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OPTIMIZATION OF UV-C RADIATOR TO ENHANCE MECHANICAL PROPERTIES OF IRRADIATED SEMI-FINISHED POTATO TUBER FOR EXTENDED STORAGE PERIOD

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1. ABSTRACT

The effectiveness of surface treatment technology depends significantly on both dimensional and operational parameters. UV-C is a widely used surface treatment method for semi-processed crops. This study utilized a simultaneous optimization approach for a multi-objective function to determine the best combination of variables—UV-C dose, storage period, and distance from the light—that could maintain the mechanical properties of semi-finished potato tubers. The results indicate that the optimal values are approximately 40.5 mJ/cm², 7 days, and 48 cm, which provide resistance values of 756 N for compression, 6.7 N for bending, and 9 N for cutting force. The sample treated at these optimized values was further validated experimentally, demonstrating higher resistance to forces on a stress-time curve as compared to non-irradiated sample.

2. INTRODUCTION

Ultraviolet-C (UV-C) is considered a safe, effective, and economical treatment that can be used to maintain the postharvest quality of fruit and vegetables during storage. However, the efficiency of UV stimulation on crops is affected by factors, such as light source, product composition, and geometric configuration. The optimization of other surface treatment technologies on various characteristics was investigated previously on different vegetable crops [1], [2]. Simultaneous optimization is the proposed technique for this study to evaluate a set of responses best serving the objectives (maximum, minimum, or some target values) for which it was developed. This approach involved the graphical optimization called desirability functions an important approach. A method that can meet these requirements uses the Desirability Function that was introduced by Derringer and Suich [3]. The objective of this research is to optimize some of the decisive factors (UV-C dose (x1), storage period (x2) and distance from the light(x3)) that influence the performance of UV-C chamber efficacy in maintaining the mechanical properties of semifinished potato tuber.

3. METHODOLOGY

3.1. UV-C chamber

Potato tubers of the Innovator variety were used to prepare potato strips (6 cm x 1 cm). A UV-C NBV15 radiator (**Fig. 1**) with a light wavelength of 253.7 nm, a power of 15 W, and a maximum power density of 100 µW/cm² was utilized. The radiator is housed in a chamber measuring 1.2 m in length and 0.55 m in width. It is enhanced with an aluminum reflector with a high reflection coefficient. The irradiation setup and procedures were adopted from Jakubowski 2019 [6]. The UV-C dose was calculated based on intensity and exposure time, as shown in **Eq (1)**.

$$\text{Dose (J/cm2)} = \text{Intensity (W/cm}^2\text{)} * \text{exposure time (s)} \qquad (1)$$

3.2. Mechanical testing

The universal testing machine MTS insight 2 was used in compliance with ASTM D695-15 for the determination of rupture force under stress (compression, cutting, and bending) of the UV-C exposed samples and control samples [4].

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The testing was equipped with a 2000N compression load cell for compression test and 25 N for cutting and bending force. The crosshead was set at a constant speed of 30 mm/min.

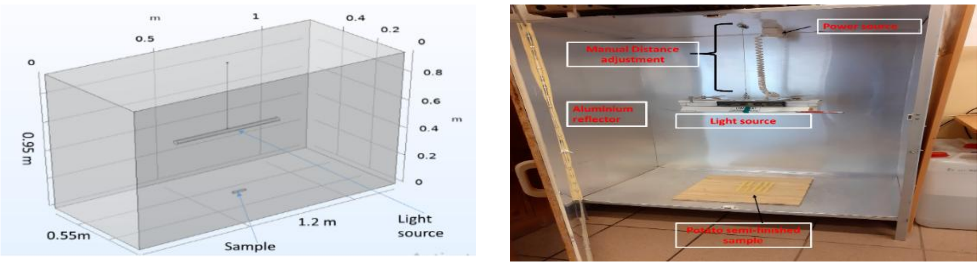

Fig. 1 UV-C chamber (a) schematic and (b) Actual appearance

3.4. Optimization

A central composite design method was used as a selected experimental design that combines three factors including UV-C dose, storage period, and distance from the light. A desirability function approach was used to optimize the multiple functions simultaneously into a single function. The overall desirability was obtained by combining the normalized individual desirability (**Eq (2)**) found with a geometric mean, given by **Eq (3)** [3]:

$$di = \begin{cases} 0 \\ 1 \end{cases} \left[\frac{\hat{Y}i - Y_{i*}}{Y_i^* - Y_{i*}}\right], \begin{cases} \hat{Y}i \leq Y\_(i*) \\ Y_{i*} < \hat{Y}i < Y_i^* \\ \hat{Y}i \geq Y_i^* \end{cases} \quad (2), \qquad D = (d1 \times d2 \times \ldots \times dk)\ 1/k \quad (3)$$

Where D is the overall desirability; dk (1,2, ..., k) is the individual desirability within the interval 0≤dk≤1 from the combination of the transformed responses in the geometric mean; Yk (1,2, ...,k) is each of the responses of the original set [5]. The statistical analysis was performed in the form of analysis of variance (ANOVA).

4. RESULTS

The goal of the analysis was to maximize the mechanical properties (as described in model functions in **eq. (4)-(6)**) of semi-finished potato tubers under specific conditions, known as constraints: Compressive force (N), 500 ≤ Y1 ≤ 900; Cutting force (N), 5 ≤ Y2 ≤ 7; and Bending force (N), 7 ≤ Y3 ≤ 9. The response at the overall optimal desirability is 0.8142013 resulted in 756 N, 6.7 N, and 9 N compressive, cutting, and bending forces, respectively, at the corresponding variables of ~ 40.5 mJ/cm², 7 days, and 48 cm. **Error! Reference source not found.** shows the contour plot that identifies the optimal region offering maximum desirability.

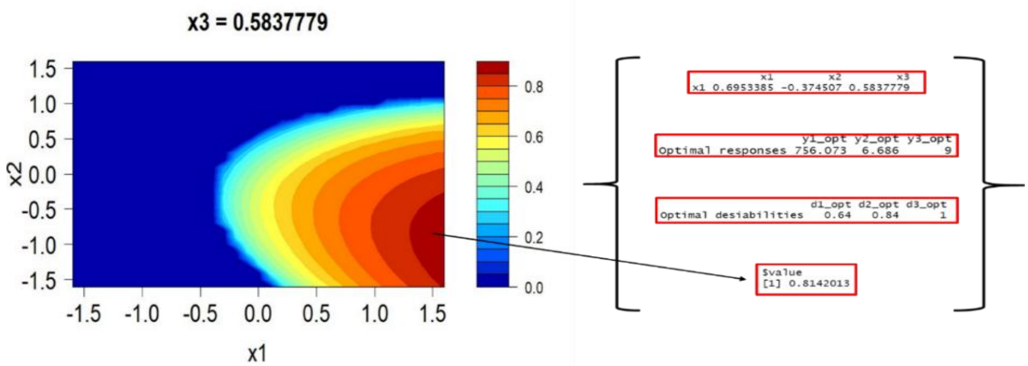

Fig. 2. Desirability contour plot for optimal operational variables and their responses

Y1 (N) =633.395 + 122.319*(x1) - 71.172*(x2) + 55.791*(x3) - 46.707*(x12) - 69.078*(x22), 0.92 (4)
Y2 (N) =6.71367 + 0.61345*(x1) + 0.68706 *(x2) +0.76969*(x3)-0.91592*(x12)-0.99865*(x12), 0.91 (5)
Y3 (N) =8.443058 + 1.566436*(x1) - 1.197801*(x2) - 0.867128*(x3) - 0.846179*(x22) - 0.725202*(x32), 0.86 (6)

Fig. 3 (a)-(c) displays the comparison of the behaviour of force versus time graphs for non-irradiated and irradiated samples conducted at the optimal interaction of variables, demonstrating higher resistance to mechanical force than the non-irradiated sample. **Table 1** presents the mechanical properties of the semi-finished samples derived from the optimization function and validation. The cutting and bending forces are not statistically different between the validated and predicted values.

Table 1. Values of experimentally validated compared to the predicted values

Sample type	Compressive force (N)	P-Value	Cutting force (N)	P-Value	Bending force (N)	P-Value
Optimized predicted	756		6.7		9	
Optimized experimental	725.6±8.63	0.01306*	4.31±0.07	0.1341	7.43±0.21	0.06065
Control sample	569.58±13.33		2.52±0.07		6.265±0.18	

***significant term (t-test)*

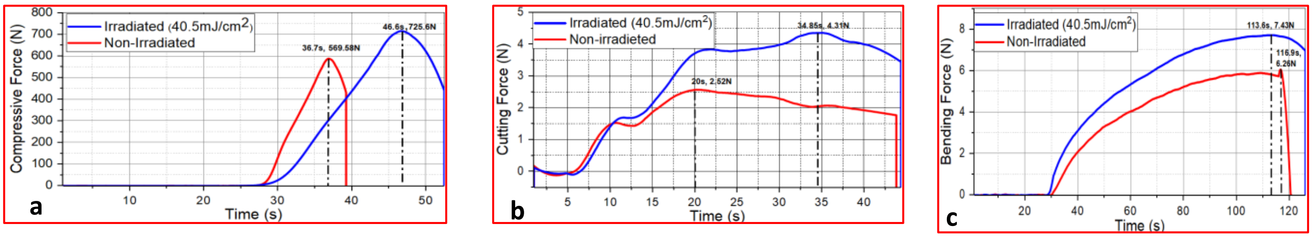

Fig. 3 Time vs. force curve for optimized Irradiated and Non-irradiated sample applied on (a) Compressive force, (b) Cutting force, and (c) Bending force

5. CONCLUSIONS

The simultaneous optimization approach was implemented to achieve the optimal combination of variables in UV-C surface treatment that offered the highest possible mechanical resistance in semi-finished potato tubers. The overall desirability (0.8142013) predicted from the analysis suggested an optimal combination of variables, with a UV-C dose of approximately 40.5 mJ/cm², a distance of 48 cm from the light, and a storage period of 7 days, could offer 756 N, 6.7 N, and 9 N for compressive, cutting, and bending forces, respectively.

REFERENCES

[1] M. Younis *et al.*, “Response Surface Methodology (RSM) Optimization of Pulsed Electric Field (PEF) Pasteurization Process of Milk-Date Beverage,” *Processes*, vol. 11, no. 9, Sep. 2023, doi: 10.3390/pr11092688.

[2] H. Chen, C. I. Moraru, and V. V. Protasenko, “Maximizing the disinfection effectiveness of 254 nm UV-C light with a special design unit: simulation and experimental approaches,” *Frontiers in Food Science and Technology*, vol. 3, p. 1223829, Oct. 2023, doi: 10.3389/FRFST.2023.1223829.

[3] R. Suich and G. C. Derringer, “Is the Regression Equation Adequate?—A Further Note,” *Technometrics*, vol. 22, no. 1, pp. 125–126, Feb. 1980, doi: 10.1080/00401706.1980.10486110.

[4] ASTM International, “Standard test method for compressive properties of rigid plastics. ASTM international.,” 2010.

[5] L. Vera Candioti, M. M. De Zan, M. S. Cámara, and H. C. Goicoechea, “Experimental design and multiple response optimization. Using the desirability function in analytical methods development,” *Talanta*, vol. 124, pp. 123–138, Jun. 2014, doi: 10.1016/J.TALANTA.2014.01.034.