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Research Article

Effects of Different Applications in the Processing Stage on the Quality Characteristics of Potato Chips

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Abstract – This study investigates the effects of process parameters on the moisture and oil content of potato chips both experimentally and statistically. The experimental design was determined using the Taguchi L_{27} orthogonal array. The experiments were conducted with three different slice washing temperatures (25˚C, 55˚C, and 85˚C), three different frying temperatures (180˚C, 185˚C, and 190˚C), and three different frying times (177 s, 190 s, and 205 s). Moisture and oil quantities were measured as output parameters in the study. Signal-to-noise (S/N) ratio and variance analysis methods were employed to determine the optimal values of process parameters for minimum moisture and oil. According to S/N ratio analyses, the most ideal process parameters for moisture content were found to be a slice washing temperature of 85 ˚C, frying temperature of 190 ˚C, and frying time of 205 s, while for oil content, they were a slice washing temperature of 25 ˚C, frying temperature of 190 ˚C, and frying time of 177 s. Variance analysis results indicated that the most influential process parameter on moisture content was the frying temperature, with a value of 49.68%, followed by frying time with an impact rate of 26.87%. For oil content in chips, frying time had the most significant effect with a percentage of 45.15%, followed by slice washing temperature with 30.89%.

Keywords – Potato Chips, Moisture, Oil, Taguchi.

INTRODUCTION

Potatoes are an annually produced commodity in tons worldwide, serving as an inexpensive source of energy and high-quality protein. Consequently, there is a high demand for potatoes and potato products worldwide (Babazadeh et al., 2016). Potato chips are an industrially produced snack that is widely consumed by a large population globally. Due to its high consumption, potato chips have become a daily staple in our lives. The growing awareness among consumers has led to an increased demand for high-quality food products (Tuta et al., 2016). Therefore, there is a significant focus among researchers on producing potato chips of sensorially high quality.

The moisture and oil values of fried potato chips are crucial criteria. The impact of moisture on the sought-after physical property of crispiness in fried products is significant. Excess moisture results in the loss of the desired crispy texture, leading to an undesirable structure. Water activity expresses the degree to which a food item retains moisture. The high heat transfer during frying causes water to evaporate from potato slices, contributing to the formation of a crispy texture (Pandey et al., 2012). The presence of oil in the food content plays a crucial role in the flavor of the fried product. Oils are among the most important components determining the taste of many snack food products (Kalita et al., 2017). Excessive oil, however, leads to an unpleasant taste in the chip, and the appearance of the chip deviates from the desired image. Our study examined the influence of technological parameters in production on the moisture and oil content of potato chips to achieve the desired quality standards.

In the production of potato chips, after peeling the skins off the potatoes, they undergo a slicing process to achieve a specific thickness. As a pre-processing step, the potato slices are washed at a specific temperature, and after this step, any remaining water on the slices is removed with air. Finally, the potato slices are subjected to frying at a specific temperature and duration.

MATERIALS AND METHODS

Materials

In the production of chips, opal potatoes (*Solanum tuberosum* L.) with sizes ranging from 37 to 85 mm were used. These potatoes were sourced from Derpat Tohumculuk Sanayi ve Ticaret A.Ş. (Hatay, Türkiye). Palm olein oil was used for frying the chips, and the oils were supplied by Cargill Foods (Turkey).

Preparation of potato samples

The potatoes underwent an initial peeling process using a Florigo machine from England. Subsequently, the potatoes were sliced to a thickness of 2.60 mm using a machine (Bigtem, Türkiye). The sliced potatoes were subjected to a washing process at three different temperatures (25˚C, 55˚C, and 85˚C) using another machine (Bigtem, Türkiye). After washing, the water on the potato slices was dried, and the potatoes were then fried at three different temperatures (180˚C, 185˚C, and 190˚C) and three different durations (177 s, 190 s, and 205 s) using a frying system (Rosenqvists CF10, Sweden). After frying, the cooled potato slices were filled into polypropylene-based packaging using a modified atmosphere packaging machine (Ishida Astro S 103 L, Japan) with a gas mixture of 98% nitrogen and 2% oxygen.

Using the abovementioned process stages and variables, 27 different product (chip) groups were created. The process parameters and their levels are presented in Table 1. Samples were taken from the 27 product groups for moisture and oil analyses.

Table 1. Process parameters and their levels

Parameters → **Levels ↓**	Slice wash temperature (°C)	Frying temperature (°C)	Frying time(s)
1	25	180	177
2	55	185	190
3	85	190	205

Methods

Temperature measurements: The temperatures of the washing water for potato slices and frying oil were recorded using a digital thermometer (Testo 110, Germany).

Slice thickness measurement: The measurement of potato slice thickness was conducted using a digital caliper (Mitutoyo ABS ID-C547, Japan) according to the AOAC (2000) method.

Moisture content determination: Moisture determination in fried potato slices (chips) was carried out according to the AOAC (2000) method. The slices were kept in an oven at 105 ^{0}C (Binder ED 53, Germany) until reaching a constant weight, and weight measurements were then taken.

Oil content determination: The determination of oil content in fried potato slices (chips) was performed using a Soxhlet extraction apparatus (Behr Labor ES 2+2, Germany) according to the AOAC (2000) method.

Statistical Analysis: The data obtained from experimental studies were analyzed to determine the optimal slice washing temperature, frying temperature, and frying time to achieve the desired quality characteristics. The Taguchi method was employed for determining these optimal process parameters. The Taguchi method, a statistical approach, is designed to address factors that are uncontrollable and contribute to variability in experimental studies. This method minimizes trial-and-error losses (Ghasemian et al., 2014). In the Taguchi method, experimental design theory and orthogonal (vertical) arrays are utilized to examine a large number of variables (Cibik & Duran, 2023).

Experimental Design

In this study, the Taguchi method was applied using L_{27} standard orthogonal arrays (Table 2) to determine the process parameters that need to be investigated. With the L_{27} experimental design, the number of experiments required to observe the effect of three variables on the results was determined through different combinations (Alvarez & Saldaña, 2013). To reach the optimum process parameters, slice washing temperature, frying temperature, and frying time were considered as input parameters, while oil ratio and moisture ratio values were taken as the output parameter. Furthermore, the relationship between independent experimental variables (slice washing temperature, frying temperature, and frying time) and dependent variables (oil, moisture values) was defined through Signal-to-Noise (S/N) ratio analysis and Analysis of Variance (ANOVA). The formula in Equation 1 was used to calculate S/N ratios (Rubilar et al., 2012). The "smaller is better" approach was adopted for moisture and oil results.

$$\eta = S \div N = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

n: number of experiment repetitions

y_i : experimental data

Table 2. Experimental design

Experiment No	Slice Washing Temperature (˚C)	Frying Temperature (˚C)	Frying Time (sec)
1	25	180	177
2	25	180	190
3	25	180	205
4	25	185	177
5	25	185	190
6	25	185	205
7	25	190	177
8	25	190	190
9	25	190	205
10	55	180	177
11	55	180	190
12	55	180	205
13	55	185	177
14	55	185	190
15	55	185	205
16	55	190	177
17	55	190	190
18	55	190	205
19	85	180	177
20	85	180	190
21	85	180	205
22	85	185	177
23	85	185	190
24	85	185	205
25	85	190	177
26	85	190	190
27	85	190	205

RESULTS

Chemical Analyses

Chemical analyses for moisture and oil were conducted on potato slices fried with different cooking parameters. Moisture and oil analyses in the study were measured in triplicate. The averages of the three replicates were taken for statistical calculations, and the results, along with S/N ratios, are presented in Table 3.

Table 3. Experimental results and S/N values

Experiment No	Moisture value (%)	S/N ratio for moisture	Oil value (%)	S/N ratio for oil
1	1.67	-4.454	32.2	-30.16
2	1.58	-3.973	34.1	-30.66
3	1.51	-3.580	34.4	-30.73
4	1.57	-3.918	30.3	-29.63
5	1.38	-2.798	33.1	-30.40
6	1.21	-1.656	34.2	-30.68
7	1.38	-2.798	30.3	-29.63
8	1.16	-1.289	32.1	-30.13
9	1.04	-0.341	33.2	-30.42
10	1.61	-4.137	34.1	-30.66
11	1.47	-3.346	34.3	-30.71
12	1.35	-2.607	35.2	-30.93
13	1.45	-3.227	32.2	-30.16
14	1.21	-1.656	34.1	-30.66
15	1.11	-0.906	35.1	-30.91
16	1.21	-1.656	32.1	-30.13
17	1.09	-0.749	33.1	-30.40
18	1.02	-0.172	34.3	-30.71
19	1.51	-3.580	34.3	-30.71
20	1.36	-2.671	35.2	-30.93
21	1.14	-1.138	36.2	-31.17
22	1.27	-2.076	34.1	-30.66
23	1.11	-0.906	34.3	-30.71
24	1.04	-0.341	36.1	-31.15
25	1.09	-0.749	32.4	-30.21
26	1.03	-0.257	34.2	-30.68
27	1.01	-0.086	35.1	-30.91

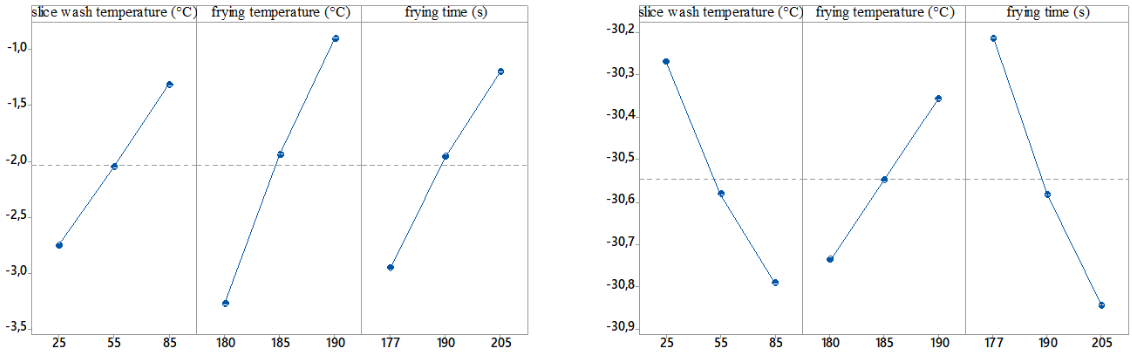
Analysis of S/N Ratios

To analyze and interpret the obtained values in the study, a statistical calculation known as the S/N ratio was utilized. In this method, S represents the true value given by the system, and N indicates the factors influencing the experimental outcome. All values referred to as N are considered as variables causing deviations from the targeted result (Hu et al., 2005).

The S/N response table for moisture and oil values is illustrated in Table 4. The level values of the process parameters, slice washing temperature, frying temperature, and frying time, for moisture and oil are visually represented in Figure 1. In this table, values with the highest S/N ratio are considered when determining the optimum parameters for slice washing temperature, frying temperature, and frying time. Accordingly, the optimum process parameters for the lowest moisture content are determined as a slice washing temperature of 85˚C, frying temperature of 190˚C, and frying time of 205 seconds, while the optimum process parameters for the lowest oil content are determined as a slice washing temperature of 25˚C, frying temperature of 190˚C, and frying time of 177 seconds. When production is carried out according to the determined process values, it is observed that the oil and moisture values in potato chips fall within an acceptable range according to the local potato chip standard (TS 3628/T1, 2017).

Table 4. S/N response table output parameters

	Level	Slice wash temperature (°C)	Frying temperature (°C)	Frying time(s)
Moisture content	1	-2.7562	-3.2761	-2.9548
	2	-2.0506	-1.9427	-1.9605
	3	**-1.3115**	**-0.8995**	**-1.2029**
	Delta	1.4447	2.3766	1.7519
Oil content	1	**-30.27**	-30.74	**-30.21**
	2	-30.58	-30.55	-30.58
	3	-30.79	**-30.36**	-30.85
	Delta	0.52	0.38	0.63



(a) (b)

Figure 1. Effect of factors on S/N ratios for moisture (a) and oil (b)

According to the results in Figure 1a, it is observed that an increase in slice washing temperature leads to a minimal decrease in moisture values. In contrast, an increase in frying temperature results in a decrease in moisture values. Additionally, an increase in frying time also causes a decrease in moisture values.

According to the results in Figure 1b, an increase in frying temperature causes a minimal decrease in the oil level in the chips. However, a decrease in frying time shows the highest decrease in oil values. Moreover, a decrease in slice washing temperature also leads to a decrease in oil values.

Variance Analysis (ANOVA)

Variance analysis was conducted to determine the effect levels of process parameters (slice washing temperature, frying temperature, and frying time) on moisture and oil levels. The results are provided in Table 5. According to the table, the P-value indicates significance, and the F-value represents the effect level. The parameter with the highest F-value is considered the factor that has the greatest impact on the results (Akgün., 2022).

Table 5. Analysis of variance for the chemical analysis results

	Factors	Degree of freedom	Adjusted sum of squares	Adjusted mean of squares	F-value	P-value	Impact ratio (%)
Content of moisture	Slice wash temperature (°C)	2	0.21	0.10	36.75	0.000	18.44
	Frying temperature (°C)	2	0.56	0.28	99.04	0.000	49.68
	Frying time(s)	2	0.30	0.15	53.56	0.000	26.87
	Error	20	0.06	0.002			5.02
	Total	26	1.13				100
Content of oil	Slice wash temperature (°C)	2	18.19	9.09	41.04	0.000	30.89
	Frying temperature (°C)	2	9.68	4.84	21.84	0.000	16.44
	Frying time(s)	2	26.59	13.30	60.00	0.000	45.15
	Error	20	4.43	0.22			7.53
	Total	26	58.89				100

According to the results of the variance analysis, frying temperature, frying time, and slice washing temperature factors all have an effect on moisture content. Among the process applications, the parameter with the most significant impact on moisture is found to be frying temperature, while slice washing temperature has the least effect. The most effective parameter, frying temperature, exhibits high effect rates on moisture, with a percentage as high as 49.68%.

According to the results of the variance analysis, frying temperature, frying time, and slice washing temperature factors all have an effect on oil content. Among the process applications, the parameter with the most significant impact on oil is found to be frying time, while frying temperature has the least effect. The most effective parameter, frying time, exhibits high effect rates on oil, with a percentage as high as 45.15%.

DISCUSSION

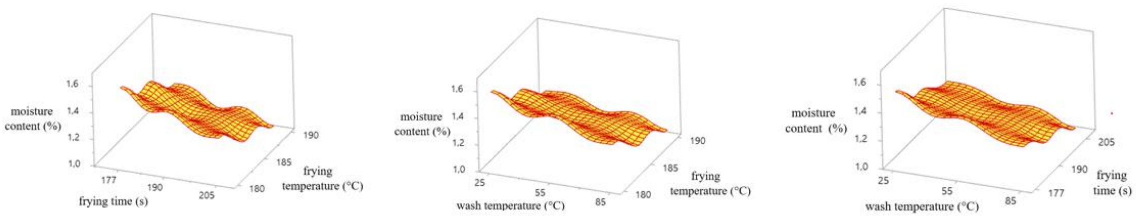


Figure 4. 3D surface plots for the interactions of "frying temperature, frying time, and slice washing temperature" on moisture percentage during chip production.

Figure 4 illustrates the interaction of frying temperature, slice washing temperature, and frying time on the moisture percentage. As discerned from the figure, an increase in frying temperature and frying time leads to a decrease in the moisture percentage in chips. An elevation in frying temperature corresponds to a reduction in the moisture percentage. Cruz et al. (2018) observed a decrease in moisture content with an increase in frying time in potato frying. In the same study, they found that an increase in moisture content in potato chips resulted in the chips absorbing more oil (Cruz et al., 2018). The decrease in moisture content in potato chips with an increase in frying temperature is supported by other studies as well (Arias-Mendez et al., 2013).

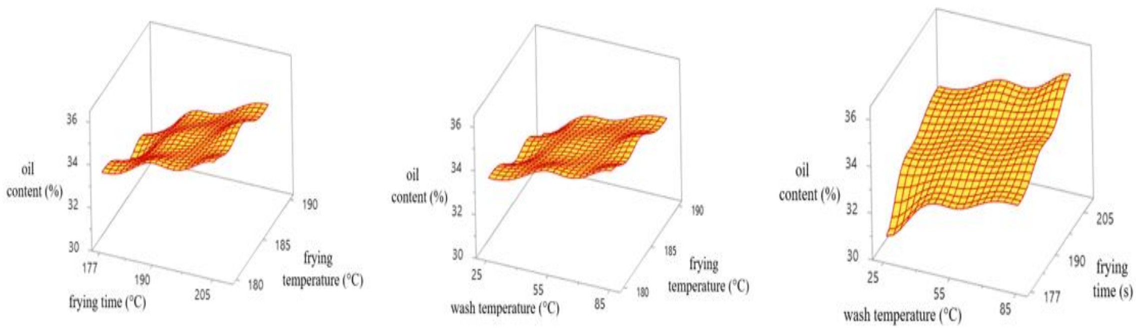


Figure 5. 3D surface plots for the interactions of "frying temperature, frying time, and slice washing temperature" on the percentage of oil during chip production

Figure 5 illustrates the interaction of frying temperature, slice washing temperature, and frying time on the percentage of oil. As deduced from the plot, an increase in slice washing temperature and frying time corresponds to an increase in the percentage of oil in chips. Kalita et al. (2017) found an average oil content of 32.2% in continuously fried potato chips and 27.20% in kettle-fried potato chips in their study. Some studies have supported that an increase in frying time contributes to an increase in oil content of potato chips (Cruz et al., 2018). Pedreschi et al. (2005) confirmed that the pre-washing process applied to potato slices enhances oil absorption in fried potato chips.

RECOMMENDATIONS

The fried potato slices were examined in terms of moisture and oil content. It was observed that frying temperature and frying time parameters have a significant impact on the moisture and oil content in potato chips. Notable changes in the quality of chips could be achieved by making certain modifications in the process steps. Parameter adjustments can be made in the production of potato chips without additional investments and without incurring extra costs, leading to significant improvements in the quality characteristics of the product.

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