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THE EFFECT OF OHMIC HEATING ON THE QUALITY PROPERTIES OF COUSCOUS DURING COOKING

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Abstract: Couscous has been widely eaten around the world because it has a low glycemic index, is low in fat, and is simple to prepare. However, it should be cooked before consumption. Therefore, novel heating methods, such as ohmic heating, can be used to cook couscous. This study aimed to investigate the potential use of ohmic heating at a voltage gradient of 17 V/cm to cook couscous and compare it with the conventional cooking method. To determine the effect of ohmic heating and conventional methods on the quality properties (color, texture profile analysis, cooking loss, moisture content, and weight increase (%)) of couscous, samples were cooked in a 0.1% salt solution. The samples were analyzed at different cooking times (4, 8, 12, and 16 min). The results obtained in the present study revealed that the total color difference also increased with an increase in cooking time. In addition, similar trends were observed for cooking loss, moisture content, and weight gain. Furthermore, the couscous samples treated with ohmic heating and conventional heating methods were completely cooked after 12 minutes. Overall, compared to the conventional cooking method, the ohmic heating process did not induce any negative effects on the quality parameters of couscous.

Keywords: Couscous, Quality, Ohmic heating, Cooking, Texture profile analysis

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1. Introduction

Couscous, often called kusksi or kseksu, is a Middle Eastern and northwestern African dish consisting of small steamed granulated durum wheat semolina (Yüksel et al., 2017). Couscous is an essential food source that is highly preferred in the cuisines of Algeria, Tunisia, Morocco, Libya, and other North African countries (Yüksel et al., 2017; Benayad et al., 2021). It began to appear in French and European cuisine in the early twentieth century through the French colonial empire. Nowadays, it has been widely consumed worldwide in various ways such as in salads and meals due to its cheapness, low glycemic index, low fat, and simplicity of preparation (Bellocq et al., 2018). However, dried couscous must be cooked before consumption.

There are several methods to cook couscous based on the culture of people in each region (Jittanit et al., 2017; Benayad et al., 2021). Since couscous is cooked in a similar way to cooking pasta and rice, it has already been cooked with an electric heater, gas heater, and similar heating methods. In the conventional method of cooking couscous, couscous is taken into a bowl, and then water and salt are added to it and left to boil (Yüksel et al., 2017; Cankurtaran and Bilgiçli, 2021). It is cooked in boiling water including salt until it reaches the desired softness and then drained. Nevertheless, during conventional heating, too many heat losses occurred due to indirect heating (Jittanit et al., 2017). In addition, the physicochemical properties and eating quality of cooked couscous could be influenced by the cooking methods and utensils as reported for rice or pasta in the previous studies (Jittanit et al., 2017; Ding et al., 2021). Therefore, new approaches are needed to reduce energy losses and not affect the physicochemical properties and eating quality of cooked couscous.

Many approaches, such as ohmic, infrared, microwave, and radiofrequency, for heating have been developed so far (Jittanit et al., 2017; Gómez-López et al., 2021; Goksu et al., 2022). Among these heating methods, ohmic heating (OH) called Joule heating, electrical resistance heating, or electroconductive heating has gotten more attention from researchers due to its high electrothermal efficiency, simple structure, easy control of equipment, uniform, and rapid heating (Ding et al., 2021; Goksu et al., 2022). In addition, the absence of waste products and the very low operating costs appear as advantages of the ohmic system (Ding et al., 2021). Hence, there are several applications of ohmic heating, such as extraction, evaporation, cooking, and thawing (Jittanit et al., 2017; Parmar et al., 2018; Angel-Rendon et al., 2019; Gavahian et al., 2019; Makroo et al., 2020; Sabanci and Icier, 2020; Cevik and Icier, 2020; Alcantara-Zavala and Figueroa-Cardenas, 2022). Currently, ohmic heating has been used to cook grains and pasta in some studies where it was reported that there were no significant differences in the textural properties of the foods treated with the ohmic and conventional cooking treatments (Jittanit et al., 2017; Gavahian et al., 2019; Rokhbin et al., 2021; Goksu et al., 2022).

Therefore, the aim of this study was to investigate the effects of applying ohmic heating on the quality parameters including color, texture profile analysis, moisture content, weight increase (%), and cooking loss of the dried couscous during the cooking period.

2. Materials and Methods

2.1. Materials

The dried couscous (Filiz, Bolu, Türkiye) used in the study was purchased from a local market. After the couscous came to the laboratory, they were packed in 10 g packages with a vacuum packaging machine (Lipovak, MV-20/30, Türkiye) in order not to absorb moisture and stored in a dark and cool environment. Before each cooking process, the vacuum packages were opened, and the cooking process was immediately begun.

2.2 Ohmic Cooking System

The ohmic heating system used in the present study consists of a heating cell, electrodes, a T-type thermocouple (Cole Parmer, UK), a custom-made microprocessor, a computer, and a voltage-regulated variac (0-360 V: 50 Hz). The electrodes used in the experiment were stainless steel and their dimensions were 150x10x1 mm (Figure 1). The ohmic heating cells were made of polyoxymethylene, and their dimensions were 60x60x10 mm. The temperature, the current, and the voltage values were recorded with the microprocessor per second intervals.

2.3 Cooking Procedure

Ten grams of couscous and 100 ml of 0.1% NaCl solution were filled into the ohmic heating cell. Later, couscous samples were cooked at a voltage gradient (17 V/cm) and cooking times (0, 4, 8, 12, and 16 min). The temperature of the solution was initially about 23 °C, and then the ohmic system was turned on to heat samples in the solution. After that, the cooking process started when the temperature of the solution reached the boiling point. The cooked couscous samples were filtered through a strainer to separate the solid and liquid parts. The solid part was quickly cooled with cold water and then wiped with a napkin. Afterward, these couscous samples were used for the analysis of color, texture, and moisture content. The liquid part remaining from the couscous cooking process was also used to measure the total soluble solid content (TSSC) as reported in Section 2.6. In addition, before and after the ohmic heating process, the weight of the solid and liquid parts in the heating cell was weighed and recorded.

For conventional cooking, an adjustable (Awox, Lotus, Türkiye) heater used as a heat source was used to cook couscous samples. The temperature was measured with a T-type thermocouple and the amount of energy consumed by the heater was measured with a power meter (UNİ-T, UT230B-EU, China) throughout the cooking process. The cooking time for the conventional heating was 12 min because the cooking time of couscous samples treated with OH was 12 min due to the absence of an opaque white center, which is used for that the cooking process is completed (Bayram, 2006). The experiments were repeated in triplicate.

2.5 Moisture Content

A moisture analyzer (Radwag-MA-110R, Poland) was used to measure the moisture content of couscous samples cooked with the ohmic system at 17 V/cm and conventional heating methods.

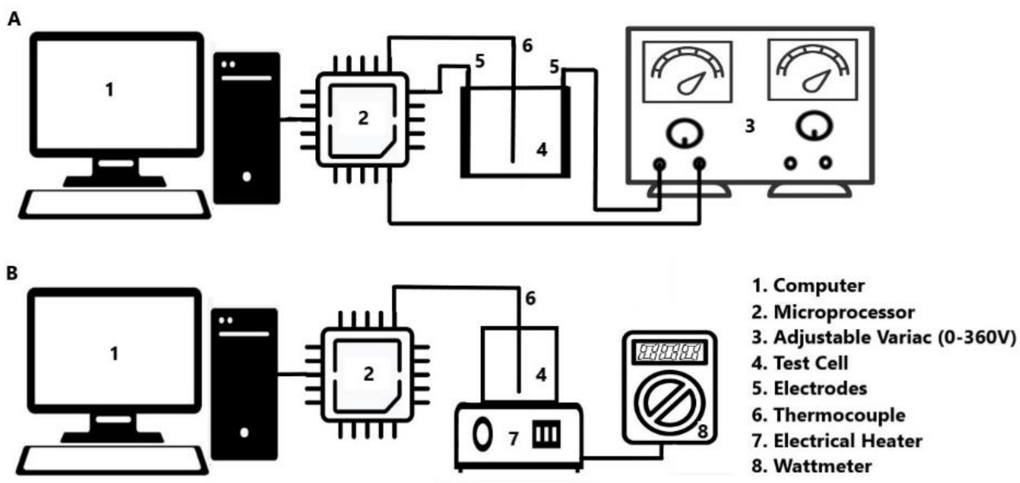

Figure 1. Schematic representation of (A) Ohmic cooking (B) Conventional cooking system.

2.6 Cooking Loss

A digital refractometer (Hanna, HI 96801, Romania) was used to determine the total soluble solid content (TSSC) that passed into the water during the cooking process and TSSC values were measured when the water was cooled to room temperature (~23 °C). TSSC values were expressed in °Brix.

2.7 Analysis of Percent Changes in Weight Increase (WI %)

The method reported by Demir et al. (2010) was followed with minor modifications. Ten grams of couscous were cooked in 100 ml distilled water including 0.1% NaCl for each cooking time (0, 4, 8, 12, and 16 min). Then, distilled water was used to wash the cooked samples. After that, the samples were drained for 2 min and allowed to dry on paper for 2 min. Later, weight increase (WI) was calculated by using equation 1.

$$WI(\%) = 100\,\frac{(b-a)}{a} \tag{1}$$

where, a and b are the weight of raw couscous and the weight of cooked couscous, respectively.

2.8 Texture Profile Analysis and Color Parameters of Cooked Couscous

In general, the procedure of Goksu et al. (2022) was followed with minor modification for determining Texture Profile Analysis (TPA) and color parameters. The cooked couscous samples (1.0 ± 0.1 g) were used to determine the TPA including hardness, adhesiveness, cohesiveness, springiness, gumminess, and chewiness of the samples at room temperature (23±1 °C). A Texture Analyzer (TA.XT.Plus, Stable Micro Systems, Surrey, UK) interfaced with the computer software Texture Exponent (version 6.1.16.0) was used to manage the texture analysis. A cylindrical aluminum probe of 31 mm was used to compress the samples to 80 % strain for two cycles with the test conditions: 1 mm/s of pre-test and post-test, and 0.5 mm/s of the test. The trigger force and time between the cycles used in TPA were 5 g and 5 s, respectively. The presented TPA results were an average of twenty measurements.

The color values of couscous samples prepared for each time (0, 4, 8, 12, and 16 min) were determined by measuring the CIE L* (100 = white; 0 = black), a* (+, red; -, green) and b* (+, yellow; -, blue) values using a Chroma Meter (Konica Minolta, CR-400, Japan) calibrated with a white ceramic as reference. An average of twenty measurements were used for the color parameters of the samples. Then, the hue angle (h, equation 2), chroma or saturation index (C, equation 3), and total color change (*ΔE,* equation 4) were calculated as

$$h = tan^{-1}(\frac{b^*}{a^*}) \tag{2}$$

$$C = \sqrt{(a^*)^2 + (b^*)^2} \tag{3}$$

$$\Delta E = \sqrt{(L_0^* - L_t^*)^2 + (a_0^* - a_t^*)^2 + (b_0^* - b_t^*)^2} \tag{4}$$

herein, L_0^*, a_0^*, and b_0^* represent the color values of dried couscous, and L_t^*, a_t^*, and b_t^* represent the color values of cooked couscous at a specific cooking time.

2.9 Data Analysis

Results were indicated as the mean and standard deviation. The data were compared by using the SPSS (version 20.0, 2011, IBM, USA) software to perform the statistical analysis. The one-way analysis of variance (ANOVA) using Duncan`s multiple range test and student`s t-test were separately used to display the differences in samples cooked with OH for different cooking times (0, 4, 8, 12, and 16 min) and samples cooked with OH and conventional heating method for a constant cooking time (12 min), respectively. Statistical significances were demonstrated at the P<0.05 levels.

3. Results and Discussion

3.1. Analysis of Color Parameters

Color is one of the crucial outward aspects of the food matrix because it not only affects consumer acceptability but also it is used for process controlling (Sadika Tuly et al., 2021). The cooking process influences the degree of color formation due to the caramelization reactions progress (Yüksel et al., 2018). It was reported that the higher lightness (L*) and yellowness (b*) values are more desirable for couscous, bulgur, pasta, and semolina products due to consumer acceptance (Yüksel et al., 2017). The color values of the couscous treated with the ohmic heating are presented in Table 1. The L*-value (60.20±1.43) of the samples cooked with conventional heat treatment for 12 min was not different from that for the samples cooked with OH for 16 min and 12 min (P>0.05), but it was significantly different from that for the samples cooked with OH for 0, 4, and 8 min. As expected, the lowest L*-value was observed for the samples cooked for 0 min, which is significantly different from this value for 8 min. In addition, the L*-value of the samples cooked for 4 min was not significantly different from that for 0, and 8 min. In addition, the lightness value of the couscous samples treated with OH for 16 min increased from an initial value of 57.68±0.81 to a value of 60.49±1.40 during the cooking process (Table 1). This increase in lightness may be due to water absorption. Wang et al. (2010) reported that the changes in the lightness value of potato starch noodles were related to the water content. Similarly, Hatcher et al. (1999) found that the amount of water absorbed by noodles affected their lightness value.

The highest b-value was found for the couscous samples cooked with OH for 0 min (P<0.05). This was followed by 4 min, 8 min, and 12 min (P<0.05). The lowest b-value was measured for the samples cooked for 16 min (P<0.05), which was very close to the b-value (15.41±0.33) obtained from the samples treated with conventional heat treatment (P>0.05). In addition, the increase in the cooking time up to 12 min caused significant changes in the a-values (P<0.05) while the a-values of couscous samples cooked for 12 min and 16 min were not different from each other (P>0.05).

Table 1. The color parameters, including L*, a*, b*, C (Chrome), ΔE (Total color change), and BI (Browning index) of couscous cooked with the ohmic heating (OH) at different cooking times

Heat treatment	The cooking time (min)	L	a	b	C	BI	ΔE
Ohmic heating	0.00	57.68^{a} (0.81)*	-2.09^{a} (0.23)*	21.22^{a} (1.41)*	21.32^{a} (1.38)*	41.70^{a} (3.96)*	9.05^{a} (1.15)*
	4.00	57.94$^{a, b}$ (1.03)*	-2.51^{b} (0.14)*	18.81^{b} (0.74)*	18.97^{b} (0.74)*	34.79^{b} (1.92)*	10.69^{b} (0.84)*
	8.00	58.45^{b} (0.89)*	-2.73^{c} (0.13)*	17.32^{c} (0.45)*	17.53^{c} (0.43)*	30.59^{c} (1.35)*	11.65^{c} (0.59)*
	12.00	59.83^{c} (1.04)*	-3.00^{d,e} (0.14)*	16.64^{d} (0.37)*	16.91^{d} (0.38)*	27.84^{d} (0.78)*	11.72^{c} (0.60)*
	16.00	60.49^{c} (1.40)*	-2.98^{d} (0.20)*	15.96^{e} (0.36)*	16.23^{e} (0.38)*	26.04^{e} (0.96)*	12.14^{c,d} (0.63)*
Conventional heating	12.00	60.20^{c} (1.47)	-3.12^{e} (0.15)	15.41^{e} (0.34)	15.72^{e} (0.36)	24.82^{e} (0.39)	12.76^{d} (0.76)

* Standard deviation, $^{a, b}$= the values in a column with the same lowercase letter are not significantly different (P>0.05).

Furthermore, there was no distinct difference in a-values among the samples cooked with conventional heat treatment (-3.12±0.15) and OH for 12 min, but the a-values of the samples treated with conventional heat treatment were significantly different from those of other samples cooked with OH for 0, 4, 8, and 16 min (P<0.05). According to these results obtained from the present study, yellowness (b*) and redness (a*) values of couscous samples reduced with increasing cooking time (Table 1). These results were in agreement with the results of Cocci et al. (2008) and Gull et al. (2015). This decrease in these values during cooking is probably because of the quantity of the carotenoid pigment and enzymatic reactions (Islas-Rubio et al., 2014). Yilmaz (2019) stated that total carotenoid content (TCC) was significantly reduced during bulgur production due to the strong effect of exposure to heat, light, and hydroperoxide.

As observed for b* and a* values, chrome (C) and browning index (BI) values decreased throughout the increase in cooking time (Table 1). The C and BI values of samples treated with OH reduced from an initial value (0 min) of 21.32±1.38 and 41.70±3.96 to a value of 16.2±0.38 and 26.04±0.96, respectively, at the end of the cooking (16 min). There were significant differences in the C and BI values among the samples cooked with OH for 0, 4, 8, 12, and 16 min. and the conventional heat treatment whereas no significant difference was observed between OH for 16 min and the conventional heat treatment. In addition, the total color difference (ΔE) increased when the cooking time was increased (Table 1). It was found that the ΔE values of samples treated with OH for 8, 12, and 16 min were not significantly different (P>0.05) from each other, but they were significantly different (P<0.05) from that for samples treated with OH for 0 and 4 min. Moreover, the ΔE value (12.76±0.54) of samples cooked with conventional heat treatment was like this value for the sample cooked with OH for 16 min. (P>0.05), but it was significantly different from those values for other samples cooked with OH for 0, 4, 8, and 12 min. Based on our results, the changes in *C*, *BI*, and ΔE values were directly related to moisture content (Lefkir et al., 2017).

3.2 Analysis of Texture Profile Analysis (TPA)

The texture profile analysis of the couscous cooked with ohmic heating at 17 V/cm is given in Table 2. The textural attributes including hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience of the couscous samples changed during the cooking process. The hardness, gumminess, and chewiness values of samples cooked with OH for 0 and 4 min were significantly different from each other and other samples cooked with OH for 8, 12, and 16 min and conventional heating (P<0.05) whereas there were no significant differences (P>0.05) between samples cooked with OH for 8, 12, and 16 min and conventional heating. This result may be due to the fact that the It was reported that the hardness of noodles was related to the compositions of the starch, gluten, and dietary fiber (Zou et al., 2021).

There were also significant differences (P<0.05) in adhesiveness values of samples treated with OH for 0, 4, and 8 min, but these values were not significantly different (P>0.05) among samples cooked with OH for 12 and 16 min and conventional heating. These results showed that the surface of the cooked couscous was not changed after the cooking time was equal to 12 min and over because the adhesiveness commonly attributed to the surface of the cooked couscous (Jittanit et al., 2017). Similarly, in a study, it was reported that the adhesiveness of spaghetti cooked with conventional heating for 15, 18, and 21 min was not significantly different (Sozer and Kaya, 2003). Furthermore, the springiness values of all cooked samples were not different (P>0.05) because springiness was not affected by the cooking time (Bello et al., 2006). Finally, the results of this study revealed that all the textural properties except the cohesiveness of samples cooked with OH for 12 and 16 min and conventional heat treatment were not significantly different (P>0.05).

Table 2. Texture profile analysis (TPA) parameters (H: Hardness; A: Adhesiveness; S: Springiness; C: Cohesiveness; G: Gumminess; CH: Chewiness; R: Resilience) of couscous cooked with the ohmic heating (OH) at different cooking times

Heat Treatment	The cooking time (min)	H (g)	A (g.sec)	S (%)	C (%)	G	CH	R (%)
Ohmic heating	0.00	30684[a] (5073)*	-1171[a] (320)*	0.80[a] (0.08)*	0.67[a] (0.03)*	20652[a] (4199)*	16724[a] (4451)*	0.52[a] (0.05)*
	4.00	14967[b] (2073)*	-871[b] (174)*	0.58[b] (0.05)*	0.55[b] (0.03)*	8232[b] (1589)*	4839[b] (1190)*	0.32[b] (0.04)*
	8.00	7866[c] (931)*	-376[c] (86)*	0.54[b] (0.04)*	0.48[c] (0.02)*	3774[c] (560)*	2037[c] (402)*	0.21[c,d] (0.01)*
	12.00	6220[c] (803)*	-156[d] (40)*	0.54[b] (0.04)*	0.47[c] (0.03)*	2899[c] (459)*	1561[c] (305)*	0.21[c] (0.02)*
	16.00	5035[c] (567)*	-96[d] (29)*	0.51[b] (0.06)*	0.44[d] (0.04)*	2199[c] (166)*	1126[c] (164)*	0.21[c,d] (0.03)*
Conventional heating	12.00	5135[c] (548)*	-117[d] (39.87)*	0.51[b] (0.03)*	0.42[d] (0.01)*	2139[c] (195)*	1088[c] (138)*	0.19[d] (0.01)*

* Standard deviation, [a, b, c, d]= the values in a column with the same lowercase letter are not significantly different (P>0.05).

Table 3. The moisture content (%), total soluble solid content (˚brix), and weight increase (%) of couscous cooked with the ohmic heating at different cooking times

Heat treatment	The cooking time (min)	TSSC (˚brix)	Moisture content (%)	Weight increase (%)
Ohmic heating	0.00	0.27[a] (0.06)*	35.20[a] (2.66)*	5.65[a] (1.03)*
	4.00	0.60[b] (0.01)*	47.73[b] (1.13)*	10.45[b] (0.28)*
	8.00	0.97[c] (0.06)*	55.94[c] (1.47)*	13.79[c] (0.67)*
	12.00	1.30[d] (0.01)*	59.86[d] (1.05)*	16.14[d] (0.52)*
	16.00	1.77[e] (0.06)*	63.89[e] (1.04)*	18.44[e] (0.46)*
Conventional heating	12.00	1.20[d] (0.10)*	64.42[e] (0.67)*	19.23[e] (1.06)*

* Standard deviation, [a, b, c, d, e]= the values in a column with the same lowercase letter are not significantly different (P>0.05).

3.3 The Cooking Loss

This term was defined as the number of solids dissolving in the water throughout the cooking process and it can be used as an indicator of couscous structural integrity throughout the cooking process. The cooking loss is also important for consumer acceptance (Song et al., 2013). Hence, a low cooking loss is a sign of a high-quality product (Turgut et al., 2021). The total soluble solid content (TSSC) values passing into the boiling water during the different cooking times (4, 8, 12, and 16 min) were presented in Table 3.

In the present study, the highest cooking loss was measured for the couscous samples cooked with OH for 16 min (P<0.05). This was followed by the conventional heat treatment (12 min) and the OH for 12 min. The differences in cooking loss values of samples are because of the change in cooking times of couscous samples (Turgut et al., 2021). Likewise, Sobota et al. (2013) reported that the cooking loss of spaghetti increased with the cooking time.

3.4 Moisture Content and Weight Increase

During cooking, the amount of water absorbed by couscous is an important factor demonstrating the cooking quality of couscous as presented in Table 3. Since deficient water absorption may result in couscous with a hard and coarse texture and an overabundance of water absorption generally forms very soft and stick couscous. The highest water absorption was calculated for the couscous samples treated with conventional heat treatment (P<0.05). The quantity of water absorbed by the samples cooked with OH for 16 min and conventional heat treatments were not significantly different (P>0.05). This result was likely because these couscous samples were exposed to high temperatures for longer periods as seen in Table 3. It was reported that water absorption was related to the temperature of the cooking medium and degree of starch gelatinization (Cunningham et al., 2007). Turgut et al. (2021) pointed out that a relatively low-level gelatinization occurred for the samples exposed to temperatures lower than 70 °C.

The percentage in weight increase displayed a similar trend to the moisture content (Table 3). Although the highest cooking loss took place in the samples treated with OH for 16 min (P<0.05), the percentage of a weight increase of the samples cooked with OH for 16 min and conventional heat treatments were not significantly different (P>0.05).

4. Conclusion

In addition, the color and textural properties of couscous samples were not significantly different from the conventional heat treatment if a suitable cooking time was selected for OH at 17 V/cm as found in the present study. However, the total soluble solids content (TSSC), remaining in the boiling water after the cooking process was done, had a linear relation with the cooking time when the ohmic heating process was used. Therefore, the cooking time should be reduced by increasing the voltage gradient as reported in our previous study (Goksu et al., 2022). Thus, it is needed to find an appropriate voltage gradient for the OH treatment to reduce the TSSC in the boiling water during the cooking process of dried couscous before consumption.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	B.O.	A.G.	E.I.	S.S.
C	30	30	10	30
D	25	25	25	25
S				100
DCP	25	25	25	25
DAI	25	25	25	25
L	30	30	20	20
W	30	20	20	30
CR	25	25	25	25
SR	25	25	25	25
PM	25	25	25	25
FA	25	25	25	25

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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