

EVALUATING THE CHLOROPHYLL CONTENT OF SOME POTATO VARIETIES LEAVES, AGRONOMIC FEATURES AND YIELD USING SPAD METER

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Abstract

Between 2023-2024 at NIRDPSB Brasov, Romania were performed research to determine the leaf greenness index SPAD and selected potato characteristics, i.e. plant height, yields and tubers starch content on twelve varieties. With SPAD 502 Plus meter (Chlorophyll Meter) were carried out 3 determinations on the leaves of the middle level of 3 plants from each variety taken into the study. Values recorded on 22.06.2023 were between 47.9 and 42.5 units, and those on 18.07.2023 between 47.6 and 42.1 units and the yield varied between 14 t/ha and 45.47 t/ha. Values recorded on 18.06.2024 were between 49.9 and 41.4 units, and those on 08.07.2024 between 47.0 and 39.9 units and the yield varied between 25.72 t/ha and 7.58 t/ha. The results showed that threshold SPAD values decrease as the growing season progresses for all varieties and the yield is strongly influenced by climatic conditions.

Key words: leaf greenness index SPAD, potato, plant development, starch, yield.

INTRODUCTION

The potato, because of its adaptability, yielding capacity, and nutrition contribution, and as an important component of diversified cropping systems, has a long history of helping relieve food insecurities (Devaux et al., 2021). Previous studies strongly suggest that SPAD hand-held chlorophyll meter is a promising tool to assess the nitrogen status of potato foliage, and offers opportunities to minimize the influences of other factors on N estimation based on SPAD measurements (Li et al., 2012). In recent years, many destructive and non-destructive methods have been developed to estimate the chlorophyll content of leaves (Liu et al., 2020). With the rapid development of intelligent agriculture, the rapid and non-destructive estimation of chlorophyll content has been realized, which is of great significance for evaluating and managing crop canopy photosynthetic capacity (Shi, 2024).

The first attempt to use the SPAD chlorophyll meter for potato was reported by Vos and Bom (1993). SPAD-502 meter is a hand-held device used for rapid, accurate, and non-destructive measurement of leaf chlorophyll concentrations

(Ling et al., 2011). Effectivity of SPAD-502 meter is tested with various crops such as corn (Bullock and Anderson, 2008), rice, coffee, potato (Guanli and Huachun, 2007) and sugarcane (Jangpromma et al., 2010). It works by emitting two frequencies of light, 660 nm (red) and 970 nm (infrared).

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).

The chlorophyll content is significantly correlated with the content of nitrogen (Gaurav et al., 2019) which is one of the most important nutrients for the potato plant's healthy growth (Zhou et al., 2018), development (Clevers and Kooistra, 2012) and production (Nigon et al., 2014).

Chlorophyll meter utilization to evaluate plant N status at real time is suitable for precision agriculture and canopy greenness might serve as a useful diagnostic tool to assess plant N demand (Wiesler et al., 2002).

Climate change has emerged as one of the most significant issues over the past two decades. The primary cause of this climate change is known to be the phenomenon of increasing

atmospheric temperature due to the rise in carbon dioxide (CO₂) concentration in the atmosphere (Lobell et al., 2011; Mora et al., 2013). Consequently, the global average temperature is predicted to increase by 2.4-6.4°C by the end of this century. Climate change not only increases the frequency of abiotic stress factors such as droughts, floods, and heavy rainfall, but also has severe impacts on ecosystems, food production, and human health (Calzadilla et al., 2013). Furthermore, climate change in the agricultural sector is expected to cause soil erosion and water scarcity, deteriorating crop cultivation environments, altering suitable cultivation areas, and raising concerns about the emergence of new pests and weeds (Ahn et al., 2017; Park et al., 2025).

Starch is the main carbohydrate found in the potato, and the most important component of the tuber's dry weight (Chakraborty et al., 2022). It is composed of two polysaccharide components: amylose (15-30%) and amylopectin (70-85%) (Brażkiewicz et al., 2025). Its content in potato tubers and quality depend on many factors: genetic and environmental conditions (place of cultivation, temperature and amount of precipitation, time of harvest), as well as applied agrotechnology (Liszka-Skoczylas, 2020).

The purpose of the work was to assess the influence of leaf greenness index SPAD on the potato plant development, tuber yield and starch content.

MATERIALS AND METHODS

Experiments were carried out at the National Institute of Research and Development for Potato and Sugar Beet Braşov, Romania, on a cambic chernozem soil, with 6.7 pH, humus 4.68% and clay 27%. The pre-crop was wheat in both years and for current fertilizer was used 1000 kg/ha N:P:K:15:15:15+S.

Planting distance was 75 cm between rows and 30 cm between plants per row, having 4 rows with 10 plants each one. Planting was done manually in April 28, 2023 and April 10, 2024. During the vegetation period were applied the usual maintenance works (hilling,

herbicides, treatments for late blight and Colorado beetle) for potato crop.

In the two years of study, it was aimed the dynamics of potato plant growth and tuber yield accumulation of twelve Romanian potato varieties (Brasovia, Azaria, Castrum, Marvis, Sarmis, Darilena, Cezarina, Ervant, Asinaria, Foresta, Sevastia, Cosiana). It has been carried out two harvesting in dynamic for each variety. With SPAD 502 Plus meter (Chlorophyll Meter) on the days of 22.06 and 18.07.2023, and respectively, 18.06 and 08.07.2024, three determinations (readings) were carried out on the leaves of the middle layer of 3 plants from each genotype taken into the study.

For interpretation of chlorophyll results was used the formula of nitrogen index (Shapiro et al., 2006): N index = readings average/control average x 100%.

Potato tubers were harvested semi-mechanized on September 13, 2023, respectively September 19, 2024. Brasovia variety was taken as a control variant and all the tubers from two central rows in each repetition/variant were weighed. For the determination of starch content have been taken from tuber mass average samples of one kilo from each variety on 3 replications. Determination of the percentage of starch was done using the Polikeit balance.

Statistical evaluation of the experimental data was performed using Microsoft Excel 2013 and SPSS for Windows 13.0. For the evaluation of the results, analysis of variance and Pearson's correlation analysis were used.

RESULTS AND DISCUSSIONS

To NIRDPSB Braşov, the periods from October 1, 2022, to March 31, 2023, and from October 1, 2023, to March 31, 2024, were characterized by monthly mean air temperatures higher than the long-term averages. In the 2022-2023 agricultural year, the highest mean air temperature relative to the long-term average of -5°C was recorded in January, reaching 3.1°C, whereas in the 2023-2024 agricultural year, the maximum was observed in February, with a mean temperature of 6 °C compared to the long-term average of -2.5°C. At the beginning of November, soil

moisture conditions were favorable for performing autumn plowing. Winter precipitation was generally low; however, in January 2023, 44 mm of rainfall was recorded, exceeding the long-term average of 25.5 mm, while in March 2024, the precipitation reached 72.4 mm, significantly above the long-term average of 28.9 mm. April of the spring of 2023 was cooler than normal, with a mean temperature of 7.3 °C, whereas in April 2024, temperatures were higher than normal, reaching 12.2 °C. Total precipitation in April 2023 amounted to 83.1 mm, while in April 2024 only 43.5 mm was recorded, 6.5 mm below the long-term average. In May, the air temperature was close to the long-term average, but precipitation in 2024 was significantly below normal, amounting to only 42.7 mm compared to 82 mm. The summer months (June-August) were characterized by higher-than-average temperatures. In June 2023, the mean temperature was 17.6°C, increasing substantially to 21.1°C in June 2024, compared to the long-term average of 16.5°C. Precipitation was generally low, although in June 2023 a total of 111.1 mm was recorded, above the long-term average of

96.7 mm. During the summer of 2024, atmospheric and soil drought conditions prevailed throughout the season. Moreover, precipitation distribution was extremely uneven, as exemplified in August 2024, when approximately 90 % of the monthly total fell within only four days (Figure 1).

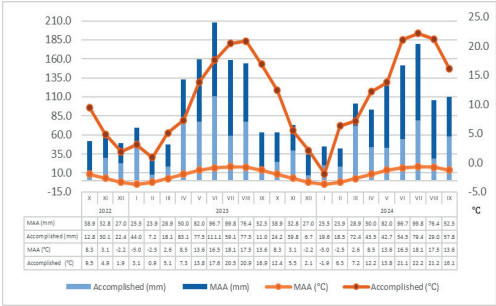


Figure 1. The climatic conditions during the experimental period in Brasov

Drought in the early part of the potato vegetation determines the poor development of the aerial vegetative apparatus, the plants remain smaller, with reduced leaf area, which has a negative influence on the subsequent growth of the tubers.

Table 1. The mean measurements of plant and SPAD-value carried out in dynamics - 2023 Braşov

Variety	Plant height (cm)		Median leaf length (cm)		Total biomass weight (g)		Tuber no./hill		Tuber weight/hill (g)		SPAD values	
	22.06	18.07	22.06	18.07	22.06	18.07	22.06	18.07	22.06	18.07	22.06	18.07
Cosiana	57.00	71.25	24.00	20.00	334.25	520.00	3.25	6.88	41.50	263.38	47.5	47.6
Marvis	44.50	65.13	21.75	24.88	348.75	541.00	10.50	10.25	160.25	875.25	47.6	46.6
Darilena	39.13	50.63	21.38	21.50	182.75	267.88	3.00	5.50	38.00	400.50	47.7	44.3
Asinaria	45.88	58.63	24.88	21.63	240.00	402.75	6.63	7.13	91.75	494.00	45.0	44.7
Sarmis	39.50	51.88	20.13	21.13	231.25	323.25	4.13	6.63	91.00	487.00	47.6	46.2
Cezarina	34.50	55.00	21.63	29.38	140.50	548.00	2.25	9.25	20.75	547.25	47.9	46.4
Foresta	37.00	52.75	23.38	22.25	156.25	426.00	2.88	5.25	40.75	303.50	46.2	47.1
Ervant	61.75	79.00	23.75	23.00	422.00	462.50	10.88	14.00	275.13	1052.25	45.9	44.4
Sevastia	39.25	67.00	22.88	23.75	207.25	479.75	2.63	10.75	26.50	650.75	42.5	42.1
Brasovia	35.63	53.00	19.75	22.13	211.25	423.25	5.63	12.25	66.50	658.25	45.4	43.4
Azaria	50.13	80.63	24.38	26.25	372.25	555.50	11.25	7.63	107.00	632.00	47.4	44.9
Castrum	47.50	81.75	23.38	25.75	364.25	738.50	8.13	8.75	99.00	527.75	46.4	44.2

Plant height varied significantly depending on variety. Cosiana variety produced the tallest plants (57.00 cm, respectively 71.25 cm) to both assessments, whereas Cezarina produced the shortest (34.50 cm) to the first assessment and Sarmis (51.88 cm) to the second assessment. We consider that both genetic and environmental factors influence plant height.

The numbers of tubers per plant are determined by different parameters such as numbers of stolons and stems, varieties grown and status of vegetative growth (Adhikari, 2005; Abeytilakaratna, 2022) (Figure 2). To the first assessment Azaria variety had the highest number of tubers, 11.25, whereas Cezarina had substantially fewer, 2.25. To the second assessment Ervant variety presented the highest

number of tubers, 14.00, and Foresta variety the lowest, 5.25. Between tuber weight there were differences, to the first assessment Ervant variety reach to 275.13 g while Cezarina reach only 20.75 g.

The average weight of tubers increases with temperature, but at temperatures above 25°C, it begins to decrease, and the number of tubers in the hill also decreases. The stems elongate while the leaf area decreases. Too much solar radiation can cause leaves burn.

The SPAD values recorded on the reading of 22.06.2023 were between 42.5 units for the Sevastia variety and 47.9 units for the Cezarina variety, and on the reading of 18.07.2023 between 42.1 units for the Sevastia variety and 47.6 units for the Cosiana variety.

As the vegetation progresses, generally, a decrease in the chlorophyll content value is observed, depending on the leaf mass of the variety and its exposure. Cosiana, variety with later accumulation, continued to provided high

values (47.6 units) and Foresta variety (47.1 units). Chlorophyll content decreased pronounced in the varieties Darilena (44.3 units), Azaria (44.9 units) and Castrum (44.2 units) (Table 1).



Figures 2. Evolutionary elements of sacrificed and analyzed potato plants

Table 2. The mean measurements of plant and SPAD-value carried out in dynamics - 2024 Braşov

Variety	Plant height		Median leaf lenght		Total biomass weight		Tuber no./hill		Tuber weight/hill		SPAD values	
	18.06	8.07	18.06	8.07	18.06	8.07	18.06	8.07	18.06	8.07	18.06	8.07
Cosiana	63.63	66.25	19.00	19.38	469.50	300.75	3.13	9.75	49.75	149.25	41.4	43.8
Marvis	52.63	54.13	19.25	18.13	398.25	284.25	13.75	17.00	292.00	656.75	46.5	42.1
Darilena	49.50	48.75	18.50	16.38	255.25	183.63	7.38	10.25	275.25	337.50	48.9	43.8
Asinaria	58.13	63.75	22.63	21.38	305.00	268.75	9.25	12.00	327.25	512.50	48.4	43.3
Sarmis	52.63	63.63	19.13	17.88	347.25	314.75	8.00	10.50	266.00	579.25	47.2	44.2
Cezarina	50.75	57.75	20.38	21.13	309.75	268.75	13.38	11.88	232.50	423.50	47.9	46.2
Foresta	63.00	61.38	23.00	19.63	288.50	267.25	5.75	9.25	199.50	413.75	49.9	45.7
Ervant	65.38	62.50	21.13	17.00	390.25	173.25	15.00	15.50	579.25	758.00	47.0	41.5
Sevastia	56.88	55.38	21.50	20.50	303.75	208.50	8.13	8.00	186.75	409.50	44.0	42.7
Brasovia	47.13	47.63	17.63	17.75	326.25	166.50	10.25	12.75	215.75	314.25	44.8	39.9
Azaria	62.88	72.88	22.50	22.00	531.75	495.13	12.00	14.25	343.00	549.50	48.2	47.0
Castrum	59.13	64.00	20.25	20.00	476.50	350.25	13.50	16.63	186.75	326.50	47.3	43.4

In 2024 Ervant variety produced the tallest plants (65.38 cm) to the first assessment, whereas Brasovia produced the shortest (47.13 cm). To the second assessment Azaria variety produced the tallest plants (72.88 cm) and Brasovia the shortest (47.63 cm). To the first assessment Ervant variety had the highest number of tubers, 15.00, whereas Cosiana had substantially fewer, 3.13. To the second assessment Marvis variety presented the highest number of tubers, 17.00, and Sevastia variety the lowest, 8.00. Between tuber weight continue to be differences, to the first assessment Ervant variety reach to 579.25 g while Cosiana reach only 49.75 g and to the second assessment

Ervant variety continued to have the highest weight (758.00 g) while Cosiana just had 149.25 g (Table 2).

The SPAD values recorded on the reading of 18.06.2024 were between 49.9 units for the Foresta variety and 41.4 units for the Cosiana variety, and on the reading of 8.07.2024 between 47.0 units for the Azaria variety and 39.9 units for the Braşovia variety.

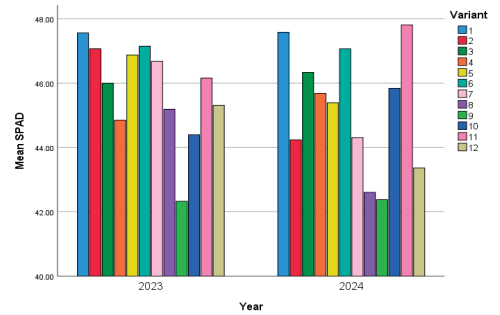
Also in 2024, Cosiana variety recorded an increase in chlorophyll values, compared to its more pronounced decrease in the Marvis, Asinaria, Darilena varieties. Also, the Ervant variety, which accumulates early and has a spreading grow habit, showed a significant

decrease, from 47.0 units to 41.5 units. In contrast, the Cezarina and Azaria varieties continued to show high chlorophyll content, decreasing only 1.7 units (from 47.9 to 46.2 units) and 1.2 units (from 48.2 to 47.0 units), respectively. We consider that the presence of water is essential during tuber formation and growth. If plants are subjected to water stress then the leaves increase stomatal conductance to reduce their temperature.

The experience confirms that the SPAD values of a potato crop decrease as the plants progress in vegetation.

Analyzing the average readings from the two years, we can see the different reaction of some varieties to the influence of climatic conditions. While the Cosiana variety remained approximately at the same level, the Marvis variety recorded a significant decrease in 2024. For the Castrum variety, the situation was similar, recording a pronounced decrease in 2024, while the Azaria variety recorded a spectacular increase in SPAD values. The

varieties Darilena and Asinaria recorded higher values in 2024 compared to 2023, Cezarina and Sevastia varieties performed in the same way in both years, Brasovia variety recorded an insignificant decrease, but Sarmis, Ervant and Foresta varieties recorded stronger decreases in 2024 compared to 2023 (Figure 3).



*Variant codes: 1 = Cosiana, 2 = Marvis, 3 = Darilena, 4 = Asinaria, 5 = Sarmis, 6 = Cezarina, 7 = Foresta, 8 = Ervant, 9 = Sevastia, 10 = Brasovia, 11 = Azaria, 12 = Castrum.

Figure 3. Average SPAD values in the two years of experiment

Table 3. Correlations describing relationship between the years, the plants and SPAD values

		Year	Observation	Variant	Repetition	Plant	Reading	SPAD
Year	Pearson Correlation	1	-.677**	.000	.000	.000	.000	-.067**
	Sig. (2-tailed)		.000	1.000	1.000	1.000	1.000	.006
Observation	Pearson Correlation	-.677**	1	.000	.000	.000	.000	.247**
	Sig. (2-tailed)	.000		1.000	1.000	1.000	1.000	.000
Variant	Pearson Correlation	.000	.000	1	.000	.000	.000	-.149**
	Sig. (2-tailed)	1.000	1.000		1.000	1.000	1.000	.000
Repetition	Pearson Correlation	.000	.000	.000	1	.000	.000	-.014
	Sig. (2-tailed)	1.000	1.000	1.000		1.000	1.000	.552
Plant	Pearson Correlation	.000	.000	.000	.000	1	.000	-.037
	Sig. (2-tailed)	1.000	1.000	1.000	1.000		1.000	.128
Reading	Pearson Correlation	.000	.000	.000	.000	.000	1	-.048*
	Sig. (2-tailed)	1.000	1.000	1.000	1.000	1.000		.047
SPAD	Pearson Correlation	-.067**	.247**	-.149**	-.014	-.037	-.048*	1
	Sig. (2-tailed)	.006	.000	.000	.552	.128	.047	

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

We believe that a negative correlation between SPAD values and the plants on which the readings were taken occurred due to thermo-hydric stress, the relationship being reversed, as

the water content in the leaves decreased, chlorophyll increased, probably in response to stress or other physiological changes (Table 3).

Table 4. Total yield tuber/ha (t/ha) and starch content

Variety	Yield (t/ha)		Starch content (%)	
	13.09.23	19.09.24	09.11.23	05.11.24
Cosiana	21.11	20.61	14.25	13.25
Marvis	35.06	12.03	15.13	14.27
Darilena	21.06	21.11	14.83	14.42
Asinaria	31.64	17.39	15.04	14.63
Sarmis	26.94	14.11	14.44	13.75
Cezarina	26.08	7.58	14.25	13.33
Foresta	14.00	17.39	11.06	13.09
Ervant	45.47	21.11	10.27	10.56
Sevastia	25.69	13.08	12.13	11.58
Brasovia (Mt)	26.11	12.58	16.35	14.67
Azaria	40.69	25.72	15.96	13.33
Castrum	41.31	21.86	13.71	13.69
DL 5% =	4,99 t	3,34 t	Mean:	Mean:
DL 1% =	6,69t	4,47t	13.95	13.38
DL 0,1% =	8,83 t	5,90 t		

The total production in both years was not at the level of the productive potential of most varieties, the decreases being major especially in 2024.

The values recorded in 2023 varied between 14.00 t/ha to Foresta variety and 45.47 t/ha to Ervant variety and in 2024 ranged between 25.72 t/ha to Azaria variety and 7.58 t/ha to Cezarina variety (Table 4).

Comparing the productions obtained in 2024 with those in 2023, which from a climatic point of view was warmer and with less precipitation, it can be observed that the most varieties (Castrum, Azaria, Ervant, Sevastia, Asinaria, Sarmis and Brasovia) had their productions cut in half, the Cosiana and Foresta varieties maintained their production levels, the Marvis and Cezarina varieties recorded dramatic decreases.

The highest level of starch content in 2023 (16.35%) was observed to Brasovia variety, followed by Azaria (15.96%) and Marvis (15.13%). At the lowest level were the varieties Foresta (11.06%) and Ervant (10.27%).

In 2024, the Brasovia variety (14.67%) showed the highest starch content after harvest, followed by Asinaria (14.63%) and Darilena (14.42%) and the lowest values were registered to Sevastia (11.58%) and Ervant (10.56%) varieties (Table 4).

High differences in starch content between the years presented varieties Foresta, Brasovia and Azaria.

The differences in starch content are due to genetic conditions and the agrotechnology used at the time of cultivation. Rymuza et al. (2015), studying different potato varieties, showed that the starch content in tubers depends highly on

precipitation level. The authors also reported on the diversified response of varieties to weather conditions in different growing seasons in terms of starch accumulation in tubers.

CONCLUSIONS

SPAD measurements were performed to study the possibilities of non-invasive assessment of the vegetation status of potato plants in the experimental field compared to measurements on plants sacrificed at the two dynamics.

Values recorded on 22.06.2023 were between 47.9 and 42.5 units, and those on 18.07.2023 between 47.6 and 42.1 units. Values recorded on 18.06.2024 were between 49.9 and 41.4 units, and those on 8.07.2024 between 47.0 and 39.9 units.

The production was significantly influenced by the climatic conditions, being between 45.47 t/ha and 14.00 t/ha in 2023 and between 25.72 t/ha and 7.58 t/ha in 2024. Starch, the main biochemical component of potato tubers, presented average values ranging between 13.95% in 2023 and 13.38% in 2024, the highest average values of starch content in tubers being determined to Brasovia variety in both years (16.35% in 2023 and 14.67% in 2024).

SPAD values of potato varieties grown under current climatic conditions could be useful traits to identify their heat-tolerant and the abilities to resist to higher temperatures.

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REFERENCES

Abeytilakarathna, P.D. (2022). Factors Affect to Stolon Formation and Tuberization in Potato: A Review. *Agricultural Reviews*, 43(1). 91–97. doi: 10.18805/ag.R-187.

Adhikari, R.C. (2005). Performance of different size true potato seed seedling tubers at Khumaltar. *Nepal Agriculture Research Journal*, 6. 28–34.

Ahn, S.H., Kim, D.W., Lee, H.S., Jeong, J.H., Jeong, H.Y., Hwang, W.H., Baek, J.S., Choi, K.J., Choi, I.B., Park, H.K. (2017). Changes in physicochemical properties in wheat grains as influenced by average

- temperature rise during ripening stage. *J. Korean Soc. Int. Agric.*, 29. 50–55.
- Brązkiewicz, K., Pobereźny, J., Wszelaczyńska, E. (2025). Potato starch quality in relation to the treatments and long-term storage of tubers. *Sci Rep.*, 15, 4144. <https://doi.org/10.1038/s41598-025-85657-0>
- Bullock, D., Anderson, D. (2008). Evaluation of the Minolta SPAD-502 chlorophyll meter for nitrogen management in corn. *Journal of Plant Nutrition*, 21. 741–755. <https://doi.org/10.1080/01904169809365439>
- Calzadilla, A., Rehdanz, K., Betts, R., Fallon, P., Wiltshire, A., Tol, R.S.J. (2013). Climate change impacts on global agriculture. *Clim. Change*, 120. 357–374.
- Chakraborty, I., Mal, N. P., Paul, S. S., Rahman, U. C., Mazumder, N. M. H. (2022). An insight into the gelatinization properties influencing the modified starches used in food industry: A review. *Food Bioprocess Tech.*, 15. 1195–1223. <https://doi.org/10.1007/s11947-022-02761-z>
- Clevers, J.G.P.W., Kooistra, L. (2012). Using hyperspectral remote sensing data for retrieving canopy chlorophyll and nitrogen content. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, 5. 574–583.
- Devaux, A., Goffart, J.P., Kromann, P., Andrade-Piedra, J., Polar, V., Hareau G. (2021). The potato of the future: Opportunities and challenges in sustainable agri-food system. *Potato Research*, 64. 681–720.
- Gaurav, S., Babankumar, B., Lini, M., Jonali, G., Burhan, U.C., Raju, P.L.N. (2019). Chlorophyll estimation using multi-spectral unmanned aerial system based on machine learning techniques. *Remote Sens. Appl.: Soc. Environ.*, 15, 100235.
- Guanli, X., Huachun, G. (2007). SPAD value of leaf at different positions on main stem in potato as influenced by temperature and photoperiod. *Chinese Potato Journal* http://en.cnki.com.cn/Article_en/CJFDTotol-MLSZ200703004.htm.
- Jangpromma, N., Songri, P., Thammansirirak, S., Jaisil, P. (2010). Rapid assessment of chlorophyll content in sugarcane using a SPAD chlorophyll meter across different water conditions. *Asian Journal of Plant Sciences*, 9(6). 368–374. <https://scialert.net/abstract/?doi=ajps.2010.368.374>.
- Li, L., Qin, Y., Yanchun, L., Yuncai, H., Mingshou, F. (2012). Leaf positions of potato suitable for determination of nitrogen content with a SPAD meter. *Plant Prod. Sci.*, 15(4). 317–322.
- Ling, Q., Huang, W., Jarvis, P. (2011). Use of a SPAD-502 meter to measure leaf chlorophyll concentration in *Arabidopsis thaliana*. *Photosynth Res.* 107(2). 209–14. <https://www.ncbi.nlm.nih.gov/pubmed/21188527>
- Liszka-Skoczylas, M. (2020). Effect of potato plants (*Solanum tuberosum* L.) fertilization on content and quality of starch in tubers. *ŻNTJ*, 27. 31–46. <https://doi.org/10.15193/zntj/2020/122/320>.
- Liu, N., Liu, G., Sun, H. (2020). Real-time detection on SPAD value of potato plant using an in-field spectral imaging sensor system. *Sensors*, 20(12). 3430. <https://doi.org/10.3390/s20123430>.
- Lobell, D.B., Schlenker, W.S., Costa-Roberts, J. 2011. Climate trends and global crop production since 1980. *Science*, 333. 616–620.
- Mora, C., Frazier, A.G., Longman, R.J., Dacks, R.S., Walton, M.M., Tong, E.J., Sanchez, J.J., Kaise, L.R., Stender, Y.O., Anderson, J.M. (2013). The projected timing of climate departure from recent variability. *Nature*, 502. 183–187.
- Nigon, T.J., Mulla, D.J., Rosen, C.J., Cohen, Y., Alchanatis, V., Rud, R. (2014). Evaluation of the nitrogen sufficiency index for use with high resolution, broadband aerial imagery in a commercial potato field. *Precis. Agric.*, 15. 202–226.
- Park, H. H., Ei, E., Kuk, Y. I. (2025). Effects of climate variation on spring potato growth, yield, and quality in South Korea. *Agronomy*, 15(1). 149. <https://doi.org/10.3390/agronomy15010149>.
- Rymuza, K., Radzka, E., Lenartowicz, T. (2015). Influence of precipitation and thermal conditions on starch content in potato tubers from medium-early cultivars group. *J. Ecol. Eng.* 16. 176–179. <https://doi.org/10.12911/22998993/59367>.
- Shapiro, C.A., Schepers, J.S., Francis, D.D., Shanahan, J.F. (2006). Using a chlorophyll meter to improve N management. University of Nebraska, Lincoln: *Neb Guide G1632*. 13–16.
- Shi, H., Lu, X., Sun, T., Liu, X., Huang, X., Tang, Z., Li, Z., Xiang, Y., Zhang, F., Zhen, J. (2024). Monitoring of chlorophyll content of potato in Northern Shaanxi based on different spectral parameters. *Plants*, 13(10).1314. doi: 10.3390/plants13101314. PMID: 38794385; PMCID: PMC11124996.
- Vos, J., Bom, M. (1993). Hand-held chlorophyll meter: a promising tool to assess the nitrogen status of potato foliage. *Potato Research* 36(4). 301–308.
- Wiesler, F., Bauer, M., Kamh, T., Engels, Reusch, S. (2002). The crop as indicator for sidedress nitrogen demand in sugar beet production – limitations and perspectives. *J. Plant Nutr. Soil Sci.*, 165. 93–99.
- Zarzecka, K., Gugala, M., Mystkowski, I., Sikorska, A. (2021). The leaf greenness index SPAD and selected features of potato following an application of herbicides and biostimulants. *Journal of Ecological Engineering*, 22(8). 54–63.
- Zhou, Z., Jabloun, M., Plauborg, F., Andersen, M.N. (2018). Using ground-based spectral reflectance sensors and photography to estimate shoot N concentration and dry matter of potato. *Comput. Electron. Agric.*, 144. 154–163.