



Designing a STEAM-Based Science Curriculum through. Alternative Ice Making Activities

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Abstract

This study focuses on the development of an alternative ice that can be safely consumed by people with milk allergies, and presents the design and implementation of an inquiry-based activity applicable to secondary school science classes. Milk allergy is observed in approximately 5% of school-aged children, and milk has been reported as one of the major allergens [1]. An alternative ice was prepared using soy milk and rice flour, and both sensory evaluation and physical property analysis were conducted. In the sensory evaluation, “appearance” and “texture” received particularly high scores, while “richness” and “aftertaste intensity” were rated lower, indicating that the product had a light and refreshing quality. Compared with commercial ice, the soy-based ice was relatively soft and characterized by ease of eating [2]. In addition, to make the activity feasible for use in secondary school lessons, a simple measuring device was prototyped based on existing texture analysis equipment, confirming that basic comparisons of hardness and adhesiveness could be performed [3]. Through these results, the study developed educational materials to support scientific inquiry and positioned the activity as a STEAM education model that integrates science (understanding of physical changes), technology (preparation and measurement), engineering (optimization of freezing conditions), mathematics (data analysis), and art (food design) [4]. This study is expected to contribute to the development of scientific thinking and data analysis skills, as well as to foster students’ interest in science through familiar foods, deepen understanding of milk allergies and health, and promote awareness of social issues.

Keywords: Inquiry-based learning; STEAM education; inclusive science education; food science education; milk allergy

1. Background and Objective

Food-related topics have increasingly been recognized as effective contexts for science education, as they connect abstract scientific concepts with students’ everyday experiences. In particular, food science provides opportunities to explore physical changes, material properties, and data analysis in ways that are both tangible and motivating for learners. Previous studies have shown that inquiry-based activities using familiar materials can enhance students’ engagement, conceptual understanding, and scientific reasoning skills.

At the same time, the diversification of learners’ needs has highlighted the importance of inclusive science education. Food allergies, such as milk allergy, affect a significant proportion of school-aged children and may limit their participation in common food-based educational activities. Milk has been identified as one of the major food allergens worldwide, and the exclusion of affected students from hands-on activities may negatively impact both learning opportunities and classroom inclusion. Therefore, the development of allergen-free experimental materials that allow all students to participate safely is an important challenge for contemporary science education.

From a pedagogical perspective, STEAM education emphasizes the integration of Science, Technology, Engineering, Arts, and Mathematics through problem-solving and design-oriented learning. Food preparation and evaluation naturally align with this framework: scientific concepts such as phase transitions and material properties can be examined (Science), preparation and



measurement procedures involve tools and techniques (Technology), optimization of ingredients and conditions reflects design thinking (Engineering), sensory evaluation relates to aesthetics and perception (Arts), and data handling and statistical analysis require quantitative reasoning (Mathematics). However, concrete classroom-ready examples that integrate all these elements while addressing issues of inclusion remain limited.

Ice, as a familiar and popular food, offers a particularly suitable subject for inquiry-based learning. Its texture and physical properties change dynamically with temperature and composition, allowing students to investigate hardness, adhesiveness, and cohesiveness as measurable variables. Previous research in food science has demonstrated that plant-based ingredients such as soy milk and rice flour can significantly influence these properties, suggesting their potential use as educational materials. Nevertheless, few studies have explored how such food science research can be translated into inquiry-based activities for secondary school education.

Against this background, the present study aims to bridge food science and science education by developing a milk-free ice using soy milk and rice flour and positioning it as a model inquiry activity for secondary school classrooms. By combining sensory evaluation, instrumental measurement of physical properties, and comparisons with commercial products, this study seeks to demonstrate how inclusive, inquiry-based, and STEAM-oriented learning can be realized through familiar food materials.

2. Methods

Preliminary Study (Determination of the Basic Recipe)

Prior to the main experiment, a preliminary study was conducted to determine the basic formulation of the soy-based ice. While keeping the sugar concentration constant, several prototype samples were prepared by varying only the amount of rice flour. Five participants evaluated the samples in terms of texture, flavor, and overall preference.

In this preliminary study, the effect of ingredient composition on food properties was examined by manipulating a single factor (rice flour content) while controlling all other conditions. The formulation that received the highest overall evaluation was adopted as the standard recipe for the main experiment. This process was designed to illustrate the importance of condition setting and optimization in scientific inquiry and is suitable for implementation as an inquiry-based activity in secondary school education.

2. Main Study

2.1 Preparation of Rice Flour Ice and Sensory Evaluation

Two types of rice were used as raw materials: Koshihikari rice produced in Niigata Prefecture and glutinous rice produced in Yamagata Prefecture. Each rice sample was milled to 60 mesh using a rice milling machine (Kome Ace A-8, Kokko Co., Ltd.), and 45 g of rice flour was obtained. The rice flour was mixed with 900 g of unsweetened soy milk, 150 g of sugar, and vanilla essence, and the mixture was heated over medium heat while stirring until a uniform viscosity was achieved. After heating, the mixture was cooled to room temperature.

The cooled mixture was poured into a household ice maker (Cuisinart ICE-70) and churned for 25 minutes to produce the ice. This preparation method does not require specialized laboratory equipment and can be reproduced using household cooking tools, making it suitable for implementation in school educational settings.

Sensory evaluation was conducted with 27 panelists. A total of 13 evaluation items were used, including appearance, richness, mouthfeel, smoothness, aftertaste, refreshing quality, and overall preference. A rating scale method was employed, and all samples were randomly coded and presented to minimize bias caused by prior expectations. This sensory evaluation enabled the comparison of subjective impressions with objective physical measurements described below.

2.2 Measurement of Hardness, Adhesiveness, and Cohesiveness

Physical property measurements were performed using four commercially available ice (Super Cup, Sou, Häagen-Dazs, and MOW) and two rice flour ice (Koshihikari and glutinous rice). A creep meter (RE-33005CXZ, Yamaden Co., Ltd.) equipped with a cylindrical plunger and a 200 N load cell was used for the measurements.



The plunger insertion speed was set at 1 mm/s, and the plunger was inserted vertically into the surface of each sample. All samples were stored at $-20\text{ }^{\circ}\text{C}$ for 24 hours prior to measurement. After removal from the freezer, measurements of hardness, adhesiveness, and cohesiveness were taken at 1-minute intervals from 1 to 15 minutes at room temperature ($22\text{ }^{\circ}\text{C}$). Measurements were repeated multiple times at each time point to confirm reproducibility.

By focusing on changes over time after removal from the freezer, this method allowed quantitative analysis of the transition from a solid to a semi-molten state. Comparisons with commercial ice were included to help learners relate experimental samples to familiar foods encountered in daily life.

Statistical analysis was conducted using two-way analysis of variance (two-way ANOVA) with ice type and measurement time as factors. When significant differences were detected, Tukey's multiple comparison test was applied to examine differences between groups.

2.3 Measurement of Sweetness

Quantitative evaluation of sweetness was conducted using a taste sensor system (TS-5000Z, INSENT Inc.). Each sample was returned to room temperature and diluted threefold by weight. The diluted sample was thoroughly mixed and then centrifuged to remove solid particles and lipids. The supernatant aqueous layer was used as the measurement sample.

The GL1 sensor was used to measure sweetness, and measurements were repeated multiple times under identical conditions. Sweetness values were compared by calculating the average potential difference between the rice flour ice samples and the commercial ice. This approach enabled comparison between human sensory evaluation and objective measurements obtained using analytical instruments, highlighting the role of scientific technology in food evaluation.

3. Results

3.1 Physical Properties of Soy-Based and Commercial Ice

The physical properties of soy-based and commercial ice samples—hardness, adhesiveness, and cohesiveness—were analyzed using a two-way analysis of variance (ANOVA), with ice type (six levels) and measurement time (1–15 min) as factors. For all physical properties, the main effects of ice type and measurement time, as well as their interaction, were statistically significant ($p < 0.05$). The mean values and results of Tukey's multiple comparison test are summarized in Table 1.

Table 1: Multiple comparisons for each sample

	Glutinous rice	Koshihikari	Super Cup	MOW	Saw	Haagen-Dazs
Hardness	14.20 ^a	30.46 ^{bc}	33.26 ^c	6.791 ^d	26.64 ^b	13.26 ^a
Adhesion	3339 ^e	2930 ^f	3610 ^g	3229 ^e	2238 ^h	0.452 ⁱ
Cohesiveness	0.335 ^k	0.338 ^k	0.381 ^l	0.442 ^m	0.322 ^k	0.452 ^m

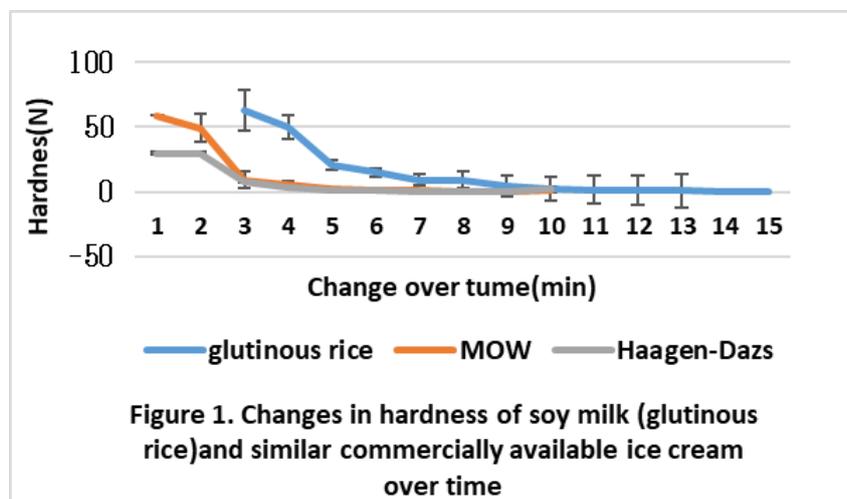
※Different letters within a column indicate significant differences.

3.1.1 Hardness

Multiple comparison analysis revealed no significant difference in hardness between soy-based ice made with glutinous rice and the commercial ice Häagen-Dazs ($p > 0.05$). In contrast, soy-based ice made with Koshihikari rice showed no significant difference compared with the commercial ice *Sou* and *Super Cup*, indicating similar hardness values among these samples (Table 1).



Fig. 1 illustrates the time-dependent changes in hardness. Soy-based ice made with glutinous rice exhibited extremely high hardness immediately after removal from the freezer, showing almost no deformation at 1 min. Thereafter, hardness decreased rapidly from 2 min onward, followed by a gradual decline over time. This pattern of change was similar to that observed for the commercial ice Häagen-Dazs and MOW (Fig. 1).



3.1.2 Adhesiveness

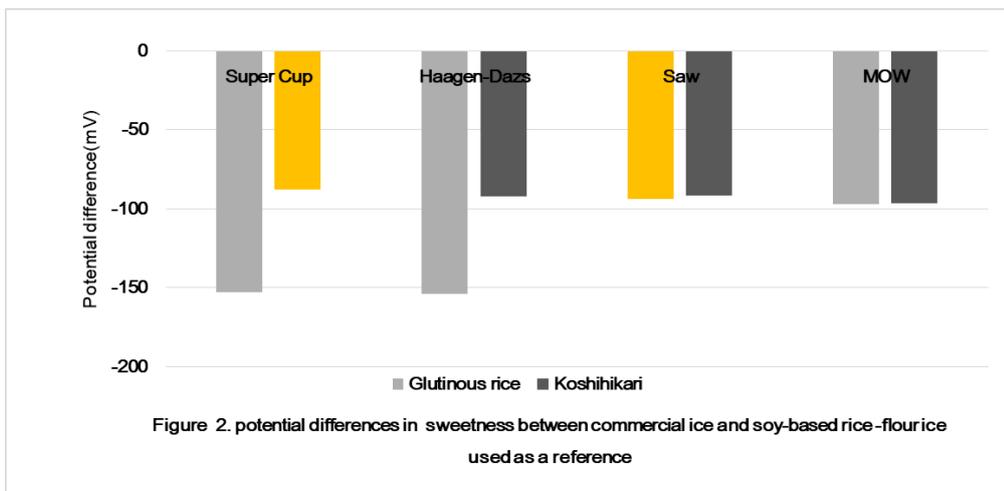
Multiple comparison analysis of adhesiveness showed no significant difference between soy-based ice made with glutinous rice and the commercial MOW ($p > 0.05$). In contrast, soy-based ice made with Koshihikari rice exhibited significantly lower adhesiveness than both soy-based ice made with glutinous rice and MOW ($p < 0.05$). Significant differences in adhesiveness were also observed among the commercial ice samples (Table 1).

3.1.3 Cohesiveness

For cohesiveness, no significant differences were observed among soy-based ice made with glutinous rice, soy-based ice made with Koshihikari rice, and the commercial ice *Sou* ($p > 0.05$). In contrast, MOW and Häagen-Dazs exhibited significantly higher cohesiveness compared with these samples ($p < 0.05$) (Table 1).

3.2 Sweetness

The results of sweetness measurements obtained using a taste sensor are shown in Figure 2. In this study, membrane potential changes were first measured for each sample, and the membrane potential change of the soy-based rice-flour ice was subtracted as a reference. The mean values of the resulting potential differences were used as a comparative index of sweetness. When soy-based ice made with glutinous rice was used as the reference, the potential difference relative to the commercial ice *Sou* was small, indicating similar sweetness characteristics. In contrast, when soy-based ice made with Koshihikari rice was used as the reference, the potential difference relative to Super Cup was relatively small, suggesting comparable sweetness profiles.



✂ The mean potential differences were calculated by subtracting the membrane potential change of the soy-based rice-flour ice from that of each commercial ice, as measured using a taste sensor. Smaller potential differences indicate closer similarity in sweetness characteristics.

4. Discussion

In this study, non-dairy ice made from soy milk and rice flour were prepared and compared with commercial ice in terms of physical properties and sweetness. The results demonstrated that the type of rice flour used significantly influenced the physical properties of the ice, allowing the reproduction of textural characteristics comparable to different categories of commercial products.

The soy-based ice made with glutinous rice showed no significant differences in hardness and adhesiveness compared with premium ice such as Häagen-Dazs and MOW, indicating a dense and viscous texture. In contrast, the soy-based ice made with Koshihikari rice exhibited hardness and cohesiveness similar to lighter commercial products such as Sou and Super Cup, suggesting a softer and less stable structure. These differences can be attributed to the higher amylopectin content of glutinous rice, which contributes to increased viscosity and structural stability, whereas Koshihikari rice, a non-glutinous variety, contains relatively lower amylopectin.

Sweetness evaluation using a taste sensor was conducted using a relative assessment method in which the membrane potential change of the rice-flour ice was used as a reference. The potential differences were calculated by subtracting the reference value from the measurements of each commercial ice. The results showed that the soy-based ice made with glutinous rice exhibited sweetness characteristics similar to Sou, while the soy-based ice made with Koshihikari rice showed sweetness closer to Super Cup. This reference-based evaluation method highlights the importance of relative comparison in food analysis and provides a clear framework for interpreting sensor-based data.

A key feature of this study is that these food science findings were structured to be directly applicable to inquiry-based learning in secondary education. By measuring continuous changes in physical properties after removal from frozen storage, students can quantitatively observe phase transitions and coexistence of solid and liquid states, which are often difficult to address using textbook-based instruction alone. In addition, comparison with familiar commercial ice enables students to connect experimental data with their everyday sensory experiences.

Furthermore, comparing sensory evaluation with instrumental analysis provides opportunities for students to examine the relationship between subjective perceptions of palatability and objective numerical data. The treatment of potential differences in sweetness measurements also offers a suitable context for discussing measurement variability and the validity of reference settings, thereby fostering scientific data interpretation skills.

The inquiry activity proposed in this study can be positioned within the framework of STEAM education. From the perspective of Science, students investigate phase changes and texture formation through



quantitative measurements. From Technology, they learn about food processing and sensor-based evaluation techniques. From Engineering, modifying the type of rice flour to design specific textural properties promotes optimization-oriented thinking. From Mathematics, students analyze experimental data using graphical and statistical methods. Finally, sensory evaluation of taste and texture incorporates artistic and creative elements (Arts) related to food design. Overall, the soy- and rice-based ice proposed in this study serves as an effective educational material that integrates scientific inquiry, data analysis, and consideration of societal issues such as food allergies, thereby contributing to new perspectives in science education.

5. Future Perspectives

This study proposed an inquiry-based learning model using soy milk and rice flour ice as a teaching material that integrates food science and science education. To further enhance the educational and scientific significance of this research, several future directions should be explored.

First, expanding the range of raw materials is an important next step. In this study, two types of rice (Koshihikari and glutinous rice) were used; however, future research could include rice varieties with intermediate amylopectin content or rice flours with different degrees of polishing. Such extensions would allow for a more detailed investigation of continuous changes in physical properties and texture, enabling students to better understand how material selection influences experimental outcomes.

Second, further simplification and validation of measurement methods are required. While the prototype simplified measuring device demonstrated that relative comparisons of hardness and adhesiveness are feasible, future work should systematically evaluate measurement reproducibility and error ranges. This would strengthen the reliability of the activity in school settings and provide opportunities for more advanced inquiry, such as discussions on experimental uncertainty and limitations.

Third, empirical evaluation of educational effectiveness through classroom implementation is essential. Conducting lessons using this activity in secondary school classrooms and analyzing changes in students' scientific thinking, data interpretation skills, and learning motivation through both qualitative and quantitative approaches would clarify its value as an inquiry-based educational practice. Finally, by addressing food allergies as a socially relevant issue, this activity can be expanded into interdisciplinary learning involving health education and home economics. Experiencing food evaluation and design based on scientific data allows students to recognize the close connection between science, everyday life, and societal challenges.

Through these future developments, the inquiry activity using soy milk and rice flour ice is expected to evolve into a practical and inclusive model for science education.

6. REFERENCES

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