USE OF VOLUME-WEIGHTED AVERAGE DIAMETER IN EVALUATION OF GRAININESS OF POST-HEAT-TREATED YOGURT

TECHNICAL FIELD

[0001] The present invention relates to the technical field of yogurt, and in particular to the use of the volume-weighted average diameter in evaluation of graininess of a post-heat-treated yogurt.

BACKGROUND OF THE INVENTION

[0002] Yogurt is a refrigerated snack typically served at the breakfast table, but the emergence of ambient-temperature yogurt has overturned this tradition. For millions of Chinese young people, ambient-temperature yogurt is now a portable drink, a trend that is also spreading in Asia, Africa and Latin America. The widespread popularity of ambient-temperature yogurt in China and other countries has been driven by growing consumer demand for convenience, nutritional value, and taste. Shelf-stable ambient-temperature yogurt provides a nutritional value similar to that of traditional fermented, refrigerated yogurt, yet it lacks probiotics and can be consumed while traveling since it requires no refrigeration.

[0003] Post-heat treatment ("secondary pasteurization") is a key operating procedure for the production of ambient-temperature yogurt (stirred yogurt). The aim is to inactivate the microorganism to extend the shelf life (4~25°C /150~180 days), but this easily leads to a granular texture, reduces creaminess, and produces a heterogeneous product structure. Different post-heat treatment temperatures can lead to different degrees of sensory defects in yogurt. Sensory texture properties are considered to be a prominent indicator of yogurt quality and a driving factor of consumer choice. Generally, sensory texture defects have less impact on acceptability decisions when they are not easily detectable. However, once these defects are perceived, even if slightly perceived as unfavorable textures, they are likely to be a primary factor leading to sensory rejection.

[0004] In view of this, the present invention is proposed to evaluate the graininess of a post-heat-treated yogurt.

SUMMARY OF THE INVENTION

[0005] All post-heat-treated yogurts in the present invention refer to stirred yogurt, and the graininess is a common texture defect in post-heat-treated yogurt products. Fermentation results in aggregation of casein into a weak gel network which, by further post-treatment, such as stirring or smoothing, is broken down into dense clusters of aggregated proteins having a size of about 10-250 μm, or occasionally greater than 1 mm. Such clusters are defined as microgels, in which interactions occur between microgels. Post-heat treatment plays an important role in promoting the aggregation and rearrangement of these microgels. Increasing the post-heat treatment temperature may change the balance between hydrophobic interactions and electrostatic repulsion of microgels, increase the thermal motion of microgel particles, and lead to further aggregation of microgel clusters. Therefore,

the aggregation process must be controlled during post-heat treatment to avoid widespread particle aggregation, which is associated with common texture defects such as graininess.

[0006] Particle properties (e.g. size, hardness, and shape), dispersion matrix properties (e.g. viscosity), and ingredient (e.g. particle concentration) are considered to be the primary factors determining the threshold of particle identification, especially for typical semi-solid foods. Yogurt and cheese have been widely agreed that (i) “higher viscosity tends to increase the particle perception threshold”; (ii) “when mass concentration or number concentration is held constant, larger, harder, and more angular particles are more likely to be perceived as gritty than smaller, softer, rounded or flattened particles”; and (iii) meanwhile, “the size, hardness, and shape of the particles determine the concentration range at which the granulous properties are perceived”. These insights provide a perspective of producing a smooth and acceptable texture by adjusting properties such as particle distribution of the matrix in which the particles are located.

[0007] However, through comparative research, the present invention found that when the particle size distribution test is carried out on the post-heat-treated yogurt, the conventional test process and the evaluation index of the average particle size cannot effectively direct the application research of the post-heat-treated yogurt in the aspect of graininess.

[0008] Specifically, the present invention provides for the use of the volume-weighted average diameter $D_{[4,3]}$ in post-heat-treated yogurt, particularly in evaluation of graininess of post-heat-treated yogurt. In some embodiments, the present invention provides a method for evaluating post-heat-treated yogurt, comprising a step of obtaining the volume-weighted average diameter $D_{[4,3]}$ of the post-heat-treated yogurt.

[0009] The threshold for graininess identification is defined as the minimum detectable change in the number or/and size of particles that results in perceivable graininess. However, few people have conducted in-depth research. As mentioned above, the graininess is related to the gel network structure in ambient-temperature yogurt, and in the existing test method for the gel network structure, microscopic image analysis is commonly used. Specifically, the gel structure in post-heat-treated yogurt is obtained through the process involving sample preparation - image acquisition - particle analysis. The present invention unexpectedly discovered that, during particle size distribution test, the volume-weighted average diameter $D_{[4,3]}$ can reflect the gel structure of post-heat-treated yogurt more accurately than other particle size indicators, achieving a testing accuracy comparable to that of microscopic image analysis. Furthermore, Furthermore, compared to existing microscopic image analysis methods, this method is simpler, more efficient, and has a broader range of applications.

[0010] The use or method as described above provided according to the present invention comprises: evaluating a microgel structure of post-heat-treated yogurt by using a volume-weighted average diameter $D_{[4, 3]}$.

[0011] In the particle size distribution test, a sample of the post-heat-treated yogurt to be tested cannot be directly used for testing, but require to be diluted with a dispersant. During dilution, different dispersants may have different effects on the microgel structure in the post-heat-treated sample to be

tested. In order to avoid the test error caused by the test conditions, the invention preferably uses whey in the sample of the post-heat-treated yogurt to be tested as a dispersant for the particle size distribution test, which is more consistent with the results of the existing microscopic image analysis method compared with other dispersants, such as water and simulated ultrafiltrate.

[0012] The use or method provided according to the present invention as described above, comprising:

[0013] centrifuging a sample of the post-heat-treated yogurt to be tested to obtain whey;

[0014] filtering the whey through an ultrafiltration membrane to obtain filtered whey serving as a dispersant;

[0015] wherein the dispersant is used for particle size distribution test of the sample of the post-heat-treated yogurt to be tested, so as to obtain the volume-weighted average diameter $D_{[4,3]}$.

[0016] Different post-heat-treated yogurt samples may have different test results. For post-heat-treated yogurt samples, viscosity is the primary factor affecting the dispersion or aggregation of microgel structures. The present invention finds that when the viscosity of the sample of the post-heat-treated yogurt to be tested is 100~500mPa·s, the volume-weighted average diameter $D_{[4, 3]}$ can be effectively measured, and the value is consistent with the results of the existing microscopic image analysis methods.

[0017] In the use or method as described above provided according to the present invention, the viscosity of the sample of the post-heat-treated yogurt to be tested is 100~500mPa·s.

[0018] Preferably, components of the sample of the post-heat-treated yogurt to be tested mainly include: 0.1-0.4 % of low-ester pectin, 4-8 % of white granulated sugar, 2.8-3.2 % of protein, and 3.0-4.0 % of fat; preferably, 0.3% of low-ester pectin, 6.0% of white granulated sugar, 2.8~3.2% of protein, and 3.0~4.0% of fat.

[0019] Further preferably, in the particle size distribution test, the obscuration range is 4 to 6%.

[0020] The particle size distribution test in the invention can be performed by a commonly used laser diffractometer (Malvern Mastersizer S, Malvern Instruments, Worcs), which is simple to operate and has a wide range of applications. The particle size distribution test is carried out under stirring conditions, and the stirring speed may be 1,000 to 2,000 rpm.

[0021] Specifically, the process of using the volume-weighted average diameter $D_{[4,3]}$ to evaluate the microgel structure in the post-heat-treated yogurt may be performed as follows: centrifuging a sample of the post-heat-treated yogurt to be tested (*e.g.*, 5000g × 30 min, 4°C) to obtain the corresponding whey, then filtering it through an ultrafiltration membrane (with a molecular weight cut-off of 10,000 Da), and heating to 37 ± 2°C in a water bath, and subsequently using it to disperse the sample of the post-heat-treated yogurt to be tested during particle size measurement. The particle size distribution is determined by a laser diffractometer (Malvern Mastersizer S, Malvern Instruments, Worcs), in which the dispersant refractive index is set to 1.32 and the particle refractive index is set to 1.46. The stirring speed is 1,000-2,000 rpm, preferably 1,500 rpm, the obscuration range is 4-6%. Measurement is performed automatically once the obscuration remained stable within this range for

30 s. The particle size result for each sample is derived from the average of six consecutive measurements, with three replicate measurements performed per sample.

[0022] Graininess is a complex biological process caused by the interaction of food with mechanoreceptors in the oral cavity, which depends not only on the nature of the particles and the matrix in which the particles are located, but also on the nerve impulses carried by multiple afferent nerves. Evaluation of the microgel structure of the sample of the post-heat-treated to be tested is still insufficient to accurately evaluate the graininess of the sample of the post-heat-treated yogurt to be tested, and even for samples with the same graininess texture and matrix characteristics, consumer perception of the granular sensation may vary depending on individual oral tactile sensitivity.

[0023] Currently, the commonly used sensory analysis methods are conducted by a certain number of trained professional sensory panelists or by recruiting a large number of consumers (more than 50 people), and then the evaluation results are qualitatively classified. For example, in the generalized Labeled Magnitude Scale (gLM), sensory panelists score the graininess of post-heat-treated yogurt sample to be tested. Different graininess scores correspond to different qualitative descriptions, specifically: a score of 0 is defined as “imperceptible,” 1 as “extremely weak,” 2 as “very weak,” 3 as “weak,” 4 as “slightly weak,” 5 as “moderate (neither strong nor weak),” 6 as “slightly strong,” 7 as “strong,” 8 as “very strong,” and 9 as “extremely strong.” Therefore, considering individual differences in oral tactile sensitivity, understanding the sensory panelists’ perception and recognition thresholds of graininess in the context of evaluation of graininess by sensory panelists will be of great significance for product development, which will contribute to a better understanding of the sensory texture defects of post-heat-treated yogurt after optimization.

[0024] The use or method as described above provided according to the present invention comprises: using the volume-weighted average diameter $D_{[4,3]}$ for the oral sensitivity test of graininess in post-heat-treated yogurt.

[0025] As mentioned above, individual differences in oral tactile sensitivity are an important influencing factor when sensory panelists evaluate graininess. This invention has found in its research that there is a significant power-law fitting correlation between the volume-weighted average diameters $D_{[4,3]}$ of a sample of a post-heat-treated yogurt and the graininess scores of sensory panelists. Therefore, a further research of the present invention reveals that, a high-sensitivity group among the sensory panelists can be identified by the correlation, thereby improving the accuracy of oral graininess sensitivity tests.

[0026] In the use or method as described above provided according to the present invention, the oral graininess sensitivity test comprises: identifying sensory panelists having different oral tactile sensitivities;

[0027] wherein the identifying comprises:

[0028] when the volume-weighted average diameter D[4,3] of the sample of the post-heat-treated yogurt falls within a range of 14-65 μm, determining a sensory panelist for whom a graininess score

increases with the value of the volume-weighted average diameter D[4,3] of the sample of the post-heat-treated yogurt.

[0029] The term “increasing” as used herein does not denote a strict pointwise increase, but rather an overall upward trend observed across multiple graininess evaluation tests conducted by a sensory panelist to be identified.

[0030] In the use or method as described above provided according to the present invention, the oral graininess sensitivity test comprises:

[0031] determining all sensory panelists;

[0032] individually evaluating, by each of all sensory panelists, graininess scores, wherein in the graininess score, the description of graininess is based on the intensity levels corresponding to a generalized labeled magnitude scale: defining a score of 0-3 as a weak level, 3-6 as a medium level, and 6-9 as a strong level; in the present invention, the terms “weak,” “medium,” and “strong” mentioned hereabove are relative concepts;

[0033] identifying sensory panelists with different oral tactile sensitivities among the all sensory panelists;

[0034] wherein the identifying comprises:

[0035] performing a power-law fitting on each sensory panelist’s graininess score against the volume-weighted average diameter D[4,3] of the sample of the corresponding post-heat-treated yogurt following a power-law fitting model of $Y = mX^n + k$; wherein Y represents the graininess score, X represents the volume-weighted average diameter $D_{[4,3]}$ of the post-heat-treated yogurt sample corresponding to the respective graininess score, n represents a power-law fitting exponent, m and k are constants, and R2 represents the goodness-of-fit of the power-law fitting model; and

[0036] determining the sensitivity level of each sensory panelist based on the power-law fitting exponent n and the goodness-of-fit R2 of the power-law fitting model.

[0037] Preferably, according to the sensitivity level, sensory panelists having different oral tactile sensitivities are classified into: sensory panelists of a high-sensitivity group, sensory panelists of a low-sensitivity group, and sensory panelists of a medium-sensitivity group;

[0038] after ranking the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model, classifying the sensory panelists into one or more of the following groups: high-sensitivity, medium-sensitivity, and low-sensitivity.

[0039] Further preferably, in the use or method as described above provided according to the present invention, the identifying comprises:

[0040] arranging the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model in ascending order to determine a first percentile, a second percentile, and a third percentile of all clustering parameters;

[0041] performing the identification and clustering for each sensory panelist based on the first percentile, the second percentile, and the third percentile, so as to determine sensory panelists belonging to a high-sensitivity group, a low-sensitivity group, and a medium-sensitivity group.

[0042] Specifically, when the n is higher and the R2 is closer to 1, the better. This represents that the sensory discrimination ability of the sensory panelist for particle size is closer to instrumental test accuracy; the n is lower and the R2 is closer to 0, the worse. This represents that the sensory discrimination ability of the sensory panelist for particle size deviates significantly from the objective test results of the instrument.

[0043] In the present invention, when the volume-weighted average diameter D[4,3] of the post-heat-treated yogurt sample falls within the range of 14 to 65 μm and the graininess score of the sensory panelist increases strictly according to a power-law fitting as the volume-weighted average diameter $D_{[4,3]}$ value of the post-heat-treated yogurt sample increases (i.e., both the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model are greater than the above-mentioned third percentile and strictly follow the $Y=mX^n+k$ power-law fitting model), the sensory panelist is a sensory panelist of the high-sensitivity group.

[0044] In the present invention, when the volume-weighted average diameter $D_{[4, 3]}$ of the post-heat-treated yogurt sample falls within the range of 14 to 65 μm and the graininess score of the sensory panelist exhibits an increasing trend that shows a poor fit to a power-law model as the value of D[4,3] value of the post-heat-treated yogurt sample increases (i.e., both the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model are less than the above-mentioned first percentile and they almost do not follow the $Y=mX^n+k$ power-law fitting model), the sensory panelist is a sensory panelist of the low-sensitivity group.

[0045] In the present invention, when the volume-weighted average diameter $D_{[4, 3]}$ of the post-heat-treated yogurt sample falls within the range of 14 to 65 μm and the graininess score of the sensory panelist exhibits an increasing trend of moderate power-law fitting as the volume-weighted average diameter $D_{[4, 3]}$ value of the post-heat-treated yogurt sample increases (i.e., both the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model are greater than the above-mentioned first percentile and/or less than third percentile, and basically follow the $Y=mX^n+k$ power-law fitting model), the sensory panelist is a sensory panelist of the medium-sensitivity group.

[0046] Briefly, sensory panelists having different oral tactile sensitivities have differences in compliance or degrees of compliance with the “power-law fitting increasing relationship”, and strict compliance corresponds to high sensitivity, moderate compliance to medium sensitivity, and poor or non-compliance to low sensitivity. The degree of compliance can be determined based on both the power-law exponent and the goodness-of-fit.

[0047] In the use or method as described above, the oral sensitivity test is used in graininess sensory evaluation test.

[0048] Based on the above research, it has been found that in sensory evaluation experiments involving a large number of panelists (50 or more), a small subset of highly sensitive panelists (who are classified according to the power-law fitting model described above, with panelists of medium sensitivity or above accounting for about 80%) can achieve sensory evaluation results consistent with those obtained from the full panel (50 or more) under the above-mentioned simpler correspondence

criterion. In particular, only in the sensory evaluation test conducted by highly sensitive panelists (who account for about 15% of all sensory panelists according to the above power-law fitting classification) can results be obtained that are closer to the instrumental accuracy than those from the full panel, while requiring less manpower.

[0049] The present study also found that higher post-heat treatment temperatures promote particle aggregation, leading to larger microgels, which in turn increases the surface area of microgels while reducing the number of small-sized microgels. This is because yogurt can be regarded as a weak gel network, which mainly contains four different sizes of particles generated by the aggregation of casein (0.1-0.3 μm) during acidification. The protein bonds within these weak gel particles are primarily governed by hydrophobic interactions. Higher post-heat treatment temperatures may enhance the hydrophobic interactions among these gel particles and provide a stronger initial driving force for particle aggregation, ultimately leading to two outcomes: on the one hand, the structural units, volume fractions, and contact areas between two particles may become smaller; on the other hand, more extensive particle rearrangement may lead to changes in the relative positions of particles and the formation of dense aggregated particle clusters, which in turn increases the density of aggregated particles by increasing the number of connections between them. Therefore, increasing the post-heat treatment temperature causes the rearrangement of microgels across these different surface-area categories and promotes their aggregation and growth. In a sense, post-heat treatment promotes the growth of the large-particle population within the microgels, and this “growth effect” occurs at the expense of the small-particle population.

[0050] The present invention has demonstrated that the post-heat treatment temperature may alter the balance between hydrophobic interactions and electrostatic repulsion of microgels, increase the thermal motion of microgel particles, and lead to further aggregation of microgel clusters. Therefore, the aggregation process must be controlled during post-heat treatment to avoid widespread particle aggregation, which is associated with common texture defects such as graininess. The present invention has also unexpectedly found that when post-heat-treated yogurts having different volume-weighted average diameters $D_{[4,3]}$ are mixed, the graininess of the resulting blended yogurt is significantly different. To control the graininess of the post-heat-treated yogurt to a level below medium, that is, to reduce its graininess, the use or method as described above provided according to the present invention specifically is a use or method for reducing the graininess of the post-heat-treated yogurt, comprising: mixing a post-heat-treated yogurt A with a yogurt B having a $D_{[4,3]}$ value of ≤46 μm, wherein the post-heat-treated yogurt A is obtained by subjecting the yogurt B to post-heat sterilization treatment, wherein the volume ratio of the yogurt B to the post-heat-treated yogurt A is ≥3:7.

[0051] In the use or method as described above provided according to the present invention, the volume-weighted average diameter $D_{[4, 3]}$ of the yogurt B is ≤20 μm, preferably ≤15 μm.

[0052] When the post-heat treatment temperature is 60 to 70 °C, and during mixing, the volume-weighted average diameter $D_{[4, 3]}$ of the yogurt B is ≤15 μm, and the volume ratio of the yogurt B to the post-heat-treated yogurt A is ≥ 3:7.

[0053] When the post-heat treatment temperature is from 80 to 85 °C, and during mixing, the volume-weighted average diameter $D_{[4,3]}$ of the yogurt B is ≤15 μm, and the volume ratio of the yogurt to the post-heat-treated yogurt A is ≥ 7:3.

[0054] The use or method as described above provided according to the present invention is a use or method for reducing the graininess of post-heat-treated yogurt, comprising: mixing post-heat-treated yogurt A with post-heat-treated yogurt C having a volume-weighted average diameter $D_{[4,3]}$ of ≤ 46 μm, wherein the post-heat-treated yogurt A and the post-heat-treated yogurt C are obtained by sterilizing the same yogurt at different post-heat treatment temperatures.

[0055] Preferably, the heat treatment temperature of the post-heat-treated yogurt A is from 65 °C to 85 °C; the heat treatment temperature of the post-heat-treated yogurt C is not higher than 65 °C, when the mixing, the volume ratio of the post-heat-treated yogurt C to the post-heat-treated yogurt A is ≥ 7:3;

[0056] Further preferably, the volume-weighted average diameter $D_{[4,3]}$ of the post-heat treated yogurt C is ≤15 μm.

[0057] Since post-heat-treated yogurt A and the post-heat-treated yogurt C are obtained by sterilizing the same yogurt at different post-heat treatment temperatures, when the post-heat treatment temperature of the post-heat-treated yogurt A is 65 °C, the post-heat treatment temperature of the post-heat-treated yogurt C is <65 °C.

[0058] In the present invention, when preparing any one of post-heat-treated yogurts (for example, post-heat-treated yogurt A, post-heat-treated yogurt B, and post-heat-treated yogurt C), the only difference between the yogurt required for the corresponding post-heat-treated yogurt and the post-heat-treated yogurt lies in the post-heat treatment (sterilization) temperature.

[0059] The present invention provides a use of a volume - weighted average diameter in the evaluation of the graininess of post-heat-treated yogurt, or a method of evaluating the graininess of post-heat-treated yogurt by using volume-weighted average diameter. During particle size distribution test of post-heat-treated yogurt, the present invention found that, the volume-weighted average diameter $D_{[4, 3]}$ is useful to evaluate the microgel structure of post-heat-treated yogurt, which is equivalent to the evaluation result of the existing microscopic image analysis method. It is further found that there is a significant power-law fitting correlation between the volume-weighted average diameters $D_{[4,3]}$ of post-heat-treated yogurt and the graininess scores of sensory panelists, which can identify a high-sensitivity group among the sensory panelists by the correlation, and improve the accuracy of the graininess sensory evaluation test, thereby reducing the costs. In addition, when post-heat-treated yogurts with different volume-weighted average diameters $D_{[4,3]}$ are mixed, the graininess of post-heat-treated yogurt after mixing will be significantly different. In order to reduce the graininess of yogurt after post-heat treatment and sterilization, the present invention proposes a technical solution

of mixing the yogurt having a specific volume-weighted average diameter $D_{[4, 3]}$ with the post-heat-treated yogurt having a higher graininess score after post-heat treatment and sterilization.

DESCRIPTION OF THE DRAWINGS

[0060] In order to more clearly explain the technical solution in the present invention or the prior art, the following will briefly describe the drawings required to be used in the examples or the prior art. It will be readily apparent to those of ordinary skill in the art that the drawings described below are merely examples of the present invention, and that other drawings may be obtained based on these drawings without involving any inventive effort.

[0061] FIG. 1 is a particle size distribution curve of different samples to be tested provided by the present invention.

[0062] FIG. 2 is a schematic diagram illustrating a process for particle analysis using Image J2 software, provided by the present invention.

[0063] FIG. 3 is a set of fluorescence microscopy images of different samples to be tested provided by the present invention. The fluorescence images appear green overall, wherein (A) is the NT group, (B) are the 55 °C and 65 °C groups, and (C) are the 75 °C and 85 °C groups;

[0064] FIG. 4 is a graph showing graininess scores resulting from different post-heat treatment temperatures, provided by the present invention;

[0065] FIG. 5 is a set of graphs showing representative fitting results for each sensitivity group, provided by the present invention; wherein (A) corresponds to the high-sensitivity group, (B) corresponds to the low-sensitivity group, and (C) corresponds to the medium-sensitivity group;

[0066] FIG. 6 is a set of graphs showing the relationship between average graininess score and $D_{[4,3]}$ for each sensitivity group, provided by the present invention; wherein (A) corresponds to the high-sensitivity group, (B) corresponds to the low-sensitivity group, and (C) corresponds to the medium-sensitivity group;

[0067] FIG. 7 is a set of graphs showing graininess evaluation results of different mixed systems, provided by the present invention; wherein (A) corresponds to mixing tests of the NT group and the 65 °C/25 s group, (B) corresponds to mixing tests of the NT group and the 85 °C/25s group, and (C) corresponds to mixing tests of the 65 °C/25 s group and the 85 °C/25s group.

DETAILED DESCRIPTION

[0068] In order to make the object, technical solutions and advantages of the present invention more clear, the technical solutions of the present invention will be clearly and completely described below with reference to the accompanying drawings of the present invention. Obviously, the described examples are merely some, rather than all, of the examples of the present invention. All other examples obtainable by a person having ordinary skill in the art based on the examples of the present invention without inventive efforts shall fall within the protection scope of the present invention.

[0069] The use of the volume-weighted average diameter in post-heat-treated yogurt and the

method for evaluating post-heat-treated yogurt using volume-weighted average diameter, are described hereinafter with reference to Figs. 1-7.

[0070] For techniques or conditions not specifically specified in the examples, procedures are carried out in accordance with techniques or conditions described in the literature in the art or in accordance with product instruction. Reagents or instruments for which the manufacturer is not specified are conventional products available from standard commercial sources.

[0071] **Example 1 Particle size distribution test**

[0072] (1) Sample Preparation

[0073] (1.1) Ultra-high temperature treated milk (3.2% protein, 4.0% fat) (Inner Mongolia Mengniu Dairy (Group) Co., Ltd., Hohhot, China) was heated to 45°C to 50°C in a fermenter. Then, 6.0% (w/w) of white granulated sugar and 0.30% (w/w) of low-ester pectin were added and stirred at 550 rpm until they were uniformly mixed with the milk base. After continuing to heat to 60 °C, the above mixture was homogenized at a pressure of 40 bar/150 bar. After homogenization, the mixture was continuously heated to 85°C for 20 minutes and then cooled to 42°C for inoculation and fermentation (0.03% (w/w), *Streptococcus thermophilus*). The fermentation was terminated when the pH of the yogurt dropped to 4.50 ± 0.04. The mixture was stirred at 550 rpm to disrupt the gel structure of the yogurt.

[0074] (1.2) The yogurt obtained in the step (1.1) was divided into five portions. One portion was left untreated as the NT group, while the remaining four portions were respectively heated to core temperatures of 55°C, 65°C, 75°C and 85°C and kept for 25 s, then immediately cooled to 25°C with flowing water, and stored at 4°C overnight together with NT group, and labeled as: NT group, 55°C 25s group, 65°C 25s group, 75°C 25s group and 85°C 25s group, respectively. Viscosity tests were performed for each group, and the corresponding viscosities were 175.39±10.42mPa·s, 329.98±8.64mPa·s, 436.63±33.04mPa·s, 363.47±7.68mPa·s, and 267.29±1.85mPa·s, respectively.

[0075] (2) Particle size distribution test

[0076] (2.1) Dispersant Preparation

[0077] Dispersant 1: A portion of yogurt was taken out from the yogurt obtained in step (1.1), centrifuged (5000 g ×30 min, 4°C) to obtain whey, then filtered using an ultrafiltration membrane (molecular weight cut-off of 10,000 Da), and heated to 37 ± 2 °C in a water bath to obtain filtered whey.

[0078] Dispersant 2: Ultrapure water.

[0079] Dispersant 3: Simulated ultrafiltrate, using ultrapure water as the solvent, with the remaining components and their contents listed in Table 1 below.

Table 1

Reagent Name	Addition Amount (g/L)
Potassium dihydrogen phosphate	1.58
Potassium citrate	1.2
Sodium citrate	2.12
Potassium sulfate	0.18

Calcium chloride	1.32
Magnesium chloride	0.65
Potassium carbonate	0.3
Potassium chloride	0.6

[0080] (2.2) The filtered whey (dispersant 1) obtained in step (2.1) was used to disperse the sample to be tested obtained in step (1) (NT group, 55°C 25s group, 65°C 25s group, 75°C 25s group and 85°C 25s group) during particle size measurement. The particle size distribution was determined using a laser diffractometer (Malvern Mastersizer S, Malvern Instruments, Worcs), in which the dispersant refractive index was set to 1.32 and the particle refractive index was set to 1.46. The stirring speed was 1500 rpm, and the obscuration range was 4-6%. Measurement was performed automatically once the obscuration remained stable within this range for 30 s, and the particle size result for each sample was derived from the average of six consecutive measurements, with three measurements performed per sample. The measured particle size distribution curve was shown in Fig. 1, and the various particle size index determined from the figure were presented in the table below.

Table 2

	$D_{[10]}$ (μm)	$D_{[50]}$ (μm)	$D_{[90]}$ (μm)	$D_{[4.3]}$ (μm)
NT group	7.70 ± 0.10^{d}	13.70 ± 0.36^{e}	22.98 ± 1.07^{e}	14.55 ± 0.39^{e}
55°C /25s group	7.27 ± 0.02^{d}	15.20 ± 0.48^{d}	41.15 ± 0.37^{d}	20.15 ± 0.10^{d}
65°C /25s group	9.78 ± 0.01^{c}	21.09 ± 0.06^{c}	53.00 ± 1.09^{c}	27.20 ± 0.36^{c}
75°C /25s group	14.42 ± 0.13^{b}	40.18 ± 0.56^{b}	88.18 ± 1.68^{b}	46.32 ± 0.69^{b}
85°C /25s group	17.40 ± 0.38^{a}	60.63 ± 1.54^{a}	123.17 ± 3.13^{a}	65.98 ± 1.67^{a}

[0081] Note: Within the same column in Table 2, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0082] As can be seen from Fig. 1 and Table 2, the particle size distribution (PSD) curves of yogurt obtained with different post-heat treatments were unimodal, and the peak width of the curve increased with the post-heat temperature and shifted towards a larger particle size. All particle size parameters, especially $D_{[90]}$ and $D_{[4,3]}$ parameters, increased significantly with the increase of post-heat treatment temperature ($p \leq 0.05$), except for $D_{[10]}$ in the NT group and the 55°C /25s group. The results showed that the post-heat treatment temperature had a considerable influence on the distribution of particle size in yogurt; the higher the temperature, the greater the influence. The increased $D_{[90]}$ and $D_{[4,3]}$ revealed the particle growth behavior of microgel particles of post-heat-treated yogurt, and the increased post-heat-treated temperature could provide a stronger driving force for interparticle fusion, resulting in rearrangement of particles and clusters on all length scales, which leads to particle fusion and increased structural unit size.

[0083] (2.3) is substantially the same as step (2.2) except that dispersant 1 was replaced by dispersant 2 in an equal volume. The results of particle size measurements are shown in the following table.

Table 3

	$D_{[10]}$ (μm)	$D_{[50]}$ (μm)	$D_{[90]}$ (μm)	$D_{[4.3]}$ (μm)

NT group	6.04±0.04^{c}	10.19±0.15^{c}	16.74±0.49^{d}	13.23±0.15^{c}
55°C/25s group	6.37±0.11^{c}	10.53±0.18^{c}	16.69±0.21^{d}	13.61±0.18^{c}
65°C/25s group	8.14±0.02^{b}	16.53±0.10^{b}	33.10±0.77^{c}	18.80±0.29^{b}
75°C/25s group	9.07±0.02^{a}	19.28±0.17^{a}	37.68±0.71^{b}	21.50±0.28^{a}
85°C/25s group	8.50±0.03^{ab}	18.78±0.05^{a}	42.15±1.53^{a}	22.45±0.45^{a}

[0084] Note: Within the same column in Table 3, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0085] (2.4) was basically the same as step (2.2) except that dispersant 1 was replaced by dispersant 3 in an equal volume. The results of particle size measurements are shown in the following table.

Table 4

	$D_{[10]}$ (μm)	$D_{[50]}$ (μm)	$D_{[90]}$ (μm)	$D_{[4.3]}$ (μm)
NT group	7.95±0.02^{b}	14.63±0.22^{d}	25.25±0.75^{e}	15.70±0.28^{e}
55°C/25s group	8.57±0.03^{b}	17.73±0.12^{c}	38.00±2.02^{d}	20.97±0.78^{d}
65°C/25s group	8.78±0.04^{b}	18.63±0.17^{c}	41.68±2.23^{c}	22.38±0.80^{c}
75°C/25s group	10.00±0.18^{a}	25.10±0.61^{b}	62.75±7.71^{b}	31.30±2.46^{b}
85°C/25s group	11.13±0.05^{a}	29.48±0.43^{a}	71.70±2.71^{a}	36.08±0.93^{a}

[0086] Note: Within the same column in Table 4, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0087] (3) Fluorescence microscope image test

[0088] (3.1) Sample Preparation

[0089] The preparation was basically the same as the sample preparation in step (1), except that the fast-green solution (0.2%) was added to the milk base at the same time as the low-ester pectin was added. Subsequently, stirring and post-heat treatment were performed in the dark, and the mixture was then allowed to stand overnight for later use. The samples were labeled as: microscope image-NT group, microscope image-55°C 25s group, microscope image-65°C 25s group, microscope image-75°C 25s group, and microscope image-85°C 25s group, respectively.

[0090] (3.2) The microscopic images analysis was performed according to the procedure modified by Gilbert *et al.* (2020) and Li *et al.* (2020) (Gilbert, A., Rioux, L. E., St-Gelais, D., & Turgeon, S. L. (2020). Studying stirred yogurt microstructure using optical microscopy: How smoothing temperature and storage time affect microgel size related to syneresis. Journal of Dairy Science, 103(3), 2139-2152; Li, R., Rovers, T. A. M., Jger, T. C., Wijaya, W., & Ipsen, R. (2020). Interaction between added whey protein ingredients and native milk components in non-fat acidified model systems. International Dairy Journal, 115, Article 104946). Specifically, for each sample, 1 mL of the sample prepared in step (3.1) was aspirated through a pipette and diluted 10 times with the filtered whey obtained in step (2.1). The samples were then gently shaken and mixed. Finally, 25 μL of labeled and diluted samples were transferred and spread on microscope slides (25 mm ×76 mm) equipped with microscope coverslips (25 mm ×25 mm ×0.13 - 0.16 mm) and observed in fluorescence mode using an inverted microscope

under a 10× objective lens. Three slides were prepared from the three replicate samples of each treatment group (one per replicate sample). Three images were taken randomly on each slide. According to the method of Gilbert *et al.* (2020), particle analysis was performed on the obtained images using Image J2 software, and the analysis process was shown in Fig. 2. Briefly, the background noise in the image was first eliminated by "Bandpass Filter", and the threshold adjustment was defined as the default red mode. The image was then bipolarized and the "watershed process" was used to distinguish the particles. It should be noted that particles intersected by the image edges were excluded and not included in the analysis. A total of nine images could be obtained from three replicates of each group of samples. Although individual particle surface areas derived from each image via software processing varied, they could overall be divided into four distinct grades: particle surface area < 1000 μm^2, 1000-2000 μm^2, 2000-3000 μm^2, and > 3000 μm^2. Further, the average surface area of each group of sample particles could be calculated and obtained by counting the number of particles contained in each image and the particle surface area, and the particle diameter could be further calculated and obtained based on the average surface area. The average surface area and calculated diameter of the microgels measured using image analysis were listed in the following table.

Table 5

	Average Surface Area (μm^2)	Calculated Diameter (μ m)
Microscopic Image - NT Group	183.77 ± 6.77^{e}	15.30 ± 0.28^{e}
Microscopic Image - 55°C /25s Group	272.52 ± 9.12^{d}	18.61 ± 0.29^{d}
Microscopic Image - 65°C /25s Group	427.66 ± 3.80^{c}	23.32 ± 0.12^{c}
Microscopic Image - 75°C /25s Group	1400.17 ± 86.30^{b}	42.22 ± 1.30^{b}
Microscopic Image - 85°C /25s Group	2930.57 ± 91.50^{a}	61.09 ± 0.96^{a}

[0091] Note: Within the same column in Table 5, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0092] In addition, in order to more intuitively reflect the changes in the microstructure and particle cluster size of the sample, fluorescence microscope images of each sample were recorded as shown in FIG. 3.

[0093] It could be seen from the above data that the mean surface area and diameter of the microgels increased significantly with the increase of post-heat temperature ($p \leq 0.05$).

[0094] More importantly, it could be seen from the diameter calculated based on image analysis and the results based on laser diffraction measurements that the particle sizes of the samples in the NT group, the 55℃/25s group, the 65℃/25s group, the 75℃/25s group and the 85℃/25s group were 15.30±0.28μm, 18.61±0.29μm, 23.32±0.12μm, 42.22±1.30μm, 61.09±0.96μm, respectively. Compared with the imaging results, the $D_{[4,3]}$ particle size value of ultrapure water (dispersant 2) dilution system was generally small, which deviated greatly from the actual particle size level reflected by imaging. The concordance between the $D_{[4,3]}$ particle size values obtained with the simulated ultrafiltrate (dispersant 3) dilution system and the imaging results was conditional: for yogurt samples heat-treated below 65 °C/25 s, good concordance was observed; however, for samples treated above

65 °C/25 s, because the microgel particles were relatively large due to polymerization, they suffered some size loss upon dispersion in the simulated ultrafiltrate, resulting in a marked deviation from the actual imaging results. Considering comprehensively, the whey (dispersant 1) diluent system could more accurately reflect the particle size result of yogurt system, which could be used as a technical means of yogurt particle size identification.

[0095] **Example 2 Evaluation of Graininess**

[0096] (1) Traditional sensory analysis methods

[0097] (1.1) Sensory panelists: Evaluation was performed by 58 semi-trained professional sensory panelists (32 women, 26 men, mean age: 35 years) who had been engaged in dairy development for more than 3 years and were familiar with descriptive evaluation of dairy sensory and textural properties.

[0098] (1.2) Sample Preparation

[0099] The NT group, the 55°C 25s group, the 65°C 25s group, the 75°C 25s group and the 85°C 25s group obtained in step (1.2) of Example 1.

[0100] (1.3) Test Process

[0101] After removal from the condition of 4 °C, they were randomly arrayed. Approximately 60 g of each group of samples were placed in 100 mL unscented clear plastic cups, coded with a 3-digit random number, and equilibrated at room temperature for 30 minutes. Sensory evaluation was required to be completed within two days, and five randomly selected samples were evaluated for graininess in the morning and afternoon of each day by 58 semi-trained sensory panelists (*i.e.*, sensory panelists defined in (1.1) above). The sensory analysis was conducted in a separate compartment in the sensory laboratory of Mengniu Dairy Group's ambient-temperature dairy research and development center. The evaluation was determined with reference to the generalized labeled magnitude scale (gLM), in which a score of 0 to 3 was defined as a "weak" particle intensity level, a score of 3 to 6 was defined as a "medium" particle intensity level, and a score of 6 to 9 was defined as a "strong" particle intensity level. The evaluation results were shown in Fig. 4, from which it could be seen that the increase in particle size caused by post-heat treatment affected not only the microstructure of yogurt, but also its sensory properties, especially the graininess. As shown in Fig. 4, different post-heat treatment temperatures resulted in different graininess of the yogurt samples. The NT and 55°C/25s groups were classified as "weak", the 65°C/25s group was classified as "medium", and the 75°C/25s and 85°C/25s groups were classified as "strong" according to the intensity levels defined by the gLM.

[0102] Through microscopic image analysis, the microgel area of each group below 55°C/25s was mainly distributed below 2,000 μm^2, while the microgel area of each group above 75°C/25s was mainly distributed between 2,000 and 3,000 μm^2 or above 3000 μm^2. Generally, the larger and harder the microgel, the higher the perceived graininess intensity, probably mainly because some of the larger shear-resistant particles were more prone to granular defects when pressed against the upper jaw with the tongue. However, there were no significant differences in sensory scores between the NT group and the 55°C/25s group, and between the 75°C/25s group and the 85°C/25s group ($p > 0.05$). These findings were inconsistent with significant differences ($p \leq 0.05$) in microgel size from laser diffraction

(Table 1) and image analysis (Table 4). This inconsistency between sensory perception and instrumental analysis in particle size evaluation was thought to be related to individual differences in oral tactile sensitivity.

[0103] Therefore, in order to identify and cluster sensory panelists with different oral tactile sensitivities, it was meaningful to select sensory panelists with high sensitivity for improving the accuracy of the oral sensitivity test for the graininess.

[0104] (2) Identifying and clustering sensory panelists with different oral tactile sensitivities

[0105] (2.1) The present invention performed power-law fitting on the evaluation results, specifically:

[0106] A power-law fitting was performed on the graininess scores of each sensory panelist and the volume-weighted average diameter $D_{[4,3]}$ of the corresponding post-heat-treated yogurt sample. The fitted relationship followed a power-law fitting model of $Y = mX^n + k$, wherein, Y represents the graininess score, X represents the $D_{[4,3]}$ value, n represents a power-law fitting exponent, m and k represent constants, and R^2 represents the goodness-of-fit of the this power-law fitting model.

[0107] The fitted data for each sensory panelist is shown in the following table.

Table 6

Sensory panelist No.	n	R^2
No. 1	0.7062	0.6918
No. 2	1.0315	0.8098
No. 3	0.8506	0.7799
No. 4	0.9402	0.8828
No. 5	1.1319	0.7487
No. 6	0.6828	0.689
No. 7	0.3228	0.4218
No. 8	0.5076	0.7472
No. 9	1.0703	0.9576
No. 10	0.6048	0.853
No. 11	0.7624	0.872
No. 12	1.0346	0.5609
No. 13	0.8173	0.7949
No. 14	0.9548	0.9509
No. 15	1.025	0.7244
No. 16	1.3082	0.789
No. 17	0.7138	0.8604
No. 18	1.0179	0.959
No. 19	0.8339	0.3749
No. 20	0.7552	0.5759
No. 21	1.0645	0.5744
No. 22	1.2894	0.7628
No. 23	1.0432	0.8187
No. 24	1.3809	0.776
No. 25	1.2416	0.7201

No. 26	1.0121	0.8784
No. 27	0.8462	0.7041
No. 28	0.7804	0.8441
No. 29	0.7099	0.7114
No. 30	0.7324	0.6916
No. 31	0.5663	0.8496
No. 32	0.8151	0.8753
No. 33	0.7286	0.7453
No. 34	0.7076	0.7468
No. 35	0.776	0.7304
No. 36	0.7239	0.7349
No. 37	0.7269	0.7769
No. 38	0.7313	0.7591
No. 39	0.6916	0.7939
No. 40	0.5944	0.6916
No. 41	1.2796	0.7966
No. 42	1.3267	0.9439
No. 43	1.2676	0.7612
No. 44	1.0222	0.7843
No. 45	1.425	0.9033
No. 46	1.2257	0.8733
No. 47	1.2436	0.7839
No. 48	1.3779	0.9318
No. 49	1.1293	0.9009
No. 50	1.3895	0.9106
No. 51	0.1886	0.3011
No. 52	0.2858	0.3091
No. 53	0.7788	0.4348
No. 54	0.5084	0.3551
No. 55	0.6826	0.5588
No. 56	0.6057	0.4462
No. 57	0.575	0.6474
No. 58	0.5388	0.6353

[0108] (2.2) The fitting parameters were arranged in ascending order, as shown in the following table.

Table 7

n	R^2	
0.1886	0.3011	
0.2858	0.3091	
0.3228	0.3551	
0.5076	0.3749	
0.5084	0.4218	
0.5388	0.4348	
0.5663	0.4462	

0.575	0.5588	
0.5944	0.5609	
0.6048	0.5744	
0.6057	0.5759	
0.6826	0.6353	
0.6828	0.6474	
0.6916	0.689	
0.7062	0.6916	First Percentile
0.7076	0.6916	
0.7099	0.6918	
0.7138	0.7041	
0.7239	0.7114	
0.7269	0.7201	
0.7286	0.7244	
0.7313	0.7304	
0.7324	0.7349	
0.7552	0.7453	
0.7624	0.7468	
0.776	0.7472	
0.7788	0.7487	
0.7804	0.7591	
0.8151	0.7612	Second Percentile
0.8173	0.7628	
0.8339	0.776	
0.8462	0.7769	
0.8506	0.7799	
0.9402	0.7839	
0.9548	0.7843	
1.0121	0.789	
1.0179	0.7939	
1.0222	0.7949	
1.025	0.7966	
1.0315	0.8098	
1.0346	0.8187	
1.0432	0.8441	
1.0645	0.8496	
1.0703	0.853	Third Percentile
1.1293	0.8604	
1.1319	0.872	
1.2257	0.8733	
1.2416	0.8753	
1.2436	0.8784	
1.2676	0.8828	
1.2796	0.9009	

1.2894	0.9033	
1.3082	0.9106	
1.3267	0.9318	
1.3779	0.9439	
1.3809	0.9509	
1.3895	0.9576	
1.425	0.959	

[0109] (2.3) The description results of n and R^2 for power-law fitting summarized from Tables 6 and 7 above are shown in the following table.

Table 8

	n	$\mathbf{R}^2$
Minimum Value	0.18	0.30
Maximum Value	1.43	0.96
Average Value	0.88	0.73
First Percentile	0.71	0.69
Second Percentile	0.81	0.76
Third Percentile	1.07	0.85

[0110] The power-law fitting exponent n and the R^2 derived from the power-law fitting model were selected as criteria for sensitivity discrimination. The power-law fitting exponent n was used for characterizing an increase rate at which the perceived graininess score increased with the volume-weighted average diameter $D_{[4,3]}$, and R^2 was used for characterizing the goodness-of-fit of the power-law model. Further, the classification criterion for the high-sensitivity group was defined as follows: both the power-law exponent n and the R^2 exceeded the third percentile of clustering parameter distributions (specifically, the 75% for the distributions of the R^2 coefficient and the power-law exponent n were equal to 0.85 and 1.07, respectively). The classification criterion for the low-sensitivity group was defined as follows: both the power-law exponent n and the R^2 coefficient were below the first percentile of clustering parameter distributions (specifically, the 25% for the distributions of the R^2 coefficient and the power-law exponent n were equal to 0.69 and 0.71, respectively). The classification criterion for the medium-sensitivity group was defined as follows: the power-law exponent n and the R^2 coefficient exceeded the first percentile of clustering parameter distributions and/or were below the third percentile.

[0111] Specifically, in the present application, the first percentile refers to the value at the 25th percentile of the clustering parameter values arranged in ascending order across all samples; the second percentile refers to the value at the 50th percentile; and the third percentile refers to the value at the 75th percentile. After all the clustering parameters (the R^2 coefficient and the power-law fitting exponent n) were obtained from the power-law fitting model and arranged in ascending order, all the clustering parameters were divided into intervals based on the first, second, and third percentiles. When both the R^2 value and the power-law fitting exponent n were lower than the first percentile, it could be inferred from the definition of percentiles that “the rate of increase in the sensory panelist’s perceived graininess scores with increasing volume-weighted average diameter D[4,3]” and “the adherence of

the sensory panelist's perceived graininess scores and volume-weighted average diameter D[4,3] to the power-law model" were lower than the bottom 25% level after ranking of all sensory panelists, and thus are used to characterize the low-sensitivity group. Conversely, when both the R^2 value and the power-law fitting exponent n were greater than the third percentile, it could be inferred from the definition of percentiles that "the rate of increase in the sensory panelist's perceived graininess scores with increasing volume-weighted average diameter D[4,3]" and "the adherence of the sensory panelist's perceived graininess scores and volume-weighted average diameter D[4,3] to the power-law model" were greater than the top 25% level after ranking of all sensory panelists, and thus are used to characterize the high sensitivity group. When the value of R^2 coefficient and the value of power-law fitting exponent n were greater than the third percentile and/or lower than the third percentile, it could be inferred from the definition of percentiles that "the rate of increase in the sensory panelist's perceived graininess scores with increasing volume-weighted average diameter D[4,3]" and/or "the adherence of the sensory panelist's perceived graininess scores and volume-weighted average diameter D[4,3] to the power-law model" were in a level between the top 25% and the bottom 25% of all sensory panelists, and thus are used to characterize the medium sensitivity group.

[0112] Finally, all sensory panelists were divided into high (N =9), low (N =11), and medium (N =38) sensitivity groups, and the representative fitting results for each sensitivity group were shown in panels (A) - (C) of Fig. 5. Meanwhile, the relationship between the average graininess score and $D_{[4,3]}$ for each sensitivity group was shown in panels (A) - (C) of Fig. 6. In Fig. 6, the dots of the circle, the square, the upper triangle, the lower triangle, and the diamond represented the NT group, the 55°C 25s group, the 65°C 25s group, the 75°C 25s group, and the 85°C 25s group respectively. The following can be seen from the figure.

[0113] Regarding the high-sensitivity group, as shown in Fig. 6 (A), with a significant increase in the $D_{[4,3]}$ parameter, the graininess score of the sensory panelists increased significantly ($p \leq 0.05$), showing that they had similar discrimination abilities to instrumental tests, and could distinguish samples as "weak" (approximately 14-20 μm, Table 2), "medium" (approximately 27 μm, Table 2), and "strong" (approximately 46-65 μm, Table 2).

[0114] Regarding the low sensitivity group, as shown in Fig. 6 (B), the graininess scores were significantly different ($p \leq 0.05$) in the groups below and above 55 °C/25 s. The 75°C/25s group was classified as "strong", while the other treatment groups were classified as "medium".

[0115] Regarding the medium sensitivity group, as shown in Fig. 6 (C), the "weak", "medium" and "strong" levels were also clearly distinguished similarly to the high sensitivity group, but no significant differences were observed between the groups below 55°C/25s ($p > 0.05$) and above 75°C/25s ($p > 0.05$).

[0116] Ultimately, approximately 81% of the sensory panelists classified as "medium" and "high" sensitivity obtained roughly consistent results in terms of the overall effect of individual sensitivity on graininess. That is, volume-weighted mean diameter $D_{[4,3]}$ <20 μm was generally classified as "weak"

level, volume-weighted mean diameter $D_{[4,3]}$> 46 μm was classified as "strong" level, and volume-weighted mean diameter $D_{[4,3]}$ between the two was classified as "medium" level.

[0117] When the vast majority of sensory panelists had a similar ability to distinguish yogurts of different particle sizes, this did not affect the overall evaluation results of the graininess level.

[0118] **Example 3 Method for Reducing the Graininess of Post-Heat-Treated Yogurt**

[0119] It could be seen from the above examples that yogurts with post-heat treatment temperatures above 75°C/25s had more pronounced particle characteristics than yogurts with post-heat treatment temperatures below 55°C/25s. Therefore, the present invention further studied the volume-weighted average diameter $D_{[4, 3]}$, and found that using the volume-weighted average diameter $D_{[4, 3]}$ as a key index could effectively direct how to reduce the graininess of post-heat-treated yogurt.

[0120] Specific tests were performed as follows.

[0121] Yogurts having different volume-weighted average diameters $D_{[4, 3]}$ were mixed at different volume ratios (1:9, 3:7, 5:5, 7:3, and 9:1), including: NT group obtained in step (1.2) in Example 1, 65 °C/25 s group, and 85 °C/25 s group, and the post-heat treated yogurts obtained by mixing, wherein the mixing test was performed as follows.

[0122] For the mixing tests of the NT group and the 65°C/25s group, their mixing ratios and particle size parameters were shown in the following table. A1, A2, A3, A4, and A5 represented the volume ratios of the NT group and the 65°C/25s group at volume ratios of 1:9, 3:7, 5:5, 7:3, and 9:1, respectively.

Table 9

	$D_{[10]}$(μm)	$D_{[50]}$(μm)	$D_{[90]}$(μm)	$D_{[4.3]}$(μm)
65°C /25s groups	9.78±0.01^{a}	21.09±0.06^{a}	53.00±1.09^{b}	27.20±0.36^{a}
A1	7.61±0.05^{b}	17.04±0.38^{b}	59.36±1.16^{a}	25.80±2.55^{a}
A2	7.64±0.04^{b}	17.42±0.16^{b}	59.78±1.36^{a}	26.14±0.45^{a}
A3	7.36±0.03^{b}	15.68±0.13^{c}	49.02±0.98^{c}	22.80±0.39^{b}
A4	7.40±0.03^{b}	15.34±0.11^{c}	43.14±1.28^{d}	20.80±0.37^{c}
A5	7.35±0.03^{b}	15.64±0.09^{c}	40.40±0.59^{e}	20.14±0.23^{c}
NT group	7.70±0.10^{b}	13.70±0.36^{c}	22.98±1.07^{f}	14.55±0.39^{d}

[0123] Note: Within the same column in Table 9, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0124] Accordingly, the post-heat-treated yogurts obtained by the mixing test of the NT group and the 65 °C/25 s group were evaluated for graininess by the method of Example 2, and the results were shown in the following table.

Table 10

	A1	A2	A3	A4	A5	NT group	65°C /25s group
$D_{[4,3]}$ value	$D_{[4,3]}$(μm)						
	25.8	26.14	22.8	20.8	20.14	14.55	27.2
Sensory panelist No.	Graininess Score						
1	4	4	1	2	1	3	7

2	4	5	4	3	2	2	5
3	2	2	2	1	1	3	5
4	4	3	1	0	4	2	3
5	4	6	4	2	2	2	3
6	5	6	2	4	1	2	4
7	7	6	3	3	0	3	4
8	3	4	3	2	1	3	4
9	4	2	2	1	3	2	4
10	2	5	2	1	0	3	4
11	6	6	3	3	2	2	4
12	7	3	2	1	2	3	5
13	5	5	3	3	4	3	3
14	5	6	3	4	4	2	3
15	4	3	2	3	1	2	2
16	5	5	3	3	2	2	3
17	5	5	3	3	1	3	6
18	2	2	1	1	3	2	3
19	6	4	3	5	2	4	3
20	2	4	1	1	2	4	6
21	5	5	3	4	2	2	1
22	8	4	3	4	2	2	4
23	4	5	4	3	2	2	2
24	7	5	4	5	4	2	3
25	6	5	2	3	1	2	2
26	7	5	6	5	2	2	4
27	7	8	3	4	4	3	5
28	4	6	4	3	5	3	4
29	7	4	3	1	1	3	4
30	3	5	1	2	4	3	4
31	5	5	3	3	4	4	4
32	1	1	1	1	2	2	4
33	4	4	3	1	5	3	6
34	2	2	2	3	2	3	6
35	2	4	1	1	4	3	5
36	7	4	2	1	2	4	6
37	6	6	4	4	3	3	7
38	4	4	2	2	4	3	5
39	3	5	3	2	2	4	6
40	3	2	1	0	3	3	5
41	2	2	1	0	2	1	5
42	8	7	3	4	3	1	3
43	6	5	3	3	1	1	6
44	4	3	1	1	4	1	4
45	7	5	2	2	2	1	5
46	4	5	2	3	2	1	4
47	4	4	1	2	2	1	6
48	1	8	2	5	1	1	4
49	5	5	3	4	2	2	5

50	4	6	4	4	3	1	3
51	5	5	4	2	1	3	5
52	4	4	2	3	1	3	5
53	7	6	5	5	3	2	1
54	5	5	5	3	1	3	5
55	6	7	3	4	1	4	6
56	5	5	3	1	2	3	2
57	3	5	2	2	1	4	4
58	5	5	3	4	2	4	4

[0125] For the mixing tests of the NT group and the 85°C/25s group, their mixing ratios and particle size parameters were shown in the following table. B1, B2, B3, B4, and B5 represented the volume ratios of the NT group and the 85°C/25s group at volume ratios of 1:9, 3:7, 5:5, 7:3, and 9:1, respectively.

Table 11

	$D_{[10]}$(μm)	$D_{[50]}$(μm)	$D_{[90]}$(μm)	$D_{[4.3]}$(μm)
85°C /25s group	17.40±0.38^{a}	60.63±1.54^{a}	123.17±3.13^{a}	65.98±1.67^{a}
B1	16.95±0.13^{a}	58.03±0.66^{a}	138.25±10.01^{a}	68.83±3.04^{a}
B2	14.33±0.10^{b}	49.83±0.51^{b}	116.00±1.83^{b}	58.28±0.73^{b}
B3	14.17±0.25^{b}	40.87±2.03^{c}	90.93±7.87^{c}	47.40±3.04^{c}
B4	10.60±0.35^{c}	25.24±0.46^{d}	66.98±1.89^{d}	32.78±0.37^{d}
B5	8.19±1.48^{d}	17.93±4.04^{e}	50.87±2.67^{e}	24.53±2.78^{e}
NT group	7.70±0.10^{d}	13.70±0.36^{f}	22.98±1.07^{f}	14.55±0.39^{f}

[0126] Note: Within the same column in Table 11, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0127] Accordingly, the post-heat-treated yogurts obtained by the mixing test of the NT group and the 85 °C/25 s group were evaluated for graininess by the method of Example 2, and the results were shown in the following table.

Table 12

	B1	B2	B3	B4	B5	NT	85°C /25s group
$D_{[4,3]}$ value	$D_{[4,3]}$(μm)						
	68.83	58.28	47.4	32.78	24.53	14.55	65.98
Sensory panelist No.	Graininess Score						
1	8	7	6	5	4	3	7
2	8	6	7	7	2	2	7
3	7	6	6	6	4	3	9
4	9	7	7	5	4	2	9
5	5	6	6	8	4	2	7
6	7	7	8	2	1	2	4
7	8	8	6	6	4	3	4
8	6	4	4	5	4	3	8
9	8	7	8	5	4	2	9
10	7	6	5	4	3	3	8
11	5	5	5	3	1	2	8

12	6	6	5	2	2	3	9
13	8	5	5	3	3	3	9
14	7	5	5	5	3	2	8
15	8	8	5	5	2	2	6
16	5	6	6	7	3	2	9
17	6	6	6	6	5	3	8
18	7	4	4	3	2	2	8
19	6	5	8	8	6	4	6
20	8	7	5	6	1	4	8
21	9	7	8	4	3	2	7
22	8	8	8	7	5	2	9
23	6	6	4	5	4	2	9
24	8	8	8	6	4	2	9
25	6	5	6	4	3	2	7
26	6	7	8	2	0	2	7
27	5	5	5	4	1	3	7
28	7	5	4	2	1	3	7
29	5	5	6	6	3	3	7
30	9	7	4	5	4	3	7
31	8	8	8	5	2	4	7
32	7	7	7	5	4	2	7
33	7	6	6	5	4	3	7
34	7	6	8	2	2	3	8
35	9	5	8	5	4	3	7
36	8	8	8	8	7	4	8
37	7	4	8	8	6	3	7
38	7	5	8	4	3	3	8
39	9	6	5	3	1	4	8
40	9	5	8	5	2	3	6
41	7	7	5	5	4	1	9
42	9	9	6	8	4	1	7
43	6	9	3	3	1	1	9
44	5	6	9	5	4	1	6
45	6	6	5	2	2	1	9
46	8	9	6	5	3	1	8
47	7	6	5	6	2	1	8
48	5	5	7	2	1	1	8
49	9	7	6	1	2	2	9
50	8	8	8	8	4	1	9
51	8	8	5	5	3	3	4
52	6	5	4	3	1	3	4
53	7	5	6	7	4	2	6
54	7	5	6	3	1	3	4
55	8	5	5	4	3	4	8
56	8	5	5	5	3	3	8
57	5	5	6	5	5	4	7
58	7	4	4	3	2	4	7

[0128] For the mixing tests of the 65°C/25s group and the 85°C/25s group, their mixing ratios and

their particle size parameters were shown in the following table. C1, C2, C3, C4, and C5 represented the volume ratios of the 65°C/25s group and the 85°C/25s group at volume ratios of 1:9, 3:7, 5:5, 7:3, and 9:1, respectively.

Table 13

	$D_{[10]}$(μm)	$D_{[50]}$(μm)	$D_{[90]}$(μm)	$D_{[4.3]}$(μm)
85 °C /25s group	17.40±0.38[a]	60.63±1.54[a]	123.17±3.13[a]	65.98±1.67[a]
C1	17.28±0.13[a]	58.83±0.79[a]	131.00±4.24[a]	67.25±1.52[a]
C2	14.85±0.06[b]	50.65±0.55[b]	122.50±1.73[b]	60.73±0.73[b]
C3	14.08±0.17[b]	43.98±0.77[c]	106.50±5.20[c]	53.00±1.78[c]
C4	10.70±0.30[c]	26.60±0.10[d]	71.54±1.26[d]	34.54±0.39[d]
C5	10.52±0.04[c]	25.04±0.18[d]	61.20±0.94[e]	31.08±0.36[e]
65℃/25s group	9.78±0.01[c]	21.09±0.06[e]	53.00±1.09[f]	27.20±0.36[f]

[0129] Note: Within the same column in Table 13, values sharing the same letter indicated no significant difference between groups ($p > 0.05$), whereas values with no same letter indicated a significant difference between groups ($p \leq 0.05$).

[0130] Accordingly, the post-heat-treated yogurts obtained by the mixing test of the 65 °C/25 s group and the 85 °C/25 s group were evaluated for graininess by the method of Example 2, and the results were shown in the following table:

Table 14

	C1	C2	C3	C4	C5	65°C /25s group	85°C /25s group
$D_{[4,3]}$ value	$D_{[4,3]}$(μm)						
	67.25	60.73	53	34.54	31.08	27.2	65.98
Sensory panelist No.	Graininess Score						
1	6	6	6	4	6	7	7
2	6	6	9	5	4	5	7
3	5	6	6	5	4	5	9
4	5	6	6	6	7	3	9
5	7	8	8	4	8	3	7
6	5	5	8	5	5	4	4
7	6	5	5	4	2	4	4
8	7	7	6	5	7	4	8
9	7	4	8	3	4	4	9
10	7	5	7	6	7	4	8
11	7	8	7	7	7	4	8
12	7	7	9	4	4	5	9
13	6	5	9	5	7	3	9
14	7	9	6	2	2	3	8
15	5	5	5	6	5	2	6
16	6	7	5	6	5	3	9
17	7	6	6	7	6	6	8
18	8	8	8	6	6	3	8
19	6	7	8	7	5	3	6
20	8	8	6	7	3	6	8
21	6	5	5	6	4	1	7
22	5	5	4	5	5	4	9
23	7	7	7	7	6	2	9
24	7	5	5	4	5	3	9

25	9	8	8	7	9	2	7
26	7	7	6	7	6	4	7
27	6	6	6	3	4	5	7
28	6	6	6	8	4	4	7
29	6	6	8	7	5	4	7
30	8	8	6	9	5	4	7
31	6	7	6	5	5	4	7
32	6	6	5	6	6	4	7
33	7	7	2	2	2	6	7
34	6	8	4	6	5	6	8
35	8	7	7	7	8	5	7
36	6	6	6	5	4	6	8
37	6	6	9	4	4	7	7
38	8	5	5	5	5	5	8
39	5	7	7	6	4	6	8
40	7	4	8	5	5	5	6
41	6	6	8	7	6	5	9
42	7	7	7	6	3	3	7
43	6	5	5	5	5	6	9
44	6	4	6	3	5	4	6
45	5	7	6	6	5	5	9
46	5	5	8	5	4	4	8
47	7	8	7	5	2	6	8
48	5	9	5	5	6	4	8
49	5	5	6	6	5	5	9
50	7	6	6	5	7	3	9
51	6	8	5	6	2	5	4
52	9	6	6	5	5	5	4
53	6	8	7	5	4	1	6
54	6	5	7	5	6	5	4
55	5	6	7	6	6	6	8
56	6	5	6	7	6	2	8
57	5	8	7	2	4	4	7
58	9	8	7	5	2	4	7

[0131] As could be seen from the above table, after yogurt having a volume-weighted average diameter $D_{[4, 3]} \leq 46$ μm was mixed with yogurt obtained by post-heat treatment and sterilization therefrom, or post-heat-treated yogurt having a volume-weighted average diameter $D_{[4, 3]} \leq 46$ μm was mixed into another post-heat-treated yogurt having a volume-weighted average diameter $D_{[4, 3]} > 46$ μm, the volume-weighted average diameter $D_{[4, 3]}$ of post-heat-treated yogurt having a larger volume-weighted average diameter $D_{[4, 3]} \leq 46$ μm was reduced to varying degrees. This was followed by a decrease in perceived graininess.

[0132] Specifically:

[0133] In the mixing test of the NT group and the 65°C/25s group, as the volume proportion (vol%) of the NT group became more than 30%, the $D_{[4, 3]}$ values of the mixed yogurt at the volume ratios of A3, A4 and A5 were significantly lower ($p \leq 0.05$) than that of the 65°C/25s group, as shown in Table 8. Meanwhile, as shown in Fig. 7 (A), where the dots of the solid square, the upper triangle, the diamond, the lower triangle, and the hollow square represented the volume ratios at the time of mixing: 9:1, 7:3, 5:5, 3:7, and 1:9, respectively and the solid circle and the hollow circle in the panel (A)

represented the NT group and the 65℃/25s group respectively. It could be seen that their graininess evaluations also revealed that the corresponding score decreased from “medium” to “weak”.

[0134] In the mixing test of the NT group and the 85°C/25s group, as the volume proportion (vol%) of the NT group became more than 10%, the $D_{[4, 3]}$ values of the mixed yogurt at the volume ratios of B2, B3, B4 and B5 were significantly lower ($p \leq 0.05$) than that of the 85°C/25s group, as shown in Table 11. However, as shown in Fig. 7 (B), where the dots of the solid square, the upper triangle, the diamond, the lower triangle, and the hollow square represented the volume ratios at the time of mixing: 9:1, 7:3, 5:5, 3:7, and 1:9, respectively, and the solid circle and the hollow circle in the panel (B) represented the NT group and the 85℃/25s group respectively. It could be seen that in their graininess evaluations, the graininess scores of yogurts after mixing at volume ratios of 30%(B2) and 50%(B3) in NT group were still classified as “strong.” As the vol% of the NT group was further increased to 70% (B4) and 90% (B5), the graininess score of the yogurt after mixing decreased from “strong” to “medium” (B4) and “weak” (B5).

[0135] In the mixing test of the 65℃/25s group and the 85°C/25s group, as the vol% of the 65°C/25s group was greater than 10%, the $D_{[4, 3]}$ values of the yogurt after mixing at the volume ratios of C2, C3, C4 and C5 were significantly ($p \leq 0.05$) lower than that of the 85°C/25s group, as shown in Table 13. However, as shown in Fig. 7 (C), wherein the dots of the solid square, the upper triangle, the diamond, the lower triangle, and the hollow square represented the volume ratios at the time of mixing: 9:1, 7:3, 5:5, 3:7, and 1:9, respectively, and the solid circle and the hollow circle in the panel (C) represented the 65℃/25s group and the 85℃/25s group respectively. It could be seen that in their graininess evaluations, the graininess scores of yogurts after mixing at volume ratios of 30%(C2) and 50%(C3) in 65℃/25s group were still classified as “strong.” The volume percent of the 65℃/25s group was further increased to 70% (C4) and 90% (C5), and the graininess score of the yogurt after mixing decreased from “strong” to “medium”.

[0136] Finally, it should be noted that the above examples are only used to illustrate the technical solution of the present invention, but not to limit it. Although the present invention has been described in detail with reference to the foregoing examples, those of ordinary skill in the art will understand that they can still modify the technical solutions described in the foregoing examples, or make equivalent substitutions for some technical features thereof. However, these modifications or substitutions do not make the essence of the corresponding technical solutions deviate from the spirit and scope of the technical solutions of each example of the present invention.

CLAIMS

1. A method of evaluating a post-heat-treated yogurt, characterized in that the method comprises a step of obtaining a volume-weighted average diameter $D_{[4,3]}$ of the post-heat-treated yogurt.

2. The method according to claim 1, characterized in that the method comprises: evaluating a microgel structure in the post-heat-treated yogurt by using the volume-weighted average diameter $D_{[4,3]}$.

3. The method according to claim 2, characterized in that the method comprises:

centrifuging a sample of the post-heat-treated yogurt to be tested to obtain a whey;

filtering the whey through an ultrafiltration membrane to obtain a filtered whey serving as a dispersant;

performing a particle size distribution test on the sample of the post-heat-treated yogurt to be tested by using the dispersant, so as to obtain the volume-weighted average diameter $D_{[4,3]}$.

4. The method according to claim 2 or 3, characterized in that the viscosity of the sample of the post-heat-treated yogurt is 100-500 mPa·s.

5. The method according to any one of claims 1 to 4, characterized in that components of the sample of the post-heat-treated yogurt mainly comprise:

0.1-0.4% of low-ester pectin, 4-8% of white granulated sugar, 2.8-3.2% of protein, and 3.0-4.0% of fat.

6. The method according to any one of claims 1 to 5, characterized in that the method comprises: performing an oral graininess sensitivity test of the post-heat-treated yogurt by using the volume-weighted average diameter $D_{[4,3]}$.

7. The method according to claim 6, characterized in that the oral graininess sensitivity test comprises: a step of identifying sensory panelists having different oral tactile sensitivities;

the identifying step comprises:

when the volume-weighted average diameter $D_{[4,3]}$ of the sample of the post-heat-treated yogurt falls within a range of 14-65 μm, determining a sensory panelist for whom a graininess score increases with the value of the volume-weighted average diameter $D_{[4,3]}$ of the sample of the post-heat-treated yogurt.

8. The method according to claim 7, characterized in that the oral graininess sensitivity test comprises the following steps:

determining all sensory panelists, optionally, wherein the number of the sensory panelists is 50 or more;

individually evaluating, by each of all sensory panelists, graininess scores, wherein in the graininess score, the description of graininess is based on the intensity levels corresponding to a generalized labeled magnitude scale: defining a score of 0-3 as a weak level, 3-6 as a medium level, and 6-9 as a strong level;

identifying sensory panelists with different oral tactile sensitivities;

the identifying step comprises:

performing a power-law fitting on each sensory panelist's graininess score against the volume-weighted average diameter $D_{[4,3]}$ of the sample of the post-heat-treated yogurt following a power-law fitting model of $Y = mX^n + k$; wherein Y represents the graininess score of the sensory panelist, X represents the volume-weighted average diameter $D_{[4,3]}$, n represents a power-law fitting exponent, m and k are constants, and R^2 represents the goodness-of-fit of the power-law fitting model; and

determining the sensitivity level of each sensory panelist based on the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model.

9. The method according to claim 8, characterized in that the determination of the sensitivity level of each sensory panelist comprises:

arranging the power-law fitting exponent n and the goodness-of-fit R^2 of the power-law fitting model in ascending order to determine a first percentile, a second percentile, and a third percentile of all clustering parameters;

performing the identification for each sensory panelist based on the first percentile, the second percentile, and the third percentile, so as to determine sensory panelists belonging to a high-sensitivity group, a low-sensitivity group, and a medium-sensitivity group.

10. The method according to any one of claims 7 to 9, characterized in that the oral sensitivity test is used for a graininess sensory evaluation test.

11. The method according to claim 1, characterized in that the method comprises: using the volume-weighted average diameter $D_{[4,3]}$ to guide reduction of the graininess of post-heat-treated yogurt;

mixing a post-heat-treated yogurt A with a yogurt B having a volume-weighted average diameter $D_{[4,3]}$ of ≤ 46 μm, wherein the post-heat-treated yogurt A is obtained by subjecting the yogurt B to a post-heat treatment for sterilization;

wherein the volume ratio of the yogurt B to the post-heat-treated yogurt A is $\geq 3:7$.

12. The method according to claim 11, characterized in that the volume-weighted average diameter $D_{[4,3]}$ of the yogurt is ≤ 15 μm.

13. The method according to claim 1, characterized in that it comprises a step of mixing a post-heat-treated yogurt A with a post-heat-treated yogurt C having a volume-weighted average diameter $D_{[4,3]}$ of ≤ 46 μm, wherein the post-heat-treated yogurt A and the post-heat-treated yogurt C are obtained by sterilizing the same yogurt at different post-heat treatment temperatures.

14. The method according to claim 13, characterized in that the post-heat sterilization temperature for the post-heat-treated yogurt A is from 65 °C to 85 °C; the post-heat sterilization temperature for the post-heat-treated yogurt C is 65 °C or below, and a volume ratio of the post-heat-treated yogurt C to the post-heat-treated yogurt A in the mixing step is $\geq 7:3$.