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Evaluation of frying conditions and their association with oil absorption among four varieties of potato

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Abstract

The objective of this study was to determine the optimal frying time and temperature to achieve desirable quality attributes in four potato varieties. For this purpose, a 3^2 factorial design was developed, analyzing color using the CIELAB scale, moisture, fat content, acrylamides, and texture. Process optimization was performed using a desirability function approach. µRaman spectroscopy was used to evaluate the fat content within the potato. The results indicate that each potato variety requires a specific frying process to obtain a desirable product. Furthermore, Raman spectroscopy proved to be a suitable technique for monitoring fat content.

Keywords: Frying, optimization, oil, Potato, Raman spectroscop

Introduction

Frying involves transfer of heat and mass (Liberty et al., 2025). During this process, the food item suffers a physical and chemical transformation at a high temperature range of 140° C a 180° (S. Zhang et al., 2025). Some transformations include dehydration, starch gelatinization, protein coagulation, browning due to Maillard reactions, and oil absorption (Frakolaki et al., 2023).

Dehydration, oil absorption, and the formation of crust happens in the surface of fried products. Steam formation occurs quickly. The crust in the surface does not allow the steam to escape, increasing the pressure in the core. This pressure creates cracks in the crust, which allows the oil to enter the core (Oke et al., 2018).

To control the amount of oil inside the food item, it is necessary to know the mechanisms of absorption. These mechanisms include water substitution, condensation effect, the capillary effect, and the surfactant effect (Eichenlaub & Koh, 2015). Testing these mechanisms, a study have shown that the volume of oil absorbed equals the amount of water evaporated from the sample (Liu et al., 2021). In addition, the properties of each potato variety may play a role. Macroscopic properties such as density, porosity, pore volume, surface area, and microscopic properties; such as pore size, pore volume distribution, and number of pores; could affect oil absorption (L. Rani et al., 2023).

The Raman spectroscopy may be used as proxy measure of oil content in fried products. It is based on the interaction photon-molecule in the 400-4000 cm^{-1} of the electromagnetic spectrum (Ye et al., 2023). It differs from other vibrational spectroscopy techniques, because it measures the inelastic dispersion of the radiation produced during the interaction with the sample molecules (Arroyo-Cerezo et al., 2021). A Raman spectrum is presented as a

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change in intensity vs. wavelength (Sun et al., 2022).

The aim of the study was to determine optimal time and temperature conditions to obtain a fried potato light in color, with appropriate chemical and physical characteristics using vibrational frequencies as a measure of oil content among four varieties of potato.

Materials and methods

Material

The analysis units are the recently harvested fresh potatoes without external damage. Potatoes were stored at 15 °C with 80 % humidity. Native Peruvian varieties were used: Unica (V1), Yungay (V2), Amarilis (V3) and Huevo de indio (V4). Potatoes were washed, pealed, and cut in cuboids with dimensions 1x1x4 cm (height x width x length) following the procedure by Isik et al (2016).

Frying

Sunflower oil was heated at 170 °C for 10 minutes. Ten potato cuboids were fried at three different temperatures (170 °C, 180 °C and 190° C) with three 3 different times for each temperature (1, 2.5, and 4 minutes), respectively. Oil samples before and after frying were taken. Fried potatoes were placed over paper towels at room temperature.

Color

Color was analyzed using Chroma (CM-2003d, Konica Minolta, Japan). Instrument was calibrated with a standard White board. The scale used is L* (0 = black; 100 = white), a* (-a = green; +a = red), y b* (-b = blue; +b = yellow). Ten different sites were tested for each sample.

Texture

Texture was analyzed using Brookfield Texture Analyzer (TA-CT3 Texture Technologies Corporation, Scarsdale, NY, USA). The firmness of the raw potatoes was defined as the maximum penetration force. The sample was penetrated with a needle in a 30° angle (TA-17). The needle was introduced at 0.1mm/s for a depth of 3mm. mechanical strength of the potatoes was defined as the minimum force to break them (Zheng & Moreira, 2020).

Fat content

Procedure 920.39C by AOAC was run (M. Rani & Chauhan, 1995). Samples (5 grams each) were extruded for 180 minutes using diethyl ether as solvent (150ml/ sample). Oil content was expressed as g/g dry weight.

Humidity

Procedure 964.22 by AOAC was run. Samples (4 grams) were desiccated in an oven (POL-EKO) at 105 ± 2°C until constant weight. Humidity was expressed as g/g wet weight.

Acrylamide content

Liquid chromatography with tandem mass spectrometry (LC/MS-MS) was used. Result were expressed as µg/ kg.

Scanning electron microscopy (SEM)

Fried potatoes were cut in little pieces and frozen using liquid nitrogen. Samples were dried using Thermo Scientific model Telstar LyoQuest at 0.9 °C at 10.00 mBar for 12 hours.

Copper and carbon strips were used to fix the samples in the platform. The SEM analysis was run using FEI model Quanta 650. Acceleration voltage of 5 kV and an electron bean size of 3 was used for the images. The lyophilized samples were cover with gold before measuring them in the electronic microscope. Images were obtained at 200X.

***µ**Raman spectroscopy*

Several wave lengths were tested: 514 nm, 785 nm, and 633 nm corresponding to an Argon laser, diode laser, and helium neon; in order to identify the best conditions for the Raman signal.

The wave length 785 nm showed the best signal-to-noise ratio. Measures were conducted with a 50X objective with a 10% laser intensity.

Statistical analysis

The experiment was run in triplets based on a factorial factor 3^2.

The desirability function was used to determine the best combination of factors. Analysis was run using Software R and Statistica V 10.0

Results and discussions

Effects on physical and chemical characteristics.

Table 1 shows the associations between temperature/time and color/acrylamide/humidity/fat/ texture for each variety. The R^2 for L*, a*, b*, acrylamide,

Table 1. Association between temperature/time and physical/ chemical characteristics

	Temperature				Time			
	V1	V2	V3	V4	V1	V2	V3	V4
L		* (+)	* (-)		* (+)	* (-)	* (+)	* (+)
a	* (+)	* (+)		* (+)	* (+)	* (+)	* (+)	* (+)
b	* (+)	* (+)		* (+)	* (+)	* (+)		* (+)
Acrylamide	* (+)	* (+)	* (+)	* (+)	* (+)	* (+)	* (+)	* (+)
Moisture	* (-)	* (-)	* (-)	* (-)	* (-)	* (-)	* (-)	* (-)
Fat	* (-)	* (-)	* (-)	* (-)	* (+)	* (-)	* (+)	* (+)
Texture					* (-)	* (+)	* (+)	* (+)

* ($p<0.05$), (+) or (-) shows direction of effect on variable

humidity, fat y texture was 76.13%, 86.9%, 82.5%, 78.3%, 94.2%, 96.4% y 98.6%; respectively. Time produced more significant associations than temperature with the highest impact on texture. According to Pedreschi (2012), the longer time produces cellular separation due to the degradation of pectin during thermal treatment.

Time had a profound effect on browning (L) with starchy varieties showing a better color. According to Dhital et al. (2018), varieties with higher starch content show a positive effect due to Maillard reaction. Similarly, both time and temperature had a significant effect on acrylamide production which also contribute to browning. Acrylamide is a byproduct of the Maillard reaction and lipid oxidation in fried products (Z. Zhang et al., 2025).

Figure 1 shows SEM pictures of the samples cores for each variety at different time and temperatures. Figure 1(a) shows variety V1 exposed to different times and temperatures. Compared to the raw sample, we observed a decrease in porosity due to starch cells being broken by the heat leading to gelatinization. When time and temperature increased, individual starch cells aggregate as a solid mass due to higher oil absorption. Similar behavior was observed in variety V2 as shown in figure 1(b).

Figure 1(c), shows the morphology of variety V3. Similar to the previous sample, there was a decrease in starch granules. As temperature increased for the 1-minute time slot, an increase in porosity was observed. However, this trend decreased as the time increased, probably due to the absorption of oil. In figure 1(d), there was a decrease in starch granules for variety V4 compared to the raw sample. Increasing time caused an

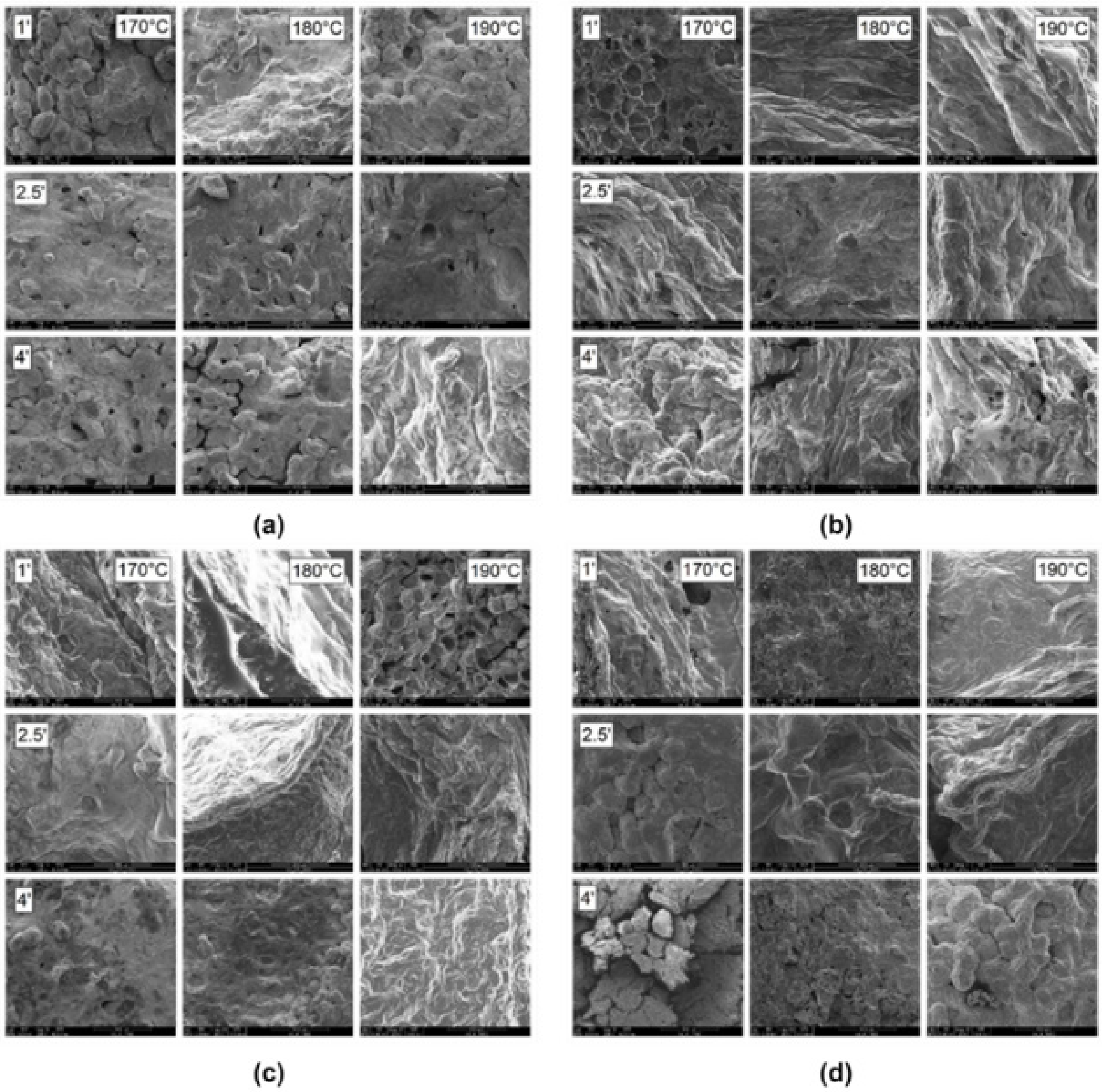


Figure 1. SEM pictures of the sample cores for each variety (a) V1, (b) V2, (c) V3, (d) V4 at different temperatures (left to right: 170°C, 180°C y 190°C) and times (top to bottom: 1', 2.5',4')

increase in porosity. However, an increase in temperature caused cell fusion due to degradation.

The behavior in these varieties is similar to the one observed in the Helan variety (Yang et al., 2019), where polygonal shapes for the starch cell were reported at baseline. However, cell membranes were broken around 240 seconds. The polygonal shapes were lost due to starch gelatinization in varieties with high starch content (Dhital et al., 2018).

Table 2, shows the appropriate time and temperatures to obtain a fried potato with clear color (L_{max}, a_{max} y b_{max}) and optimal physical-chemical features ($acrylamide_{min}$, fat_{min}, $humedity_{min}$ y $texture_{max}$). These conditions changed according to the variety. To obtain these values, a complex function was set with temperature and time as predictors to get the desired color and physical-chemical characteristics.

μRaman spectroscopy

Figure 2(a), shows the oil samples before and after frying with no significant differences. In figure 2(b), the four raw varieties were compared. The spectrums can be visualized in the 478 y 2902 cm^{-1} wave lengths. The four varieties showed the same bands with different intensities. Only V4 showed an additional band at 1654 cm^{-1}.

When oils are heated, physical-chemical and structural changes are produced. These changes can be detected by ***μ***Raman spectroscopy (Alvarenga et al., 2018; Castro et al., 2022). Similarly, this method can detect acrylamides. Therefore, it is a valid tool for fried foods.

Figure 3 shows Raman spectrums for the four varieties at different times and frying temperatures. These values were compared with the spectrum for the raw potato for each variety and with the oil spectrum. Since there was no difference in the spectrum of oil before and after frying (figure 2), only the one before frying was used for comparison and it was labeled A1.

When V1 was heated at 170°C for 1 min, it shows Raman spectrums belonging to the oil. However, when it was heated at 180°C and 190°C for 1 min these spectrums disappeared. In addition, when time was increased to 2.5 min in the samples heated at 180°C and 190°C, the core absorbed oil. When time was increased to 4 min, a spectrum similar to the raw V1 was observed. This means the oil in the core moved to the crust for times longer than 2.5 min. In fact, when the crust of the samples heated at 180°C for 4 min were analyzed, oil spectrums were detected. On the other hand, when the samples heated at 190°C for 1, 2.5 y 4 min were analyzed, it was not possible to identify Raman bands, with the exception of a band at 478 cm-1 which belongs to the raw potato. The crust at this temperature started disintegrating. Therefore, the intensity of the Raman signal weakened.

In the case of V2, no oil Raman bands were observed for all combinations of time and temperature in the core. The oil was not absorbed. In contrast, when the samples were heated at 170°C and 180°C for 1 min, oil spectrums were observed at 1656 cm^{-1} in the crust. In addition, when times were increased to more than 1 min, the crust started disintegrating at all temperatures. In the case of V3, as the time and temperature increased, the oil bands started showing up. Oil was absorbed. Similarly, the oil bands appeared in the crust. Therefore, the triglycerides in the oil dominated the vibrational

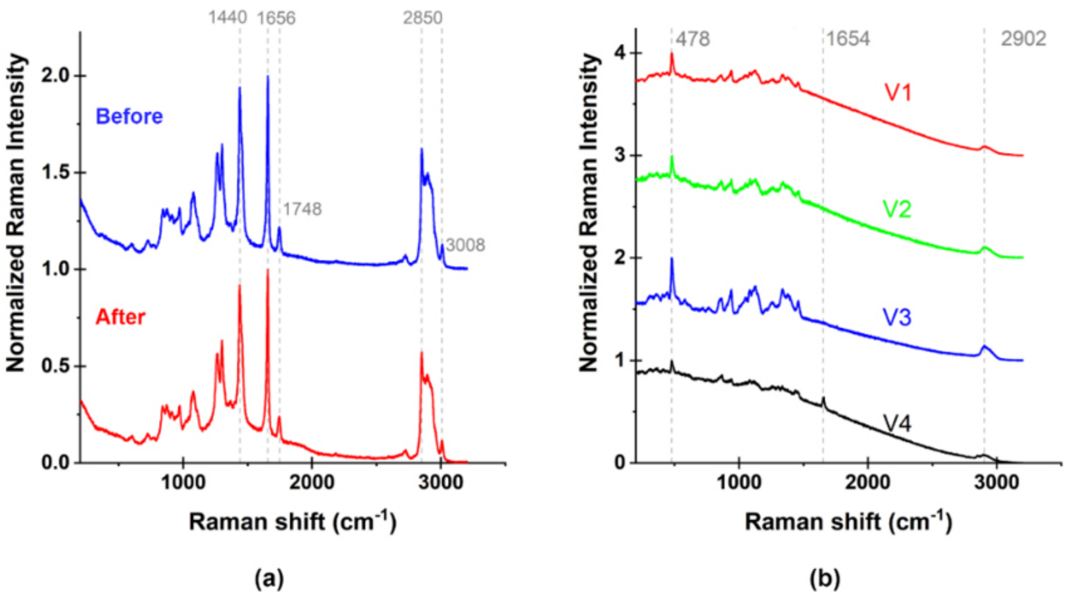
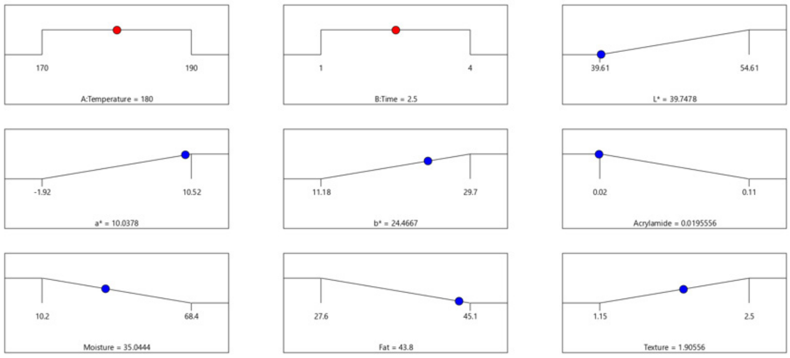
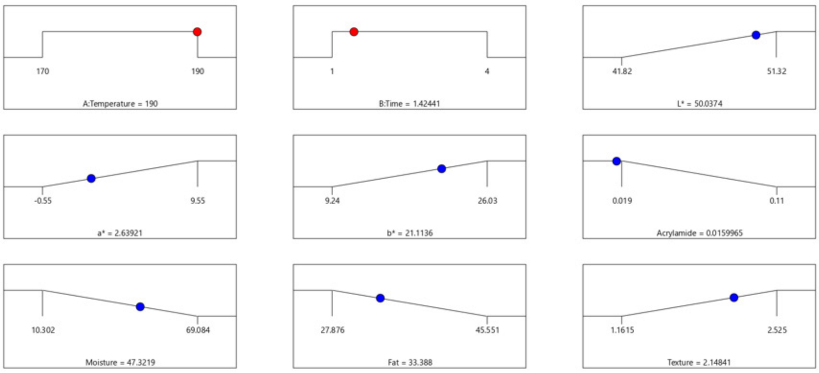
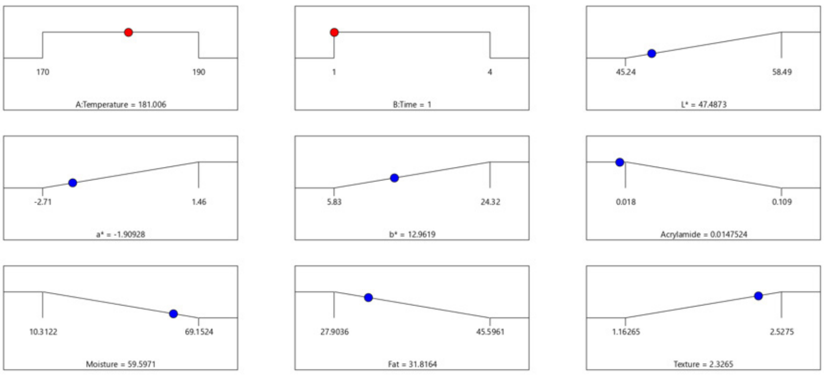
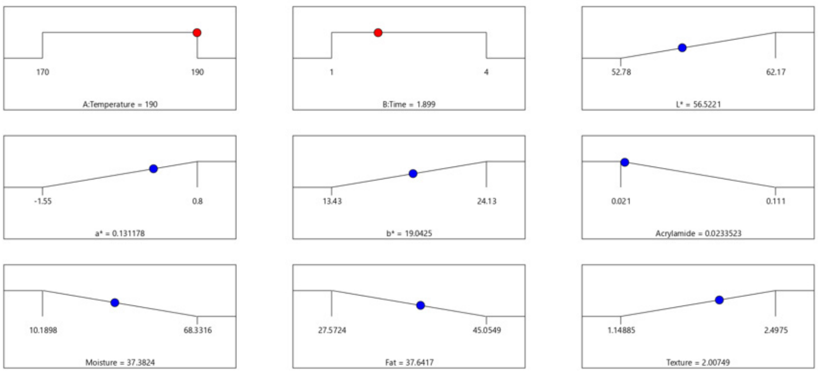


Figure 2. Raman spectrums of the oil before and after frying the potatoes (a) and of the four raw potatoes varieties (b)

Table 2. Ramps reports on numerical optimization by desirability function solutions for obtaining the most desirable numerical optimization by calculating the minimum and maximum response

<table>
<tr><th></th><th>Numeric optimization ramps</th><th>Optimal Temperature (°C)</th><th>Optimal Time (min)</th></tr>
<tr><td>V1</td><td>
</td><td>180</td><td>2.5</td></tr>
<tr><td>V2</td><td>
</td><td>190</td><td>1.42</td></tr>
<tr><td>V3</td><td>
</td><td>181</td><td>1</td></tr>
<tr><td>V4</td><td>
</td><td>190</td><td>1.9</td></tr>
</table>

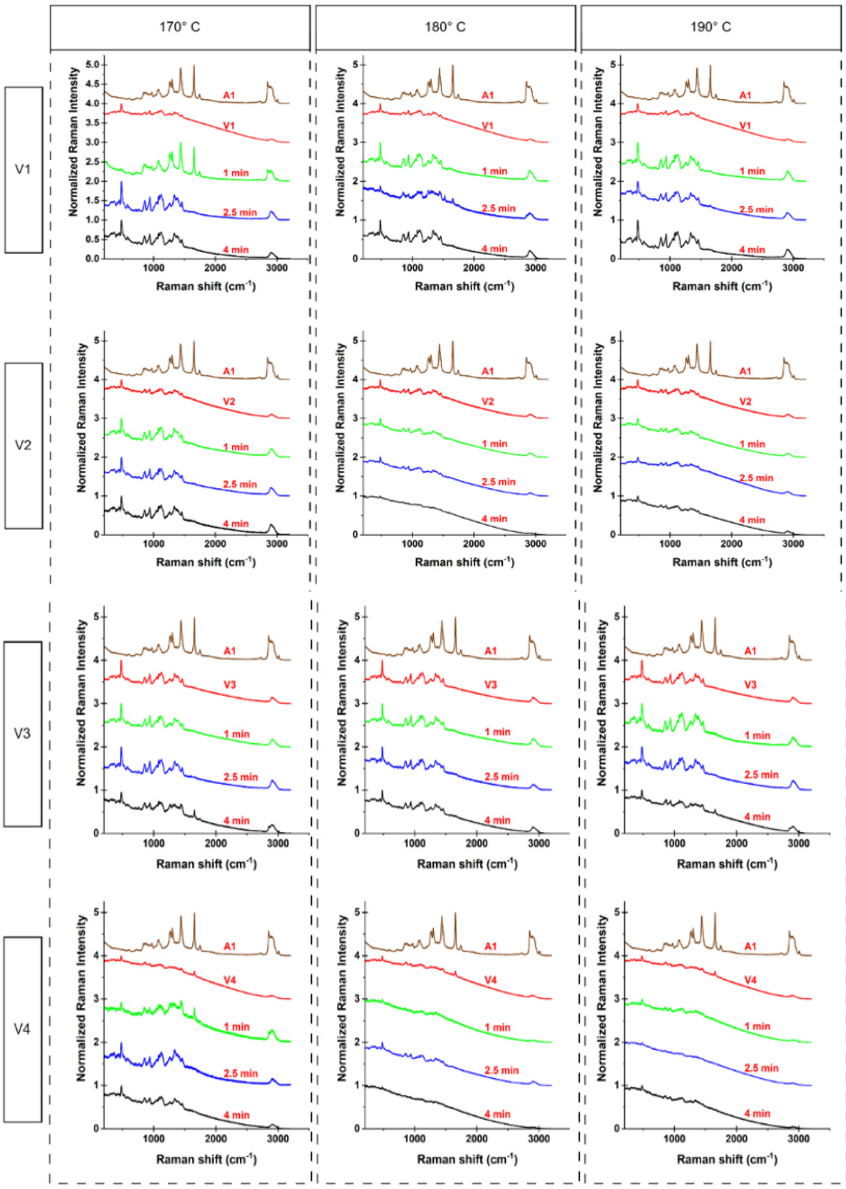


Figure 3. Raman spectrums for V1, V2, V3 y V4 at different times and temperatures

frequencies. Finally, V4 showed a weak signal, since it was easily degraded at each combination of time and temperature.

Conclusions

Based on the results of this investigation, it can be concluded that cultivar differences, time and frying temperature are important factors affecting the physico-chemical characteristics. Also, these differences mean that the frying parameters are specific to each variety. Some limitations of our study include the use of sunflower oil, which is widely used in Peru. However, other oils such as soy and corn are also used. Our results may not extrapolate to other oils. In addition, our lab is located at 2750 meters above sea level. Conditions may change at lower altitudes. To our knowledge, this is the first time μRaman spectroscopy is used as a quality control tool in fried potatoes in our region. This may be a practical tool to determine optimum time and temperature combinations in fried foods.

Conflict of interests

The authors declare no conflict of interest associated with this study

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.