biology and life sciences forum

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Proceeding

Can NDVI index be used for yield prediction in *Solanum tuberosum* L. plants biofortified with calcium? †

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† Presented at the 3rd International Electronic Conference on Agronomy,15 – 30 Oct 2023; Available online: https://iecag2023.sciforum.net/

Abstract: Remote sensing technology (namely, through UAVs) have been used to monitor potato crops. As such, this study aims to analysis the relationship between the NDVI index model and yield productivity in *Solanum tuberosum* L. plants from Agria variety submitted to 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 application and compared to Ca increase in potato tubers (at harvest) and total yield. The results highlight the fact that 24 kg/ha $CaCl_2$ presented the lowest NDVI index, however, did not show the lowest yield. Moreover, that same treatment presented the highest Ca biofortification index in tubers. Also, seems that NDVI index can be used in decision-making and improve crop management strategies considering being an indicator to detect plant growth or vigor, however in this research it's not sufficient for yield prediction.

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

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

Remote sensing technology has been increasingly used to monitor potato crops recently [1-3], namely through UAVs (Unmanned aerial vehicle). 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's and insights regarding nutrient efficiency and infestations [6]. Moreover, this technology leads to the gathering valuable data for decision making which can lead to optimizing crop management and improving agricultural practices [5, 6]. Nevertheless, can also estimates primary productivity of crops [7]. Indeed, through NDVI maps the interpretation of vegetation information is carried out considering the disparities between the green color (healthy plant leaves) [5] and lower values (stress vegetation) [4].

The global population is projected to reach 9 billion by 2020 [8], being essential to considerable increase food production between 25 to 70 % to adequately feed the future

population [9]. In the other hand, it's not only important to have more food but also with quality on order to provide the daily nutritional dietary requirements. As such, considering that potato (*Solanum tuberosum* L.) is one of the most important staple food crops worldwide [10], is the perfect food matrix for biofortification. In this context, the aim of this study is to analysis the relationship between the NDVI index model and yield productivity in *Solanum tuberosum* L. plants from Agria variety, submitted to calcium biofortification process with two different products – calcium chloride and Ca-EDTA – with two different concentrations – 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., Agria variety and was monitor from 15th March (planting date) to 29th July 2019 (harvest date). The daily average air temperatures during this period varied between 21.9 °C to 13.8 °C. During the tuberization process, potato plants underwent to seven foliar sprays with 6 to 8 days intervals, using calcium chloride or Ca-EDTA at 12 and 24 kg/ha concentrations. Due to signals of toxicity in plants, only one foliar application of 24 kg/ha Ca-EDTA was performed, while seven foliar sprays were carried out with 12 kg/ha concentration. 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 indexes and assess variations in vigor between control plants and plants submitted to Ca biofortification process. The acquired images were subsequently processes using ArcGIS Pro program and further analyzed and interpretated.

2.3. Calcium content in tubers

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

2.4. Yield

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

2.5. Statistical Analysis

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

3. Results

3.1. NDVI index

The NDVI model was carried out in Solanum tuberosum L. plants of Agria variety after six days after the 6th foliar application with Ca (**Figure 1**). As such, higher values are represented in green while lower values in red.

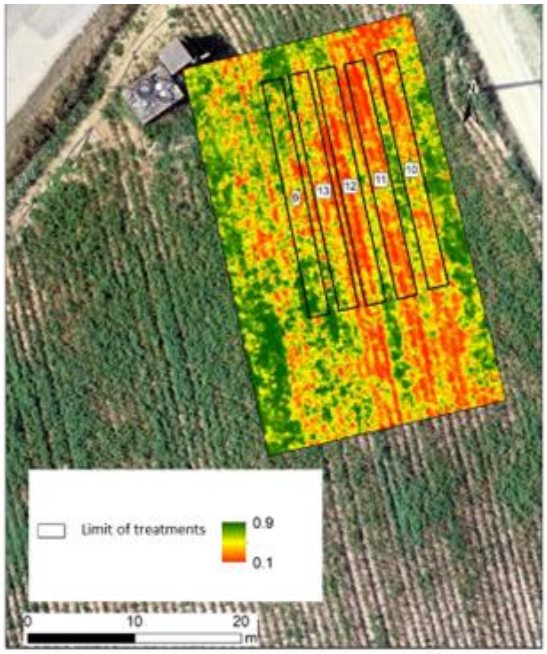

Figure 1. NDVI model of *Solanum tuberosum* L. plants (Agria variety) carried out six days after the 6th foliar application with calcium (calcium chloride or Ca-EDTA).

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

Table 1. Minimum, maximum, and average of NDVI (± 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

Calcium content in tubers at harvest was carried out in tubers with skin (full tuber) (**Figure 2**). Additionally, 12 kg/ha Ca-EDTA presented the second highest Ca content in tubers, being the second treatment, which presented the lowest NDVI index. Moreover, there were a biofortification index in of 52.7 % relative to 24 kg/ha $CaCl_2$ and of 24.4 % considering 12 kg/ha Ca-EDTA treatment.

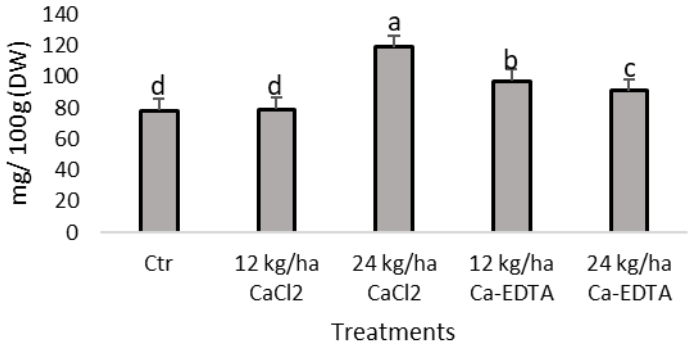

Figure 2. Calcium content (*n*=4 ±EP) (mg/100g considering the dry weight) in tubers of *Solanum tuberosum* L. (Agria variety) at harvest. Different letters (a,b,c and d) indicates significant differences between treatments.

3.3. Yield

Considering **Table 2**, it's possible to verified that 12 kg/ha Ca-EDTA treatment was the one which presented the lowest yield compared to the remain treatments. The 12 kg/ha $CaCl_2$ treatment increase the total yield compared to control plants, indicating that $CaCl_2$ applied with that concentration had beneficial effects which leads to yield increase, however, didn't show the highest NDVI index.

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

Considering the Ca content in tubers of 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 after six foliar applications. Additionally, despite 24 kg/ha $CaCl_2$ presented the lowest average NDVI (**Table 1**), didn't showed the lowest yield (**Table 2**). In this context, considering that different studies carried out with Ca with different food matrix, namely in grapes [14], peanuts [15] pomegranate [16], apples [17] or pears [18] showed a yield increase with multiple foliar applications, our results align with those previous

studies considering the 12 kg/ha $CaCl_2$ treatment (**Figure 2**). A such, this suggest that despite not displaying a higher NDVI index or even a significant increase of Ca in tubers, $CaCl_2$ applied with 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 of yield with Ca foliar applications is dependent on Ca product applied and even their concentration (**Figure 2** and **Table 2**). As such, it's 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 $CaCl_2$ presented the lowest NDVI index, however, did not show the lowest yield at harvest. Also, the same treatment presented the highest Ca biofortification index in tubers at harvest. In the other hand, 12 kg/ha $CaCl_2$ led to an increase in total yield compared to control plants, indicating a positive effect of this concentration in promoting yield enhancement, despite didn't showing a higher NDVI index or even a significant increase in Ca content in tubers. These findings indicate that NDVI index 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 stresses. Also suggest that the relationship between NDVI index, Ca content and yield is complex. As such, further research and the incorporation of additional information's are necessary to develop more precise and robust models for yield prediction in *Solanum tuberosum* L. crops, especially for Agria variety.

Supplementary Materials: Not applicable

Author Contributions: Conceptualization, F.C.L.; methodology, M.B. and J.K.; software, A.R.F.C.; formal analysis, A.R.F.C., D.D., I.C.L., A.C.M., C.C.P., M.B. and J.K.; investigation, A.R.F.C, D.D., I.C.L., A.C.M. and C.C.P.; resources, M.S., M.M.S., M.F.P., F.H.R., P.L., J.C.R., P.S.C., I.P.P., J.N.S. and F.C.L.; writing—original draft preparation, A.R.F.C.; writing—review and editing, A.R.F.C. and F.C.L.; project administration, F.C.L..; funding acquisition, F.C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was received funding from PDR2020-101-030719. This work was further supported by the grant of the Fundação para a Ciência e Tecnologia (FCT) UI/BD/150806/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors thank to Eng. Nuno Cajão and Eng. Mónica Correia (Cooperativa de Apoio e Serviços do Concelho da Lourinhã -LOURICOOP for technical assistance on the field as well as to the research center (GeoBioTec) UIDB/04035/2020, (CEF) UIDB/00239/2020 and Associate Laboratory TERRA (LA/P/0092/2020).

Conflicts of Interest: The authors declare no conflict of interest.

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