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Effect of Carrier Materials in Foam-Mat Drying on the Flow Properties of Kombucha Tea Powder

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ABSTRACT

The high water content in kombucha tea beverages can accelerate decomposition through chemical reactions and microbial contamination. Converting these beverages into powder form can reduce moisture content and extend product shelf life. Foam-mat drying is a suitable technique for producing kombucha tea powder. The selection of carrier materials during the encapsulation process significantly affects the physical characteristics of the resulting powder. This study aimed to formulate and evaluate the flow properties of kombucha tea powder prepared by the Foam-mat drying method using various carrier materials: maltodextrin (F1), inulin (F2), gum arabic (F3), maltodextrin–inulin (1:1, F4), maltodextrin–gum arabic (1:1, F5), and inulin–gum arabic (1:1, F6). The powders were assessed for compressibility index, Hausner ratio, flow rate, angle of repose, and moisture content. The results indicated that F3 had the lowest compressibility index and Hausner ratio, demonstrating the best flowability. Despite differences in formulation, all powder samples showed relatively poor flow properties, which may be attributed to the hygroscopic nature of the carriers. Moisture content ranged from 0.85% to 3.26%, with the best drying outcome observed in F1.

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ABSTRAK

Kandungan air yang tinggi pada minuman teh kombucha dapat mempercepat proses dekomposisi melalui reaksi kimia maupun kontaminasi mikroba. Konversi minuman ini ke dalam bentuk serbuk dapat menurunkan kadar air dan memperpanjang umur simpan produk. Metode *foam-mat drying* merupakan teknik yang sesuai untuk menghasilkan serbuk teh kombucha. Pemilihan bahan pembawa dalam proses enkapsulasi sangat mempengaruhi karakteristik fisik dari serbuk yang dihasilkan. Penelitian ini bertujuan untuk memformulasi dan mengevaluasi sifat alir serbuk teh kombucha yang dibuat dengan metode *Foam-mat drying* menggunakan berbagai bahan pembawa, yaitu: maltodekstrin (F1), inulin (F2), gum arab (F3), maltodekstrin–inulin (1:1, F4), maltodekstrin–gum arab (1:1, F5), dan inulin–gum arab (1:1, F6). Serbuk diuji terhadap indeks kompresibilitas, rasio Hausner, laju alir, sudut diam, dan kadar air. Hasil penelitian menunjukkan bahwa F3 memiliki nilai indeks kompresibilitas dan rasio Hausner terendah, menandakan sifat alir terbaik. Meskipun terdapat variasi formulasi, seluruh serbuk menunjukkan sifat alir yang kurang baik, diduga akibat sifat higroskopis bahan pembawa. Kadar air berkisar antara 0,85% hingga 3,26%, dengan hasil pengeringan terbaik ditemukan pada F1.

Keywords: bahan pembawa, *Foam-mat drying*, serbuk teh kombucha, sifat alir, kadar air

1. Introduction

Polyphenols are plant secondary metabolites known as natural antioxidants having various health benefits. Various studies have shown that these compounds have protective effects against various diseases such as heart disease, obesity, cancer, diabetes and other degenerative diseases [1]. One of the natural materials rich in polyphenols is tea leaves. Tea contains flavan-3-ol polyphenols, especially catechins, epigallocatechins and Epigallocatechin-3-gallate. The fermentation process in making kombucha tea from various studies showed an increase in polyphenol content and antioxidant activity compared to tea without fermentation [2].

The water content in kombucha tea beverages is a factor that limits the stability of the product because water becomes a medium for various chemical decomposition reactions. To maintain stability, the functional beverage can be processed into powder through drying [3]. The low moisture content causes the powder dosage form to have a longer shelf life, inhibits various enzymatic degradation and microbial growth on the product and reduces transportation and storage costs [1],[4]. In the process of making kombucha tea powder, various manufacturing conditions such as temperature, light, oxygen, pH and enzymes must be considered because they affect the stability of polyphenols [5].

Selection of appropriate drying and powder preparation techniques can maintain the appearance and chemical composition of the product [1],[5]. To maintain the stability of polyphenols, one of the technologies that can be used is encapsulation using a carrier material [5],[6] .

The process of drying kombucha tea into powder has problems because the content of organic acids and small molecular weight compounds results in low glass transition temperatures and high hygroscopicity, making it difficult to make into powder. To aid the powdering process, carrier materials can be added to enhance powder stability [7]. Encapsulation with carriers in the form of polysaccharides, proteins or hydrocolloids protect the product against oxygen and water, seal off unpleasant flavors or aromas, control release and improve solubility. The carriers used can be natural or synthetic including maltodextrin, gum arabic, starch, gelatin, ethylcellulose, dextrin, and inulin [8]. The choice of carrier material is one of the factors that determine the efficiency of encapsulation, stability and chemical physical properties of the resulting dry powder [7],[8],[9]. Maltodextrin and gum arabic are the most commonly used carrier materials in the encapsulation process because they have good glass transition temperatures while inulin is known to have various health benefits in addition to its function in drying technology [9].

Foam-mat drying is a method used to produce powders by converting liquids into stable foam followed by air drying. It is a simple method that can be used to dry liquid materials with low glass transition temperatures. It is also suitable for heat-sensitive materials, high sugar content, and viscous materials that are difficult to dry [10]. The foaming of the liquid will increase the surface area extensively, thereby improving the surface transfer and shortening the drying time. Widening the surface area of the foam-mat drying method sample is done by shaking the sample that has been given a frothing agent until a froth layer forms on the sample. The wider surface makes the sample drying process faster, making it suitable for making powdered beverages [11].

Based on this background, this study aims to make instant kombucha tea powder with a variety of carrier materials in the encapsulation process using the Foam-mat drying method. The obtained powder was then evaluated for its characteristics including percent compressibility, Hausner ratio, flow rate, angle of repose, and redispersibility time. The results of this study will be the basis for downstream research and commercialization of research results because it can be known that the composition of the most optimal carrier material to produce the best instant powder flow characteristics.

2. Methods

Material

Black tea (East Java & Co), SCOBY starter (Rumah Fermentasi), sucrose (Rose Brand), maltodextrin (DPH), inulin (DPH), gum arabic (DPH).

Methods

Production of Kombucha Tea

Infusa of selected tea leaves was made by mixing 100 grams of sugar with 8 grams of tea and 1 L of hot water (90°C) for 10 minutes in a sterile flask. After cooling (30°C), the tea infusion was filtered and put into a sterile glass bottle. The tea infusion was added with SCOBY culture and kept under aseptic conditions. The bottle was covered with a clean cloth and tied tightly. Fermentation was carried out by incubating the kombucha culture at 28 ± 1 °C for 1, 7 and 14 days. After 14 days, the kombucha obtained was filtered and analyzed.

Production of Kombucha Tea Powder

The fermented tea kombucha by SCOBY was made into powder through encapsulation process. Encapsulation was carried out by adding a carrier material into the filtrate of kombucha tea filtration results. Encapsulation into kombucha tea powder was carried out using the Foam-mat drying method using egg white as a foaming agent. The selection of the foaming agent was carried out after going through the previous optimization stage. In this study, 6 powder encapsulation formulas were made with a variety of carrier materials as shown in **Table 1**.

Table 1. Kombucha Powder Encapsulation Formula

Material	F1	F2	F3	F4	F5	F6
Maltodextrin	30	-	-	-	-	-
Inulin	-	30	-	-	-	-
Gum Arabic	-	-	30	-	-	-
Maltodextrin-Inulin (1:1)	-	-	-	30	-	-
Maltodextrin-Gum Arabic (1:1)	-	-	-	-	30	-
Inulin-Gum Arabic (1:1)	-	-	-	-	-	30
Egg White	15	15	15	15	15	15
Kombucha Tea (q.s. to 100 g)	✓	✓	✓	✓	✓	✓

Note :
Amounts are expressed in grams (g).
q.s. means sufficient quantity to 100 grams.

The fermented kombucha tea was added with the carrier ingredients and egg white, then whipped until formed foam for 15 minutes. The mixture was then poured into a pan and dried at 70°C. The dried solid formed was sieved to produce powder.

Evaluation of Kombucha Tea Powder

Determination of Bulk Density of Powder

Bulk density is the weight of powder per unit volume (g/mL) occupied. A total of 30 grams (W0) of kombucha tea powder was weighed and put into a 100 mL volumetric flask, then the volume occupied (V0) was observed. The specific gravity of the fruit was calculated by the formula [12]:

$$Bulk\ Density = \frac{W_0}{V_0}$$

Note :
W_0= *Weight of the powder (grams)*
V_0= *Volume occupied by the powder (milliliters)*

Determination of Tapped Density of Powder

A total of 30 grams (W0) of kombucha tea powder was weighed and put into a 100 mL volumetric flask, then placed on a *tap density tester* with a knock 500 times and recorded the volume (Vt). The specific gravity of the fruit is calculated by the formula [12]:

$$Tapped\ Density = \frac{W_0}{V_t}$$

Note :
W_0 = *Weight of the powder (grams)*
V_t = *Final volume of the powder after tapping (milliliters)*

Determination of Percent Compressibility

Percent compressibility is calculated using the data of the bulk density and tapped density of the powder using the formula [12]:

$$\%\ Kompresibilitas = \frac{Tapped\ Density - Bulk\ Density}{Tapped\ Density}\ x\ 100\%$$

Determination of Hausner Ratio

The Hausner ratio measures how easily a powder or granular material flows. It is calculated by dividing the tapped density of a material by the bulk density [12].

$$Hausner\ Ratio = \frac{Tapped\ Density}{Bulk\ Density}$$

Determination of Flow Rate

A total of 30 grams (W0) of powder was put into a funnel with the bottom closed. Then the lid was opened and allowed the granule to fall to flow completely from the funnel. The time taken for the granule (t) to flow completely from the funnel was recorded and the flow velocity was calculated using the formula [13]:

$$Flow\ Rate = \frac{W_0}{t}$$

Note :
Flow Rate = The rate at which powder flows, usually expressed in grams per second (g/s).
W_0 *= Weight of the powder that flows out (grams)*
t = Time taken for the powder to flow (seconds)

Determination of Angle of Repose

A total of 30 grams (W0) of granule was put into a funnel with the bottom closed. Then the lid was opened and allowed the granule to fall completely from the funnel. The fallen granule pile was then measured the diameter of the granule base and the height of the cone formed with a ruler. The angle of repose is then measured using the formula [13]:

$$\tan \alpha = \frac{h}{r}$$

Note :
α = *angle of repose*
h = height of granule pile
r = radius of the granule pile

Determination of Moisture Content

Moisture content was determined gravimetrically and expressed as % weight lost. A total of 1 gram of kombucha tea powder was weighed and placed in the oven. The measurement temperature was set at 105°C. The moisture content value was determined after a constant value was obtained [12].

3. Results and Discussion

Kombucha Tea Drink Powder Formulation

Tea has various chemical compounds namely polyphenols, minerals, vitamins, amino acids, methylxanthines, pigments, carbohydrates, organic acids, fats and volatile substances. Polyphenols in tea are in the form of flavonols known as catechins with the main components being epicatechin, epicatechin-3-galate, epigalocatechin, epigalocatechin-3-galate, and galocatechin. These polyphenolic components in tea act as antioxidants and are proven from various studies to inhibit fat peroxidation and reduce oxidative stress thereby reducing the risk of cardiovascular disease and other chronic diseases [14].

Tea beverages can be processed through a fermentation process using SCOBY (*Symbiotic Culture of Bacteria and Yeast*) *cultures* for 7-14 days to produce kombucha tea. This fermentation process makes kombucha tea a probiotic beverages with increasing health benefits [15]. In addition, during the fermentation process, various metabolites are also produced such as polyphenols, amino acids and organic acids so that kombucha has higher antioxidant activity than tea without fermentation [16].

The high water content in kombucha tea drinks will trigger decomposition by various chemical reactions and microbial contamination. Therefore, preservation is required by drying into powder to reduce the moisture content in the preparation and to extend the shelf life of the product. Drying also reduces the weight and volume of the product thereby reducing transportation costs and facilitating product handling [17]. Powdered beverages are classified as instant beverages. These drinks must be reconstituted first before consumption [3]. Instant beverages are products that are easy and quick to serve at the time of consumption because they only require hot or cold water to dissolve them [18].

Kombucha tea contains organic acids and sugars with low glass transition temperatures, so drying kombucha tea directly without an encapsulation process will lead several problems due to particle agglomeration and adhesion on the surface of the drying container. Therefore, it is necessary to encapsulate with a high molecular weight carrier added to the kombucha tea drink before drying. The addition of this carrier will increase the glass transition temperature, prevent the viscoplastic properties and the formation of hard deposits from the powder [19]. Encapsulation is the process of entrapping bioactive compounds into particles with the main purpose of protecting bioactive contents that are sensitive to various degradations. Various techniques can be used in the encapsulation process depending on the core material, desired particle size, physical properties, and temperature sensitivity [1],[8] .

The carrier material used in the encapsulation process in addition to functioning as a protector must be biodegradable and food grade. The carrier material will determine the efficiency and stability of the powder product. Common materials used as carriers include maltodextrin, gum arabic and inulin. These carriers will raise the glass transition temperature to prevent adhesion to the walls of the drying container [3]. Maltodextrin has a low specific gravity, low viscosity, high water solubility, can withstand volatile ingredients and is easily digested. Maltodextrin is obtained through partial hydrolysis of starch using enzymes or acids. This carrier material has a white color, neutral taste, odorless [3]. Gum arabic is a natural material obtained from the Acacia plant with a composition of galactose, ramnose, arabinose, 4-O-methylglucuronic acid and glucuronic acid. Gum Arabic has low viscosity, high water solubility, forms stable emulsions and retains volatile materials [1],[20]. Gum arabic is widely used because it has high soluble fiber content, prebiotic effect, high digestive tolerance, low caloric value, and non-coriogenic, making it suitable for functional beverage formulations [4]. Inulin is a natural polysaccharide found in various plants. Inulin has various advantages including health benefits in stimulating the immune system, regulating food intake and appetite, digestive tolerance and has a function as a prebiotic. In addition, inulin can also be used as a sweetener that can replace sucrose with a lower glycemic index (GI = 14) and low caloric value (1.5 kcal/g) so that it can be used for diabetic patients [7].

Foam-mat drying is a method used to produce powders by converting liquids into stable foam and then followed by air drying. It is a simple method that can be used to dry liquid materials with low glass transition temperatures. In addition, this method is also suitable for heat-sensitive materials, high sugar content, and viscous materials that are difficult to dry [10]. The foaming of the liquid will increase the surface area extensively, thereby improving the surface transfer and shortening the drying time. Widening the surface area of the foam-mat drying method sample is done by shaking the sample that has been given a foaming agent until a foam layer forms on the sample. The wider surface makes the sample drying process faster, making it suitable for making powdered beverages [11].

This method was chosen in the preparation of kombucha tea powder because kombucha tea contains compounds with low glass transition temperatures, has a fairly high sugar content and to maintain the stability of secondary metabolites in the preparation. When compared to other drying methods, this method has several advantages such as shorter drying time because a honeycomb-like foam structure is formed so that moisture will disappear quickly and reduce the loss of nutrients. This method is also relatively cheaper and simpler than vacuum drying, freeze drying or spray drying [17],[21]. Foam also produces a porous structure that has a larger surface area for water transfer [22].

One factor that needs to be considered in the Foam-mat drying technique is the selection of the foaming agent. The foaming agent will lower the surface tension and facilitate foam formation. It will also improve the structure and control the stability of the foam by modifying the rheological properties of the continuous phase and the interfacial region where the foam is adsorbed [23]. In this study egg white was used as a foaming agent. Egg white contains albumin protein, which has the ability as an amphiphilic emulsifier. The concentration of egg white used will affect the density of the foam produced. Sufficient amount of egg white will increase the foam volume so that the foam density value is lower [24]. The protein in egg white will bond with the interface and interact with the lamella through electrostatic bonds or hydrophobic forces, hydrogen bonds, and covalent. These interactions will trigger the formation of a viscoelastic film that is resistant to strain and can maintain film thickness.

In addition to foaming agents, other ingredients that can affect the physical and chemical quality of powders using the Foam-mat drying method are the concentration of encapsulating ingredients (fillers). The encapsulant will coat the flavor components, increase the total amount of solids, enlarge the volume, accelerate the drying process, prevent material damage due to heat and improve the solubility and organoleptic properties of powdered drinks. Therefore, in this study, formulations were made using several carrier materials to determine their effect on the physical characteristics of kombucha tea powder.

The obtained powder produced by Foam-mat drying was then calculated for its yield. The yield calculation results for each formula are shown in **Table 2** below.

Table 2. Yield of Kombucha Tea Powder

Formula	Yield (%)
F1	24.03 ± 3.63
F2	25.22 ± 2.26
F3	30.83 ± 0.13
F4	21.43 ± 0.62
F5	32.02 ± 0.47
F6	31.46 ± 1.29

F5 produced the highest yield of kombucha tea powder. This formula contains the composition of maltodextrin:gum arabic carrier (1:1). F4 with maltodextrin:inulin (1:1) composition produced the smallest powder yield. All kombucha powder formulas produced have a similar color, namely brownish white with a distinctive kombucha smell. The color is produced because the carrier component material (filler) is white and when the foaming agent is added, white foam is produced. Visual appearance of kombucha tea powder produced can be seen in **Figure 1**.

Figure 1. Visual appearance of kombucha tea powder produced by Foam-mat drying using different carrier materials: F1 (maltodextrin), F2 (inulin), F3 (gum arabic), F4 (maltodextrin-inulin), F5 (maltodextrin–gum arabic), and F6 (inulin–gum Arabic)

Evaluation of Kombucha Tea Drink Powder

The flowability of powders is a critical factor that determines the quality of beverage powder products during the processing, handling and production stages. These properties are important to ensure an efficient and cost-effective production process in the food industry. Flowability will also affect the consistency and quality of the final product. Poor flow will lead to uneven mixing processes, clogging of filling equipment, and challenges during packaging that impact the overall integrity of the final product. Good flowability will result in packaging uniformity and maintain consistency of volume to mass ratio which has an effect on weight uniformity [25].

Various factors influence the flowability of powders namely moisture content, particle shape and size and cohesive properties [25]. The presence of molecular forces results in the tendency of solid particles to stick to each other. Particle adhesion and cohesion forces are mainly due to van der Waals bonds which will increase as the particle size increases. Other attractive forces that contribute to adhesion and cohesion are surface tension forces between the adsorbed liquid layer on the particle surface and electrostatic forces that arise due to contact or friction. This leads to increased contact between particles thus increasing the quantity of van der Waals interactions. Adhesion and cohesion forces are surface phenomena that are influenced by particle size. Fine particles will be more adhesive/cohesive than coarse particles so that fine particles have poor flowability than coarse particles. Spherical particle shapes have minimal contact surface between particles so they will have better flowability than flake-shaped particles. The irregular particle shape will cause the particles to lock together, thus increasing the adhesion/cohesion force. The flowability of powders are influenced by gravitational forces so that particles with larger specific weights generally have smaller adhesion/cohesion forces than particles with small specific weights [26].

The kombucha tea powder was evaluated for its flow properties by determining percent compressibility, Hausner ratio, flow rate and angle of repose. The results in **Tables 3** shows that F3 has the smallest percent compressibility which correlates with the best flowability. Gum arabic as carrier material of F3 led to the best flowability due to its polysaccharide structure and film-forming ability.

Table 3. Bulk Density, Tapped Density, compressibility (Carr Index) and Hausner's Ratio of Kombucha Tea Powder

Formula	Bulk Density (g/mL)	Tapped Density (g/mL)	Carr Index (%)	Hausner Ratio	Flow Properties
F1	0.45 ± 0.00	0.60 ± 0.01	23.86 ± 1.62	1.31 ± 0.03	Passable
F2	0.45 ±0.02	0.60 ± 0.01	24.60 ± 5.18	1.33 ± 0.09	Passable
F3	0.41 ± 0.01	0.51 ± 0.02	20.42 ± 0.59	1.26 ± 0.01	Fair
F4	0.45 ±0.03	0.57 ± 0.02	22.17 ± 1.75	1.29 ±0.03	Passable
F5	0.39 ± 0.01	0.51 ± 0.02	23.54 ± 0.65	1.31 ± 0.01	Passable
F6	0.40 ± 0.00	0.56 ± 0.00	28.00 ± 0.00	1.39 ± 0.00	Poor

The bulk density of the powder depends on the packing of the particles and the change in consolidation of the powder. Consolidated powders will have greater bonding strength and are more resistant to flow. The Hausner ratio is related to interparticle friction. Powders with low interparticulate friction such as coarse powders have a ratio of less than 1.2 while cohesive powders that are difficult to flow will have a Hausner ratio greater than 1.5. The results show that F3 has a Hausner ratio closest to 1.2 so that it has the best flow properties than other formulas. F3 is a formula that contains a carrier material in the form of gum arabic. Inulin and maltodextrin are known to have hygroscopic properties so that they can absorb moisture/water from the environment. This will cause the powder to be more difficult to flow [27],[28].

Determination of the flow properties of kombucha tea powder was also carried out using flow rate and angle of repose measurements. The results showed that all formulas had a flow rate of less than 1.6 g/sec, which correlated with very poor flowability or very cohesive characteristics. The obtained kombucha tea powder showed a tendency to clump easily and absorb moisture, which contributed to its poor flow properties. The flow rate and angle of repose of kombucha tea powder for each formula can be seen in **Table 4**.

Table 4. Flow Rate and Angle of Repose of Kombucha Tea Powder

Formula	Flow Rate (g/sec)	Angle of Repose (°)	Flow Properties
F1	0.97 ± 0.00	18.25 ± 3.86	Very poor / very cohesive
F2	0.79 ± 0.08	26.91 ± 0.00	Very poor / very cohesive
F3	0.75 ± 0.07	29.48 ± 1.39	Very poor / very cohesive
F4	0.83 ± 0.12	31.75 ± 0.93	Very poor / very cohesive
F5	0.83 ± 0.12	27.91 ± 0.99	Very poor / very cohesive
F6	0.61 ± 0.17	23.77 ± 3.95	Very poor / very cohesive

Flowability are related to the moisture content contained in the powder. **Table 5** shows the moisture content of each tea powder formula. F3 had a lower moisture content compared to the other formulas. An increase in moisture content in the powder will increase the attractive force between particles and increase contact between particle surfaces so that the mobility of the powder decreases [29]. Therefore, F3 had a lower cohesion force which correlates with better flow properties than the other formulas.

Table 5. Moisture Content of Kombucha Tea Powder

Formula	Water Content (%)
F1	2.54 ± 0.12
F2	3.26 ± 0.35
F3	0.85 ± 0.10
F4	2.84± 0.08
F5	1.54 ± 0.64
F6	2.42 ± 0.15

Despite providing valuable insights into the effect of carrier materials on the flow properties of kombucha tea powder, this study has several limitations. Firstly, the evaluation focused solely on physical flowability parameters, without exploring the influence of particle morphology, size distribution, or surface characteristics, which are known to significantly affect powder behavior. Secondly, the study did not include a detailed analysis of the chemical composition, polyphenol retention, or antioxidant stability post-drying, which are essential for assessing the functional quality of the final product. Additionally, the drying process was conducted under fixed conditions (temperature and time), which may not represent the optimal parameters for each carrier type. The use of only one type of foaming agent (egg white) also limits the generalizability of the findings.

Therefore, future studies are recommended to employ advanced characterization techniques such as scanning electron microscopy (SEM) or laser diffraction for particle size analysis, and to assess the impact of drying parameters on both physicochemical and bioactive compound stability. Furthermore, incorporating non-hygroscopic excipients or anti-caking agents, and exploring alternative or hybrid drying technologies such as spray-drying or vacuum-assisted Foam-mat drying, may offer enhanced powder functionality and improved flowability.

4. Conclusion

This study successfully demonstrated the use of Foam-mat drying with varying carrier materials—maltodextrin, inulin, and gum arabic—for the production of kombucha tea powder. Among the six formulations, the F3 formula containing gum arabic exhibited the most favorable flow properties, as indicated by its lowest compressibility index and Hausner ratio, and the lowest moisture content (0.85%). However, overall flowability across all formulations remained suboptimal due to the hygroscopic nature of the carriers. To enhance powder performance, future studies are recommended to explore the use of non-hygroscopic carrier materials, investigate the influence of drying parameters on powder microstructure and bioactive stability, and consider hybrid drying techniques or the addition of anti-caking agents to improve flowability and storage stability.

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Conflicts of Interest:

The authors declare no conflicts of interest.

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