Section 2

Application (Case Studies)

Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

Part I

Robust Engineering: Chemical Applications

Biochemistry (Cases 1–2)
Chemical Reaction (Cases 3–4)
Measurement (Cases 5–8)
Pharmacology (Case 9)
Separation (Cases 10–11)

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CASE 1

Optimization of Bean Sprouting Conditions by Parameter Design

Abstract: In this study we observe bean sprout germination and growth as a change in weight and evaluate this change as a generic function of growth.

1. Introduction

For growing bean sprouts, we use a series of production processes where small beans are soaked in water and germinated and grown in a lightless environment. As shown in Figure 1, this process is divided into germination, growth, and decay periods. The major traits in each period are described below.

Germination Period

Although the raw material for bean sprouts is often believed to be soybeans or small beans, in actuality, they are specific types of small bean: mappe (ketsuru adzuki) and green gram. The former are imported from Thailand and Burma, and the latter mainly from China. Despite the fact that green gram has become mainstream, its price is three to five times as great as black mappe's. Because they grow under dry and hibernating conditions, they must be soaked in water and heated for germination. Germination has the important role of sprouting them and also increases the germination rate and sterilizes accompanying bacteria.

Growth Period

After germination, mappes absorb a considerable amount of water. Regarding three days before shipping as a growth period, we evaluate an SN ratio.

Decay Period

Although a plant needs photosynthesis after a growth period, bean sprouts normally decay and rot because no light is supplied in the production environment. Whether the preservation of bean sprouts is good or poor depends on the length of the decay period and the processing up to the decay period. On the basis of a criterion that cannot judge whether growth should be fast or slow, such as "a fast-growing bean sprout withers fast," or "a slowly growing bean sprout is immature and of poor quality," a proper growth period for bean sprouts has been considered approximately seven days. Additionally, a contradictory evaluation of appearance, one of which insists that completely grown bean sprouts are better because they grow "wide and long" and the other that growing young sprouts is better because they last longer, has been used. We believe that our generic function (in this case, a growth rate by weight is used) can evaluate the ideal growth, as shown in Figure 1, solving these contradictions. A state where no energy of bean sprouts are wasted for purposes other than growth is regarded as suitable for healthy bean sprouts.

2. Generic Function

Bean sprouts grow relying on absorption of water. This study observes a process of bean sprout germination and growth as a change in weight and evaluates this change as a generic function of growth. Figure 1 shows three states: actual, ideal, and optimal regarding the weight change of normal bean sprouts.

Although perpetual growth is ideal, in actuality, after using up nutrition, bean sprouts slow their

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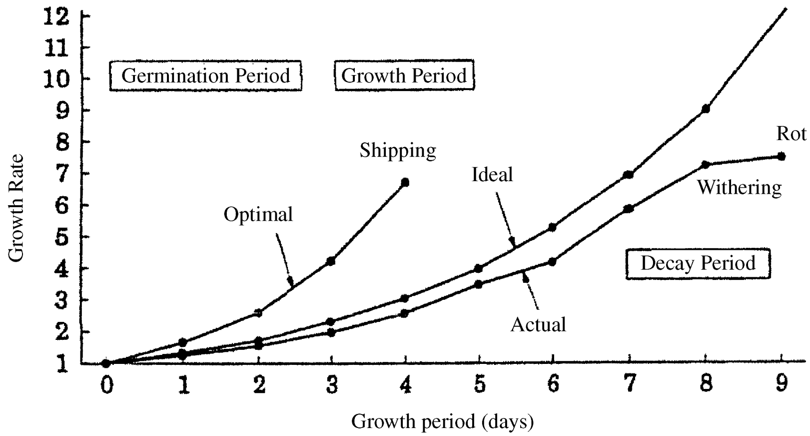

Figure 1
Growth curve of bean sprouts

growth and wither from around the seventh day because only water is supplied. This entire process, classified into germination, growth, and decay periods, cannot be discriminated perfectly. Then, for a period of water absorption and growth caused by germination, setting the initial weight of seeds to Y_0 and the grown weight after T hours to Y, we define the following as an ideal generic function:

$$Y = Y_0 e^{\beta T} \tag{1}$$

By transforming equation (1), we obtain:

$$\ln(Y/Y_0) = \beta T \tag{2}$$

Setting the left side of equation (2) to y, we have the following same zero-point proportional equation for time, as used in chemical reactions:

$$y = \beta T \tag{3}$$

We use an exponential function in equation (1), based on the idea that a seed absorbs water and then divides its cells. However, whether this is the generic equation of a plant's growth is not clear. Therefore, if there are other equations to express the water absorption and growth period of a plant, we should make the most of them. Nevertheless, we do not need to use a complicated equation analyzing natural phenomena, even if it is regarded as rational to express the growth. What is most important is to predict the rationality of our idea before putting it to a practical use. This is the quality engineering way of thinking.

1. *Selection of signal factor.* Considering the ideal function, we choose time as a signal factor. More specifically, with 24 hours as one day, we select five, six, and seven days as signal factor levels.
2. *Selection of noise factors.* Since simultaneous control of humidity and temperature is quite difficult, we focus on humidity, which is considered to be more easily regulated as an experimental noise factor.

N_1: desiccator at the humidity of 60%

N_2: desiccator at the humidity of 80%

Although we select humidity as a noise factor rather easily, we have a contradiction between the factor effects on SN ratio and sensitivity if we compute them after decomposing the two levels of the noise factor. Furthermore, under the condition of slightly high humidity, the gain in SN ratio is negative, whereas that in sensitivity is positive. This result seems to be of great significance because this result is consistent with our experience in growing bean sprouts, and the factor is likely to be one that can adjust our contradictory objectives that bean sprouts should have fast growth but delayed rot.

In addition, since according to the image of continuous water sprinkling in our operation, we might have set both humidity levels high in the experiment. As a result, it is believed that important conditions of water sprinkling selected as control factors become vague and thus lead to a lower contribution of control factors in our experiment. If we conduct another experiment, we should include humidity as a control factor and also add much drier conditions. In fact, the growth room for bean sprouts in our actual operation is not a high-humidity environment.

As an example, we calculate an SN ratio using the data for experiment 1 in the L_{18} orthogonal array.

Total variation:

$$S_T = 1.500^2 + 1.623^2 + 1.692^2 + 1.625^2 + 1.697^2 + 1.758^2 = 16.359796 \qquad (f = 6) \tag{4}$$

Effective divider:

$$\gamma = 5^2 + 6^2 + 7^2 = 110 \tag{5}$$

Linear equations:

$$L_1 = (1.500)(5) + (1.623)(6) + (1.692)(7) = 29.082 \tag{6}$$

$$L_2 = (1.626)(5) + (1.697)(6) + (1.758)(7) = 30.618 \tag{7}$$

Variation of proportional term:

$$S_\beta = \frac{(29.082 + 30.618)^2}{(2)(110)} = 16.200409 \qquad (f = 1) \tag{8}$$

Variation of differences between proportional terms:

$$S_{N\beta} = \frac{(29.082 - 30.618)^2}{(2)(110)} = 0.010724 \qquad (f = 1) \tag{9}$$

Error variation:

$$S_e = 16.359796 - 16.200409 - 0.010724 = 0.148627 \qquad (f = 6) \tag{10}$$

Error variance:

$$V_e = \frac{0.148627}{4} = 0.037157 \tag{11}$$

Total error variance:

$$V_N = \frac{0.010724 + 0.148627}{1 + 4} = 0.031870 \tag{12}$$

SN ratio:

$$\eta = 10 \log \frac{[1/(2)(110)](16.200409 - 0.031870)}{0.031870} = -3.63 \text{ dB} \tag{13}$$

Sensitivity:

$$S = 10 \log \frac{1}{(2)(110)} (16.200409 - 0.031870) = -11.34 \text{ dB} \tag{14}$$

3. Optimum Configuration and Confirmatory Experiment

To pursue an ideal function of growth, we select factors that are likely to affect growth and determine the experimental conditions. Since we study factors especially to determine a condition in the growth room in our experiment, from control factors we exclude germination conditions such as the water-soaking temperature. In each experiment we set up an identical germination condition because it influences the germination rate and sterilization effect of bacteria, which are not within the scope of this study. Table 1 shows the control factors and levels.

- *Type of seed* (A). Although this is not a condition of growth, selection of a seed (mappe) is regarded as essential to growth. Although black mappe is widely used, the demand for green gram (green bean) has started to soar because of its better growth, despite its being three to five times as high in price. We chose these two seed types for our experiment.

Table 1
Control factors and levels

Control Factor	Level 1	Level 2	Level 3
A: type of seed	Black mappe	Green gram	
B: room temperature (°C)	18	24	30
C: number of ethylene gas bathings	Morning (9 am)	Morning (9 am) Noon (12 pm)	Morning (9 am) Noon (12 pm) Evening (5 pm)
D: concentration of ethylene gas (mL/L)	10	20	30
E: sprinkling timing	Morning (9 am)	Morning (9 am) Noon (12 pm)	Morning (9 am) Noon (12 pm) Evening (5 pm)
F: number of mist sprays (0.5 mL/spray)	1	2	3
G: amount of mineral added to sprinkled water (%)	0	0.1	1.0

- *Number of ethylene gas bathings* (C). An ethylene gas, also called a plant hormone, is used for production of thick bean sprouts. In addition, it is believed that this is related to the aging and decay of bean sprouts. Furthermore, bean sprouts themselves are considered to generate an ethylene gas when they feel stress.

Figure 2 shows the response graphs for an L_{18} orthogonal array including each factor. Based on them, we select $A_2B_1C_3D_2E_1F_2G_1$ as the optimal configuration for the SN ratio. On the other hand, the counterpart for sensitivity is $A_1B_2C_1D_1E_2F_1G_1$.

The factors with the largest effects are $B_1D_2F_2$ for the SN ratio and A_1B_2 for sensitivity. Now, choosing

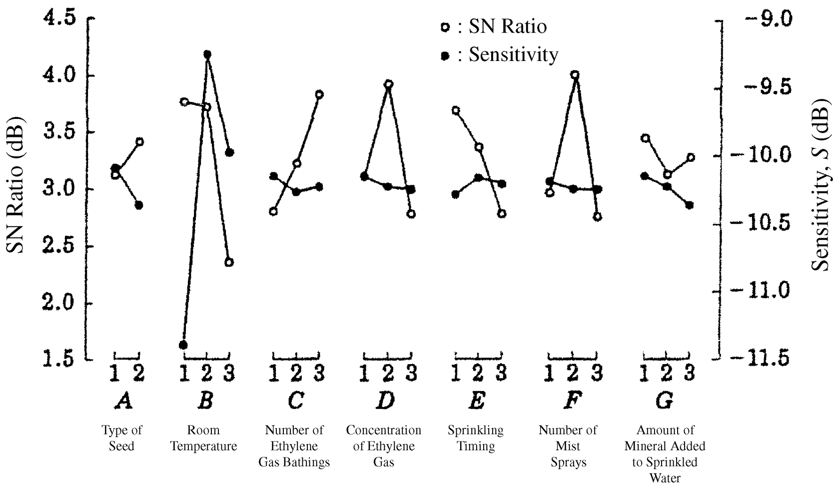

Figure 2
Response graphs

the following combinations for the optimal configurations, we estimate a sensitivity, SN ratio, and process average, respectively.

1. Optimization prioritizing growth rate (sensitivity)
2. Optimization prioritizing SN ratio
3. Optimization of SN ratio balancing growth rate (sensitivity)

For each combination, we estimate the process average. Table 2 shows the results. For the maximization of both characteristics, we can select combination 3. Table 3 summarizes the results of the confirmatory experiment.

Despite a difference from the estimated SN ratio, we conclude that fairly good reproducibility is obtained because of a small difference between the estimation and confirmation. On the other hand, we can attain gains of 2.20 and 2.56 dB in SN ratio and sensitivity, respectively, which are regarded as sufficient for our improvement in growth.

Our experiment cannot produce significant improvement in the SN ratio. Since there is a slight difference between estimation and confirmation in the SN ratio, we are somewhat skeptical of the additivity in the SN ratio. This is primarily because our selection of ranges for signal factor levels is not appropriate (i.e., we should use the growth range of an earlier stage). Other major reasons are as follows: (1) because humidity chosen as the noise factor is shifted too much to the side of high humidity, the sprinkling condition becomes ambiguous; (2) because of a long experimental period spanning approximately 20 weeks, changes in environmental conditions cannot be ignored; and (3) there is considerable variability in property among mappes.

Particularly for the variability in mappe properties mentioned above, to mitigate the variability we should have increased the number of mappes or sieved only appropriate sizes. In the case of handling organisms, it is difficult to select uniform samples because of large variability among individuals. Therefore, we need to plan an experimental method in such a way that individual variability is negligible.

The improvement in SN ratio leads to (1) smooth growth (decline or elimination of frequent occurrence in rot, prolonged period of preservation), and (2) improved controllability of a growth curve (controllability of a growth rate, shipping, or surplus and shortage in volume). In the meantime, the improvement in sensitivity brings the following: (1) a shortened period of growth, more accurate prediction of shipping day; and (2) reduction in production cost, streamlining of production operations, retrenchment of production equipment, more effective use of space for other products, mitigation of industrial waste. Shortening of a production period by improving sensitivity, *S*, leads to significant cost reduction together with high productivity.

In the meantime, among the unexpected significant benefits brought about by short-term growth or early shipping is a reduction in industrial waste. In producing bean sprouts, although little waste is caused by rottenness that occurs in normal production processes, we have had a considerable amount of waste due to excessive production by incorrect prediction of a shipped volume. The cost required to discard the waste (which is not a loss due to the discard of products themselves but the expense of turning the waste over to industrial waste disposal

Table 2
Estimation of optimal configuration

	Combination		
	1	2	3
SN ratio (dB)	4.02	5.30	5.26
Sensitivity (dB)	−9.24	−11.19	−9.24
β	0.325	0.276	0.345
Growth rate on seventh day	11.20	6.89	11.20

Table 3
Results of confirmation experiment for combination 3 (dB)

		Configuration		
		Optimal	**Current**	**Gain**
SN ratio	Estimation	5.26	—	—
	Confirmation	5.72	3.52	2.20
Sensitivity	Estimation	−9.24	—	—
	Confirmation	−8.93	−11.49	2.56

companies) sometimes amounts to several million yen monthly. Shortening a production period contributes greatly to improved prediction.

Similarly, higher production stability achieved through improvement in the SN ratio is among the benefits that is difficult to evaluate monetarily. Above all, a constant drop in the amount of rotten products is considered one of the most effective improvements, even though it is difficult to grasp.

The frequent occurrence of rotten products inside a factory is a serious problem. Although this does not take place often, when it happens, it is generally on an enormous scale. Proliferation of bacteria in a growth room with no sunlight and extremely high humidity and temperature is always of concern. Even if only a small number of bacteria proliferate, the appearance of the bean sprouts is damaged, so that not all of them can be shipped.

Although the proliferation of bacteria and rot are regarded as defects, we cannot succeed in implementing an experiment focusing on defects, where we make evaluations based on the frequency of occurrence. Therefore, a decline in rotten products through an improved SN ratio is regarded as effective. In a study of the SN ratio, rotten product is not measured as a quality characteristic but is a good countermeasure for rotten products. (If we calculate experimentally the limitation that rotten products occur, we will be able to compute the cost using the loss function based on the on-site SN ratio at the production plant.)

Reference

Setsumi Yoshino, 1995. Optimization of bean sprouting condition by parameter design. *Quality Engineering*, Vol. 3, No. 2, pp. 17–22.

This case study is contributed by Setsumi Yoshino.