Original Article

Evaluation of the texture of wet rice crackers

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Abstract
This study aims to redesign a manufacturing process of wet rice crackers for new customer acquisition at café "Nisyouan" in Mt. Tsukuba. The study tries to reveal the relationship between the physical properties and evaluation terms of wet rice crackers. Three aspects were varied in the production process, namely hoiro time, baking time, and time before application of soy sauce. The results of sensory evaluation were collected through the evaluation of the samples by an evaluator who ate samples and then answered a questionnaire concerning them. An explication of the causal structure using organoleptic evaluation and physical properties was attempted. Using the physical properties and hierarchy for each of the evaluation terms and the psychological response, principal component analysis and factor analysis were performed. Graphical modeling was applied to each hierarchy. The result indicated causality in each hierarchy. Therefore, a method for the design of food texture of wet rice crackers, which young people like, was derived.

Keywords
food texture, kansei engineering, graphical modelling, wet rice cracker, mechanical characteristic

1. Introduction

Mt. Tsukuba is a tourist spot so well-known that there has come to be a common expression: "Fuji in the east and Tsukuba in the west." For this reason, this spot attracts many tourists, more than 1.9 million, annually. A popular cafe for tourists here is Nisyouan. The purpose is to show them the attractions of Ibaraki-ken. The most popular goods here are the local rice crackers. The dough for the rice crackers is made from the locally grown Hitachi Oda rice and they are flavored using the Numaya soy sauce. Generally, these are mass-produced. However, in the cafe, they are made manually. Each batch of dough is baked and flavored. There are several sub-processes in this manufacturing process, the most difficult being the one involving the production of wet rice crackers. These vary in quality depending on the manufacturing conditions. However, when the wet rice crackers that please customers do manage to be produced, the reputation of Ibaraki-ken grows. As a result, increases in tourist traffic can be expected. Therefore, it is important to know how such products are evaluated by tourists.

Kansei engineering is a method of product design that reflects sensory evaluation. It was first defined by Nagamachi [1988] as "the technology which translates a human image into a physical design element in detail" and "the technology which does a multi-variate analysis in sensitivity data of customers and represents the result in a design." *Kansei* engineering has been often used in recent years in the research and development of products at actual companies [Habuka, 2013; Seo, 2011]. However, there have been few studies dealing with food texture [Kumaoh, 2014; Kumaoh et al., 2008]. Such studies as exist have not investigated physical properties of food. On the other hand, food texture study in the food engineering field involves quality evaluation through measurement of the physical properties, as well as sensory evaluation. However, sensory evaluation is not for measuring human needs; it has been treated as the same measurement using the equipment. The physical properties of food textures are generally investigated using a model of human chewing, by texturometer. However the relationship between the measurement of physical properties and the terms of evaluation is not yet clear. It is considered that physical properties obtained from mechanical characteristics are limited to empirical terms, defined as hardness, cohesiveness, viscosity, elasticity, and adhesion [Sato et al., 1988]. Although no objective basis is indicated in the relationship, many previous studies have used these terms. Moreover, there remains a problem that the results of the mechanical characteristics change according to the measurement conditions of the texturometer [Sagara, 2009]. This study estimates the food texture of wet rice crackers produced by Nisyouan from the perspective of the two research fields of food engineering and kansei engineering. This study derives a design method for preferred food textures for customers. The aims of this study are as follows:

- To clarify the relationship between manufacturing conditions and physical properties.
- To clarify the relationship between evaluation terminology such as delicious and the process of recognition and perception.
- To clarify the relationships among processing conditions, physical properties, and evaluation terminology and to derive a method for manufacturing the wet rice crackers that the tourists consider delicious.

2. Experiment

2.1 Manufacture of wet rice crackers

The manufacture process of general wet rice crackers can be classified into dough making and baking. This study deals with only the manual baking process of Nisyouan. This baking

process consists of three variables, namely *hoiro* time, baking time, and waiting time for soy sauce application. The manufacturing conditions of these three variables vary.

- Step 1. *Hoiro* time:
  The rice cracker dough is dried at low heat.
- Step 2. Baking time:
  The baked color is imparted to the rice cracker surface at high heat.
- Step 3. Waiting time for soy sauce application:
  A sample with the baked color is removed from heat. After several tens of seconds, soy sauce is applied for about 3s.

We created 12 samples in our experiment. The manufacturing conditions of each sample are indicated in Table 1.

Table 1: Experimental samples

Sample No.	Hoiro time (min)	Baking time (s)	Waiting time for soy sauce application (s)
1	0	60	10
2	0	100	10
3	0	140	10
4	15	60	10
5	15	100	10
6	15	140	10
7	0	60	60
8	0	100	60
9	0	140	60
10	15	60	60
11	15	100	60
12	15	140	60

2.2 Previous studies of wet rice crackers

Among the 271 evaluation terms for food texture presented to the estimators, wet rice crackers rank second in the number of terms used, after jelly [Hayakawa et al., 2011]. Rice crackers with a certain level of moisture are indicated as having a peculiar hardness and viscosity. Such samples are difficult to crunch [Wada et al., 2002; Wada et al., 2007]. Seventeen of commercial products using water content are classified into four types based on mechanical characteristics and sensory evaluation [Ibe et al., 2012]. Hardness is defined as the maximum breaking load, according to mechanical characteristics. A relationship is found to exist between the hardness of nine types of commercial rice crackers and the evaluation terms of onomatopoetic words and imitative words [Ishibashi et al., 2015]. On the other hand, no relationship has been confirmed between mechanical characteristics and sensory evaluation terms.

2.3 Measurement of mechanical characteristics

A texturometer (JSV-1000H, Japan Instrumentation System Co., Ltd.) was used to measure the mechanical characteristics. A conical plunger was used in our experiment. An example of the relationship between mechanical characteristics and physical properties is indicated in Figure 1.

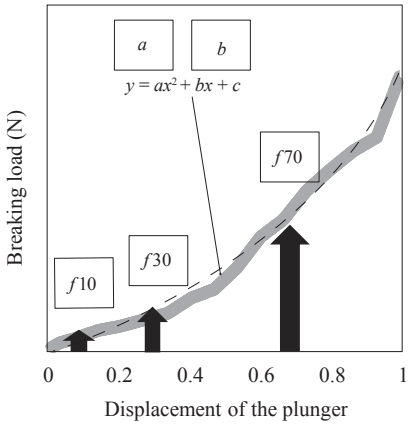

Figure 1: Example of physical properties

The mechanical characteristics indicated are the breaking load, shown on the vertical axis, and the displacement of the plunger, shown on the horizontal axis. The breaking load (N) at each displacement is measured using the plunger moved in the vertical direction to a sample under constant speed. The displacement of the plunger of a measured mechanical characteristic is defined as follows: the location where the plunger touches the sample is defined as 0 and that where the plunger touches the table in the texturometer is defined as 1. The mechanical characteristic in six different parts in the samples was measured. In previous studies, the looseness of the measurement result has often stemmed from the assumption of a homogeneous food due to the compatibility of the measuring instrument and the experiment sample. Therefore, in order to evaluate the physical properties, a second-order polynomial was calculated by applying the method of least squares to the mechanical characteristics of six different parts measured by the texturometer. The calculation method employed for this evaluation has not been used by previous studies and shows several advantages. First, these values, which considered looseness of the physical characteristics, are calculated. Second, the values reflecting the total mechanical characteristics are obtained. In this study, the physical properties obtained are a (the coefficient of the squared term) and b (the coefficient of term), and the breaking loads of $f10$, $f30$, and $f70$ are used for each displacement, as shown in Figure 1. The breaking load for each displacement has a high correlation with the onomatopoetic and imitative words [Ikeda et al., 2006].

2.4 Sensory evaluation

Before the sensory evaluation, a preliminary investigation was conducted to create the questionnaire. Candidates for the preliminary investigation included nine men and nine women (four individuals in their 20s, two in their 30s, six in their 40s, and six in their 50s), totaling 18 people. The questionnaire in

Table 2: Evaluation terms used for the sensory evaluation questionnaire

	SD method: 9 levels of antonyms
Evaluation terms	*katai* (hard, firm) – *yawarakai* (soft) (2 case: first bite and during chewing)
	kamigotaegaaru (chewy) – *kamigotaeganai* (non-chewy) (2 case: first bite and during chewing)
	hagotaegaaru (chewy) – *hagotaeganai* (non-chewy) (2 case: first bite and during chewing)
	kamiyasui (easy to bite) – *kaminikui* (difficult to bite)
	nomikomiyasui (easy to swallow) – *nomikominikui* (difficult to swallow)
	parittositeiru (crispy) – *motittositeiru* (rice cake-like)
	kokeino (solid) – *ekijouno* (liquid)
	kawaiteiu (dry) – *simetteiru* (wet)
Psychological response	good taste – bad taste
	good sound – bad sound
	good food texture –bad food texture
	good smell – bad smell
Comprehensive evaluation	delicious – unappetizing

the preliminary investigation randomly arranged 271 terms used in previous studies [Hayakawa et al., 2011]. Each evaluator was asked about each of these terms for the rice crackers at three stages (appropriate, little appropriate, and inappropriate). The terms *katai* (hard, firm), *hagotaegaaru* (chewy), *kamigotaegaaru* (chewy), *kawaita* (dry), *siketa/siketta/sikketa* (wet), and *kokei-no* (solid), which were appropriate more often than inappropriate, were selected and onomatopoetic and an imitative words were removed. To these terms were added the terms of the preceding study [Ibe et al., 2012]. The evaluation terms used for sensory evaluation are shown in Table 2. For sensory evaluation, a questionnaire including a total of 17 items at nine stages was adopted using the SD method, and the hierarchy for these terms was set according to Munechika et al.'s [2000] study.

The sensory evaluation included 30 evaluators (18 men and 12 women), all of whom had experience in eating a general wet rice cracker; the evaluators scored the samples in the SD method on the basis of this experience. The samples were divided into eight equal parts and were processed into bite-size portions. Each evaluator was shown the samples in a different order. The sensory evaluation experiment was conducted according to the following procedure.

- Step 1 The evaluator drinks mineral water.
- Step 2 The evaluator tastes wet rice crackers in the designated order.
- Step 3 After sampling, the evaluator immediately evaluates them according to the established criteria on the questionnaire using the SD method.
- Step 4 The evaluator drinks mineral water after
- responding.
- Step 5 The evaluator repeats the procedure 11 times. The evaluator writes down his/her personal information (age, sex, frequency of eating a wet rice cracker, liking for a wet rice cracker or not, etc.).

3. Results

3.1 Physical properties

The values for *a*, *b*, *f*10, *f*30, and *f*70 for each sample are indicated in Figure 2. The values for a and *f*70 decreased, while those for *b*, *f*10, and *f*30 increased for longer waiting time for soy sauce application. The result of the principal component analysis is indicated by the physical properties in Table 3. Principal component analysis was applied to five physical properties. As a result, one main ingredient was selected. The negative values for *a* and *f*70 indicate broken samples. Therefore, this main ingredient was interpreted as leading to rice crackers that were easy to break, and thus, shows that samples with high

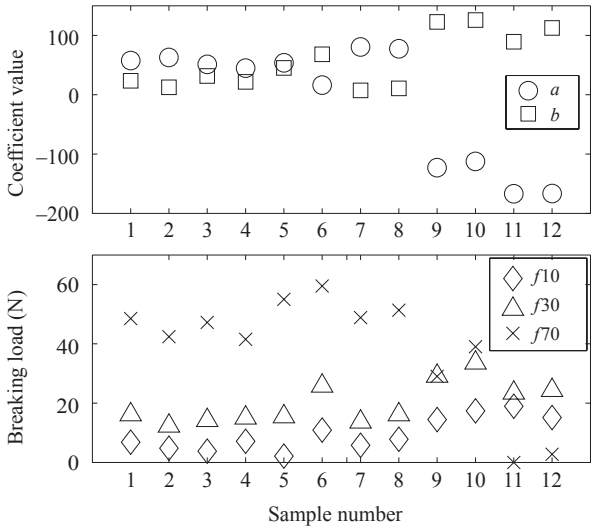

Figure 2: Coefficient values *a*, *b* and breaking loads *f*10, *f*30, *f*70

Table 3: PCA of physical properties

	Component
	Easy to break
a	–.985
b	.947
*f*10	.956
*f*30	.883
*f*70	–.772
Eigenvalue	4.158
Contribution ratio	83.151
Cumulative contribution ratio	83.151

scores tend to break easily and those with low scoring samples tend to transform and extend.

3.2 Evaluation terms

The result of the principal component analysis (PCA) of the evaluation terms is indicated in Table 4. PCA was applied to 10 items of the evaluation terms, and PC1 and PC2 were selected as the main ingredients. PC1 was interpreted as hardness depending on positive or negative value of the PC loading. The evaluation terms *katasagaaru* (hard, firm), *kamigotaegaaru* (chewy), *hagotaegaaru* (chewy), and *parittositeiru* (crispy) showed correlation to PC1. PC2 was interpareted as easy to eat. The evaluation terms of kamiyasui and nomikomiyasui showed correlation to PC2.

Table 4: PCA result of the evaluation terms

	Component	
	PC1 Hardness	PC2 Easy to eat
katasagaaru (first bite)	.990	–.032
katasagaaru (during chewing)	.970	–.129
kamigotaegaaru (first bite)	.915	–.335
kamigotaegaaru (during chewing)	.950	–.156
hagotaegaaru (first bite)	.961	–.118
hagotaegaaru (during chewing)	.982	–.013
kawaiteiru	.974	.178
parittositeiru	.965	.227
kamiyasui	.496	.825
nomikomiyasui	–.123	.970
kokeino	.985	.058
Eigenvalue	8.659	1.877
Contribution ratio	78.719	17.059
Cumulative contribution ratio	78.719	95.778

The term kamiyasui means easy to bite and nomikomiyasui means easy to swallow; the suffix – yasui indicates easiness. The scatter plot of average PC scores for each sample for the evaluation terms is indicated in Figure 3 in the psychological response. In this scatter plot, PC1 indicates the horizontal axis and PC2 indicates the vertical axis. Each number on the scatter plot shows the sample number. This scatter plot shows that for PC1, samples with short waiting time for soy sauce application have low scores, while those with long waiting time have high scores. When the waiting time is short, no clear difference is seen in PC2. However, scores for PC2 increase with waiting and baking time.

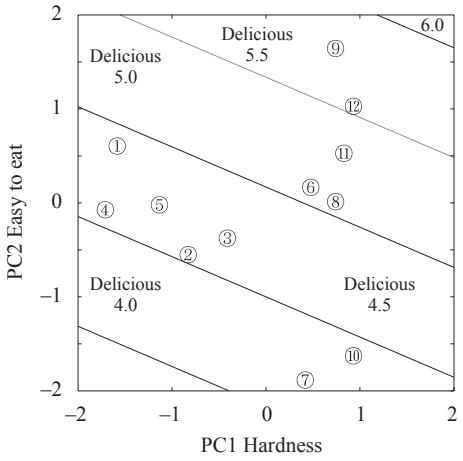

Figure 3 Scatter plot of average PC scores of the samples in evaluation terms

3.3 Psychological response

There are various factors, such as sense and feeling, for psychological response besides food texture, sound, taste, and smell. Contraction by PCA did not use these items. The common factors of these items were selected using factor analysis.

The result of the factor analysis (the principal factor method) of psychological response (promax rotations) is indicated in Table 5. Two factors were selected as the result of the analysis for four evaluation terms. Factor 1 was interpreted as good taste, good sound, and good food texture, and Factor 2 was in-

Table 5: Factors of psychological response

	Factor	
	Factor 1 Good taste sound, food and texture	Factor 2 Good smell
good taste	.937	–.0349
good sound	.856	.309
good food texture	.993	.0071
good smell	–.009	.943
Component correlation	–.069	

terpreted as good smell. The taste, tone, and food texture were the estimated items in eating the cracker. Therefore, these were summarized as Factor 1. On the other hand, good smell in Factor 2 was evaluated before each sample was eaten. Therefore, samples soaked in soy sauce were scored high.

The scatter plot of average scores of the factor scores of the samples in the psychological response is indicated in Figure 4. This scatter plot shows the mean of the evaluator's factor score for each sample. In this plot, Factor 1 indicates the horizontal axis and Factor 2 indicates the vertical axis. The numbers on the scatter plot indicate the sample numbers. Samples with a long waiting time for soy sauce application and long baking time indicated a high score for Factor 1. This was expected for food texture in rice crackers. This is because long heating can remove water from the sample, causing it to break more easily. Samples with short waiting time received a high score for Factor 2. These samples also received high score in simetteiru. They were often soaked in soy sauce and generally seemed to be wet rice crackers. The sample with the highest score for smell, sample number 1, and the lowest, sample number 7, differed only in the waiting time. Even if *hoiro* time and baking time are set appropriately, the evaluation changes due to the waiting time. Thus, when making wet rice crackers, the waiting time for the soy sauce application in the final process must receive particular attention.

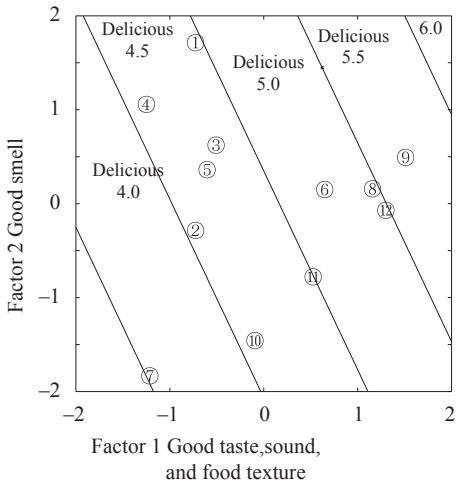

Figure 4: Scatter plot of the average scores of the factor scores of the samples

3.4 Causality in each hierarchy

Graphical modeling is a method of modeling causality in order to determine a cause. Variables are set in several hierarchies from cause to effect. Partial correlation for variables is calculated. An arrow indicates a causal relationship. If the partial correlation coefficient is 0, there is no cause-and-effect relationship. In this study, the standard cut-off value was set as 0.1.

Comparative adaptation indices for considering the hierarchy of the physical properties were $\chi^2 = 43.8$, $df = 21$, and $p = 0.00$. The cause of low of this adaptation is between the physical properties and evaluation terms of the hierarchy. The indices of fit of the physical properties and the evaluation terms of the hierarchy are $\chi^2 = 27.1$, $df = 6$, and $p = 0.00$. The indices of fit of the physical properties and the hierarchy of the evaluation terms are $\chi^2 = 27.1$, $df = 6$, and $p = 0.00$. Therefore, when removing the hierarchy of the physical properties, fitness was relatively good for the comparative fit index $\chi^2 = 14.3$, $df = 12$, and $p = 0.28$. Figure 5, with high adaptation except for the physical properties, indicates the causality of each hierarchy.

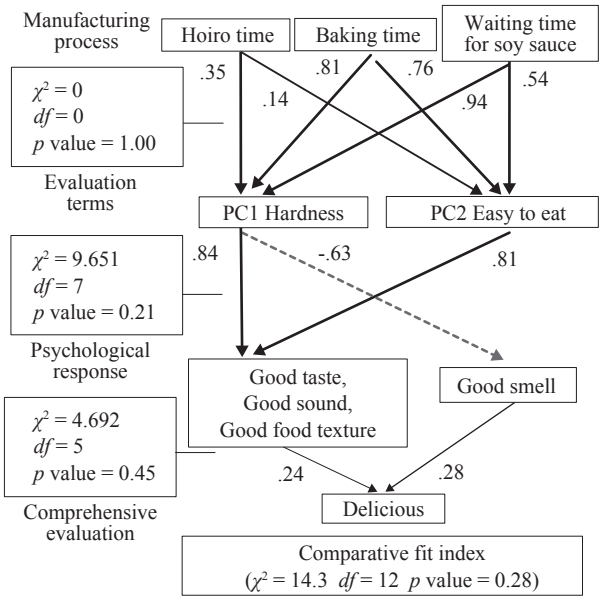

Figure 5 Result of graphical modeling

PC1, hardness, and PC2, easy to eat, in the evaluation terms increase with the process time for manufacturing. The effect of waiting time for soy sauce application, in particular, is large. As the characteristic easy to eat increases, good taste, sound, and food texture also increase. For these samples, easy to eat produces a light chewing sound as well as a pleasant food texture. These samples were easy to break. Low-scoring samples in hardness show increases in good smell. The samples are difficult to break and tend to expand. Therefore, high values of a and *f*70 are confirmed. The comprehensive evaluation delicious is decided by the characteristics good taste, sound, food texture, and good smell in the psychological response. Thus, when making wet rice crackers that an evaluator evaluates positively, it is important to make waiting time for soy sauce application as short as possible. On the other hand, when designing dried rice crackers, hardness and ease of eating are necessary. *Hoiro* time and baking time, as well as the waiting time for soy sauce application, should be set longer.

4. Influence to indigenous products in tourist spots

Nisyouan is trying to appeal to new customers for attracting them to Mt. Tsukuba. The new challenge is appointing students to the University of Tsukuba by advertising through

leaflets and seeking new seasoned young people. This study is also a trial toward this end. This study can also contribute to advertising as an advanced effort. Indigenous products of a tourist spot like Mt.Tsukuba consist of traditional ingredients and local recipes. The president of Nisyouan talked, "We must revise rice cracker in adaptation of the feeling and needs of the modern people." So this research sets the students' needs as the evaluation criteria to attract new customers at Nisyouan. A result of this study is the discovery of a food texture that the young generation likes. Therefore, acquisition of new customers of Nisyouan is expected.

5. Conclusions

This study shows a method for designing the food texture of wet rice crackers which students like. These results can contribute to the acquisition of new customers of young people to Nisyouan in Mt.Tsukuba. The conclusions of this study are as follows:

- The comprehensive evaluation delicious is correlated by Factor 1, good taste, sound, and texture and Factor 2, good smell, in the psychological response. Factor 1 increases with PC1, hardness, and PC2, easy to eat, in evaluation terms. When PC1, hardness, receives a low score, good smell increases.
- The mechanical characteristics of wet rice crackers indicate elastic behavior; they easily transform and expand. The samples with low scores for a and f70 are easy to break.
- Increases in three variables of the processing cause increases in the hardness and ease of eating. As a result, good taste, sound, and texture improve, and wet rice crackers liked by an evaluator are prepared. With short baking times and long waiting time for soy sauce application, Factor 2, good smell, and the comprehensive assessment delicious decline drastically.

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