The Application of Information Technology in Food Quality Safety Testing: Computer-assisted Evaluation of Uncertainty in the Total Plate Count of Fruit Juice

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Abstract: Objective To establish a method for evaluating the uncertainty of total bacterial count to reduce experimental errors and improve the accuracy of detection results. Methods Twenty juice samples were detected for total bacterial count according to GB 4789.2-2010 "National Food Safety Standard - Determination of Total Bacterial Count", and the sources of uncertainty of the total bacterial count were analyzed according to JJF 1059.1-2012 "Evaluation and Expression of Measurement Uncertainty"; the combined sample standard deviation was used to evaluate the uncertainty of the detection results. Results At a coverage probability of 95%, the expanded uncertainty of the total bacterial count in juice is 0.10 (logarithmic scale), and this result is applicable to the detection of similar samples. Conclusion It is relatively convenient to evaluate the uncertainty of the total bacterial count of multiple similar samples using the combined sample standard deviation. As the number of inspections increases, data can be continuously added to the combined sample, thereby reasonably determining the uncertainty of the total bacterial count, and thus correctly evaluating the hygiene of food.

Keywords: Food Safety, Total Bacterial Count, Uncertainty, Information Technology

1. Introduction

The official implementation of the new "Food Safety Law" has raised higher requirements for food safety risk monitoring. Conducting monitoring of the pollution status of food contaminants, analyzing and evaluating food contaminant data, carrying out risk monitoring and early warning, and implementing government supervision are of great significance for maintaining the health and life safety of the people. The detection of microorganisms in food is an important health indicator for evaluating food safety, and the total bacterial count is the most common test item, mainly used to judge the degree of bacterial contamination of food, which can be used for hygienic evaluation of the food [1]. Since all measurements have errors, there is a risk of whether the detection results can objectively evaluate, and it will directly affect the economic interests of enterprises and the health of the people. Therefore, it is necessary to use uncertainty to quantitatively characterize the quality of detection results, thereby reducing risks [2].

This study primarily focuses on analyzing the uncertainty introduced by repeated measurements, while other factors with a smaller impact on the results are not considered. The chosen method is straightforward and highly practical for daily use in laboratory settings. To illustrate this approach, we used the detection of total bacterial count in juice as a case study. Specifically, 20 juice samples were tested for total bacterial count according to the guidelines specified in GB 4789.2-2010 "National Food Safety Standard - Determination of Total Bacterial Count." The evaluation of the uncertainty in the total bacterial count was conducted using the principles outlined in JJF 1059.1-2012 "Evaluation and Expression of Uncertainty in Measurement."

The primary objective is to enhance the accuracy of detection results in food safety risk monitoring. By focusing on the uncertainty introduced by repeated measurements, we aim to provide a clear and systematic method for quantifying and managing this uncertainty. This approach is crucial because all measurements

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are subject to some degree of error, and these errors can affect the reliability of the detection results. In the context of food safety, inaccurate results can have significant consequences, impacting both the economic interests of food enterprises and the health of consumers.

We selected 20 juice samples from different batches to ensure a representative and diverse dataset. Each sample was processed and tested for total bacterial count following the standardized procedures outlined in GB 4789.2-2010. The uncertainty analysis was conducted using the guidelines provided in JJF 1059.1-2012, identifying and quantifying sources of uncertainty such as variations in sampling, sample preparation, culture conditions, and colony counting. This method is simple and practical, making it highly suitable for routine use in food safety laboratories. By improving the accuracy and reliability of detection results, this approach helps ensure that food products are safe for consumption, protecting public health.

2. Materials and methods

2.1. Materials

The samples used in this experiment were 20 fresh squeezed juice specimens collected from catering establishments in the Huai'an area, mainly including watermelon juice, apple juice, and orange juice. Before the experiment, the pH value of each specimen was measured with pH paper. For acidic juices, the pH value was adjusted to between 6.5 and 7.5 with a 1M NaOH solution [5].

2.2. Apparatus and reagents

The materials and equipment used in this study include Plate Count Agar (batch number: 20150616, supplied by Hangzhou Tianhe Microorganism Reagent Co., Ltd.), which is essential for the cultivation of bacterial colonies. The incubation process was carried out using a PYX-DHS50 model water-jacketed electric heating constant temperature incubator, manufactured by Shanghai Yue Jin Medical Equipment Factory. This incubator maintains a stable temperature, ensuring optimal conditions for bacterial growth. Additionally, a DZKW-C model constant temperature water bath, produced by the Jiangsu Province Medical Equipment Factory, was used for maintaining consistent temperatures during the sample preparation and dilution processes. All experiments were conducted in a 1000-class purification laboratory, which provides a controlled environment to minimize contamination and ensure the accuracy of the results.

The Plate Count Agar, with its specific batch number, was chosen for its reliability and consistency in supporting bacterial growth. The water-jacketed electric heating constant temperature incubator (PYX-DHS50) is designed to maintain a precise and stable temperature, which is crucial for the accurate and reproducible growth of bacterial colonies. The constant temperature water bath (DZKW-C) ensures that the samples are prepared and diluted under consistent thermal conditions, further enhancing the reliability of the testing process. The 1000-class purification laboratory provides a clean and controlled environment, reducing the risk of external contamination and ensuring that the test results are as accurate and reliable as possible.

2.3. Experimental methods

According to the requirements of GB 4789.2-2010[3], 25mL of the sample was aseptically drawn and added to 225mL of sterile physiological saline to make a 1:10 dilution. Based on the contamination condition of the sample, three continuous dilutions of the sample solution were prepared, and each dilution was inoculated into 2 plates with 1mL each. At the same time, 2 blanks were taken with physiological saline, and the plate count agar cooled to 46°C was poured into the plates, gently rotated and mixed, and after the agar solidified, the plates were inverted and incubated at 37°C for 48 hours to count the total bacterial count of each sample.

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2.4. Establishing the mathematical model

Based on the measurement principle, the mathematical model for the determination of total bacterial count in the test is obtained:

$$A = \frac{k \cdot x}{V} \tag{1}$$

where:
- A is the total bacterial count of the sample, CFU/mL
- k is the dilution factor
- x is the number of colonies on the test plate at a certain dilution, CFU
- V is the sample volume taken at a certain dilution, mL

2.5. Sources and analysis of uncertainty

Measurement uncertainty has many sources, which can be divided into two categories according to the evaluation method: Type A evaluation of uncertainty, which uses statistical methods to evaluate the components, mainly referring to the random errors in the experiment; Type B evaluation of uncertainty, which uses non-statistical methods to evaluate the components, mainly referring to the systematic errors in the experiment [6].

The main sources of uncertainty in this experiment are: repeated measurement of samples, sampling volume, sample dilution, capacity tolerance of glassware, incubation time, and incubation temperature, etc. [7]. The Type A uncertainty brought by random effects has a greater impact on the accuracy of the test results, while the contribution of the Type B uncertainty components, which are mainly systematic errors, to the combined uncertainty is relatively small. Therefore, the Type A evaluation of uncertainty is used to evaluate the uncertainty of the total bacterial count [8].

3. Uncertainty evaluation results

In this experiment, a total of 20 juice samples were analyzed using a consistent detection method, the same batch of nutrient agar, and the same incubation temperature and time. The results were based on the count of plates with colonies ranging between 30 and 300 (see Table 1). Notably, no colonies grew on the blank control and dilution fluid control plates, confirming the absence of contamination in the experimental setup.

Due to the significant divergence in the data, directly calculating the combined sample standard deviation using the Bessel formula would yield a very large value. To address this issue, the detection results were logarithmically transformed. This transformation helps to normalize the data distribution, making it more manageable and reducing the impact of extreme values. After the logarithmic transformation, the mean and standard deviation were calculated. Subsequently, the combined sample standard deviation of the logarithmic values of the detection results was determined using the Bessel formula. This approach allows for a more accurate determination of the range of values for each sample, ensuring that the results are reliable and meaningful.

The logarithmic transformation is particularly useful in this context because it stabilizes the variance and makes the data more normally distributed, which is essential for statistical analysis. By calculating the mean and standard deviation of the logarithmic values, we can better understand the central tendency and variability of the bacterial counts. The combined sample standard deviation derived from the logarithmic values provides a more precise measure of the spread of the data, enabling us to set appropriate ranges for the bacterial counts in each sample. This method ensures that the detection results are not only accurate but also robust, facilitating effective food safety risk monitoring.

Calculating the Combined Sample Standard Deviation of Logarithmic Values:

$$S_P = \sqrt{\frac{\sum(lgx - lg\overline{x})}{m(n-1)}} = \sqrt{\frac{0.098231}{20(2-1)}} = 0.070082 \tag{2}$$

(m=20, n=2)

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Each sample was detected twice, so the standard uncertainty of the average value of the 2 detections is:

$$u(lg\overline{x}) = \frac{S_p}{\sqrt{2}} = \frac{0.070082}{\sqrt{2}} = 0.04956 \quad (3)$$

According to the confidence probability P = 95%, the degrees of freedom v = 20, and by looking up the t-distribution table, the coverage factor k = 2.086 is obtained. The expanded uncertainty U is:

$$U = \mathrm{ku}(\lg\overline{x}) = 2.086 \times 0.04956 = 0.10 \quad (4)$$

Then, based on the range of lg x values for each sample, the antilogarithm is calculated to obtain the range of total bacterial count content for each sample at the 95% confidence level (see Table 1, results are rounded to 2 significant figures).

4. Discussion

In the evaluation of measurement instability, microbial testing differs from physicochemical testing, as it falls into a category that is non-statistical, non-rigorous, and non-metrological [9]. It has its peculiarities; when the colony count is very high, the difference between parallel test results of the same sample is significant, and repeated measurements are the main source of uncertainty, affecting the accuracy of the test results. Other systematic effects contribute less to the combined uncertainty and are ignored in this experiment.

Due to the uneven distribution of bacteria in the sample, there can be antagonistic effects when different microorganisms are co-cultivated [10], and the visible colony-forming units (CFU) may not necessarily be single bacteria, but may also be formed by a cluster of bacteria [11]. This results in a large degree of dispersion in the detection results of the total bacterial count, which does not conform to the characteristics of the normal distribution. If the Bessel formula is used to calculate the uncertainty directly, the result is quite large. When the detection results are logarithmically transformed, the obtained values are approximately normally distributed, and it is more reasonable to use the Bessel formula to calculate the combined sample standard deviation to evaluate the uncertainty of the total bacterial count [12]. When the same kind and same properties of samples are detected under measurement repeatability conditions, the new detection results can be added to the combined sample, and the combined sample standard deviation can be calculated to obtain a new uncertainty [13].

Table 1: Results and Analysis of Total Bacterial Count Detection

Number	DetectionResult	Results after Log	Sum of	Value Range

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	s		Transformation			Squared Residuals				
	X_1	X_2	Lg x_1	Ig x_2	Lg $\bar{x}$		Lg x		X(CFU)	
1	11000	13000	4.0414	4.1139	4.0777	0.002632	3.9743	4.1810	9400	15000
2	580	420	2.7634	2.6232	2.6933	0.009825	2.5900	2.7967	390	620
3	3100	2500	3.4914	3.3979	3.4447	0.004364	3.3413	3.5480	2200	3500
4	12000	9700	4.0792	3.9868	4.0330	0.004270	3.9296	4.1363	8500	14000
5	7500	11000	3.8751	4.0414	3.9582	0.013833	3.8549	4.0616	7200	12000
6	34000	39000	4.5315	4.5911	4.5613	0.001775	4.4579	4.6646	29000	46000
7	8600	5700	3.9345	3.7559	3.8452	0.015953	3.7418	3.9486	5500	8900
8	3500	4200	3.5441	3.6232	3.5837	0.003135	3.4803	3.6870	3000	4900
9	550	620	2.7404	2.7924	2.7664	0.001354	2.6630	2.8698	460	740
10	2300	2700	3.3617	3.4314	3.3965	0.002425	3.2932	3.4999	2000	3200
11	28000	21000	4.4472	4.3222	4.3847	0.007805	4.2813	4.4881	19000	31000
12	9800	7500	3.9912	3.8751	3.9331	0.006747	3.8298	4.0365	6800	11000
13	450	560	2.6532	2.7482	2.7007	0.004510	2.5973	2.8041	400	640
14	3600	4100	3.5563	3.6128	3.5845	0.001595	3.4812	3.6879	3000	4900
15	1000	1200	3.0000	3.0792	3.0396	0.003135	2.9362	3.1430	860	1400
16	3900	3500	3.5911	3.5441	3.5676	0.001104	3.4642	3.6709	2900	4700
17	32000	39000	4.5051	4.5911	4.5481	0.003691	4.4447	4.6515	28000	45000
18	8500	7200	3.9294	3.8573	3.8934	0.002598	3.7900	3.9967	6200	9900
19	6700	5900	3.8261	3.7709	3.7985	0.001525	3.6951	3.9018	5000	7900
20	2100	2700	3.3222	3.4314	3.3768	0.005956	3.2734	3.4802	1900	3000
Total						0.098231				

In the work of food safety risk monitoring, evaluating the uncertainty of the total bacterial count is an important part of the quality system of food microbiological laboratories [14]. Since all measurements have errors, there is a risk of whether the detection results can be objectively judged; when the detection results are near the limit value, it is unscientific to directly determine whether they comply with food hygiene and safety standards, and there is a greater risk [15]. Evaluating the uncertainty of the total bacterial count with measurement uncertainty can reduce experimental errors and improve the accuracy and reliability of the detection results, thereby reducing the risk of testing institutions.

5. Conclusion

With the continuous advancement of food safety detection technology, this study has introduced statistical principles and computer-assisted analysis, offering a novel method for precision evaluation in the field of food microbiological detection. By evaluating the uncertainty of the total bacterial count in juice samples at a 95% confidence level, we have significantly enhanced the accuracy and reliability of the detection results. This approach not only improves the precision of the measurements but also adds a new dimension to the quality control system of food microbiological laboratories.

The integration of statistical principles and computer-assisted analysis represents a significant step forward in the field of food safety. These tools enable us to handle large datasets more efficiently and accurately, providing deeper insights into the variability and reliability of the detection results. By focusing on the uncertainty of the total bacterial count, we have developed a robust method for quantifying and managing

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this uncertainty. This is crucial because all measurements are inherently subject to some degree of error, and understanding and mitigating these errors is essential for ensuring the accuracy of the results.

In our study, we used a 95% confidence level to evaluate the uncertainty of the total bacterial count in juice samples. This confidence level provides a high degree of assurance that the true value of the bacterial count falls within the calculated range. By doing so, we have not only improved the accuracy and reliability of the detection results but also established a more rigorous standard for quality control in food microbiological laboratories. The ability to provide precise and reliable data is essential for making informed decisions about food safety and hygiene.

The methodology employed in this study offers a dynamic and scalable assessment framework that can be adapted to various food safety monitoring scenarios. This framework is designed to be flexible and responsive to changing conditions, making it highly applicable to the evolving landscape of food safety. By providing a scientific and systematic approach to evaluating food hygiene, this method contributes to a more comprehensive and reliable quality control system. It ensures that the food products reaching consumers are safe and of high quality, thereby protecting public health and enhancing consumer confidence.

Moreover, the dynamic nature of this assessment framework allows for continuous improvement and adaptation. As new technologies and methods emerge, the framework can be updated to incorporate these advancements, ensuring that the evaluation of food hygiene remains cutting-edge and effective. This approach not only supports current food safety practices but also lays the groundwork for future innovations in the field. By fostering a more scientific and reasonable evaluation of food hygiene, this study aims to contribute to the broader goal of ensuring public health and food safety.

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