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VISUALIZATION AND MEASUREMENT OF SKILLET TEMPERATURE PROFILEUSING INFRARED THERMOGRAPHY

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Abstract

This paper presents a possibilities of infrared thermography especially focused on temperature measurement as a non-destructive to monitor temperature profile during potato frying With using three different, easily accessible skillet materials stainless steel Wock Skillet, Stainless steel with PTFE polytetrafluoroethylene material and Tefal Skillet .The thermal imaging cameras and software to read skin surface temperature and calculate an estimated core body temperature. The results recorded the internal and external temperatures at the three Skillet materials, the temperature of air, oil, fire, and potatoes, for the Wock Skillet before frying 29.8, 36.9, 21.7, 45.9, 216.7 and 17.2Cº while after frying 50.9, 61.9, 23.1, 111.9, 204 and 31.8 Cºrespectively. as they were for the Teffal Skillet before frying 131, 154.9, 25, 94.2, 206.1 and 17.2 Cºwhile after frying 200.7, 201.3, 27.8, 161.1, 260.7 and 40.1Cº respectively. as they were for the Wock Skillet before frying 59.7, 51.6, 26.7, 65.6, 129.8 and 17.2Cº while after frying 99.4, 126, 28.8, 120.1, 197.4 and 35.1Cº respectively. Therefore, the best temperature profile of frying with typesSkillet for the least heat emission, and the lowest temperature recorded for oil and potatoes, were in the Wock Skillet, followed by the Teffal Skillet, and finally the EL RAMLAY Skillet.

***Key words*: *c*hips, French fries, frying, potato, infrared thermography**

INTRODUCTION

For numerous apparent reasons, including lowering the risk of food-borne infections and improving flavor, texture, palatability, digestibility, and shelf life in both domestic and commercial settings, cooking is an essential aspect of daily living. Food-related energy demand is estimated by FAO to be 75% for cooking and food preparation, 10% for primary production, and 15% for food transportation and processing [3].
A Skillet is a physical delivery mechanism that transfers heat to the contact surface of food that is meant to be cooked from a source such as an electrical coil, natural gas, or induction. The way that food cooks is determined by the conduction of thermal energy via the food contact surface. Heat is transferred through the Skillet 's materials and from the heat source (the cooktop) to the Skillet 's base by a process known as conduction of heat. How thermal energy is delivered from the Skillet to the food is mostly determined by the materials used in the Skillet 's construction. Taking into account the aforementioned, this study examines the properties of heat transfer for Skillet s with varying compositions on different cooktops [8].
One of the oldest and most widely used food processing techniques, frying provides fried food its distinct flavour, texture, and taste. Due to their crispy texture, affordable price, and portability, fried potato strips and chips make up a sizable share of the fried food goods. But fried potatoes and other foods typically have a high oil content—between 35 and 45 percent. Consuming such fried food in excess can raise your risk of obesity, hypertension, heart disease, diabetes, and other conditions [15].
One of the most popular methods for preparing food is deep-oil frying, which is thought to be a billion-dollar industry globally. To ensure the ultimate quality of the fried food products, it is crucial to simulate and monitor the temperature time distribution in the food during frying. Frying can remove all or some of the moisture from food, depending on how intensely it is processed. In actuality, while frying, heat from hot oil is absorbed, causing a phase shift from liquid to vapor. As a result, mass transfer and

heat transfer phenomena occur concurrently when food is frying [4].

Because they are readily available, affordable, convenient, and have a delicious flavour, deep-fried potatoes are among the most often consumed food items. A number of scientists have created mathematical models to explain how potatoes fry. Based on either single-phase or two-phase systems, these models have been constructed to represent the heat and mass transmission mechanism for frying potatoes. Dincer developed an analytical correlation for heat and moisture transfer coefficients based on various potato geometries, assuming that heat and mass transfer processes occur independently. Dincer employed a single-phase model, solving the diffusion equation for both the heat and mass transfer phenomena, without coupling the two phases together [9].

When potato slices or strips are fried, heat can produce certain chemical pollutants like acrylamide and furan, which can end up in the final fried pieces in significant levels. In industrial frying procedures, the variables that can be controlled are often the kind of oil, frying temperature, frying time, and potato variety. Because of this, it is essential to analyze how quality changes during frying. By understanding kinetics parameters, one can forecast the ultimate quality of fried potatoes and increase the value of the final product by carefully choosing the processing settings [10].

Over time, there has been a significant increase in interest in frying process optimization. This method has improved our comprehension of the entire process, including the food, fryer, oil, and overall operation. The degree to which the heated fat undergoes chemical reactions such as oxidation, polymerization, and hydrolysis, which change its chemical and physical properties, determines how complex the frying process is. Maintaining ideal frying conditions and estimating the degree of each factor's influence are challenging tasks [6].

Plant and animal items have been cooked, baked, roasted, or fried from the beginning of time to increase their palatability and digestibility. Heat can be delivered to the product by conduction (Skillet-frying), convection (deep-frying), or radiation (microwave) from the medium, such as air, water, or oil. Food has been cooked using deep-fat frying on an industrial, catering, and home scale. Traditionally, based on their precise volume, several final goods might be prepared: I item that are wet and have a crisp, dry crust, like fried chicken, French fries, and doughnuts; and ii) products that are entirely dry and brittle, like potato chips (also known as crisps [13].

The range of temperatures utilized for frying is 150–200°C. Elevated temperatures stimulate the interplay between dietary ingredients such as proteins and carbohydrates, as well as the crust's surface dehydration and oil absorption. When food is heated to high degrees, it acquires a desired colour, crispness, flavour, and taste as opposed to boiling it in hot water [11].

Due to its speed and ease of use, frying is a highly popular procedure in the restaurant and industrial sectors, outperforming other cooking processes in terms of efficiency. Despite being a long-standing and widely used method, deep-frying remains little understood. Experience usually dictates the best frying oil to use as well as the correct cooking technique. A thorough understanding of the frying process aids in the optimization of the production processes with reference to food quality, fat use life, and energy consumption. Installing a management system that covers all crucial frying process points is required to provide a high-quality final product [14].

A food is a solid body that has pores and holes in it that are full of air and water. Traces of free water at the surface evaporate quickly after being submerged in the heated oil, causing the surface to violently bubble and dry out. The heat resistance of the steam evaporating from the surface means that the heat transfer rate from oil to food surface is zero when the vaporization of water occurs more quickly than the surrounding oil's capacity to remove the steam by convection. A violent bubbling is caused by the food being added to the heated oil and the food's quick evaporation of moisture. The area of interaction between oil and bubbles increases.As a result, the rate of heat transfer between oil and air rises, hastening the oil's oxidative deterioration [1].

Rapid evaporation of water from the food's surface and severe bubbling can be prevented by lowering the oil temperature, reducing the amount of food to be fried, or pre-drying the food. As the oil cooks, the number of bubbling decreases and the protective effect of the evaporating water steam increases. This reduces headspace air flow and creates a steam blanket over the oil surface, protecting it from oxidation by preventing air contact [12].

Convection from the oil to the product's surface and conduction to the product's centre are the two ways that heat is transported. There is more pressure inside the product because the water is heated to the boiling point. Water at the product's surface consequently evaporates, and as a result, water from the food's inside moves from the centre radially outward to the walls. After the first frying phase, this water transport is in charge of chilling the product's outside and preventing the food from burning or scorching. The inner portion of the meal to be fried is heated to a boiling point, which causes the starch to gelatinize and the proteins to denaturize [2].

You can utilize deep-fat frying as a substitute for other high-temperature, typically more complicated techniques like: Before pressing to extract oil, oil-rich materials (such as avocados, coconuts, and catering wastes) are dried and texturized. Forming and drying wood for outdoor usage. Coffee and cocoa are roasted and dried. Fried foods have been accused of exposing customers to health hazards including excess weight and toxicologic or mutagenic consequences because frying oils undergo chemical changes at high temperatures and stick to the product after it is taken out of the fryer. Therefore, the main areas of research have been fat chemistry and the potential health implications of fried foods [7].

The processes by which the oil impregnates fried goods and the internal alterations in the frying material have received far less attention. In fact, heat and mass transfer during the frying process have been inadequately explained and frequently restricted to a specific type of product (French fries, potato chips, fried chicken) or raw material (starchy materials, vegetables, fruit, etc.), despite a considerable amount of important work over the last ten years [5].

The main objectives of this study using infrared image to monitor temperatures distribution during potato frying and tocompare the heat transfer and energy efficiency across the various cooktops, it is important to comprehend the overall performance of the Skillets, including heating, the rate of heating that is impacted by the heating source, and the rate of heating that is influenced by the material composition of the Skillets.

MATERIALS AND METHODS

Potato tubers (Sponata) with a water content of 80% were used. The potatoes were cut into thin slices (10 mm thick and 55.1*10.33mm in diameter).

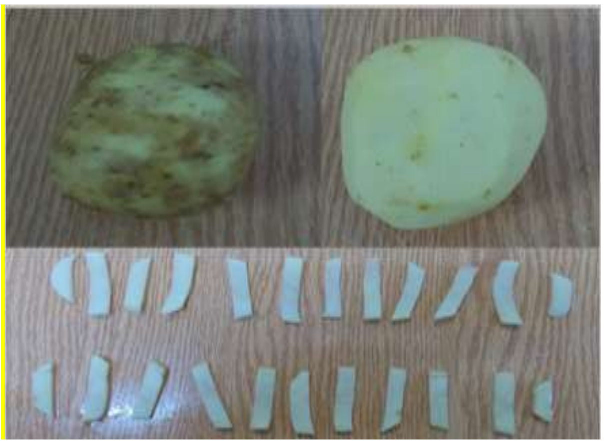

Photo 1. Potato tubers (Sponata)
Source: Photography by Authors.

Then slice into sticks (thickness 10mm and diameter 59.9*10.33mm) which were cut using manual French fry cutter.

Raw potato density was calculated from the weight and volume of potato samples. Samples were weighed on an analytical balance (Photo 1).

We used materials Stainless steel, sheet metal (steel) and Tefal skillets (Table 1).

Table 1. Skillet Properties

Properties	Stainless steel	Tefal	sheet metal (steel)
Elastic Modulus (N/m^2)	2e+11	400	190 to 210
Poisson's Ratio (N/A)	0.28	0.4 to 0.5.	0.27 to 0.30.
Shear Modulus (N/m$^{2)}$	7.7e+10	300 to 500	77 to 82
Mass Density (kg/m^3)	7,800	2,320	7,750 to 8,050
Tensile Strength (N/m^2)	513,613,000	7,580,000	300
Compressive Strength (MPa)	170 to 310	20 to 40	200
Thermal conductivity (W/mK)	18	0.25 to 0.35	15 to 60
Hardness (Rockwell)	95	50 to 65	120 to 200
Thermal Expansion Coefficient (µm/(m·K))	1.1e-05	80 to 135 x 10^{-6}	10 to 13 x 10^{-6}
Specific Heat (J/(kg·K))	460	0.5 to 0.55	0.46 to 0.51

Source: Authors' determination.

The Thermal camera characteristics

Image quality with 160 x 120 pixel infrared resolution (320 × 240 pixels using testo Super Resolution technology).

Photo 2. Thermal imaging camera- testo 865s
Source: Authors' determination.

Table 2. The specification of Thermal imaging camera-testo 865s

Infrared resolution	**160 x 120 pixels**
Thermal sensitivity	**<0.1 °C (100 mK)**
Field of view	**31° x 23°**
Minimum focus distance	**<0.5 m**
Geometric resolution (IFOV)	**3.4 mrad**
Super Resolution (Pixel)	**320 x 240 pixels**
Super Resolution (IFOV)	**2.1 mrad**
Spectral range	**7.5 to 14 µm**
Measuring range	**-20 to +280 °C**
Accuracy	**±2 °C, ±2 % of mv**
Emissivity	**0.01 to 1**

Source: From catalogue.

0.1 °C thermal sensitivity, automatic hot and cold spot detection, and free analytical software for the creation of expert reports.

Quick measurement with a fixed focus and ± 2 °C measurement accuracy.

Table 2 and Photo 2 demonstrates and providesan explanation of the Thermal Imaging Camera and its Technical Data (Testo 865s).

IRSoft · PC-Software

The testo thermal imager's captured images are processed, analyzed, and archived using the IRSoft software. Moreover, integrated reporting is included to provide data in an understandable manner. The instrument control can be used to adjust the parameters on the linked thermal imager.

System requirements

Operating system: The following operating systems are supported by the software: OS X (32-bit and 64-bit) Windows 10 (32- and 64-bit versions).

Workstation

The computer meets the specifications set forth by the relevant operating system.

USB 2.0 or higher interface. Internet Explorer version 6.0.

Intel Pentium Dual Core E2220 2.4 GHz, Intel Core i3-2310M 2.1 GHz RAM of 4 GB. 500 GB of accessible disk space. Device for graphics: DirectX 9c.

User interface

Ribbon, work area, and status bar are the three components of the interface that detect thermal images. Photo 3 presents IRSoft software interface.

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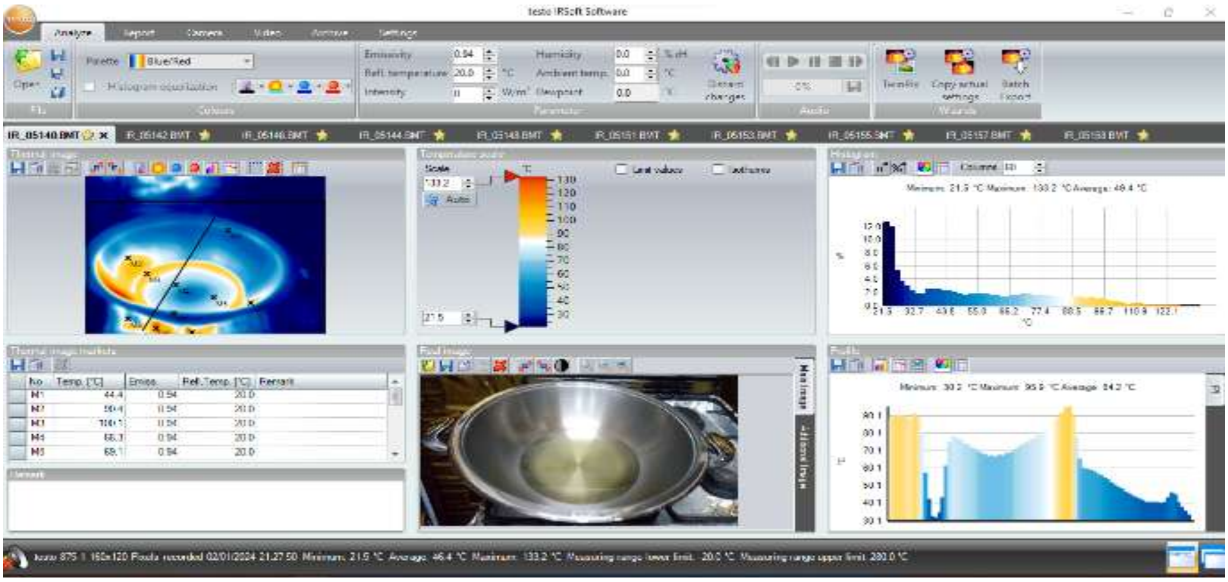

Photo 3. IR soft interface, ribbon, work space and status bar
Source: Authors' determination.

MATLAP PC-Software

The MATLAP application was used with the Image Analysis system. Digital cameras were used to take samples, and a capture card was used to transfer and save the data on a PC. The photos of Skillets were examined using the MATLAP software program. For every image, three bands—RGB—were obtained in order to get color indices.

User interface

The MATHAP Interface features a ribbon, a work area, and a status bar for image detection. The ribbon, work area, status bar, and Envi program interface are displayed in Photo 4.

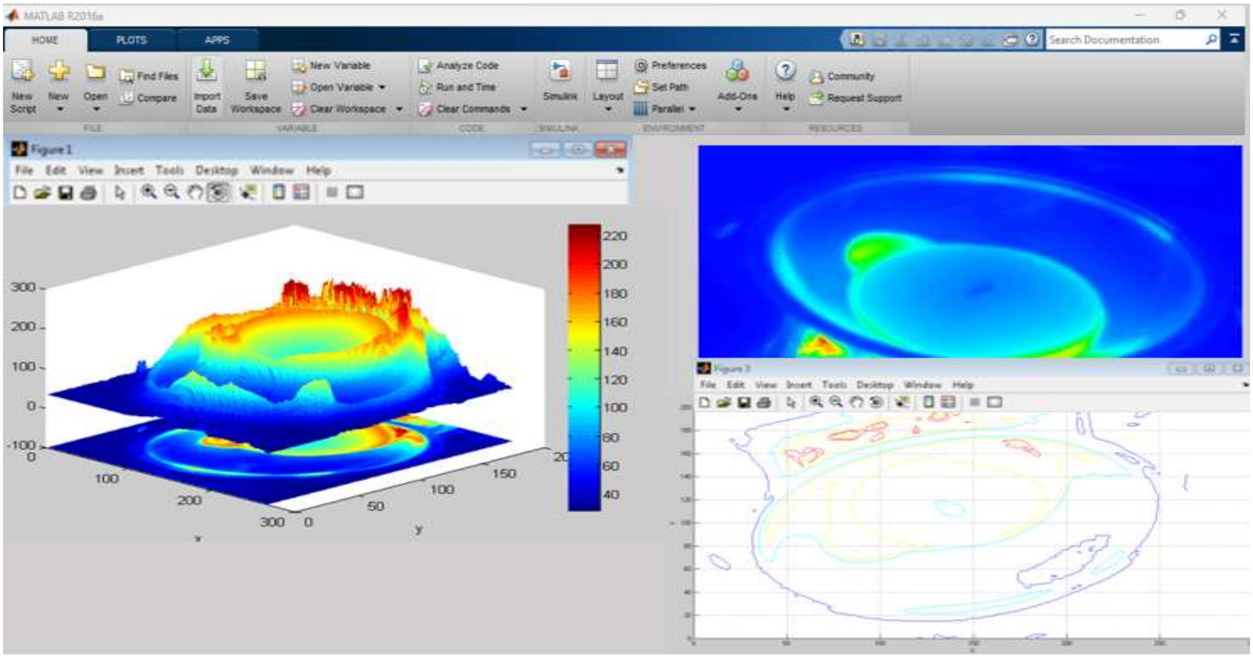

Photo 4. MATLAP interface, ribbon, work space and status bar
Source: Authors' determination.

RESULTS AND DISCUSSIONS

Photo 5 to 13 are shown using MATLAB software, where 3D images were extracted from thermal images to measure the effect of temperature on a different type of frying material when frying potato sticks.

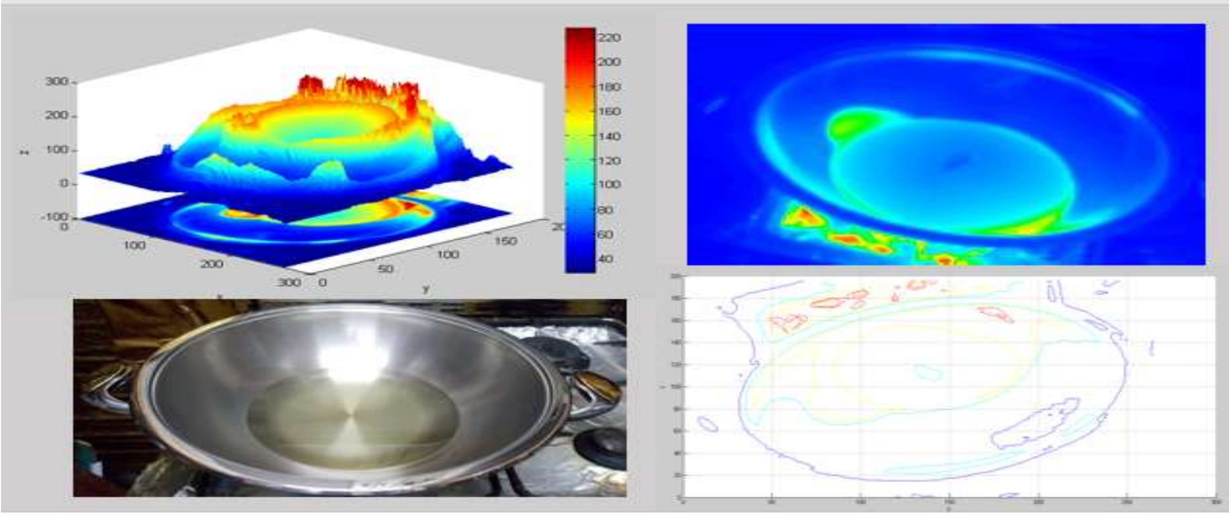

Photo 5. The Stainless steel (Wock Skillet) temperature profiles before frying potato sticks
Source: Authors' determination.

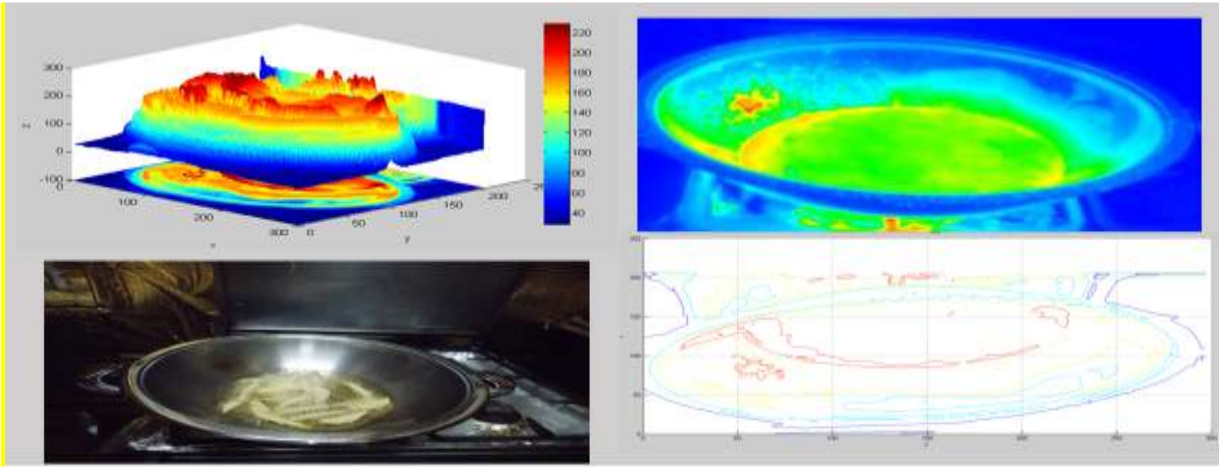

Photo 6. 6. The Stainless steel (Wock Skillet) temperature profiles during frying potato sticks
Source: Authors' determination.

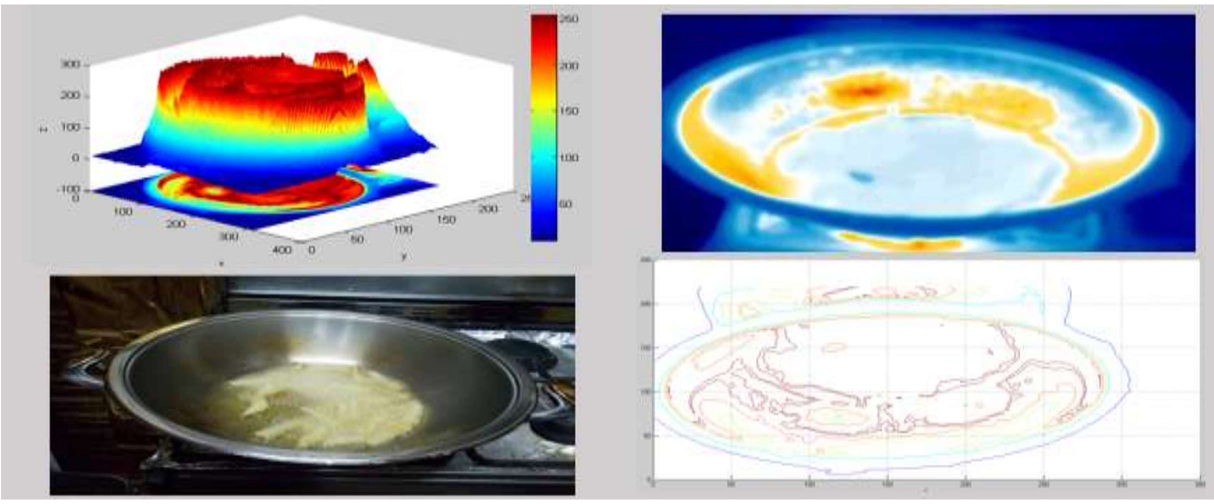

Photo 7. The Stainless steel (Wock Skillet) temperature profiles after frying potato sticks
Source: Authors' determination.

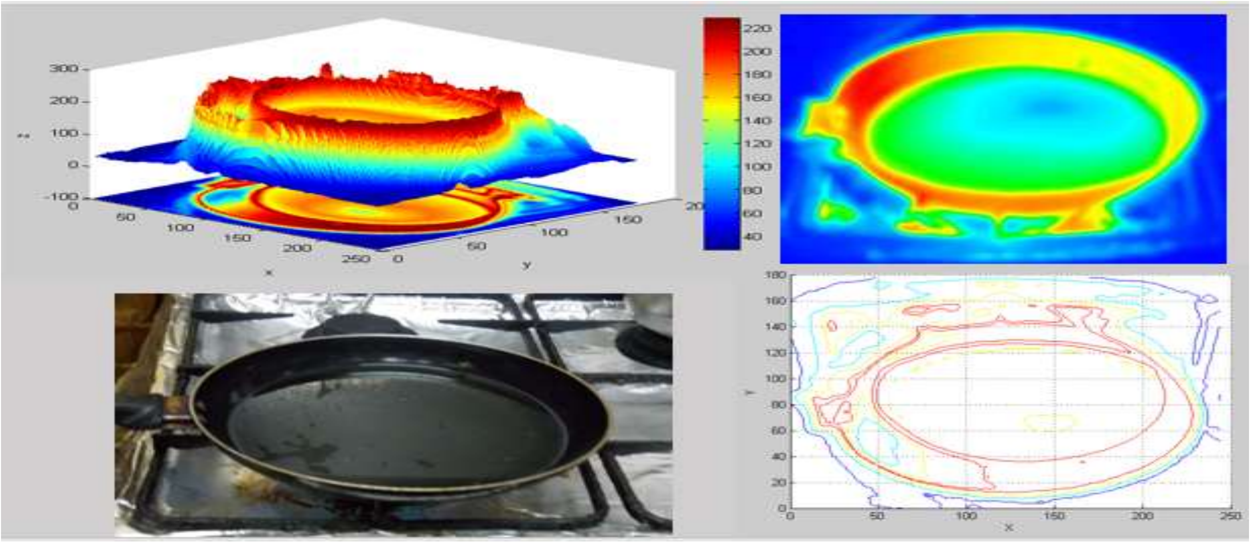

Photo 8. The material (Tefal Skillet) temperature profiles before frying potato sticks
Source: Authors' determination.

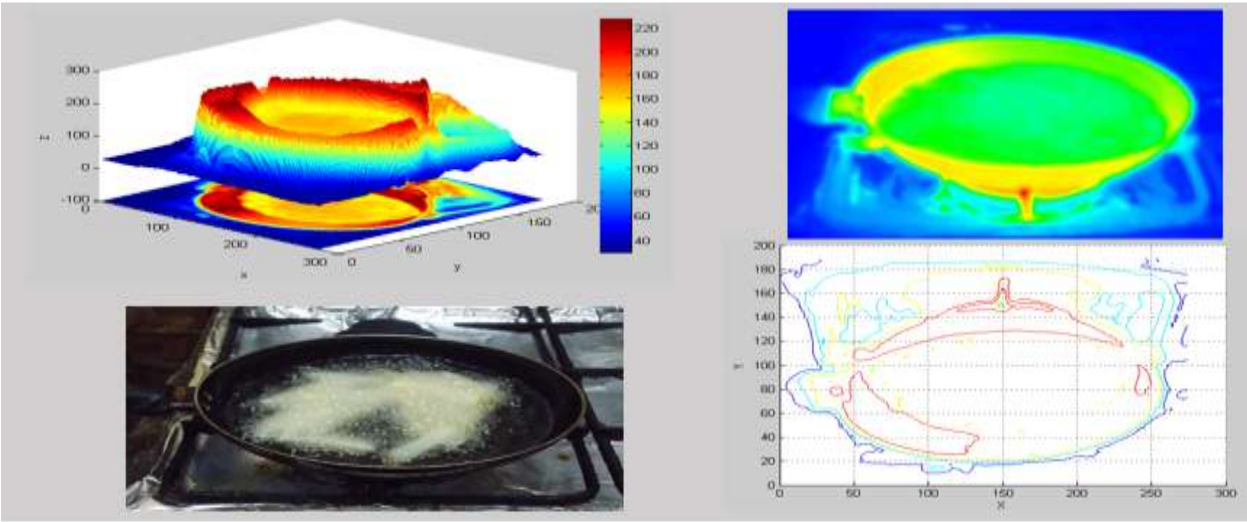

Photo 9. The material (Tefal Skillet) temperature profiles during frying at 4 min potato sticks
Source: Authors' determination.

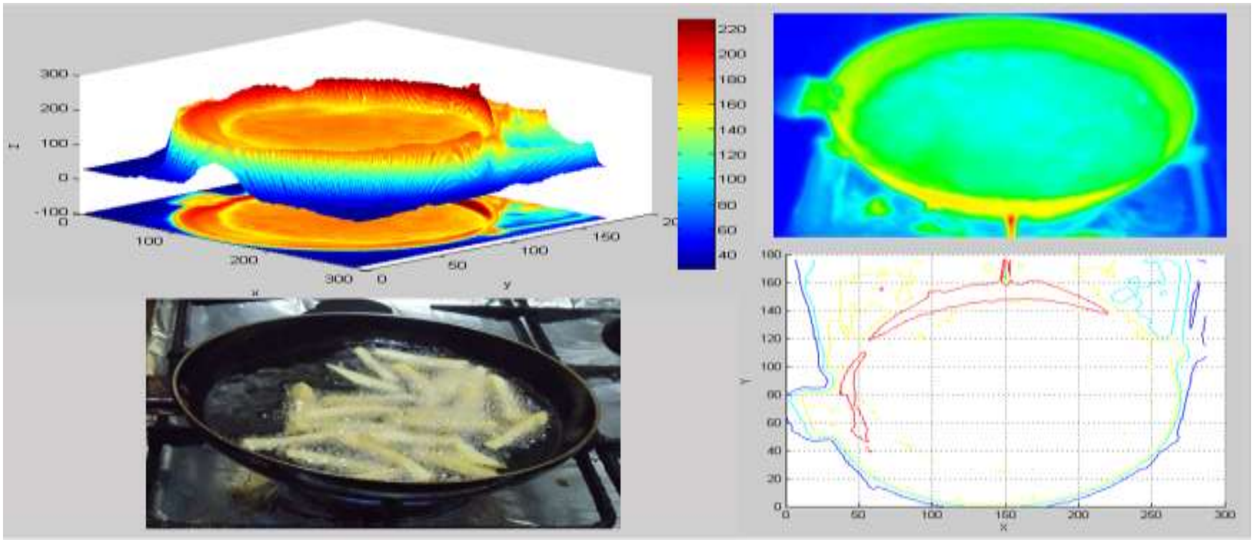

Photo 10. The material (Tefal Skillet) temperature profiles after frying potato sticks
Source: Authors' determination.

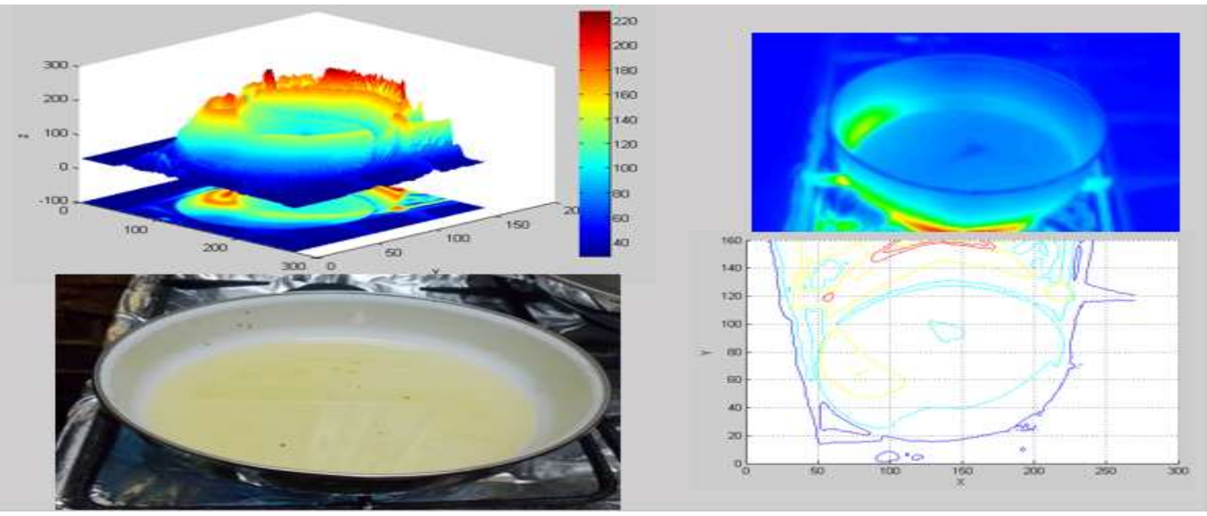

Photo 11. The sheet metal (steel) material (Ramlawi frying Skillet) temperature profiles before frying potato sticks
Source: Authors' determination.

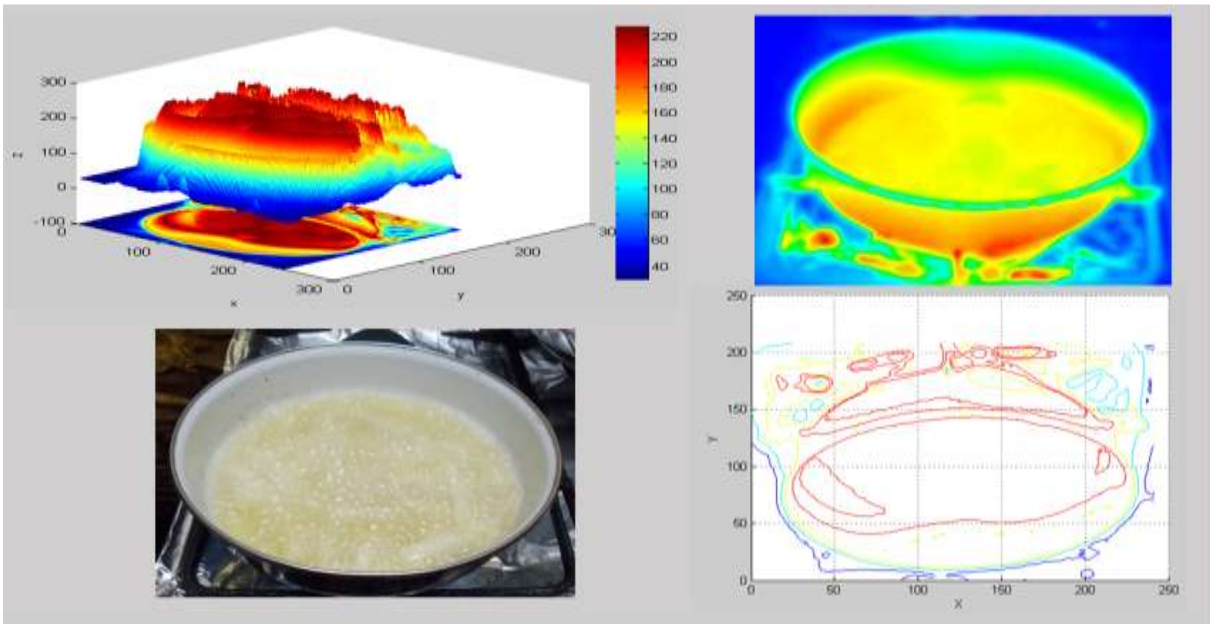

Photo 12. The sheet metal (steel) material (Ramlawi frying Skillet) temperature profiles during frying potato sticks
Source: Authors' determination.

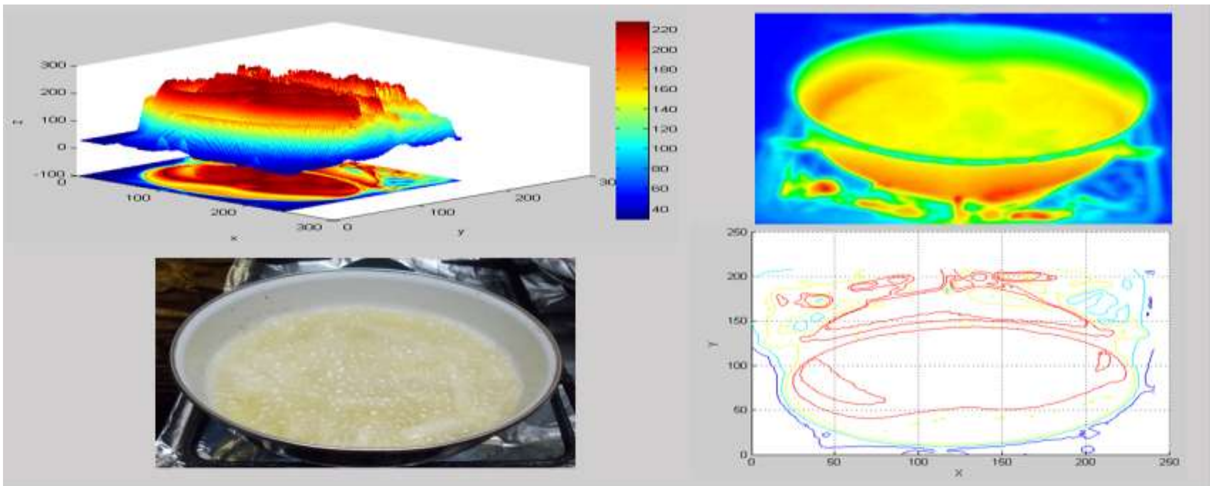

Photo 13. The sheet metal (steel) material (Ramlawi frying Skillet) temperature profiles after frying potato sticks
Source: Authors' determination.

Using infrared image to measure the internal temperature of the fryer material, the temperature of air, oil and potato in Photos 14 to 16 the external temperature of the fryer material and the temperature of fire in Photos 17 to 19 were affected by different type of fryer material when frying potato sticks by IRSoft software (Table 3).

Table 3. The internal and external temperature of the fryer material, the temperature of air, oil, fire and potato before and after frying potato sticks

Time	Wock Skillet						Teffal Skillet						EL RAMLAY Skillet					
	Before frying	2	4	6	8	After frying	Before frying	2	4	6	8	After frying	Before frying	2	4	6	8	After frying
Tair	21.7	22.6	24	25.2	26.7	23.1	25	27.5	28	29.7	31.7	27.8	26.7	27.3	30.6	34	39.1	28.8
Tin	29.8	40	64.4	73.6	117.6	50.9	131	197	204.9	201.9	234.9	200.7	59.7	66.4	185.4	186.6	192	99.4
Tout	36.9	56.4	68.7	53.3	48.9	61.4	154.4	168.9	232.7	237.8	252.3	201.3	51.6	61.4	173.8	233	345.6	126
Toil	45.9	123.2	104.8	153.4	193.2	111.9	94.2	168.7	154.3	173.1	192.5	161.1	65.5	127.9	110	189.1	209.1	120.1
Tfire	216.7	269.9	298.4	302	355	204	206.1	217.8	298.8	291.8	344.7	260.7	129.8	132.6	243.2	338.5	355	197.4
Tpotato			108.2	151.4	184.5				146.5	179.7	195.9				164.3	179.6	216.3	
Tpotato (out)	17.2				61.3	31.8	17.2				102.9	40.1	17.2				80.7	35.1

Source: Authors' determination.

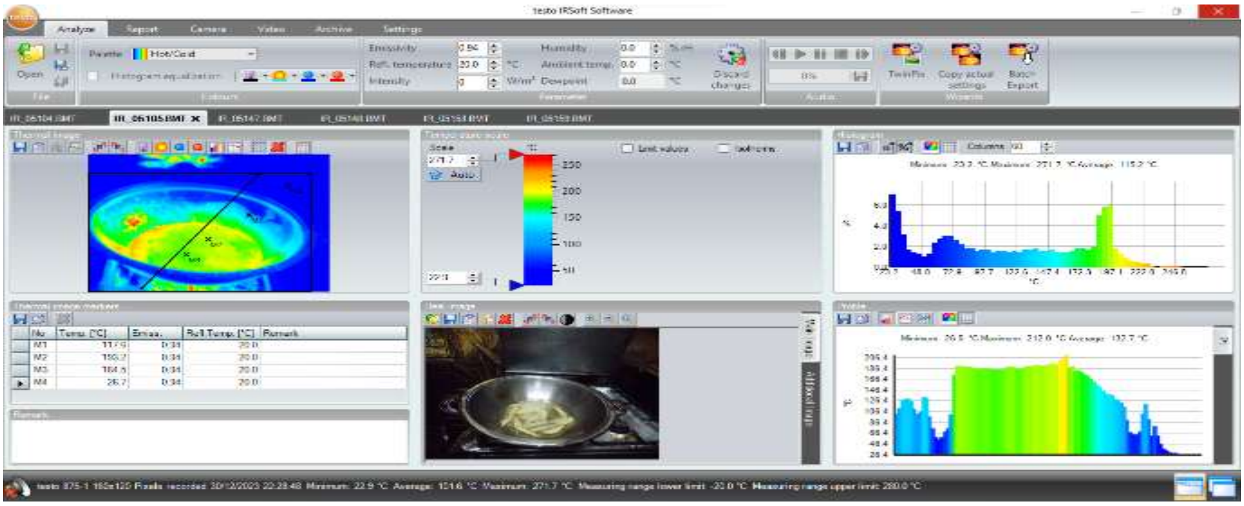

Photo 14. The internal temperature of stainless steel (Wock Skillet), the temperature of air, oil and potato by IRSoft software
Source: Authors' determination.

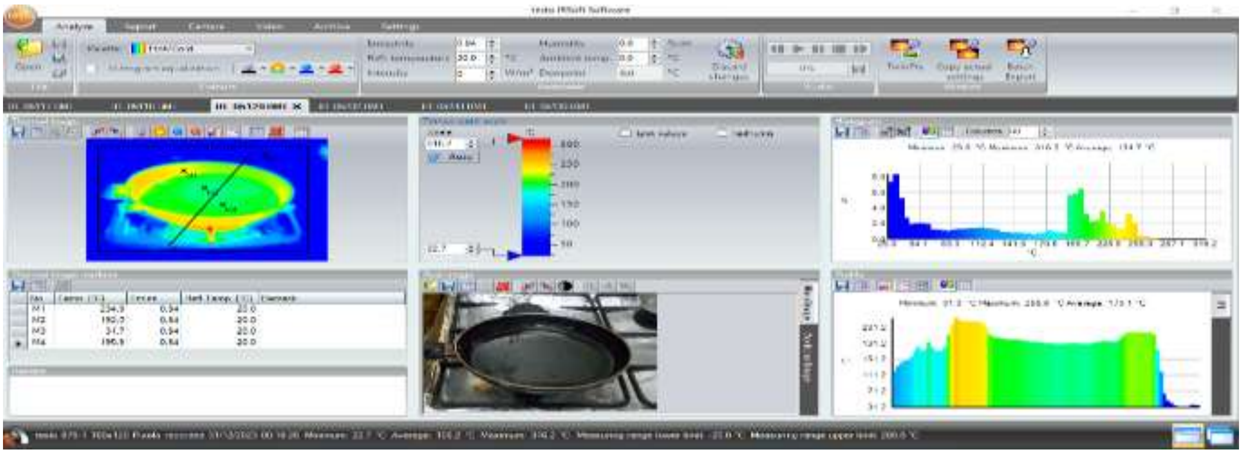

Photo 15. The internal temperature of Tefal Skillet, the temperature of air, oil and potato by IRSoft software
Source: Authors' determination.

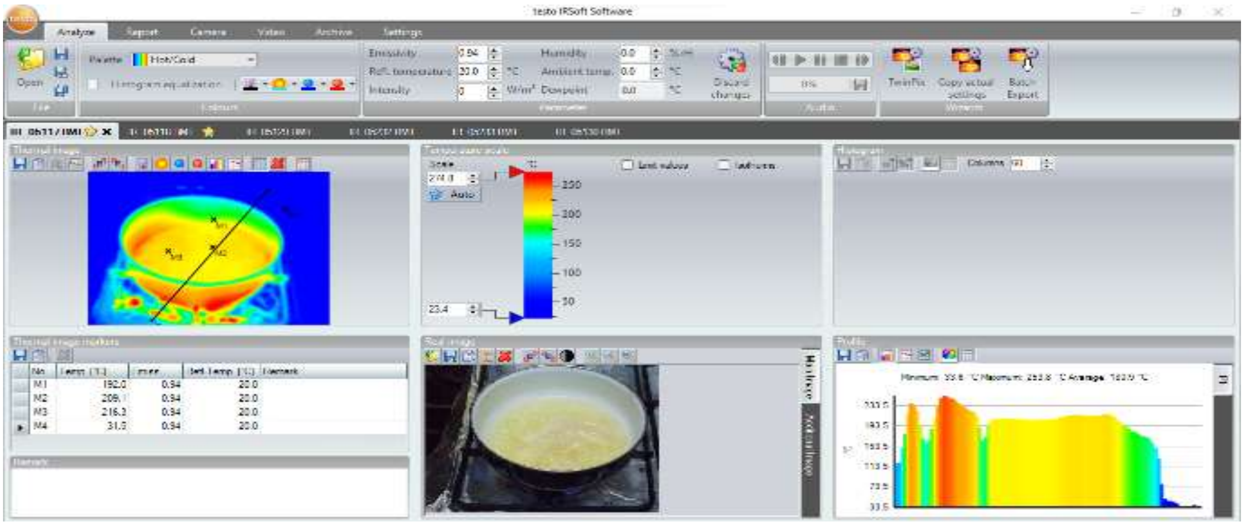

Photo 16. The internal temperature of sheet metal (steel) material (Ramlawi frying Skillet), the temperature of air, oil and potato by IRSoft software
Source: Authors' determination.

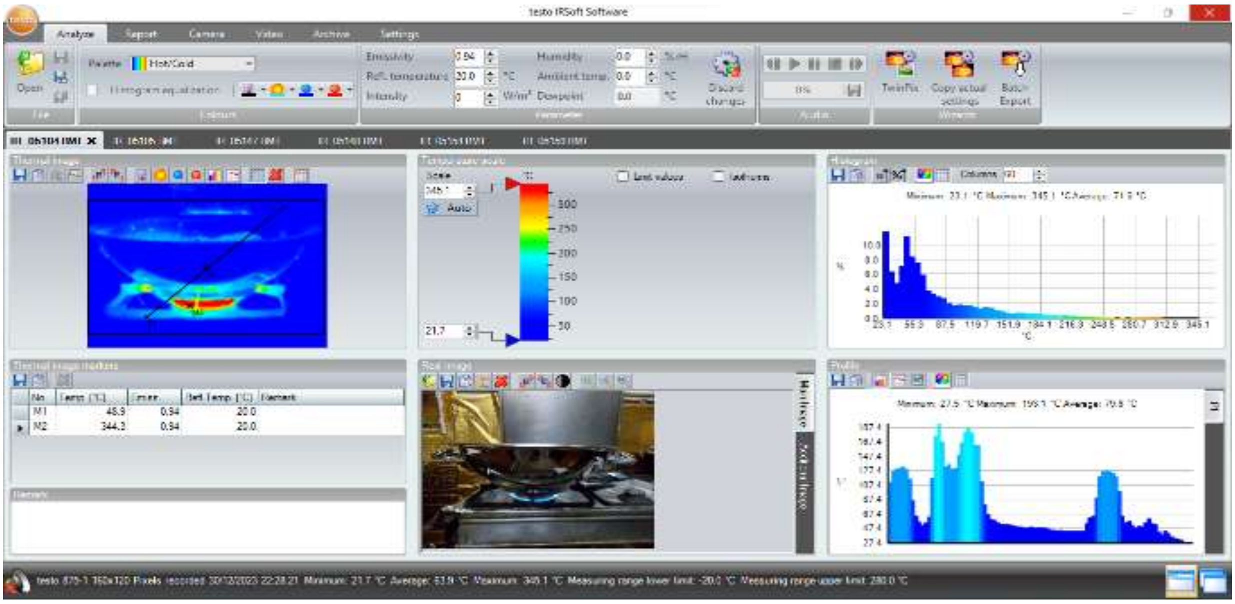

Photo 17. The external temperature of stainless steel (Wock Skillet) and the temperature of fire by IRSoft software
Source: Authors' determination.

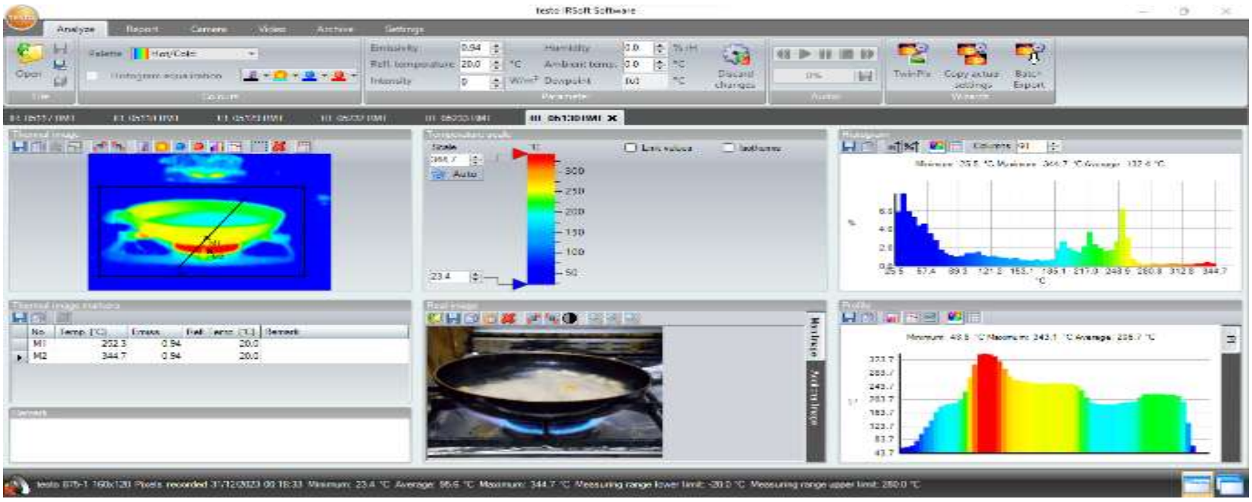

Photo 18. The external temperature of Tefal Skillet and the temperature of fire by IRSoft software
Source: Authors' determination.

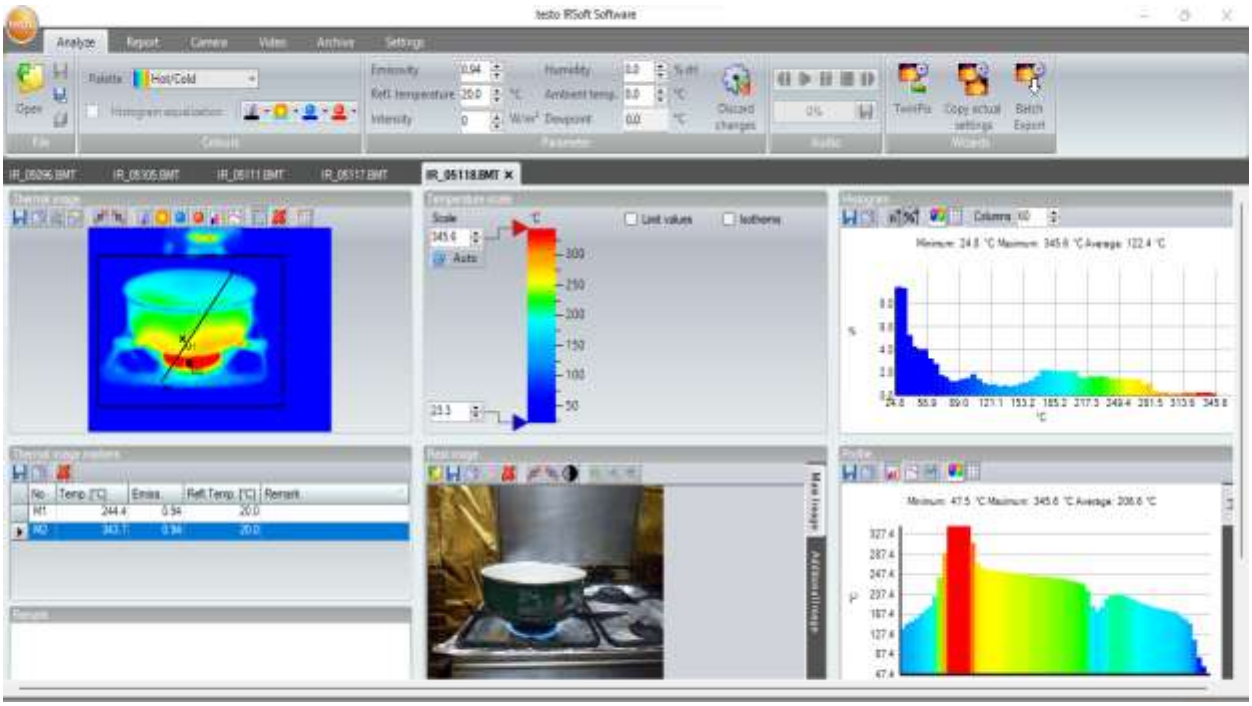

Photo 19. The external temperature of sheet metal (steel) material (Ramlawi frying Skillet) and the temperature of fire by IRSoft software
Source: Authors' determination

The effect of the type of SKILLET material on the temperaturesfor potato sticks

Figure 1 shows the effect of temperature on the stainless-steel material (Wock Skillet) during frying potato sticks in oil. The air temperatures surrounding the Skillet risefrom 21.7 to 23.1ºC, the internal and external temperatures of the Skillet rise from 29.8 and 36.9 ºC to 50.9 and 61.4 ºC, respectively.

While oil, its temperature rises from 45.9 to 123.2 ºC after two minutes of frying, then it decreases temporarily in the fourth minute to 104.8 ºC,then it returns to rise again in the last four minutes from 153.4 to 111.9 ºC, respectively. Also, the fire temperature which the frying Skillet is exposed increases from 216.7 to 204 ºC. As for the potato sticks, they are placed starting from the fourth minute and their temperature is raised from 108.2 to 184.5.

Figure 2 shows the effect of temperature on the material (Tefal Skillet) during frying potato sticks in oil. The air temperatures surrounding the Skillet rise from 25 to 31.7 ºC. The internal and external temperatures of the Skillet rise from 131 and 154.4 ºC to 234.9 and 252.3 ºC, respectively. While oil, its temperature rises from 94.2 to 168.7 ºC after two minutes of frying, then it decreases temporarily in the fourth minute to 154.3ºC, then it returns to rise again in the last four minutes from 173.1 to 192.5 ºC. Also, the fire temperature which the frying Skillet is exposed increases from206.1 to 344.7ºC. As for the potato sticks, they are placed starting from the fourth minute and their temperature is raised from 146.5 to 195.9ºC.

Figure 3 shows the effect of temperature on the sheet metal (steel) material (Ramlawi frying Skillet) during frying potato sticks in oil. The air temperatures surrounding the Skillet rise from 26.7 to 31.5 ºC. The internal and external temperatures of the Skillet rise from 59.7 and 51.6 ºC to 192 and 345.6 ºC respectively.

The oil temperature rises from 65.5 to 127.9 ºC after two minutes of frying, then it decreases temporarily in the fourth minute to 110ºC, then it returns to rise again in the last four minutes from 189.1 to 209.1 ºC. Also, the fire temperature which the frying Skillet is exposed increases from 129.8 to 355 ºC. As for the potato sticks, they are placed starting from the fourth minute and their temperature is raised from 164.3 to 216.3ºC.

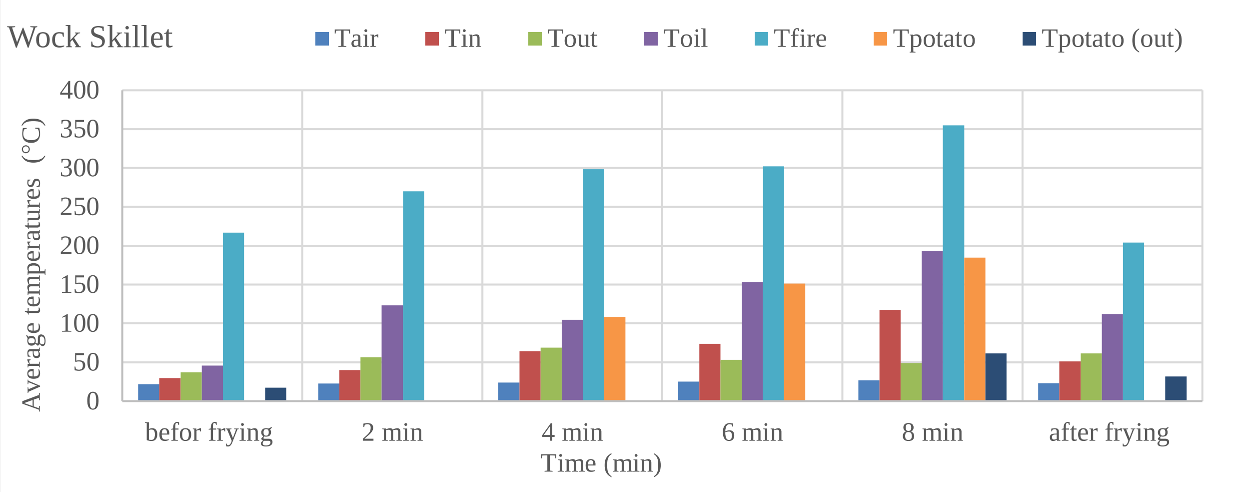

Fig. 1. The relationship between temperature and time for stainless steel (Wock Skillet) during frying potato sticks
Source: Authors' determination.

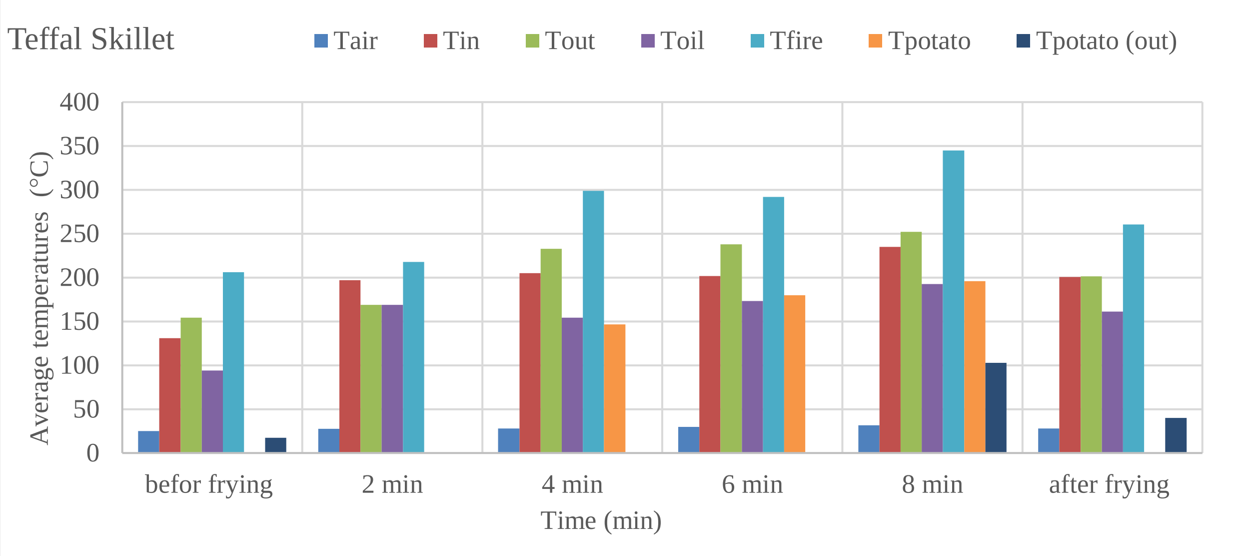

Fig. 2. The relationship between temperature and time (Tefal Skillet) during frying potato sticks
Source: Authors' determination.

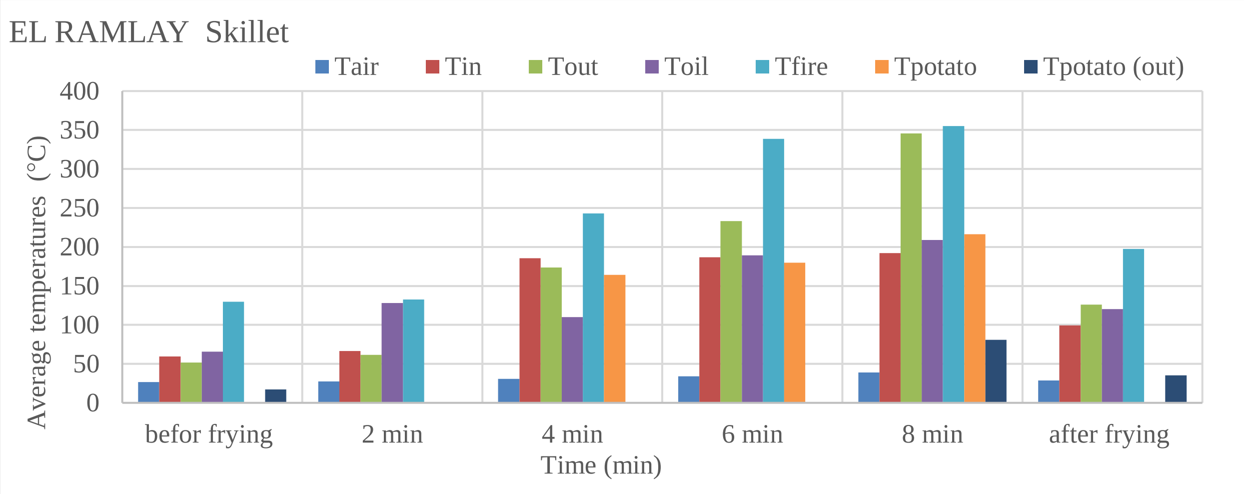

Fig. 3. The relationship between temperature and time for sheet metal (steel) material (Ramlawi frying Skillet) during frying potato sticks
Source: Authors' determination.

CONCLUSIONS

The results showed that the Wock Skillet recorded the lowest temperatures in the air surrounding the Skillet, the oil, and the French fries, and the lowest internal and external temperatures of the Skillet compared to the rest of the types mentioned, followed by the Teffal Skillet, and then the EL RAMLAY Skillet that recorded the highest temperatures.

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