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Using the mixture design approach to predict the rheological properties of low-calorie dairy desserts containing gum tragacanth exuded by three Iranian *Astragalus* species

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Abstract In this study, the flow behavior and creep parameters of saffron desserts containing gum tragacanth combinations of three species were modeled by the mixture design approach. Flow behavior and creep-recovery experiments were performed and models were predicted for apparent viscosity, consistency index, flow index, instantaneous compliance, and viscoelastic compliance. Five representative samples regarding the range of apparent viscosity at the shear rate of 50 s^{-1} were subjected to sensory evaluation. According to rheological measurements, the addition of GT species of *A. gossypinus* led to the production of a dessert with a strong structure. Then, two samples with the highest consistency index and the lowest creep parameters were compared with two commercial saffron desserts. The results revealed that the overall acceptance of the two selected samples [containing 4% (w/w) *A. gossypinus or* 2.66% (w/w) *A. gossypinus* and 1.33% (w/w) *A. fluccosus*] was similar to those of the two commercial samples.

Keywords Gum tragacanth · Rheology · Hydrocolloids · Food processing · Modeling

Introduction

Nowadays, there is an increasing demand from global healthcare organizations and health-conscious customers to reduce the salt, fat, and sugar contents of processed foods (Syarifuddin et al., 2016). This is especially true for desserts which tend to fall into the less-healthy food category because they are high in calorie, fat, and added sugars while low in other nutrients, including fiber. At the same time, desserts should be enjoyed in moderation to leave a memorable impression on consumers. Therefore, reducing the fat and sugar contents of such food products, while maintaining sensory acceptance, is a challenge for food industries (Nejatian et al., 2013).

The fat content reduction of the formulation, as one of the most common methods of creating healthier foods, can be performed by several techniques, simply by substituting it with other ingredients (fat replacers) (Zambrano et al., 2004), or complexly by several advanced technologies, including cryogenic crystallization (Brooker and Tomlines 2009) and super-critical fluid extraction and solvent extraction (Yee et al., 2007). Replacing some of the fat found in desserts with biomaterials having similar properties is a potential solution to improve the health features of

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desserts. In this case, complex changes in the production process can be avoided.

Gum tragacanth (GT; 1–4 linked α-D-galacturonic acid backbone) is a high-molecular-weight (about 840,000 Da) and branched (arabinose, xylose, glucose, fucose, galactose, and rhamnose) anionic polysaccharide (E number E413). It is obtained from the *Astragalus* genus small shrubs and can establish high-viscosity and stable emulsions in aqueous solutions (Farzi et al., 2015) with a high degree of stability in acidic conditions and against heat treatment (Balaghi et al., 2010). Recently, researches have shown an increasing interest in the food applications of GT, some of which are listed in Table 1. Additionally, producing low-chain oligosaccharide by enzymatic actions and affecting bacterial growth, especially *B. longum* subsp, is a new prebiotic potential claim for GT (Gavlighi et al., 2013a; 2013b).

As shown in Table 1, most studies conducted in the field of food applications have particularly focused on the thickening and stabilizing properties of GT, while few studies have investigated the application of GT in low-fat products (Aziznia et al., 2008; Rahimi et al., 2007). The present study, therefore, attempts to assess the effect of three types of GT (*A. gossypinus*, *A. fluccosus*, and *A. rahensis*) on the sensory acceptance and rheological properties of a low-calorie dairy model dessert.

Materials and methods

Characteristics and preparation of the sample

Using Design Expert 8 (Stat Ease Inc., Minneapolis, USA) software and mixture design methodology, 17 samples were prepared. The fixed components of the formulations consisted of skimmed milk powder (Fonterra, Auckland City, New Zealand) 9 wt%, saffron powder (Bahraman Saffron, Mashhad, Iran) 0.02 wt%, rosewater (Rabee, Tehran, Iran) 3 wt%, and stevia (Morvarid Moattar, Tehran, Iran) 0.02 wt%. The raw GT (collected from plants growing in different provinces of Iran) was powdered in an electric mill (laboratory mill 120, Perten, Germany) and, using standard sieves (Atlas Sieve, Esfahan, Iran), mesh size was adjusted to 200–500 mm. Table 2 presents the concentration of three GT species in each sample as the components of the mixture design. Based on rheological pretests, the final gum concentration was 4 wt% in each sample. Dry ingredients were mixed and added to the required amount of distilled water to gain 1 kg of the final product. Final products were prepared by adding powder mix to distilled water using the Thermomix food processor (Thermomix TN 31, Wuppertal, Germany). The dry mix was slowly added to the measured amount of distilled water and then stirred for 20 min at 90 °C in Thermomix on setting 3. At the last minute of stirring, rose water and saffron were added to the mixture. Final products were poured (hot-filling) into 125 cc plastic containers and sealed using a manual sealing machine. After cooling down the sample products to the ambient temperature, they were put in the refrigerator to become ready for rheological tests.

Rheological experiments

Rheological tests were performed on a Physica MCR 301 rheometer (Anton Paar Physica MCR 301, Graz, Austria) using a serrated plate-and-plate system (40 mm in diameter, 1 mm gap). All rheological tests were performed at 10 °C. The apparent viscosity of the samples was measured as a function of shear rate (0.01–500 s^{-1}). The power law model (Eq. 1) was used to interpret the rheological

Table 1 Recent literature on the application of GT

GT species	Food application	References
Not mentioned	The effect of gum tragacanth on the rheological properties of salep-based ice cream mix	Kurt et al. (2016)
A. gossypinus *A. compactus* *A. rahensis*	Effect of high-shear homogenization on the particle size and rheological properties of three different species	Farzi et al. (2015)
Not mentioned	Effect of xanthan, guar gum, and GT combinations on the stability and rheological properties of fresh and stored ketchup	Omidbakhsh et al. (2015)
Not mentioned	Use of GT as a bind-enhancing agent in extended restructured mutton chops	Sharma et al. (2015)
	Role of different fractions of GT in the stability and characteristic of model oil in water emulsion	Karimi and Mohammadifar (2014)
A. gossypinus	Effect of heat-treatment on GT-Milk protein gels	Hatami et al. (2014)
A. gossypinus and *A. rahensis*	Use of gum tragacanth for stabilizing date milk	Keshtkaran et al. (2013)

Table 2 GT composition of 17 dairy dessert samples

Sample	GT concentration		
	A. gossypinus (%w/w)	*A. rahensis* (%w/w)	*A. fluccosus* (%w/w)
1	1.33	0.00	2.66
2	0.00	2.66	1.33
3	0.00	1.33	2.66
4	0.00	4.00	0.00
5	1.33	2.66	0.00
6	2.66	0.66	0.66
7	0.00	0.00	4.00
8	4.00	0.00	0.00
9	2.66	0.00	1.33
10	0.66	2.66	0.66
11	0.00	4.00	0.00
12	0.00	0.00	4.00
13	4.00	0.00	0.00
14	2.66	1.33	0.00
15	2.66	1.33	0.00
16	1.33	1.33	1.33
17	0.66	0.66	2.66

properties of the samples. By fitting the shear rate versus apparent viscosity values, the flow behavior index (n) and consistency coefficient (m) values were extracted.

$$\text{Power law model}: \eta_a = m\dot{\gamma}^{n-1} \quad (1)$$

Stress sweep tests were performed between 0.1 and 10 Pa, and thus creep and recovery phases were examined at constant stress $\sigma_0 = 5$ Pa for 120 s. In the present research, based on creep regression (Eqs. 2–4), instantaneous compliance J_0 and viscoelastic compliance $Jm(t)$ were obtained. Rheoplus 3.21 (Anton Paar, Graz, Austria) was employed to collect data.

$$\text{Creep compliance}: \mathrm{J(t) = J(0) + Jm(t) + Jn(t)} \quad (2)$$

$$\text{Viscoelastic compliance}: \mathrm{Jm(t)} = \mathrm{Sum(Jm\_i(1 - exp(-(t - t_0/\lambda\_i)))} \quad \mathrm{i = 1, \ldots, 3} \quad (3)$$

$$\text{Newtonian compliance}: \mathrm{Jn(t) = t - t_0/\eta_0} \quad (4)$$

Model prediction

According to the extracted rheological parameters presented in Table 3, five responses (Table 4) were selected and their relationship with the mixture factors was monitored by predictive mathematical models obtained from the mixture design approach.

Table 3 Rheological and power law parameters for 17 samples

Sample	Flow behavior parameters (Eq. 1)				Creep parameters	
	Power law model			η_{50} (Pa s)		
	a (Pa s^n)	*b*	R^2		J_0	*Jm*(*t*)
1	95.96	0.28	0.99	5.20	0.003	0.002
2	35.56	0.37	0.99	2.80	0.007	0.008
3	44.51	0.34	0.99	3.11	0.006	0.007
4	73.88	0.29	0.99	4.10	0.004	0.005
5	48.28	0.34	0.99	3.55	0.004	0.004
6	164.38	0.24	0.99	7.68	0.001	0.001
7	76.91	0.31	0.99	4.47	0.005	0.005
8	264.83	0.24	0.99	12.14	0.001	0.001
9	186.08	0.24	0.99	8.86	0.001	0.001
10	41.87	0.35	0.98	3.07	0.005	0.006
11	73.33	0.29	0.99	4.10	0.004	0.005
12	76.99	0.30	0.99	4.47	0.005	0.005
13	262.83	0.24	0.99	12.14	0.001	0.001
14	147.18	0.23	0.99	6.93	0.001	0.007
15	147.42	0.23	0.99	6.93	0.001	0.007
16	84.04	0.28	0.98	4.37	0.003	0.002
17	170.50	0.20	0.97	6.90	0.002	0.001

Sensory evaluation

Twenty-five trained panelists (14 men and 11 women, aging 25–45 years) participated in the sensory evaluation. In the present study, sensory evaluation was implemented

Table 4 Predicted models of the relationship between three GT species and instantaneous compliance J_0, viscoelastic compliance $Jm(t)$, apparent viscosity at the shear rate of 50^{-1} η_{50} (Pa s), consistency index, and flow index

Rheological parameter	Predicted model	Model	R^2
J_0	$+ 8.598E{-}004 * A + 3.976E{-}003 * B + 5.002E{-}003 * C + 4.041E{-}004 * A * B - 4.564E{-}003 * A * C + 8.249E{-}003 * B * C - 0.033 * B * C - 0.012 * A * B * C + 2.603E{-}003 * A * C * (A - C) + 0.013 * B * C * (B - C)$	Cubic	0.96
Jm(t)	$+ 1.345E{-}003 * A + 4.909E{-}003 * B + 4.139E{-}003 * C + 0.014 * A * B + 5.616E{-}003 * A * C + 0.013 * B * C - 0.16 * A * B * C$	Special cubic	0.60
η_{50} (Pa s)	$+ 12.02 * A + 3.79 * B + 4.75 * C - 11.12 * A * B - 7.29 * A * C - 3.44 * B * C$	Quadratic	0.92
a (Pa s^n)	$+ 227.56 * A + 35.06 * B + 73.31 * C$	Linear	0.77
b	$+ 0.24 * A + 0.29 * B + 0.31 * C + 0.10 * A * B - 0.10 * A * C + 0.21 * B * C - 1.13 * A * B * C - 0.56 * A * B * C + 0.18 * A * C * (A - C) + 0.49 * B * C * (B - C)$	Cubic	0.86

A: *A. gossypinus*, B: *A. rahensis*, and C: *A. fluccosus*

in two stages. In the first stage, five samples were selected from different parts of the range for apparent viscosity (1, 2, 4, 8, and 9). A week later, in the second stage, the samples with the highest score were compared with two commercial saffron desserts (Danet, Ghazvin, Iran, composed of fresh skimmed milk, fresh cream, corn starch, sugar, lactose, natural saffron flavor, stabilizer, and *β-carotene*, and the total energy content of 125 Cal/100 g). The subjects completed a 9-point scale hedonic questionnaire for each property, including total acceptance, taste, appearance, and odor. In this questionnaire, 1 referred to the extreme disliking and 9 referred to the extreme liking of the food samples (Murray et al., 2001).

Calorie calculation

The total calorie value (Cal) of the GT-containing dessert was calculated by Atwater method and using the following equation (Cengiz and Gokoglu, 2005):

$$K = [(F_p \times P) + (F_l \times L) + (F_c \times C)], \qquad (5)$$

where K is the calorie, F denotes the multiplication factor for each component (F_p: 4.27 for protein, F_l: 9.02 for lipid, and F_c: 4.10 for carbohydrate), P represents the protein content (g/100 g), C indicates the carbohydrate content (g/100 g), and L is the lipid content (g/100 g).

Statistical analysis

One-way ANOVA was used for data analysis at the significance level of $p < 0.05$ (SPSS Inc., Chicago, IL, USA, version 21). Duncan's multiple range test was utilized to compare mean values at the confidence level of $\alpha < 0.05$.

Results and discussion

Rheological experiments

Table 3 presents the rheological parameters for 17 dairy dessert samples. The consistency index of the samples (power law model, Eq. 1) changed in the range of 0.23–0.37 Pa s^n, while the flow behavior index of the samples was in the range of 35.56–262.41. Based on results, Samples 8 and 13 (containing 4% *A. gossypinus*) had the highest value of consistency coefficient, whereas the lowest consistency coefficient was found in Sample 2. As demonstrated in Table 2, Samples 8 and 13 also had the highest values of apparent viscosity, while Sample 2 had the lowest value of apparent viscosity at the shear rate of 50 s^{-1}. Similar results in terms of GT type effect on the characteristics and stability of dairy systems were previously reported (Keshtkaran et al., 2013; Nejatian et al., 2013). The latter authors attributed the higher capacity of *A. gossypinus* in improving the flow behavior of the medium to which it has been added, to its sugar composition. This species contained higher contents of galacturonic acid and fucose than the other two Iranian GT species. Moreover, the values obtained in this study for flow behavior parameters are in agreement with those found by other studies for various food desserts with added hydrocolloids such as starch, chickpea flour, carboxymethyl cellulose, carrageenans, agar–agar, and xanthan gums (Aguilar-Raymundo and Vélez-Ruiz, 2018; Arancibia et al., 2015; Oroian, 2013).

Figure 1A depicts the flow behavior of Samples 1, 2, 4, 8, and 9 on which sensory evaluation was performed. The flow behavior of the samples (Fig. 1A) demonstrated a non-Newtonian and pseudoplastic nature. This result was in agreement with that of previous studies on dairy desserts (González-Tomás et al., 2009; Tárrega et al., 2004; Zargaraan et al., 2015). The comparison of the present flow behavior data with those of the commercial saffron dessert extracted in our previous work (m = 293.15 Pa) and our unpublished paper (m = 344.52) showed that all samples in the present study had a lower consistency coefficient and higher flow behavior index than the two commercial brands (Zargaraan et al., 2013).

The most essential application of the creep recovery test is to determine structure changes by altering formulation components (Bayarri et al., 2009). The creep recovery rheograms of all the samples are illustrated in Fig. 1B, C. Table 3 also shows the creep parameters of 17 samples. The range of instantaneous compliance values was from 0.0009 (Sample 8) to 0.007 (Sample 2) 1/Pa and the viscoelastic compliance of all the samples was observed to be between 0.0005 (Sample 8) and 0.008 (Sample 2). High values of instantaneous compliance (J_0) and viscoelastic compliance represented a weak structure (Dogan et al., 2014; Sozer, 2009). It is interesting to note that the gum fraction of Sample 2, which had the highest creep parameters, was composed of *A. rahensis* and *A. fluccosus*. On the other hand, Sample 8 which was mainly composed of *A. gossypinus* had the lowest creep parameters. Hence, by combining these data with flow behavior data, it can be

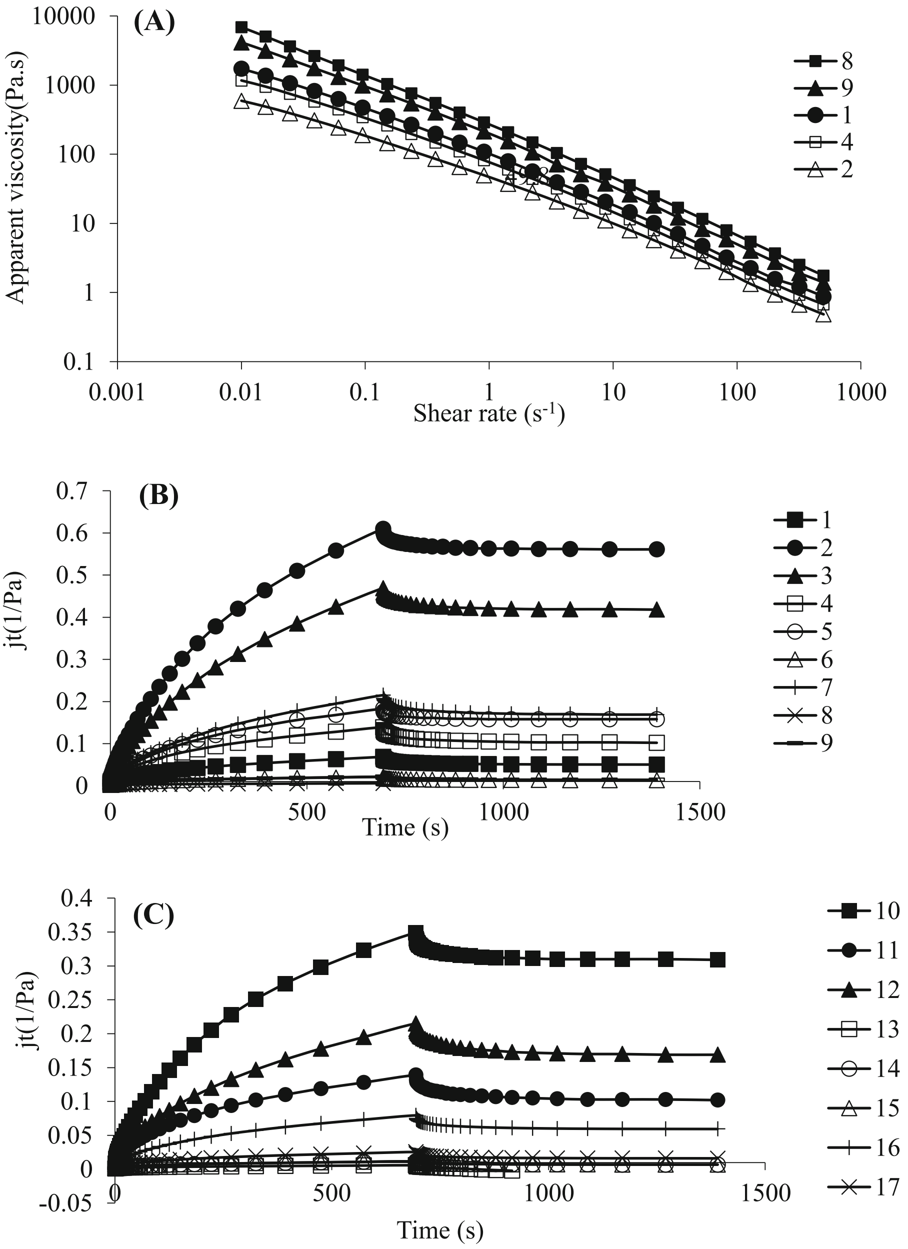

Fig. 1 Flow behavior of samples 1, 2, 4, 8, and 9 (**A**) and creep-recovery rheograms of 17 samples (**B**: Samples 1–9, and **C**: Samples 10–17)

Table 5 Mean ± SD ratings for Samples 1, 2, 4, 8, and 9 (first section of sensory evaluation)

Sample	Apparent viscosity (cP)	Liking of appearance	Liking of taste	Liking of texture	Overall acceptance
2	2.80	7.16 ± 2.11^{a}	$2.12 \pm 1.01^{c*}$	2.16 ± 1.20^{d}	2.96 ± 1.20^{d}
4	4.10	7.44 ± 1.58^{a}	2.48 ± 1.26^{c}	3.12 ± 1.50^{c}	3.80 ± 1.04^{c}
1	5.20	7.72 ± 1.30^{a}	4.04 ± 1.30^{b}	4.56 ± 1.38^{b}	5.84 ± 0.70b*
9	8.86	7.80 ± 1.00^{a}	4.96 ± 1.70^{a}	6.20 ± 1.65^{a}	7.88 ± 1.01^{a}
8	12.14	7.88 ± 0.90^{a}	5.48 ± 1.96^{a}	6.56 ± 1.55^{a}	$8.32 \pm 0.80^{a*}$
Second section of sensory evaluation					
Commercial Saffron Dessert a	10.27	–	–	–	7.56 ± 1.08^{a}
Commercial Saffron Dessert b	9.80	–	–	–	7.72 ± 0.97^{a}
9	8.86	–	–	–	7.52 ± 1.08^{a}
8	12.14	–	–	–	6.92 ± 1.11^{a}

*Numbers with different superscript letters within the same column are significantly different (Duncan's post hoc test, $p < 0.05$)

concluded that the samples containing more *A. gossypinus* had a stronger structure. In dairy desserts and in the presence of casein, instantaneous compliance may refer to an undistributed protein network (Sun et al., 2006). Therefore, at the fixed concentration of casein and GT (Samples 4, 8, and 12), and in comparison with two other GT species, *A. gossypinus* made more elastic casein networks.

Model prediction

After determining the flow behavior and creep parameters of the samples, Design Expert 8 (v8.0.1.7) was employed to predict the relationship between three GT species as mixture components and five rheological parameters, i.e. instantaneous compliance (J_0), viscoelastic compliance (Jm), apparent viscosity at the shear rate of 50^{-1} (Pa s) (η_{50}), consistency index, and flow index. Table 4 presents the predicted models and their R^2 values. The range of R^2 for the predicted models was 0.6 ($Jm(t)$) to 0.96 (J_0).

There have been limited studies on the effect of creep-recovery tests on the rheological and sensory evaluation of dairy desserts (Dogan et al., 2014; Lynch and Mulvihill, 1994; Sun et al., 2006). Among these works, only the study by Dogan et al. (2014) predicted models based on the creep parameters of four hydrocolloids. Accordingly, our results related to the predicted models based on creep parameters were only comparable with those reported by Dogan et al. (2014) which were previously described. In their study, the relationship between instantaneous compliance and four hydrocolloids was predicted by a reduced cubic model ($R^2 = 0.94$). Therefore, our predicted model for instantaneous compliance was consistent with the data obtained in Dugan et al.'s (2014) study.

Sensory evaluation

Five samples based on the ranges of apparent viscosity were subjected to sensory evaluation. As shown in Table 5, with increasing apparent viscosity, the liking of taste and texture and overall liking were increased.

Samples 8 and 9, which had the highest consistency index and the lowest creep parameters (Table 3), had the highest sensory evaluation scores. Therefore, in the second phase of sensory evaluation, the overall acceptance of Samples 8 and 9 was compared with two commercial saffron desserts. Tárrega and Costell (2007) reported a good relationship between the oral thickness (sensory data) and the apparent viscosity (instrumental data) of a dairy dessert. Similarly, Shama and Sherman (1973) observed a good correlation between the viscosity and thickness of a semi-solid product.

The results revealed that the score of the overall acceptance of Samples 8 and 9 was significantly similar to those of the two commercial samples. The most obvious finding emerging from the rheological data is that the different species of GT had caused highly diverse rheological properties in dairy desserts. These results seem to be in accordance with other research findings presented in Table 1. Keshtkaran et al. (2013) stated that the viscoelastic properties and flow behavior parameters of a flavored milk beverage were significantly affected by the concentration and type of GT (*A. gossypinus* and *A. rahensis*). Moreover, Farzi et al. (2015) reported that *A. gossypinus* GT, from among three GT species (*A. gossypinus*, *A. compactus*, and *A. rahensis*), made the highest apparent viscosity, probably due to its highest insoluble fraction.

The purpose of the present study was to determine the effect of three GT species on the rheological and sensory acceptance of low-calorie dairy desserts. Regarding the compositional profile of used commercial skimmed milk powder (32.9 g/100 g protein, 3.8 g/100 g moisture, 0.9 g/100 g fat, 54.5 g/100 g total carbohydrate, and 7.9 g/100 g minerals), the total energy content of the prepared samples was about 33.45 Cal/100 g. Therefore, the energy value of the prepared desserts was approximately a quarter of that of commercial desserts. Additionally, based on reports on the prebiotic effects of GT and acceptable sensory evaluation scores, the findings of this research provided insights into designing new prebiotic dairy desserts using GT. Another important practical implication of this research was providing a desert model to design new sugar-free dairy desserts. Finally, the results of this study indicated that GT can be successfully used to formulate low-calorie dairy desserts.

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Compliance with ethical standards

Conflict of interest The authors declare no conflicting or financial disclosures.

Human and animal rights This study does not involve any clinical human or animal testing. Written informed consent was obtained from all study participants.

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