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CHLOROPHYLL CONTENT IN LEAVES OF HIGHLAND POTATOES FOR ESTIMATING TUBERS QUALITY

CONTENIDO DE CLOROFILA EN HOJAS DE PAPAS DE ALTURA PARA ESTIMAR LA CALIDAD DE LOS TUBÉRCULOS

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Abstract

In this study, we assessed the relationship between tubers quality of three varieties (INIAP Libertad, INIAP Josefina and Diacol Capiro) of Ecuador highland early of potato and two formulations of edaphic fertilizer sources. Leaf chlorophyll content (LCC) was evaluated with Chlorophyll Meter SPAD-502Plus. Samples were taken at different heights in three phenological stages: vegetative grow, flowering–formation of tubers and ripening-thickening. Several responses were found in the three potato varieties. Correlation between SPAD value and weight of tubers (W), dry matter (DM), specific gravity (SG) and good chips (GC) were significantly correlated with potato leaves chlorophyll content. For Libertad variety and formulation ($KNO_3 + NH_4H_2PO_4 + KCl$), at vegetative grow in upper strata of plant, the optimal mathematic function for SPAD value and W, DM, SG and GC were: y = 0.262x−9.460 (R^2 = 0.9938), y = 42.948 $e^{-0,01x}$ (R^2 = 0.5240), y = $10^{0,13}x^{-0,05}$ (R^2 = 0.3277) and y = $10^{-0,36}x^{1,41}$ (R^2 = 0.8681); at plant flowering-formation of tuber stage, the optimal function models were: y = $10^{-1,57}$ $x^{1,06}$ (R^2 = 0.8553), y = 28.789 $e^{-0,0024}$ (R^2 = 0.9103), y = $10^{0,07}$ $x^{-0,02}$ (R^2 = 0.7543) and y = 0.468x + 64.361 (R^2 = 0.9935); at plant ripening-thickening, the optimal function models were: y = 0.664 $e^{0,02x}$ (R^2 = 0.7924), y = 29.370 $e^{-0,003x}$ (R^2 = 0.9572), y = $10^{0,07}$ $x^{-0,02}$ (R^2 = 0.8247) and y = 0.576x + 62.675 (R^2 = 0.9690), respectively. Our results showed that the use of SPAD-520PLUS proved to be a rapid method for the determination of LCC, being an effective tool for estimating potato tuber quality.

Keywords: Correlation analysis, Ecuador highlands, photosynthesis, *Solanum tuberosum*, SPAD-502 plus®.

Resumen

En este estudio se evaluó la relación de la calidad de tubérculos de tres variedades de papa (INIAP Libertad, INIAP Josefina y Diacol Capiro) del Altiplano ecuatoriano y dos formulaciones de fertilizante de fuentes edáficas. El contenido de clorofila foliar (CCF) se evaluó con el medidor de clorofila SPAD-502Plus. Las muestras se tomaron a diferentes alturas en tres etapas fenológicas: crecimiento vegetativo, floración-formación de tubérculos y maduración-espesamiento. Se encontraron varias respuestas en las tres variedades de papa. El valor de *SPAD* y peso de tubérculos (*W*), materia seca (*MS*), densidad específica (*GS*) y buenas papas (*GC*) se correlacionaron significativamente con el contenido de clorofila en las hojas de papa. Para la variedad y formulación Libertad (KNO_3 + $NH_4H_2PO_4$ + KCl), en el crecimiento vegetativo en estratos superiores de la planta, la función matemática óptima para SPAD y W, DM, SG y GC fueron: $y = 0,262x - 9,460$ ($R^2 = 0,9938$), $y = 42,948e^{-0,01x}$ ($R^2 = 0,5240$), $y = 10^{0,13}x^{-0,05}$ ($R^2 = 0,3277$) e $y = 10^{-0,36}x^{1,41}$ ($R^2 = 0,8681$); en la etapa de floración-formación de la planta de tubérculo los modelos de función óptima fueron: $y = 10^{-1,57}x^{1,06}$ ($R^2 = 0,8553$), $y = 28,789e^{-0,0024x}$ ($R^2 = 0,9103$), $y = 10^{0,07}x^{-0,02}$ ($R^2 = 0,7543$) e $y = 0,468x + 64,361$ ($R^2 = 0,9935$); en la maduración-espesamiento de las plantas, los modelos de función óptima fueron: $y = 0,664e^{0,02x}$ ($R^2 = 0,7924$), $y = 29,370e^{-0,003x}$ ($R^2 = 0,9572$),$y = 10^{0,07}x^{-0,02}$ ($R^2 = 0,8247$) $y = 0,576x + 62,675$ ($R^2 = 0,9690$), respectivamente. Los resultados mostraron que el uso de SPAD-520PLUS demostró ser un método rápido para determinar CCF como una herramienta efectiva para estimar la calidad del tubérculo de papa.

Palabras clave: Análisis de correlación, tierras altas del Ecuador, fotosíntesis, *Solanum tuberosum*, SPAD-502 plus®.

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1 Introduction

Chlorophyll is an essential pigment for photosynthesis. Consequently, chlorophyll content is the main index reflecting the photosynthetic capacity and health status of the plant (Chou et al., 2020). The common way to measure leaf chlorophyll content (LCC) usually need to extract leaf tissue with organic solvents such as acetone, ethanol or *N*, *N*-dimethyl formamide (Lan et al., 2011). Although this method is relatively accurate, extraction is laborious, destructive, time-consuming, and expensive. During this process, significant pigment losses may occur through the extraction and dilution and lead to highly variable results (Kaspary et al., 2019). LCC measurements, such as those performed with the SPAD-502 plus® (Konica Minolta, Tokyo, Japan) are a non-destructive, simple and portable diagnostic tool that measures the greenness or the relative chlorophyll content of leaves (Padilla et al., 2019).

By measuring the leaf transmittance in two wavelenght bands (400-500 nm and 600-700 nm), this device quantifies the relative amount of chlorophyll with a reading in arbitrary unit (SPAD-502 plus® Chlorophyll Index) that is proportional to the leaf chlorophyll concentration (Sim et al., 2015), resulting in substantial savings in time and resources. High correlations between SPAD-502 plus® value and leaf chlorophyll content have been shown for several species of rice (Yuan et al., 2016), soybean (Kühling et al., 2018), wheat (Yue et al., 2019), muskmelon (Azia and Stewart, 2001), maize (Casa et al., 2015), coffee (Netto et al., 2005) and tomato (Padilla et al., 2018). While the correlation in potato relationship was comparatively weak (Uddling et al., 2007). However some research also presented mathematical relationships between SPAD-502 plus® readings and leaf chlorophyll readings with plant growth stage (Yuan et al., 2016; Roslan et al., 2019), growing conditions (Giletto and Echeverría, 2013; Kühling et al., 2018) and genotype (Noulas et al., 2018).

Potato (*Solanum tuberosum* L.) is an important food crop for human nutrition together with wheat and rice (De Jong, 2016). Potato have better yield under cool conditions, but elevated soils reduce yields (Zommick et al., 2014). Since the 1950s, chipping potatoes have been selected for high dry matter content and for their ability to produce light-colored chips (Lulai and Orr, 1979). Tuber dry matter content (DM), which consists primarily of starch, also decreases when potato is grown at highest than upper optimal (Raymundo et al., 2018). High tuber dry matter content is beneficial because it reduces oil absorption during frying and increases of good chips (Camps and Camps, 2019). Nissen (1955) analyzed the data collected for approximately 18 years and concluded that the DM content of the potatoes is a linear function of their weight in water and not depending on the specific gravity (SG) of the tuber. Reducing sugars, glucose and fructose accumulate after harvest as a result of sucrose hydrolysis by vacuolar invertase acid, this sugars react with amino groups in a non-enzymatic Maillard reaction to produce dark-colored pigments during chip frying (Wiberley-Bradford and Bethke, 2018). Low quality tubers produce bad chips that can be rejected at processing plants, representing a financial risk for producers and may lead to supply problems (Busse et al., 2019).

Mathematical correlations between SPAD value and yield and tubers quality can be important to optimize advanced interpretations of data from the chlorophyll meter. This study was carried out to determine if there was a correlation of LCC (SPAD value) of three of early potato varieties with different sources fertilizer. The information was used to build a mathematical function to describe relationship between LCC of different plant stages and tubers quality in order to optimize a model to provide more precise, reliable and easier method for estimation of tubers quality in the industrial process.

2 Material and Methods

2.1 Plant Material and Growth Conditions

Improved commercial varieties of potatoes (V) including INIAP Libertad (v1) (crosses 380479.15 $\times$ Bk Precoz-84), INIAP Josefina (v2) (cross between the Bolona variety with a hybrid between *S. phureja* and *S. pausissectum*) and Diacol Capiro (v3) (crosses with Tuquerreña (CCC 61) $\times$ 1967 (C) (9) (CCC751), from the germplasm collection of the International Potato Center – Quito, were used for the study. Two formulations of edaphic fertilizers (F) were used. The composition of the formulations was as follows: (f1: 23-24-45) and (f2: 20-31-40) with the sources: KNO_3 + $NH_4H_2PO_4$(MAP) + KCl(MOP) and NH_4NO_3 + MAP + K_2SO_4 (SOP) respectively. The first fertilization was 25 days after planting (DAP) at a dose of 90 kg ha^{-1} of N, 198 kg ha^{-1} of P and 180 kg ha^{-1} of K. The second fertilization was 60 DAP at a dose of 130 kg ha^{-1} of N, 20 kg ha^{-1} of P and 250 kg ha^{-1} of K.

In March of 2018, the experimental plots were located in Pujilí, Cotopaxi, central highlands of Ecuador at 3,060 m.a.s.l. (01° 03′ 0.7″ South / 78° 41′ 29.8″ West). The soil was silty sandy – Inceptisol, with 2 % slope and surface irrigation was weekly by furrows. During the experiment, temperature was 16±1.2°C, 6 h light^{-1} day^{-1} average annual. Mean relative humidity was maintained above 60 %. The pH of the soil solution and the electrical conductivity were monitored periodically and maintained at approximately 6.5 and 2.0-3.0 dS m^{-1}, respectively. Six treatments were evaluated, resulting from the interaction of the study factors (varieties and formulations). Three repetitions were performed. In each block, the six treatments (F × V) were distributed randomly. No pesticides were applied during the experiment. Experiment was implemented in 900 m^2. Each net plot was 41.25 m^2. In each net plot, six rows of 1.1 m were made between them and 30 cm between plants. The rows were planted east-west. Plants randomly selected of the four central furrows of each net plot were evaluated to avoid the edge effect of the treatments. The plants were in complete competition, located inside each plot and completely surrounded by other plants.

2.2 SPAD-502 plusSPAD Value Measurement

After selection, the plants were evaluated for chlorophyll content with a SPAD-502 plus® KONICA MINOLTA, in consecutive and non-destructive readings between 10 and 12 AM. Before measurement, the SPAD-502 plus® was calibrated using the reading checker supplied by the manufacturer. Readings were performed in completely irradiated leaflets at 30, 60 and 90 DAP in the lower, middle and upper third part of the plant. Each leaf SPAD value obtained was the average of thirty readings in mature terminal leaflets (Matsuda and Fujiwara, 2014).

2.3 Tubers Yield and Quality Parameters

At harvest, 120 DAP, a classification by size and/or categories of the tuber were made according to their diameter (Huaraca et al., 2009). This variable was expressed in kg total tubers plant−1, with their respective categories (first, second and third). A Mettler Toledo (SB 8001) balance of 0.1 g precision was used.

Quality parameters analyzes were performed in the frying laboratories of the National Roots and Tubers Program (NRTP) and in the Department of Nutrition and Food Quality of National Institute of Agricultural Research (INIAP) located at the Santa Catalina Experimental Station, Quito, Ecuador. All quality variables were evaluated at 20 and 40 days after harvest (DAH). The percentage of Dry Matter (DM) and Specific Gravity (SG) in tubers was determined in the laboratory. The calibration and lecture followed the protocol established by the user manual of the PW-2050 weighing system equipment (Weltech International Limited, Cambridgeshire, U.K.). Five tubers per treatment were used for reducing sugars (RS). The Clerget Method (micro colorimetric method with hydrochloric acid inversion) and protocols manual for the genetic improvement of potatoes (Cuesta et al., 2015) was followed. The results were expressed in mg 100 g^{-1}. A sample of five tubers was selected and washed, peeled and cut potato. The best 100 flakes were selected and fried (ECOSERV 25 lb. min^{-1} industrial potato peeler, 10 Lb ROBOT COUPLE CL 50 cutters, and 11-liter CROYDON electric fryer) at a temperature of 175°C ± 5°C for 2.5 minutes. After frying, the chips were classified into three categories: good, regular and bad (Cuesta et al., 2015).

2.4 Statistical Analysis

Correlation analysis and regression analysis was done with Excel 2019 (v19.0) (Microsoft, USA) and InfoStat version 2016 software and Analysis of Variance (ANOVA) test at level of significance $\alpha = 0.05$. When differences in interaction were found, depending on the number of treatments, the Tukey's test was performed. Correlation tests of Pearson and regressions analysis were performed between: weight of tubers, dry matter, specific gravity, reducing sugars, good chips, and the chlorophyll content of the leaves. In order to determine the trend and establishing the best model: linear, logarithmic, power and index, in the significant cases.

3 Results

3.1 SPAD value

The relationships between crop phenological age and LCC (SPAD-502 plus®) are shown in Table 1. With increase of phenological age, the SPAD values showed a trend of quadratic increase. SPAD value was constant and incremental in leaves of the three strata evaluated until sixty DAP, independent of variety and edaphic formulation. There was a highly significant effect ($p < 0{,}01$) in the edaphic fertilizer formulations with LCC at 30 DAP in the lower strata of the plant and significant effect ($p < 0{,}05$) at 90 DAP in the middle strata; that is, during the stages of vegetative development and thickening of the tuber. Highly significant differences were observed between potato varieties and LCC at 30 and 60 DAP in all strata; and at 90 DAP, only in the middle strata of plants. Significant differences in the LCC were found in the interaction (FxV) in leaves at 60 DAP in the middle stratum of the plants (Table 1). Tukey test $\alpha = 0{,}05$ presented three ranges of statistical significance. The f1v1 treatment maintained the highest values; while the f1v2 treatment had the lowest chlorophyll content means.

Table 1. SPAD value and descriptive statistics of the factors of study in the crop phenology.

Factors	LEAF CHLOROPHYLL CONTENT (SPAD)							
	30 DAP		60 DAP			90 DAP		
	lower	upper	lower	midlle	upper	lower	midlle	upper
Formulation (F)	$p < 0{,}001$	$p = 0{,}027$	$p = 0{,}453$	$p = 0{,}168$	$p = 0{,}497$	$p = 0{,}187$	$p = 0{,}009$	$p = 0{,}349$
f1	42.31 ± 2.83 b	44.5 ± 2.29 b	49.83 ± 3.18 a	54.69 ± 3.67 a	52.72 ± 5.16 a	42.82 ± 2.24 a	43.75 ± 2.80 b	46.00 ± 4.97 a
f2	44.52 ± 2.52 a	45.93 ± 3.04 a	50.77 ± 2.62 a	53.48 ± 1.83 a	52.06 ± 3.19 a	44.49 ± 2.62 a	46.39 ± 2.77 a	47.56 ± 2.90 a
Variety (V)	$p < 0{,}001$	$p < 0{,}001$	$p = 0{,}041$	$p < 0{,}01$	$p0{,}001$	$p = 0{,}073$	$p < 0{,}01$	$p = 0{,}031$
v1	41.02 ± 1.45 c	44.12 ± 1.07 b	48.55 ± 2.22 b	55.13 ± 2.79 a	55.48 ± 4.12 a	45.83 ± 1.85 a	48.11 ± 2.22 a	50.01 ± 3.25 a
v2	42.62 ± 1.81 b	42.86 ± 0.87 b	49.59 ± 2.18 ab	51.36 ± 2.27 b	53.85 ± 2.00 b	42.73 ± 2.80 a	43.27 ± 2.18 b	43.89 ± 3.77 b
v3	46.61 ± 1.43 a	48.67 ± 1.62 a	52.77 ± 2.18 a	55.77 ± 1.43 a	47.85 ± 1.51 a	42.41 ± 1.23 a	43.82 ± 2.18 b	46.44 ± 2.82 ab
Interaction (FxV)	$p = 0{,}387$	$p = 0{,}396$	$p = 0{,}224$	$p = 0{,}0104$	$p = 0{,}063$	$p = 0{,}971$	$p = 0{,}8038$	$p = 0{,}195$
f1v1	40.08 ± 0.74 d	43.75 ± 0.72 c	49.39 ± 1.96 a	57.67 ± 0.56 a	57.57 ± 4.79 a	44.97 ± 1.63 a	46.51 ± 2.10 ab	49.75 ± 3.85 a
f1v2	41.08 ± 1.05 d	42.35 ± 0.15 c	47.69 ± 3.09 a	50.06 ± 2.06 c	47.50 ± 1.82 a	41.73 ± 2.23 a	42.33 ± 2.48 b	40.99 ± 2.16 a
f1v3	45.77 ± 1.32 ab	47.41 ± 1.26 ab	52.42 ± 2.35 a	56.33 ± 1.67 ab	53.08 ± 1.66 a	43.06 ± 0.71 a	42.39 ± 1.22 b	47.25 ± 3.74 a
f2v1	41.95 ± 1.39 cd	44.49 ± 1.22 bc	47.71 ± 2.18 a	52.58 ± 1.50 bc	53.38 ± 1.48 a	46.69 ± 1.64 a	49.71 ± 0.64 a	50.26 ± 2.48 a
f2v2	44.15 ± 0.88 bc	43.37 ± 0.98 c	51.49 ± 0.52 a	52.68 ± 1.65 bc	48.19 ± 2.11 a	43.73 ± 2.95 a	44.21 ± 1.25 b	46.79 ± 2.64 a
f2v3	47.46 ± 0.96 a	49.94 ± 0.70 a	53.11 ± 0.58 a	55.2 ± 0.80 ab	54.62 ± 0.77 a	43.06 ± 1.30 a	45.25 ± 1.99 ab	45.64 ± 0.72 a
MEAN	43.42 ± 2.83	45.22 ± 2.78	50.3 ± 2.95	54.08 ± 2.96	52.39 ± 4.30	43.66 ± 2.58	45.07 ± 3.08	46.78 ± 4.15
CV	2.07	2.59	5.06	3.19	3.76	5.72	3.92	7.20

Fisher´s Test for factors and Tukey for interaction at $\alpha = 0.05$
Means with different letters are statistically different (p-value)
Coefficient of variation (*CV*)
Standard error (±)

3.2 Yield and after-harvest tubers quality

Regarding tubers yield, the weight for category presented the following mean values. f1: 1.54 and f2: 1.84 kg plant^{-1}. The formulations f1:1.05 of first, 0.62 of second and 0.17 kg plant^{-1} of third category; while f2 fertilizers obtained yields per category of 1.01 of first, 0.38 of second and 0.15 kg plant^{-1} of third. The difference in second category tubers is reflected in statistical significant values (Fig. 1A). INIAP Libertad presented the best response with 2.18, followed by INIAP Josefina with 1.51, and DIACOL Capiro with 1.39 kg plant^{-1} (Fig. 1B). The statistical differences found between varieties occur mainly in the yield expressed in the weight of tubers of the first and third category, according to orthogonal comparisons. The greatest relevance is provided by the first category tubers. No significance was observed for interactions FxV.

Overall, there is a trend in DM and SG increase with storage for all treatments. However, there was no statistical significant difference. The content of RS and chips good for industrial processing of tubers decreases from 20 to 40 DAH ($p < 0{,}01$). No significance was found in fertilizer formulations for the percentage of DM at 20 and 40 DAH. The effects of potato varieties in DM are significant at 20 DAH ($p < 0{,}01$) and 40 DAH ($p < 0{,}05$) (Fig. 2A). INIAP Libertad presented the highest percentages of DM with a mean of 24.45%. Capiro and INIAP Josefina are statistically similar, with a DM content of 22.29 and 21.82%, respectively (Fig. 2A). The Tukey test for interaction ($\alpha = 0{,}05$), presented three ranges of significance. The f1v1 treatment had the highest DM content, with a mean of 25.17%. The f1v2 treatment presented the lowest DM contents, with a mean of 21.50%.

There was no significant difference of the formulations in SG. Significant effects were observed between potato varieties and SG in the values at 20 and 40 DAH. INIAP Libertad presented the highest specific gravity value (1.101) followed by Capiro (1.091) and INIAP Josefina (1.088), in the same range of significance (Fig. 2B). Significant differences were found for the interaction at 20 DAH, as showed for the variable DM. According to the Tukey test $\alpha = 0{,}05$ for treatments, two ranges of significance were observed. The f1v1 treatment showed the highest SG, with a mean of 1.104; while the f1v2 treatment, the lowest values, with 1.086. No significance was observed for formulations, varieties and interaction in RS content.

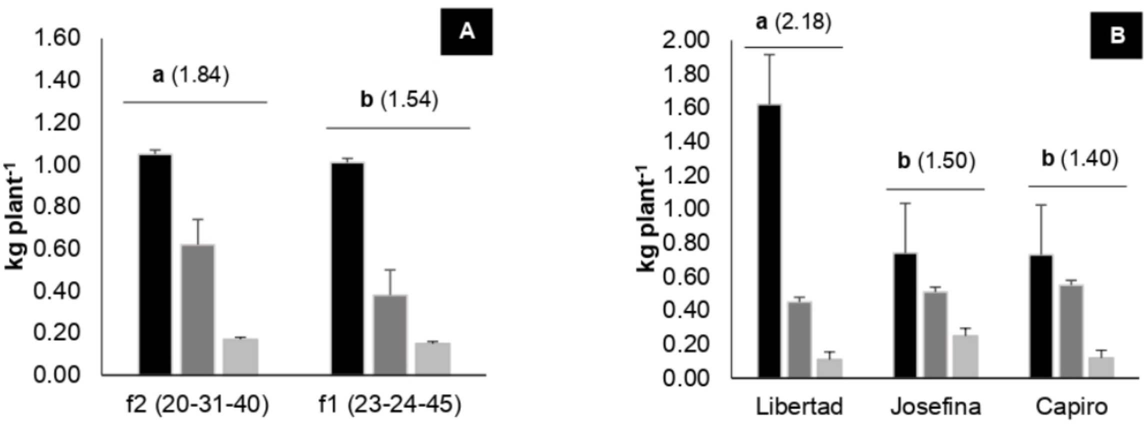

Figure 1. Effect of the fertilizer formulations and varieties on tuber yields.
A) Test: LSD Fisher $\alpha = 0.05$ DMS = 0.19. B) Test: LSD Fisher$\alpha = 0.05$ DMS = 0.24.
Means with different letters are statistically different ($p < 0.05$). Values in parentheses are totals. Black bars: first, gray: second and clearer: third category.

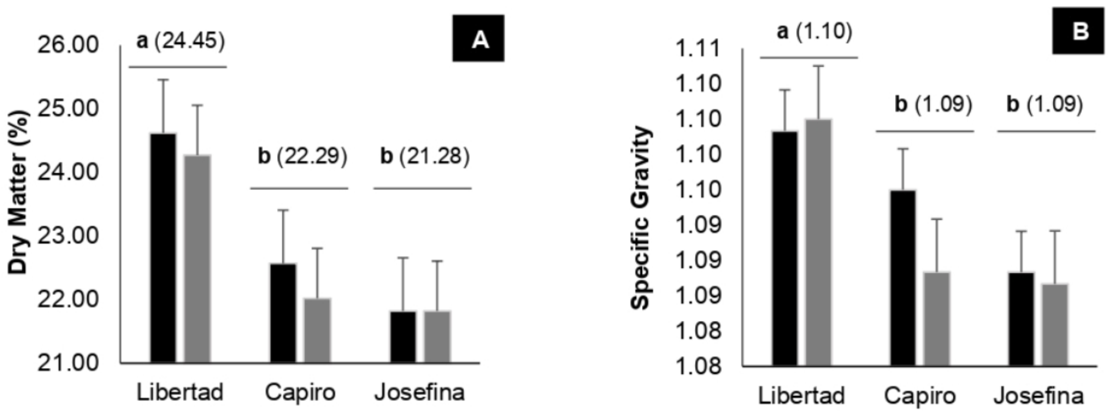

Figure 2. Dry matter and Specific gravity for effect of potatoes varieties.
A) Test: LSD Fisher $\alpha = 0.05$ DMS = 3.93. B) Test: LSD Fisher $\alpha = 0.05$ DMS = 0.06.
Means with different letters are statistically different ($p < 0.05$). Values in parentheses are totals. Black bars: 20 days after harvest; gray: 40 days after harvest.

For the variable lost by frying, there is no significance for fertilizers. There were highly significant differences for varieties in the percentage of good and regular chips, and significant differences for the percentage of bad chips. The Capiro and INIAP Libertad varieties obtained the lowest percentages of frying losses with 4.4 and 4.6% respectively, leaving a total of approximated 95.5% of usable chips. INIAP Josefina presented the greatest losses due to frying, with 19.4% of bad chips. There were significant effects for the interaction in the percentages of good and regular chips. Tukey test $\alpha = 0{,}05$, showed that the f1v1 treatment maintained the highest values and the f1v2 treatment presented the lowest percentages.

3.3 Correlation and regression analysis of SPAD value with yield and tubers quality

Dependent effects were observed among other variables at upper strata of plant (Fig. 3-4). Correlation analyses of yield (kg plant^{-1}) were highest ($p < 0{,}01$) at 90 DAP, independent of plant height.

For INIAP Libertad variety and formulation (KNO_3 + $NH_4H_2PO_4$ + KCl), at different stages of crop, in upper strata of plant, different mathematic modeling functions, correlations between LCC (SPAD value), as x, weight of tubers (kg plant^{-1}); DM; SG; GC (data 20 DAH), as y, were significantly different and correlations changed with different adjustment for model (Tab. 2). For W (kg plant^{-1}), the highest correlation occurred in different model function. At 30 DAP linear model function, with $y = 0.262x - 9.460$ ($R^2 = 0.9938$); at 60 DAP power model function, with $y = 10^{-1{,}57}\ x^{1{,}06}$ ($R^2 = 0.8553$) and 90 DAP index model function, with $y = 0.664\ e^{0{,}02}x$ ($R^2 = 0.7924$).

For DM, the highest correlation occurred in the third stages in index model function. At 30 DAP with $y = 42.948\ e^{-0{,}01x}$ ($R^2 = 0.5240$); $y = 28.789\ e^{-0{,}0024}$ ($R^2 = 0.9103$) at 60 DAP and $y = 29.370\ e^{-0{,}003x}$ ($R^2 = 0.9572$) at 90 DAP. For SG, the highest correlation occurred in the third stages in power model function. At 30 DAP with $y = 10^{0{,}13}\ x^{-0{,}05}$ ($R^2 = 0.3277$); $y = 10^{0{,}07}$ x-0.02 ($R^2 = 0.7543$) at 60 DAP and $y = 10^{0{,}07}\ x^{-0{,}02}$ ($R^2 = 0.8247$) at 90 DAP. For GC, the highest correlation occurred in different model function. At 30 DAP power model function, with $y = 10^{-0{,}36}\ x^{1{,}41}$ ($R^2 = 0.8681$). For 60 and 90 DAP the highest correlation occurred in linear model function, with $y = 0.468x + 64.361$ ($R^2 = 0.9935$) and $y = 0.576x + 62.675$ ($R^2 = 0.9690$) respectively.

4 Discussion

It is important to study the correlation between LCC and canopy spectra, which could reflect the characteristics of crop groups and the comprehensive information of canopy spectra (Guo et al., 2018). In respect to potatoes plant architecture, upper parts of the canopy constitute about 50% of the aerial biomass and together with different growth stages, would determine the best chlorophyll content at the top of the canopy (Clevers et al., 2017). On the other hand, chlorophyll is sensitive to high temperatures (chlorophyll "a" more than chlorophyll "b"). High temperatures disintegrate the cell structure, leaving the pigment exposed to various enzymatic and non-enzymatic reactions. Reports indicate that the optimum temperature for chlorophyllase activity (the enzyme that catalyzes chlorophyll degradation) ranges from 60 to 82.2°C (Todorov et al., 2003). Qiqige et al. (2017) and (Kamrani et al., 2019) have determined a positive relationship of LCC with DM tubers and plant yield under different levels of influence. In addition, we demonstrate that in some early varieties, there is a correlation with the SG and good chips.

Regression analysis (showed in Table 2) presented different optimal mathematic function model of correlations between SPAD value with yield and tubers quality based on coefficient value of R^2. Previous research usually reported a single mathematic regression. The linear model is mostly used to perform regression analyze relationships between SPAD values and yield (Netto et al., 2005; León et al., 2007; Hawkins et al., 2009). Uddling et al. (2007), determined that relationships in potato were non-linear with an increasing slope with higher SPAD unites. The relationships of potato was comparatively weak ($R^2 = 0.5$).

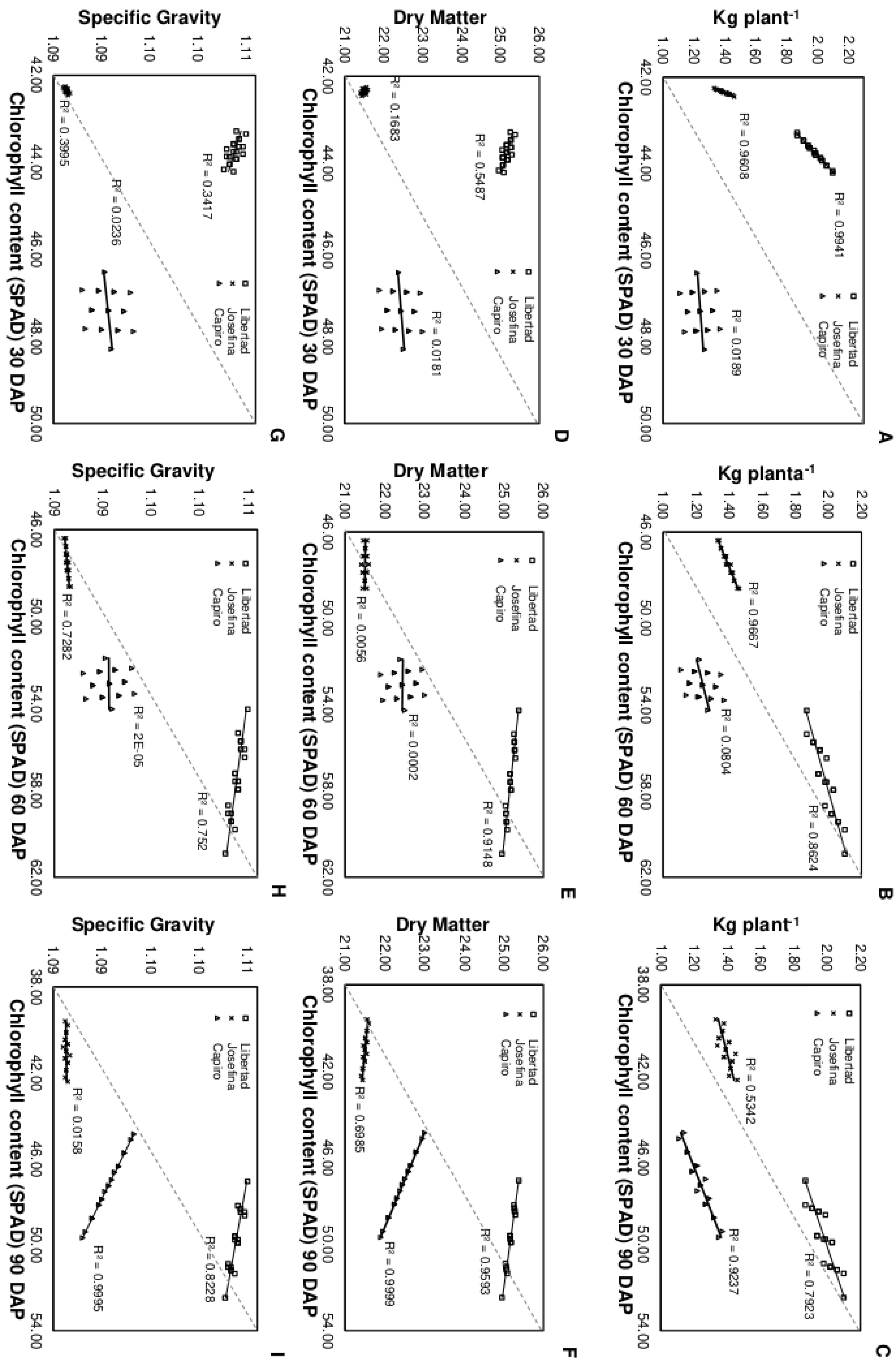

Figure 3. Correlation coefficient of the SPAD value with kg plant^{-1} (A, B, C), Dry matters (D, E, F) and Specific gravity (G, H, I).

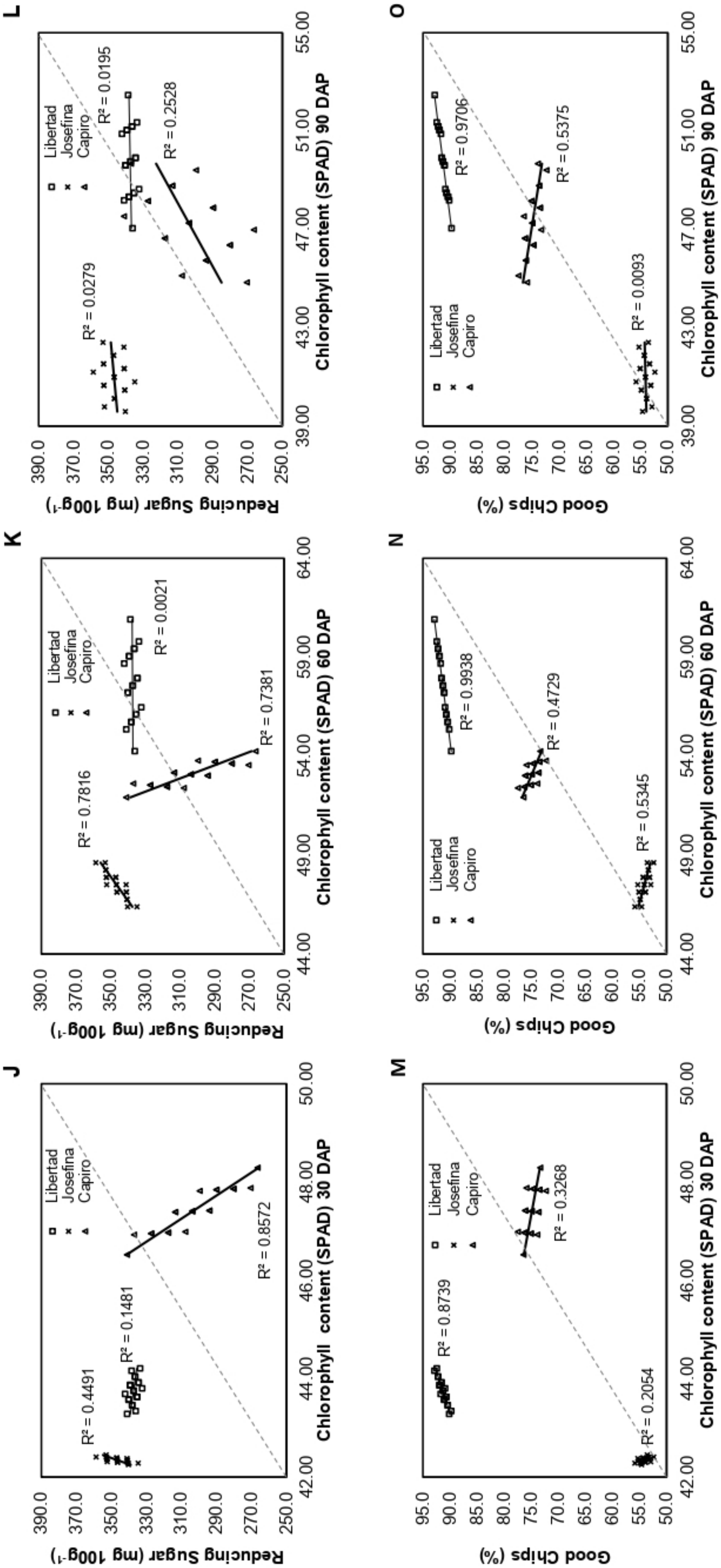

Figure 4. Correlation coefficient of the SPAD value with Reducing sugar (J, K, L) and Good chips (M, N, O).

Table 2. Regression analysis of correlations and SPAD value with several mathematic models of yield 242 and tubers quality in different vegetative stages.

Days after planting	**Component**	**Linear model,** $y = ax + b$	**Logarithmic model,** $y = aln(x) + b$	**Power model,** $y = ax^b$	**Index model,** $y = ae^{bx}$
vegetative growth (30 DAP)	Weight of tubers (kg plant^{-1})	$y = 0{,}262x - 9{,}460$ $R^2 = 0{,}9938$ $p < 0{,}0001$	$y = 11{,}430ln(x) - 41{,}203$ $R^2 = 0{,}9937$ $p < 0{,}0001$	$y = 10^{-9{,}22}x^{5{,}80}$ $R^2 = 0{,}9936$ $p < 0{,}0001$	$y = 0{,}0062e^{0{,}13x}$ $R^2 = 0{,}9934$ $p < 0{,}0001$
	Good chips (%)	$y = 2{,}934x - 37{,}041$ $R^2 = 0{,}8669$ $p < 0{,}0001$	$y = 128{,}200ln(x) - 339{,}070$ $R^2 = 0{,}8669$ $p < 0{,}0001$	$y = 10^{-0{,}36}x^{1{,}41}$ $R^2 = 0{,}8681$ $p < 0{,}0001$	$y = 22{,}421e^{0{,}03x}$ $R^2 = 0{,}8675$ $p < 0{,}0001$
	Dry matter of tubers (%)	$y = -0{,}309x + 38{,}670$ $R^2 = 0{,}5236$ $p = 0{,}0002$	$y = -13{,}480ln(x) + 76{,}104$ $R^2 = 0{,}5235$ $p = 0{,}0002$	$y = 10^{2{,}28}x^{-0{,}54}$ $R^2 = 0{,}5181$ $p = 0{,}0002$	$y = 42{,}948e^{-0{,}01x}$ $R^2 = 0{,}5240$ $p = 0{,}0002$
	Specific gravity of tubers	$y = -1{,}4E^{-03}x + 1{,}164$ $R^2 = 0{,}3052$ $p = 0{,}0068$	$y = -0{,}061ln(x) + 1{,}333$ $R^2 = 0{,}3050$ $p = 0{,}0068$	$y = 10^{0{,}13}x^{-0{,}05}$ $R^2 = 0{,}3277$ $p = 0{,}0049$	$y = 1{,}162e^{-0{,}0012x}$ $R^2 = 0{,}2898$ $p = 0{,}0084$
flowering–formation of tubers (60 DAP)	Weight of tubers (kg plant^{-1})	$y = 0{,}036x - 0{,}115$ $R^2 = 0{,}8548$ $p < 0{,}0001$	$y = 2{,}098ln(x) - 6{,}517$ $R^2 = 0{,}8543$ $p < 0{,}0001$	$y = 10^{-1{,}57}x^{1{,}06}$ $R^2 = 0{,}8553$ $p < 0{,}0001$	$y = 0{,}691e^{0{,}02x}$ $R^2 = 0{,}8548$ $p < 0{,}0001$
	Good chips (%)	$y = 0{,}468x + 64{,}361$ $R^2 = 0{,}9935$ $p < 0{,}0001$	$y = 26{,}944ln(x) - 17{,}868$ $R^2 = 0{,}9931$ $p < 0{,}0001$	$y = 10^{1{,}44}x^{0{,}30}$ $R^2 = 0{,}9928$ $p < 0{,}0001$	$y = 68{,}033e^{0{,}01x}$ $R^2 = 0{,}9933$ $p < 0{,}0001$
	Dry matter of tubers (%)	$y = -0{,}060x + 28{,}605$ $R^2 = 0{,}9101$ $p < 0{,}0001$	$y = -3{,}431ln(x) + 39{,}076$ $R^2 = 0{,}9099$ $p < 0{,}0001$	$y = 10^{1{,}64}x^{-0{,}14}$ $R^2 = 0{,}9074$ $p = 0{,}0002$	$y = 28{,}789e^{-0{,}0024}$ $R^2 = 0{,}9103$ $p < 0{,}0001$
	Specific gravity of tubers	$y = -3{,}1E^{-04}x + 1{,}122$ $R^2 = 0{,}7382$ $p < 0{,}0001$	$y = -0{,}018ln(x) + 1{,}176$ $R^2 = 0{,}7384$ $p < 0{,}0001$	$y = 10^{0{,}07}x^{-0{,}02}$ $R^2 = 0{,}7543$ $p < 0{,}0001$	$y = 1{,}116e^{-0{,}00027x}$ $R^2 = 0{,}7210$ $p < 0{,}0001$
ripening-thickening (90 DAP)	Weight of tubers (kg plant^{-1})	$y = 0{,}043x - 0{,}179$ $R^2 = 0{,}7808$ $p < 0{,}0001$	$y = 2{,}161ln(x) - 6{,}456$ $R^2 = 0{,}7804$ $p < 0{,}0001$	$y = 10^{-1{,}57}x^{1{,}09}$ $R^2 = 0{,}7818$ $p < 0{,}0001$	$y = 0{,}664e^{0{,}02x}$ $R^2 = 0{,}7924$ $p < 0{,}0001$
	Good chips (%)	$y = 0{,}576x + 62{,}675$ $R^2 = 0{,}9690$ $p < 0{,}0001$	$y = 28{,}610ln(x) - 20{,}444$ $R^2 = 0{,}9686$ $p < 0{,}0001$	$y = 10^{1{,}43}x^{0{,}31}$ $R^2 = 0{,}9680$ $p < 0{,}0001$	$y = 66{,}686e^{0{,}01x}$ $R^2 = 0{,}9687$ $p < 0{,}0001$
	Dry matter of tubers (%)	$y = -0{,}076x + 28{,}951$ $R^2 = 0{,}9570$ $p < 0{,}0001$	$y = -3{,}775ln(x) + 39{,}919$ $R^2 = 0{,}9567$ $p < 0{,}0001$	$y = 10^{1{,}66}x^{-0{,}15}$ $R^2 = 0{,}9548$ $p < 0{,}0001$	$y = 29{,}370e^{-0{,}003x}$ $R^2 = 0{,}9572$ $p < 0{,}0001$
	Specific gravity of tubers	$y = -4{,}0E^{-04}x + 1{,}124$ $R^2 = 0{,}8129$ $p < 0{,}0001$	$y = -0{,}020ln(x) + 1{,}182$ $R^2 = 0{,}8128$ $p < 0{,}0001$	$y = 10^{0{,}07}x^{-0{,}02}$ $R^2 = 0{,}8247$ $p < 0{,}0001$	$y = 1{,}127e^{-0{,}00036x}$ $R^2 = 0{,}7967$ $p < 0{,}0001$

The effect of non-uniformly distributed chlorophyll is likely to be more important in explaining the nonlinearity in the empirical relationships, since the effect of scattering was predicted to be comparatively weak. We determined that the regression coefficient between SPAD value and yield (kg plant^{-1}) were significant in the three strata of plant at evaluation 90 DAP (Table 2). Our results confirmed that plant age condition would affect the accuracy of correlation analysis (Retta et al., 2016; Ucar et al., 2018).

Our results suggest that highland potato has a different behavior than other crops regarding the mathematical fit of the studied relationships. It was necessary to adjust research means according to specific plant and growth stage. Meanwhile, the significant difference of coefficient values suggested the importance and need of calculation method in estimation.

5 Conclusions

There was a significant relationship between SPAD-520 plus® value in potato leaves with yield and tubers quality. However, the optimized mathematical model for estimation tubers quality with SPAD value of leaves at different growth stages and high of plant were different.

Highest correlation efficiency of four mathematic modeling functions at different growth stage was showed. In general, for INIAP Libertad variety and formulation ($KNO_3 + NH_4H_2PO_4 + KCl$), the results demonstrated that optimal model for yield was linear function at 30 DAP; index model for DM at 90 DAP; power model for SG at 90 DAP and linear model for GC at 60 DAP.

Further work is planned to evaluate late varieties and planting density for adequate correlation interpretation in the estimate.

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References

Azia, F. and Stewart, K. (2001). Relationships between extractable chlorophyll and spad values in muskmelon leaves. *Journal of Plant Nutrition*, 24(6):961–966. Online:https://n9.cl/jf8i1.

Busse, J., Wiberley-Bradford, A., and Bethke, P. (2019). Transient heat stress during tuber development alters post-harvest carbohydrate composition and decreases processing quality of chipping potatoes. *Journal of the Science of Food and Agriculture*, 99(5):2579–2588. Online:https://n9.cl/ah7rz.

Camps, C. and Camps, Z. (2019). Optimized prediction of reducing sugars and dry matter of potato frying by ftnir spectroscopy on peeled tubers. *Molecules*, 24(5):967. Online:https://n9.cl/2wokl.

Casa, R., Castaldi, F., Pascucci, S., and Pignatti, S. (2015). Chlorophyll estimation in field crops: an assessment of handheld leaf meters and spectral reflectance measurements. *The Journal of Agricultural Science*, 153(5):876–890. Online:https://n9.cl/7n60q.

Chou, S., Chen, B., Chen, J., Wang, M., Wang, S., Croft, H., and Shi, Q. (2020). Estimation of leaf photosynthetic capacity from the photochemical reflectance index and leaf pigments. *Ecological Indicators*, 110:105867. Online:https://n9.cl/x6mo9.

Clevers, J., Kooistra, L., and Van den Brande, M. (2017). Using sentinel-2 data for retrieving lai and leaf and canopy chlorophyll content of a potato crop. *Remote Sensing*, 9(5):405. Online:https://n9.cl/2zdl7.

Cuesta, X., Rivadeneira, J., and Monteros, C. (2015). *Mejoramiento Genético de papa: Conceptos, procedimientos, metodologías y protocolos*. Instituto Nacional de Investigaciones Agropecuarias.

De Jong, H. (2016). Impact of the potato on society. *American journal of potato research*, 93:415–429. Online:https://n9.cl/tok4h.

Giletto, C. and Echeverría, H. (2013). Chlorophyll meter for the evaluation of potato n status. *American journal of potato research*, 90:313–323. Online:https://n9.cl/9bnoc.

Guo, T., Tan, C., Li, Q., Cui, G., and Li, H. (2018). Estimating leaf chlorophyll content in tobacco based on various canopy hyperspectral parameters. *Journal of Ambient Intelligence and Humanized Computing*, 10:3239–3247. Online:https://n9.cl/h19dcv.

Hawkins, T., Gardiner, E., and Comer, G. (2009). Modeling the relationship between extractable chlorophyll and spad-502 readings for endangered plant species research. *Journal for Nature Conservation*, 17(2):123–127. Online:https://n9.cl/88936.

Huaraca, H., Montesdeoca, F., and Pumisacho, M. (2009). *Guía para facilitar el aprendizaje sobre el manejo del tubérculo-semilla de papa*. INIAP, Estación Experimental Santa Catalina.

Kamrani, M., Rahimi, A., and Hosseinniya, H. (2019). Effects of different growing media on yield and growth parameters of potato minitubers (solanum tuberosum l.). *Communications in soil science and plant analysis*, 50(15):1838–1853. Online:https://n9.cl/2rt8l.

Kaspary, T., Cutti, L., Bellé, C., Casarotto, G., Groth, M., Da Silva, G., and De Aguiar, A. (2019). Non-destructive analysis of photosynthetic pigments in'avena strigosa'and'avena sativa'. *Australian Journal of Crop Science*, 13(3):354–359. Online:https://n9.cl/fb6wr.

Kühling, I., Hüsing, B., Bome, N., and Trautz, D. (2018). Soybeans in high latitudes: effects of bradyrhizobium inoculation in northwest germany and southern west siberia. *Organic Agriculture*, 8:159–171. Online:https://n9.cl/mlzf4.

Lan, S., Wu, L., Zhang, D., Hu, C., and Liu, Y. (2011). Ethanol outperforms multiple solvents in the extraction of chlorophyll-a from biological soil crusts. *Soil Biology and Biochemistry*, 43(4):857–861. Online:https://n9.cl/etx1o.

León, A., Viña, S., Frezza, D., Chaves, A., and Chiesa, A. (2007). Estimation of chlorophyll contents by correlations between spad-502 meter and chroma meter in butterhead lettuce. *Communications in soil science and plant analysis*, 38(19-20):2877–2885. Online:https://n9.cl/vnl5k.

Lulai, E. and Orr, P. (1979). Influence of potato specific gravity on yield and oil content of chips. *American Potato Journal*, 56:379–390. Online:https://n9.cl/dfarc.

Matsuda, R., O. N. and Fujiwara, K. (2014). Leaf photosynthesis, plant growth, and carbohydrate accumulation of tomato under different photoperiods and diurnal temperature differences. *Scientia Horticulturae*, 170:150–158. Online:https://doi.org/10.1016/j.scienta.2014.03.014.

Netto, A., Campostrini, E., de Oliveira, J., and Bressan-Smith, R. (2005). Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and spad-502 readings in coffee leaves. *Scientia Horticulturae*, 104(2):199–209. Online:https://n9.cl/hgafm.

Nissen, M. (1955). The weight of potatoes in water. *American Potato Journal*, 32:332–339. Online:https://n9.cl/9rh3a.

Noulas, C., Herrera, J., Tziouvalekas, M., and Qin, R. (2018). Agronomic assessment of nitrogen use efficiency in spring wheat and interrelations with leaf greenness under field conditions. *Communications in soil science and plant analysis*, 49(7):763–781. Online:https://n9.cl/km8ys.

Padilla, F., de Souza, R., Peña-Fleitas, M., Grasso, R., Gallardo, M., and Thompson, R. (2019). Influence of time of day on measurement with chlorophyll meters and canopy reflectance sensors of different crop n status. *Precision Agriculture*, 20:1087–1106. Online:https://n9.cl/s1j29.

Padilla, F., Thompson, R., Peña-Fleitas, M., and Gallardo, M. (2018). Reference values for phenological phases of chlorophyll meter readings and reflectance indices for optimal n nutrition of fertigated tomato. In *V International Symposium on Ecologically Sound Fertilization Strategies for Field Vegetable Production 1192*, pages 65–72. Online:https://n9.cl/xg11j.

Qiqige, S., Jia, L., Qin, Y., Chen, Y., and Fan, M. (2017). Effects of different nitrogen forms on potato growth and development. *Journal of Plant Nutrition*, 40(11):1651–1659. Online:https://n9.cl/d09iw.

Raymundo, R., Asseng, S., Robertson, R., Petsakos, A., Hoogenboom, G., Quiroz, R., Hareau, G., and Wolf, J. (2018). Climate change impact on global potato production. *European Journal of Agronomy*, 100:87–98. Online:https://n9.cl/anli9.

Retta, M., Yin, X., van der Putten, P., Cantre, D., Berghuijs, H., Ho, Q., Verboven, P., Struik, P., and Nicolaï, B. (2016). Impact of anatomical traits of maize (zea mays l.) leaf as affected by nitrogen supply and leaf age on bundle sheath conductance. *Plant science*, 252:205–214. Online:https://n9.cl/s88vm.

Roslan, N., Aznan, A., Ruslan, R., Jaafar, M., and Azizan, F. (2019). Growth monitoring of harumanis mango leaves (mangifera indica) at vegetative stage using spad meter and leaf area meter. In *IOP Conference Series: Materials Science and Engineering*, volume 557, page 012010. Online:https://n9.cl/1oku5.

Sim, C., Zaharah, A., Tan, M., and Goh, K. (2015). Rapid determination of leaf chlorophyll concentration, photosynthetic activity and nk concentration of elaies guineensis via correlated spad-502 chlorophyll index. *Asian Journal of Agricultural Research*, 9(3):132–138. Online:https://n9.cl/25fhu.

Todorov, D., Karanov, E., Smith, A., and Hall, M. (2003). Chlorophyllase activity and chlorophyll content in wild and mutant plants of arabidopsis thaliana. *Biologia plantarum*, 46:125–127. Online:https://n9.cl/hz5df.

Ucar, E., Ozyigit, Y., Eruygur, N., Güven, D., Yur, S., Turgut, K., Özek, T., and Kütük, N. (2018). The effect of the plant age and growth period on the nutritional substance, chlorophyll and steviol glycoside rates in stevia (stevia rebaudiana bertoni) leaves. *Communications in Soil Science and Plant Analysis*, 49(3):291–302. Online:https://n9.cl/z42or.

Uddling, J., Gelang-Alfredsson, J., Piikki, K., and Pleijel, H. (2007). Evaluating the relationship between leaf chlorophyll concentration and spad-502 chlorophyll meter readings. *Photosynthesis research*, 91:37–46. Online:https://n9.cl/iagn0.

Wiberley-Bradford, A. and Bethke, P. (2018). Suppression of the vacuolar invertase gene delays senescent sweetening in chipping potatoes. *Journal of the Science of Food and Agriculture*, 98(1):354–360. Online:https://n9.cl/29jcz.

Yuan, Z., Ata-Ul-Karim, S., Cao, Q., Lu, Z., Cao, W., Zhu, Y., and Liu, X. (2016). Indicators for diagnosing nitrogen status of rice based on chlorophyll meter readings. *Field crops research*, 185:12–20. Online:https://n9.cl/zxqxjo.

Yue, X., Hu, Y., Zhang, H., and Schmidhalter, U. (2019). Evaluation of both spad reading and spad index on estimating the plant nitrogen status of winter wheat. *International Journal of Plant Production*, 14:67–75. Online:https://n9.cl/pfdjh.

Zommick, D., Knowles, L., Pavek, M., and Knowles, N. (2014). In-season heat stress compromises postharvest quality and low-temperature sweetening resistance in potato (solanum tuberosum l.). *Planta*, 239:1243–1263. Online:https://n9.cl/k14er.