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Proceeding Paper

Can the Normalized Difference Vegetation Index Be Used for Yield Prediction in *Solanum tuberosum* L. Plants Biofortified with Calcium? †

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Abstract: Remote sensing technology (namely UAVs) has been used to monitor potato crops. As such, this study aims to analyze the relationship between the NDVI model and yield productivity in *Solanum tuberosum* L. plants from the Agria variety, submitted to a Ca biofortification process with two different concentrations (12 and 24 kg/ha) of $CaCl_2$ or Ca-EDTA. The NDVI values were collected six days after the six foliar applications and analyzed alongside the Ca content in the potato tubers (at harvest) and the total yield. The results highlight the fact that 24 kg/ha of $CaCl_2$ presented the lowest NDVI value, yet these plants did not show the lowest yield. Moreover, that same treatment presented the highest Ca biofortification index in tubers. Also, it seems that the NDVI can be used in decision making to improve crop management strategies, considering that it is an indicator for detecting plant growth or vigor; however, in this research, it is not sufficient for yield prediction.

Keywords: calcium biofortification; NDVI; smart farming; *Solanum tuberosum* L.

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1. Introduction

Remote sensing technology has been increasingly used to monitor potato crops recently [1–3], namely through UAVs (unmanned aerial vehicles). Among the different utilized indices, the normalized difference vegetation index (NDVI) is one of the most used [4], being valuable to assess growth or vigor in plants [5], as well as to provide information and insight regarding nutrient efficiency and infestations [6]. Moreover, this technology leads to gathering valuable data for decision making, which can lead to optimizing crop management and improving agricultural practices [5,6]. Nevertheless, it can also estimate the primary productivity of crops [7]. Indeed, through NDVI maps, the interpretation of vegetation information is carried out considering the disparities between the green color of plants (healthy plant leaves) [5] and lower NDVI values (stressed vegetation) [4].

The global population is projected to reach 9 billion by 2020 [8], and so it is essential to considerably increase food production by between 25 and 70% to adequately feed the future population [9]. On the other hand, it is not only important to simply have more food, but also to have quality food in order to meet daily nutritional dietary requirements. As such, considering that the potato (*Solanum tuberosum* L.) is one of the most important staple food crops worldwide [10], it is the perfect food matrix for biofortification. In this context, the aim of this study is to analyze the relationship between the NDVI model and yield productivity in *Solanum tuberosum* L. plants from the Agria variety, which are submitted to a calcium biofortification process with two different products—calcium chloride and Ca-EDTA—at two different concentrations of 12 and 24 kg/ha.

2. Materials and Methods

2.1. Biofortification Workflow

In western Portugal (Lourinhã), an experimental potato field was used to grow *Solanum tuberosum* L. of the Agria variety, which were monitored from 15 March (planting date) to 29 July 2019 (harvest date). The daily average air temperatures during this period varied between 21.9 °C and 13.8 °C. During the tuberization process, the potato plants underwent seven foliar sprays with 6-to-8-day intervals, using calcium chloride or Ca-EDTA at 12 and 24 kg/ha concentrations. Due to signals of toxicity in the plants, only one foliar application of 24 kg/ha of Ca-EDTA was performed, while six foliar sprays were carried out for the 12 kg/ha concentration. The control plants remained untreated with calcium chloride or Ca-EDTA.

2.2. Normalized Difference Vegetation Index (NDVI)

Six days after the six foliar applications, an unmanned aerial vehicle (UAV) equipped with altimetric measurement sensors and GPS was flown over the experimental field. The flight aimed to capture vegetation index values and assess variations in vigor between the control plants and the plants that were submitted to the Ca biofortification process. The acquired images were subsequently processed using the ArcGIS Pro program and further analyzed and interpretated.

2.3. Calcium Content in Tubers

At harvest, the calcium content in the tubers of the *Solanum tuberosum* L. Agria variety was assessed using an XRF analyzer (model XL3t 950 He GOLDD+) under a He atmosphere, according to [11], after the tubers were dried until they reached a constant weight at 60 °C and subsequently ground.

2.4. Yield

At harvest, the yield was measured for the Agria variety, considering 57 plants for each treatment (control and Ca biofortification treatments).

2.5. Statistical Analysis

A statistical analysis was carried out using a one-way ANOVA to assess the differences among the treatments in the *Solanum tuberosum* L. (Agria variety) crops, followed by Tukey's analysis for a mean comparison. A 95% confidence level was adopted for all tests.

3. Results

3.1. NDVI

NDVI model were carried out on the Solanum tuberosum L. plants of the Agria variety six days after the sixth foliar application of Ca (Figure 1). As such, higher values are represented in green, while lower values are depicted in red.

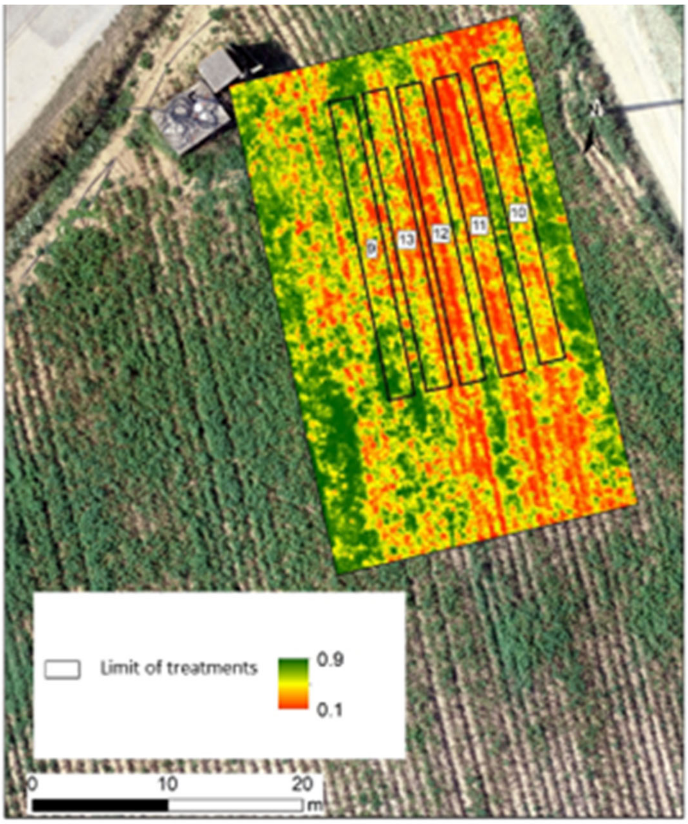

Figure 1. NDVI model of *Solanum tuberosum* L. plants (Agria variety) carried out six days after the 6th foliar application with calcium (calcium chloride or Ca-EDTA) (9—Ctr, 10—12 kg/ha $CaCl_2$, 11—24 kg/ha $CaCl_2$, 12—12 kg/ha Ca-EDTA, 13—24 kg/ha Ca-EDTA).

Moreover, considering both Figure 1 and Table 1, it is possible to verify that the Ca biofortification treatment had effects on the decrease in the foliage of the plants. In fact, the 24 kg/ha $CaCl_2$ treatment presented the lowest average NDVI value (Table 1), as well as the minimum and maximum NDVI values, followed by the 12 B treatment. Also, the Ctr presented the highest average and maximum NDVI values. Indeed, the 24 kg/ha Ca-EDTA treatment presented the highest minimum NDVI value; however, it is important to consider that this treatment was only applied once due to toxicity symptoms in the *Solanum tuberosum* L. plants.

Table 1. Minimum, maximum, and average NDVI values (±SD) of the different treatments in *Solanum tuberosum* L. plants (Agria variety), six days after the 6th foliar application with calcium.

Code	Treatment	Minimum NDVI	Maximum NDVI	Average NDVI
9	Ctr	0.17	0.88	0.65 ± 0.16
10	12 kg/ha $CaCl_2$	0.13	0.85	0.50 ± 0.15
11	24 kg/ha $CaCl_2$	0.11	0.82	0.40 ± 0.15
12	12 kg/ha Ca-EDTA	0.12	0.83	0.44 ± 0.17
13	24 kg/ha Ca-EDTA	0.18	0.85	0.54 ± 0.17

3.2. Tubers' Ca Content

The calcium content in the tubers at harvest was measured in tubers with skin (full tubers) (Figure 2). Additionally, those treated with 12 kg/ha of Ca-EDTA presented the second highest Ca tuber content and the has the second lowest NDVI value. Moreover, there was a biofortification index of 52.7% relative to 24 kg/ha of $CaCl_2$ and of 24.4% considering the 12 kg/ha Ca-EDTA treatment.

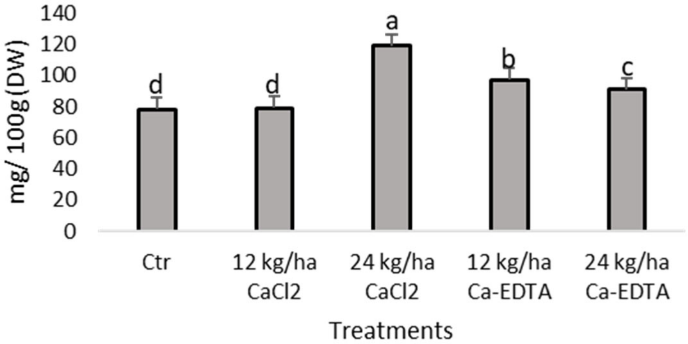

Figure 2. Calcium content (n = 4 ± EP) (mg/100 g, considering the dry weight) in tubers of *Solanum tuberosum* L. (Agria variety) at harvest. Different letters (a, b, c, and d) indicate significant differences between treatments.

3.3. Yield

Considering Table 2, it is possible to verify that the 12 kg/ha Ca-EDTA treatment presented the lowest yield compared to the other treatments. The 12 kg/ha $CaCl_2$ treatment increased the total yield compared to the control plants, indicating that $CaCl_2$ applied at that concentration had beneficial effects that led to a yield increase; however, this treatment did not show the highest NDVI value.

Table 2. Total yield (kg) of *Solanum tuberosum* L. (Agria variety) at harvest.

Treatment	Total Yield (Kg)
Ctr	75.4
12 kg/ha $CaCl_2$	81.5
24 kg/ha $CaCl_2$	64.1
12 kg/ha Ca-EDTA	28.9
24 kg/ha Ca-EDTA	40.3

4. Discussion

Based on the NDVI values obtained using UAVs after six foliar applications (Figure 1 and Table 1), it is evident that the average NDVI value of the *Solanum tuberosum* L. plants (Agria variety) varied among the different treatments, in which the control exhibited the highest average NDVI value. The NDVI values ranged between −1 and 1, where values closer to 1 indicated healthier vegetation/foliage [12,13] and lower values represented stress symptoms in the plants [4]. Outstandingly, the Ctr plants presented a much healthier foliage compared to those subjected to the Ca biofortification treatments (Figure 1 and Table 1). Indeed, this also indicates that plants submitted to Ca biofortification treatments, especially in the 24 kg/ha $CaCl_2$ treatment, showed stress symptoms (Figure 1 and Table 1).

Considering the Ca content in the tubers of the Agria variety at harvest (Figure 2), it was observed that the treatment with the highest Ca content was the one with the lowest average NDVI value after six foliar applications. Additionally, despite the 24 kg/ha $CaCl_2$ treatment having presented the lowest average NDVI value (Table 1), these plants did not show the lowest yield (Table 2). In this context, considering that different studies carried out with Ca using different food matrices—namely grapes [14], peanuts [15], pomegranates [16], apples [17], or pears [18]—showed a yield increase with multiple foliar applications, our results align with those previous studies when considering the 12 kg/ha $CaCl_2$ treatment (Figure 2). A such, this suggests that, despite not displaying a higher NDVI value or even a significant increase in Ca in the tubers, $CaCl_2$ applied at a 12 kg/ha concentration showed a positive effect in promoting yield enhancement in tubers of *Solanum tuberosum* L. (Agria variety). Furthermore, even with the same food matrix (potatoes), other studies carried out with different varieties [19–21] showed higher yields with Ca foliar applications. However, according to our findings, the increase in yield with Ca foliar applications is dependent on the Ca products being applied and their concentration (Figure 2 and Table 2). As such, it is important to realize a careful consideration and selection of the Ca biofortification workflow in order to optimize yield improvements in potato crops.

5. Conclusions

Our study revealed that 24 kg/ha of $CaCl_2$ presented the lowest NDVIindex, yet they did not show the lowest yield at harvest. Also, the same treatment presented the highest Ca biofortification index in tubers at harvest. On the other hand, 12 kg/ha of $CaCl_2$ led to an increase in total yield compared to the control plants, indicating a positive effect of this concentration in promoting yield enhancement, despite these plants not showing a higher NDVI value or even a significant increase in the Ca content in the tubers. These findings indicate that the NDVI alone may not be sufficient for accurately predicting yield in *Solanum tuberosum* L., despite being a valuable indicator for detecting plant growth, vigor, or even plant stress. This also suggests that the relationship between the NDVI, Ca content, and yield is complex. As such, further research and the incorporation of additional information are necessary to develop more precise and robust models for yield prediction in *Solanum tuberosum* L. crops, especially for the Agria variety.

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References

1. Hunt, E.R.; Rondon, S.I. Detection of potato beetle damage using remote sensing from small unmanned aircraft systems. *J. Appl. Remote Sens.* **2017**, *11*, 026013. [CrossRef]
2. Zaeen, A.A.; Sharma, L.; Jasim, A.; Bali, S.; Buzza, A.; Alyokhin, A. In-season potato yield prediction with active optical sensors. *AGE* **2020**, *3*, e20024. [CrossRef]
3. Fernández, C.I.; Leblon, B.; Haddadi, A.; Wang, J.; Wang, K. Potato late blight detection at the leaf and canopy level using hyperspectral data. *Can. J. Remote Sens.* **2020**, *46*, 390–413. [CrossRef]
4. Karnieli, A.; Agam, N.; Pinker, R.; Anderson, M.; Imhoff, M.; Gutman, G.; Panov, N.; Goldberg, A. Use of NDVI and land surface temperature for drought assessment: Merits and limitations. *J. Clim.* **2010**, *23*, 618–633. [CrossRef]
5. Xue, J.; Su, B. Significant remote sensing vegetation indices: A review of developments and applications. *J. Sens.* **2017**, *2017*, 1353691. [CrossRef]
6. Radoglou-Grammatikis, P.; Sarigiannidis, P.; Lagkas, T.; Moscholios, I. A compilation of UAV applications for precision agriculture. *Comput. Netw.* **2020**, *172*, 107148. [CrossRef]
7. Liu, C.; Hu, Z.; Islam, A.T.; Kong, R.; Yu, L.; Wang, Y.; Chen, S.; Zhang, X. Hyperspectral characteristics and inversion model estimation of winter wheat under different elevated CO_2 concentrations. *Int. J. Remote Sens.* **2021**, *42*, 1035–1053. [CrossRef]
8. Alexandratos, N.; Bruinsma, J. World Agriculture Towards 2030/2050: The 2012 Revision. Available online: http://www.fao.org/fileadmin/templates/esa/Global_persepctives/world_ag_2030_50_2012_rev.pdf (accessed on 4 July 2022).

9. Sylvester, G. *E-Agriculture in Action: Drones for Agriculture*; Food and Agriculture Organization of the United Nations and International Telecommunication Union: Geneva, Switzerland, 2018.
10. Xiao, Q.; Bai, X.; He, Y. Rapid Screen of the Color and Water Content of Fresh-Cut Potato Tuber Slices Using Hyperspectral Imaging Coupled with Multivariate Analysis. *Foods* **2020**, *9*, 94. [CrossRef] [PubMed]
11. Luís, I.C.; Lidon, F.C.; Pessoa, C.C.; Marques, A.C.; Coelho, A.R.F.; Simões, M.; Patanita, M.; Dôres, J.; Ramalho, J.C.; Silva, M.M.; et al. Zinc Enrichment in Two Contrasting Genotypes of *Triticum aestivum* L Grains: Interactions between Edaphic Conditions and Foliar Fertilizers. *Plants* **2021**, *10*, 204. [CrossRef] [PubMed]
12. Shafi, U.; Mumtaz, R.; García-Nieto, J.; Hassan, S.A.; Zaidi, S.A.; Iqbal, N. Precision Agriculture Techniques and Practices: From Considerations to Applications. *Sensors* **2019**, *19*, 3796. [CrossRef] [PubMed]
13. Loures, L.; Chamizo, A.; Ferreira, P.; Loures, A.; Castanho, R.; Panagopoulos, T. Assessing the Effectiveness of Precision Agriculture Management Systems in Mediterranean Small Farms. *Sustainability* **2020**, *12*, 3765. [CrossRef]
14. Ma, T.; Hui, Y.; Zhang, L.; Su, B.; Wang, R. Foliar Application of Chelated Sugar Alcohol Calcium Fertilizer for Regulating the Growth and Quality of Wine Grapes. *Int. J. Agric. Biol. Eng.* **2022**, *15*, 153–158. [CrossRef]
15. Liu, C.; Li, Y.; Huo, W.; Li, T.; Wei, Q.; Huang, M.; Geng, C.; Yan, D. Effect of Sorbitol Calcium Chelate on Yield and Calcium Nutrient Absorption of Peanut. *Am. J. Biochem. Biotechnol.* **2021**, *17*, 160–173. [CrossRef]
16. Korkmaz, N.; Aşkın, M.A. Effects of Calcium and Boron Foliar Application on Pomegranate (Punica granatum L.) Fruit Quality, Yield, and Seasonal Changes of Leaf Mineral Nutrition. *Acta Hortic.* **2015**, *1089*, 413–422. [CrossRef]
17. Asgharzade, A.; Valizade, G.A.; Babaeian, M. Effect of Calcium Chloride ($CaCl_2$) on Some Quality Characteristics of Apple Fruits in Shirvan Region. *Afr. J. Microbiol. Res.* **2012**, *6*, 2000–2003. [CrossRef]
18. Raese, J.T.; Drake, S.R. Calcium Sprays and Timing Affect Fruit Calcium Concentrations, Yield, Fruit Weight, and Cork Spot of 'Anjou' Pears. *HortScience* **1995**, *30*, 1037–1039. [CrossRef]
19. Mohammed, S.R.; Eskov, I.D.; Zeitar, E.M. Effect of Chitosan and Calcium Chloride Application on Tuber Yield and Vegetative Parameters against Potato Gangrene under Field Conditions. *Plant Arch.* **2020**, *20*, 3149–3153.
20. El-Hadidi, E.; El-Dissoky, R.; AbdElhafez, A. Foliar Calcium and Magnesium Application Effect on Potato Crop Grown in Clay Loam Soils. *J. Soil Sci. Agric. Eng.* **2017**, *8*, 1–8. [CrossRef]
21. Seifu, Y.W.; Deneke, S. Effect of Calcium Chloride and Calcium Nitrate on Potato (*Solanum tuberosum* L.) Growth and Yield. *J. Horticult.* **2017**, *4*, 207–211.