054	oo
1930/3	0.89	0.051	**	0.88	-0.037	oo
1897/2	0.88	0.040	*	0.91	-0.011	oo
2165/6	0.89	0.046	**	0.88	-0.042	oo
2165/2	0.90	0.057	**	0.85	-0.070	ooo
1927/3	0.90	0.058	***	0.89	-0.029	oo
2151/7	0.88	0.036	*	0.90	-0.024	oo
CASTRUM (Ct)	0.84			0.92		
DL 5%		0.002		DL 5%		0.002
DL 1%		0.044		DL 1%		0.045
DL 0,1%		0.057		DL 0,1%		0.058

In the Pearson correlation tables, the link between the breeding lines and their physiological performance was evaluated. Thus, there is a significant positive correlation ($r=.166$, $p=.028$) between the genotype and the SPAD index (Table 3), but the Pearson coefficient value of .166 is considered a weak correlation. That is, although the genetic influence exists and is certain, there are other factors that contribute to the total variation of the SPAD index.

Table 3. Correlations between genotype and SPAD index

Correlations			
SPAD	Pearson Correlation	1	.166*
	Sig. (2-tailed)		.028
	N	174	174
Genotype	Pearson Correlation	.166*	1
	Sig. (2-tailed)	.028	
	N	174	174

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

There is a significant negative correlation ($r=-.224$, $p=.003$) of weak to medium intensity between genotype and NDVI index (Table 4), but since the correlation is significant at the 0.01 threshold, the link is stronger than in the case of SPAD. Thus, the NDVI index proves to be a more suitable selection tool than the SPAD index to differentiate potato breeding lines.

Table 4. Correlations between genotype and NDVI index

Correlations			
Genotype	Pearson Correlation	1	-.224**
	Sig. (2-tailed)		.003
	N	174	174
NDVI	Pearson Correlation	-.224**	1
	Sig. (2-tailed)	.003	
	N	174	174

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

The standard deviation, an indicator of the variability of measurements within the same genotype, detected the homogeneous breeding lines with high stability from the heterogeneous lines with high variability. Thus, according to the SPAD index (Figure 1), genotypes with short error bars (e.g. 1968/1, 2165/2) are stable and have a uniform manifestation, while genotypes such as 1979/4, 1979/5, 2011/4 (in June) or

2018/1 (in August) present wide error bars, which denotes a greater sensitivity to environmental conditions.

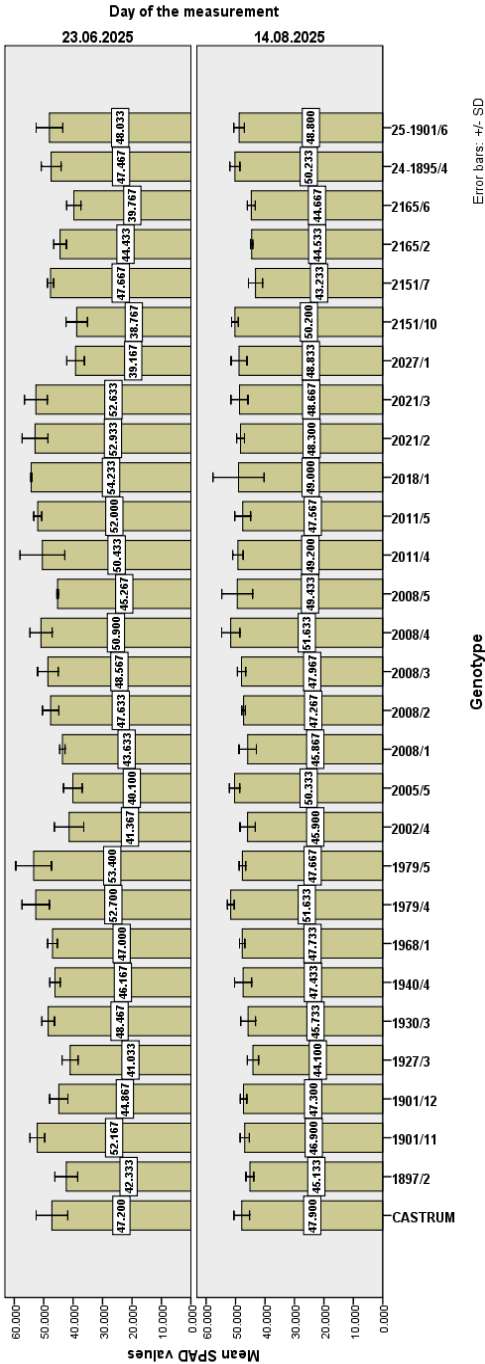


Figure 1. Standard deviation of the SPAD index



Figure 2. Standard deviation of the NDVI index

From the analysis of the stability and uniformity of the NDVI index measurements (Figure 2),

phenotypic canopy stability is observed, given by the small error bars in most genotypes, especially in August, but genotypes such as 1940/4 are also distinguished that had a non-uniform response to environmental conditions, observed by the increase in the standard deviation.

CONCLUSIONS

Modelling and identifying new potato genotypes with climate resilience is the most versatile way to respond to climate change.

The analysis of vegetation indices contributed to the identification of differences in the aging process of potato genotypes, for selection.

The data highlighted genotypes with discrepancies between biomass (NDVI) and cellular health (SPAD), indicators of early senescence processes.

As a global dynamic from June to August 2025, the August data acquisition statistically proved to be more beneficial for discrimination between genotypes.

Thus, the genotype 2151/10 stood out through rapid senescence despite still reasonable leaf cover (NDVI 0.89) becoming one of the genotypes with the lowest chlorophyll concentration (38.8 SPAD units), respectively a potential new early potato variety.

Genotypes such as 2011/5 and 1979/5 maintained or reached values higher than the control in both NDVI and SPAD in August. This indicates a well-maintained photosynthetic capacity throughout the season and a late maturity.

For the selection of future new potato varieties, it is necessary to monitor the efficient conversion into tubers.

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