A FINAL REPORT ON THE COMMERCIAL QUALITY AND VALUE OF NORI PRODUCED IN AN OTEC-LIKE SYSTEM IN HAWAII

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WORKING PAPER NO. 53

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ABSTRACT

Nori (Porphyra sp.) produced in the experimental OTEC system at the Natural Energy Laboratory of Hawaii, Keahole Point, Hawaii was transported to Japan for processing into nori sheets. The resulting nori sheets were evaluated by qualified experts as a commercial product. Mostly due to damage when frozen for transport, the OTEC nori was judged to be of very low quality and worth about 6 yen (2.5 cents) per sheet if saleable at all. From the small amount of material that was undamaged in each sheet, the experts estimated the undamaged value at about twice, i.e. 12 yen (5 cents) per sheet. While this price may be considered low (an average Japanese nori sheet was purchased for about 20 yen (8.5 cents) this year), most of the Japanese experts emphasized that cultivating and processing high quality nori requires highly developed skills, favorable conditions and elements of luck, and that the Hawaii nori product was quite good for a "first try." They were optimistic that better quality sheets could be produced in OTEC systems. Corrective techniques were suggested, but with most technical improvements additional costs would be incurred. These results indicate that more quality improvement research is required if nori is to be grown commercially in Hawaii.

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INTRODUCTION

Research on the production of nori (Porphyra sp.) in OTEC-like effluents has been conducted at the Natural Energy Laboratory of Hawaii (NELH) at Keahole Point, Hawaii during 1982. Biological feasibility of growing nori in these effluents was demonstrated. Preliminary economic analyses (Woessner, et al., 1982) were also performed. To do these analyses, certain assumptions was that OTEC nori could be sold for 11 cents per sheet. This study was undertaken to test the commercial quality and value of nori grown in OTEC systems. Quality is determined once the nori has been processed into sheets.

Nori Processing

Nori sheets are the main product of nori. Nori in sheet-form has a long history. Three hundred years ago nori was made into sheets much like the sheets on sale in modern times. Until about 25 years ago, nori was processed by hand. Presently, sophisticated machines are used to process nori. Whatever technique is used, the steps in the process are the same.

Nori is traditionally harvested in the morning and quickly transported to the processing facilities. The production and processing unit is usually a family. The family members receive the freshly harvested material from the head-of-household, who does the harvesting, and quickly begin the processing steps. Those steps are illustrated in Figure 1 with a schematic of the operation where the OTEC nori was processed.

If the harvested nori is dirty, it is prewashed in seawater to remove dirt and debris. Then, the nori material is cut into small pieces in a mincing machine. Nori which is judged to be too hard is pumped with freshwater to the softening tank. Nothing can be done to cells which are already too soft. Freshwater tends to soften the cells. When the right hardness is achieved, the material is washed in freshwater and centrifuged to remove excess water. The resulting mush can be held for a short time in this condition in a holding tank. Just before pumping the material into the processing machine, the mush is mixed with water and nori in the apportioner to form a slurry. The proportion of water and nori in this mixture is controlled electronically according to settings made in the control box.

The slurry is pumped into the distributor where the slurry is run onto mats called "su" in precise amounts. The su are made of small (2-3 mm.) plastic cylinders. The flexibility of these su allow easy removal of the sheets after drying. The su are five abreast on a conveyor. A rectangular form that comes down on the mats restricts the slurry to 18 by 20 centimeters, the size of the resulting nori sheets. Excess water is pressed from the sheets with sponges and sucked away with a vacuum system. The su are then run past a bank of flourescent lights, where the operator of the machine inspects the sheets for consistency and thickness. Adjustments for subsequent sheets are made in the mixture remaining in the apportioner as necessary.

Finally, the damp sheets are conveyed into the dryer. To attain maximum quality the nori cells must still be alive upon entering the dryer. The temperature and humidity in the dryer are maintained at about 40°C and 40%, respectively. After about two hours, the dried sheets, still on the su, begin exiting the machine.

The sheets are immediately removed from the su by hand or by machine, stacked and folded in groups of ten sheets. Ten groups of ten folded sheets are stacked and bundled with a single paper strip. These bundles are put in boxes and transported to the local cooperative for grading. Wholesalers bid on the nori at centralized bidding places a couple times per month. Wholesalers or customers of the wholesalers package the nori in groups of ten sheets or process the sheets into yaki-nori (toasted nori) or ajitsukenori (flavored nori) for sale in retail stores.

Nori Grading

Grading nori is a well-developed skill. Graders can divide nori into about 100 different categories. Although the category designations vary by prefecture, the goal is to achieve uniformity within each lot. Once the wholesalers purchase the nori at the local fisheries cooperatives and resell it, the secondary processors may then regrade the nori into even finer categories. Nori grading is subjective, but the range of variation in estimates between graders is small.

Nori Quality

The value of nori is directly related to its overall quality. Consumers' perception of nori quality is an instantaneous impression based on several factors. All the sensations of taste are the primary basis for consumers' opinions, but are not direct factors for selection in retail stores. All the categories of nori sheet characteristics are listed in Tables 1 and 2.

Because luster and color are closely related to the taste and are the two easiest factors to evaluate in retail nori (usually packaged in transparent wrappers), these have become the most important superficial factors in nori quality. Consistency (even edges and no holes), contamination by foreign plant and animal material, and texture (roughness) can also be examined through the wrapper. After purchase, the consumer can check the flavor, aroma and hardness against the visible factors.

The highest quality nori is completely glossy, deep black with perhaps a greenish cast, unbroken, without holes, contaminating organisms or debris. Accompanying these factors should be the right flavor, aroma and hardness all of which are difficult to describe (see Table 2). Attractive packaging also conveys an impression of quality.

When wholesalers purchase nori sheets at bidding centers, samples of the sheets are placed in the bidding area without wrappers for their inspection. The wholesalers can then check for all the factors listed above. If taste does not correspond with appearance, the discrepancy is reflected in the bid price.

Table 1. OTEC Nori batch history and quality evaluation

batch #	1	2	3	4
initiation date	Jan. 7	Jan. 7	Jan. 7	Jan. 31
harvest date	Feb. 10	Feb. 10	Feb. 10	Feb. 12
handling method	frozen	frozen	frozen	fresh
transport method	frozen	frozen	frozen	fresh
arrival condition	unthawed	unthawed	unthawed	"undamaged"
pre-processing characteristics	"fluffy" reddish tasteless no aroma wrinkled	"fluffy" reddish tasteless no aroma wrinkled	"fluffy" reddish tasteless no aroma wrinkled	"fluffy" reddish tasteless no aroma wrinkled
	batch #2 was clearly superior to the other three batches, especially in color			
processing notes	with 3 & 4		with 1 & 4	with 1 & 3
<u>sheet characteristics</u>				
color	very red	red	very red	very red
luster	irregular 5-50% cloudy	irregular 5-50%	irregular 5-50% cloudy	irregular 5-50% cloudy
consistency	fluffy holes	fluffy holes	fluffy holes	fluffy holes
average weight	4.0 g	3.7 g	4.0 g	4.0 g
contamination	none	none	none	none
aroma	weak	weak	weak	weak
hardness	okay	okay	okay	okay
taste	flat	flat	flat	flat
price per sheet	$.013	$.026	$.013	$.013
suitable product	none	none	none	none

Table 2. Quality of OTEC nori processed on-site compared to Japanese nori

cultivation situation	on-site OTEC	average Japanese	best Japanese
grow out period	3-4 weeks	4-6 weeks	4-6 weeks
handling method	fresh	fresh	fresh
transport method	fresh	fresh	fresh
pre-processing characteristics	cohesive reddish flat taste weak aroma flat/ruffled	cohesive blackish nori taste fragrant flat/ruffled	cohesive black nori taste fragrant flat/ruffled
<u>sheet characteristics</u>			
color	reddish	blackish	black
luster	regular 80-100%	regular 70-90%	regular 100%
consistency	flat no holes	flat no holes	flat no holes
average weight	3.5 g	3.0 g	3.0 g
contamination	none	little	none
aroma	weak	normal	normal
hardness	okay	okay	okay
taste	flat	normal	normal
price per sheet	$.051	$.085	$.30-$.50
suitable product	ajitsuke	yakinori ajitsuke raw sheets	raw sheets

PROJECT OBJECTIVE

The primary objective of this project was to determine the quality and value of nori produced in OTEC-like effluents. Machines and skills for making nori sheets occur only in the orient, primarily in Japan, as is the expertise for judging commercial value. Consequently, it was necessary to transport raw nori produced at the Natural Energy Laboratory of Hawaii directly to Japan for processing and evaluation.

QUALIFICATIONS AND ROLES OF EXPERT CONTACTS

This project could not have been accomplished without the aid of several Japanese and American professionals. Their valuable contributions are hereby acknowledged. Their qualifications and roles in the success of this project are listed below along with their addresses:

Dr. Akio Miura, Department of Botany, Tokyo University of Fisheries, Konan-4, Minato-ku, Tokyo 108, Japan--Entire professional life devoted to academic studies of various biological aspects of nori resulting in numerous published papers; a long, close association with and involvement in the nori industry; the main contact in Japan; made the request to Mr. Seki of the Chiba Prefectural Fisheries Laboratory for assistance; provided many valuable comments.

Dr. Tuyosi Oohusa, Yamamoto Nori Research Laboratory, 5-2-12 Oomori-Higashi, Ootaku, Tokyo 143, Japan--Head of a private sector laboratory dedicated to providing basic information on factors affecting nori quality; his group has produced numerous academic papers on this subject; personally arranged the evaluation session by experts on the commercial quality and value of nori; his assistance and inputs added greatly to this project.

Yamamoto Nori Co., 1-6 Muromachi, Nihonbashi, Tokyo 103, Japan--Among the top three nori processing, distributing and retailing companies; specializes in only the highest quality nori products; has roots in the nori industry of over two hundred years; the only nori company with its own industry-wide-oriented laboratory.

Dr. Thomas Mumford, Jr., Marine Botanist, Department of Natural Resources, Olympia, Washington 98504--Entire professional life devoted to nori studies; conducting similar nori research in Puget Sound using traditional Japanese cultivation methods; has experience sending raw nori to Japan for processing and evaluation; provided much valuable information on transporting the OTEC nori to Japan.

Mr. Robert Iversen, Regional Fisheries Attache, United States Embassy, Tokyo, APO San Francisco, CA 96503--Assisted with inquiries to the Tokyo Customs Office.

Mr. Tatsuya Seki, Section Chief, Nori Experiment Station, Chiba Prefectural Fisheries Laboratory, 3091 Kokubo, Futtsu-shi, Chiba-ken 299-14, Japan--Directly involved in nori research for entire tenure at laboratory; his laboratory is very prominent among prefectural laboratories for nori research; with the assistance of Mr. Kaneko arranged for nori sheet processing by Miki family operation.

Mr. Kambee Miki, 3089 Minatomachi, Kokubo-aza, Futtsu-shi, Osawa-cho, Chiba-ken 299-14, Japan--His family has over thirty years experience in nori cultivation and processing; his personnel processed the OTEC nori into nori sheets with a Nichimo Wonman ("One Man") Fully Automatic Nori Sheet Processing Machine.

Dr. Osamu Imada, Kyowa Hakko Kogyo Co., Ltd., Ohtemachi Bldg., Ohte-machi, Chiyoda-ku, Tokyo 100, Japan--Has done several years of research on nori production; was involved in discussions of arranging this project; facilitated acquisition of the nori seed stock for culture in the OTEC-like system at NELH.

Dr. Yusho Aruga, Department of Botany, Tokyo University of Fisheries, Konan-4, Minato-ku, Tokyo 108, Japan--Has done much research on nori physiology resulting in many published papers; is closely affiliated with Dr. Miura; provided many useful comments.

Dr. Sachito Enomoto, Kobe University Marine Biological Station, Iwaya, Awaji Island, Hyogo-ken 656-24, Japan--Highly qualified seaweed expert; arranged meeting with Mr. Mori.

Mr. Yoshikazu Mori, Vice President, Federation of Fisheries Cooperatives Associations, 2205-5 Kuruma, Awagi-cho, Tsuna, Hyogoken, Japan--Has long involvement in development of floating culture systems around Awaji Island; prominent official in five nori organizations; provided valuable insight into development of nori production techniques.

Professor Saburo Ueda, Zennori, 2-16-5 Takanawa, Minato-ku, Tokyo 108, Japan--President of three prominent nori organizations; author of numerous publications on nori including THE HANDBOOK OF NORI CULTIVATION (1973); provided basic insight into nori tank culture.

Mr. Eiichiro Kaifu, Sales Manager, Zennori, 2-16-5 Takanawa, Minato-ku, Tokyo 108, Japan--Provided industrial view of non-Japanese efforts to cultivate nori.

Zennori, 2-16-5 Takanawa, Minato-Ku, Tokyo 108, Japan--Nori cooperative system; provides organizational structure; distributes information inside and outside the nori industry; facilitates financial assistance to nori cultivators; central clearinghouse for nori equipment.

EVALUATION GROUP

Mr. Kishi--Head of the grader group at Yamamoto Nori
Mr. Itakura--Assistant Head Buyer for Yamamoto Nori
Mr. Goto--Head Nori Buyer for Ohmori Suisan
Mr. Tanaka--Nori Buyer for Ohmori Suisan

Ohmori Suisan, 2-9-12 Higashi, Ohmori 143, Japan--A Marine products company speicalizing in nori; is closely affiliated with Yamamoto Nori.

METHODS AND RECORD OF EVENTS

To avoid problems with international transport of biological material, I called ten Hawaii state and federal agencies to inquire about proper procedures prior to taking the OTEC nori from the facilities at Keahole Point, Hawaii. Mr. Iversen made similar inquiries to the Tokyo Customs Office. All said that non-commercial nori materials would be unrestricted.

Specific preparations and arrangements were also made to have the OTEC nori processed and evaluated in Japan. I contacted Drs. Imada and Miura about arranging for processing. Dr. Miura made a direct request to Mr. Seki for assistance, who in turn made all local arrangements, while Drs. Miura and Mumford made suggestions on transport methods.

Raw Materials

The nori used for the processing and evaluation tests was raised at the Natural Energy Laboratory of Hawaii, Keahole Point, Hawaii, by personnel of the OTEC-Aquaculture Macroalgae Experiments project. Some nori material from the Japanese frozen nets was first placed in the experimental tanks on January 7, 1983. Seed stock nori which has been properly dried, frozen and later thawed will be alive when reemersed in seawater. The grow-out method is described in a paper by Mencher et al. (1983).

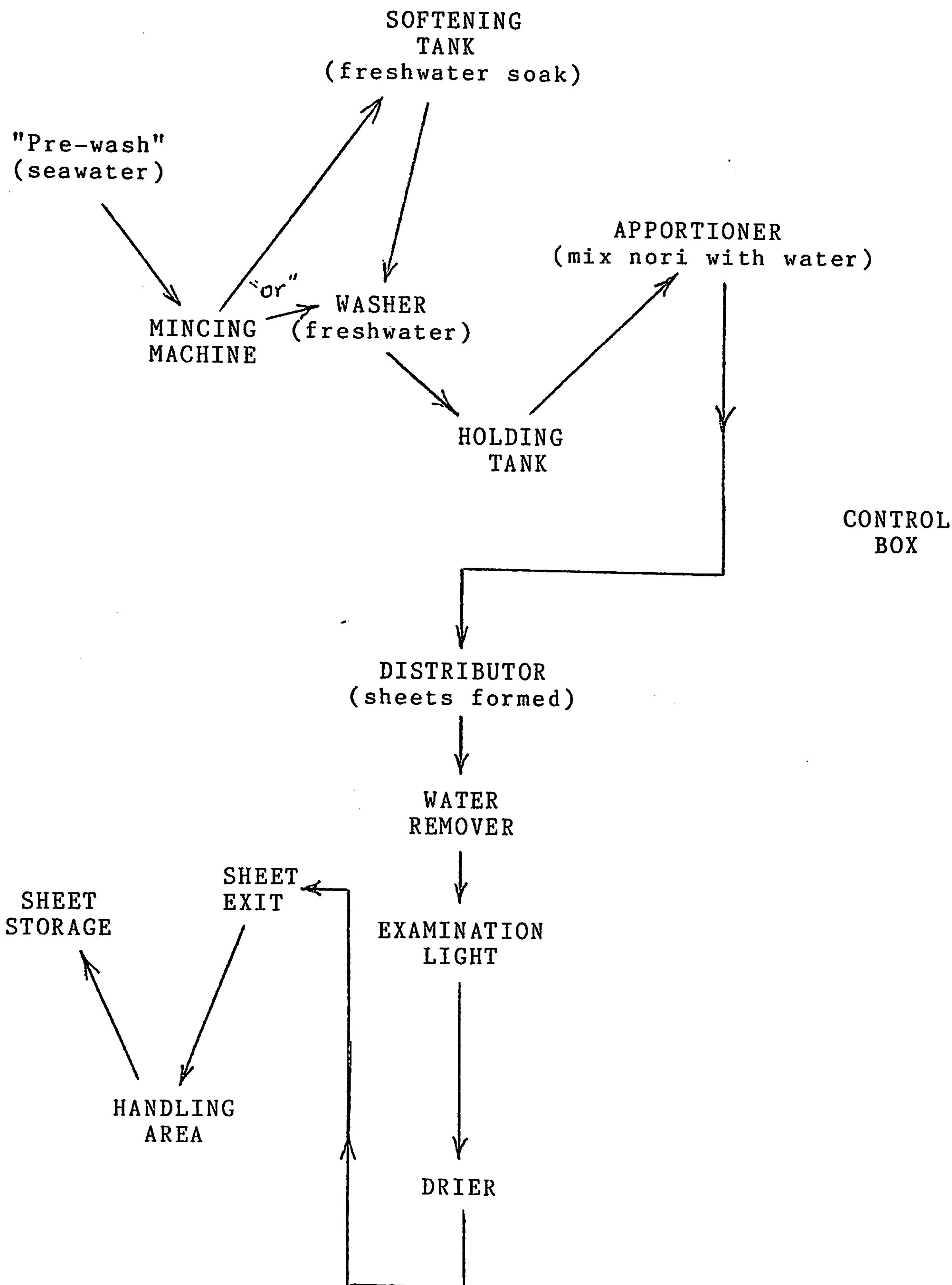
After 34 days, this material was harvested, centrifuged in a washing machine to remove excess water, weighed and frozen to about -16°C on February 10, 1983. Additional nori material was initiated on January 31, 1983, and then harvested, centrifuged and weighed after 13 days for transport fresh (not frozen) on February 12, 1983. Dr. Richard Spencer of the OTEC-Aquaculture project designated four separate batches (their history is traced in Table 1) of material according to probable quality. The total wet weight of this material was about 20 kg.

The frozen nori was packed with dry ice and the fresh material with "blue ice". All of this material was delivered to me in Honolulu by Mr. Fred Mencher of the OTEC-Aquaculture project on the evening of February 12, 1983. That same night I transported the material to Honolulu International Airport, boarded China Airlines flight 002, and went through Japanese Customs without incident by 8:30 a.m. (Tokyo time) on February 14, 1983 (one day gained crossing the International Dateline).

Processing

Dr. Oohusa met me at Haneda International Airport on the morning of February 14, 1983. We proceeded together by taxi with the material to the Chiba Prefectural Fisheries Nori Experiment Station at Futtsu on Tokyo Bay. We arrived at about noon. After exchanging amenities and eating lunch, Mr. Seki assisted in thawing the frozen material in cold (5-10°C) seawater. All of the frozen material arrived completely frozen, and with no sign of damage because of premature thawing during 26 hours of transit.

Figure 1. Schematic of nori processing facilities and the processing pathway



As the OTEC nori was thawing, it was taken directly to the Miki operation, about a five-minute drive. Dr. Oohusa, Mr. Seki, Mrs. Miki (who actually handles daily processing) and myself decided together that batch #2 was the highest quality raw material. The fresh material, batch #4, was judged to be clearly of lesser quality than batch #2 and was too small to be kept separate. Thus, batches #1, #3 and #4 were combined. Before processing, all of this raw material was judged to be too red, without aroma, too flat in taste and without cohesiveness (stickiness). It also contained many unusual wrinkled fronds (see Table 1).

All the material was clean enough not to require prewashing. It was first mixed with freshwater and minced with a #0 grid and a #8 blade. The resulting slurry was maintained automatically at a specific consistency (nori to water ratio) in a special tank called an "apportioner". From the apportioner the slurry was pumped directly into the "Wonman" processing machine. The Wonman distributed the slurry as 18 by 20 centimeter squares on small mats. Before the first sheets entered the drying compartment, they were inspected on the mats in front of a bank of fluorescent lights. Accordingly, thickness and consistency (presence or absence of holes) were adjusted and the material remaining in the apportioner was pumped in and processed. The combined batches (#1, #3 and #4) were handled likewise.

Processing nori into sheets requires constant observations and adjustments to achieve the maximum quality from the raw material. With small quantities, appropriate and optimum adjustments are difficult to make. There were some problems balancing sheet thickness against sheet consistency, i.e., sheets were made thick to avoid holes. Slightly high drying temperatures resulted in brittle sheets which broke easily when removed from the mats. Of 2,027 sheets processed from the OTEC nori about 79 sheets were broken.

After about two hours the first sheets began to emerge from the dryer. As some of the Miki personnel began to peel the sheets from the mats, these sheets were markedly without luster except for 5-50% of the surface area of each sheet. In addition, much of the glossy area had a "cloudy" appearance. Most of the material had been damaged. Evidently, this damage was a result of the nori cells not being strong due to the tumble culture method (traditional net culture of nori promotes stronger cells by greater environmental stresses) and being frozen with too much water. Many cells were probably dead before the processing began. The processing water consequently turned red from cell pigments. Without natural cohesiveness, the sheets were extremely rough and excess material had been necessary to prevent holes. The result was thick, fluffy sheets. Nori sheets are usually a consistent 3 grams per sheet. These sheets were variable from 3.5 to 4.3, averaging 3.9 grams. The second group of sheets (batches #1, #3 and #4) was similar but of even lower quality.

Tank Culture in Japan

On February 15, 1983, I visited Dr. Miura at Tokyo University of Fisheries and discussed producing nori in OTEC effluents. There have been numerous efforts to cultivate nori in tanks in Japan. These efforts have been in indoor tanks with low water exchange rates, relatively weak artificial lights and no periodic drying. The last condition, i.e., no periodic drying, is the only similarity to the OTEC-like system at NELH. The products of those tank cultures have been too soft, tasteless and without luster when dried. Dr. Miura expressed skepticism about producing acceptable nori in tanks.

During a visit to Zennori on February 16, 1983, Professor Ueda and Mr. Kaifu talked with me about OTEC nori. Prof. Ueda emphasized the favorable effects of periodic drying out of water on nori quality. He said that metabolic processes change in the nori while out of the water. Obviously, during emergence temperature and water relations differ from submerged conditions resulting in different biochemical results, i.e., different quality. Quality of nori continuously submerged is indeed different from nori which is periodically submerged. Mr. Kaifu felt that under any conditions, OTEC or otherwise, raising and processing high quality nori is extremely difficult and the Japanese industry is presently willing to help anyone who is willing to try nori cultivation.

Evaluation

On February 18, 1983, Dr. Oohusa assembled a group of experienced experts from Yamamoto Nori and Ohmori Suisan to evaluate the OTEC nori samples. Messrs. Kishi, Itakura, Tanaka and Goto probably represent over 50 years of experience in determining the quality and price of nori sheets. Prior to showing them the samples, I provided a short description with slides of the culture method. The following evaluation is a consensus of their opinions. Values are in terms of the price paid by wholesalers at the central bidding places.

Their initial impression was that the OTEC nori samples were "ge no ge" (bottom of the bottom) They thought them rough, completely without luster, too red, too thick and flat in taste, but clean and not too hard. Those samples were not judged to be of sufficient quality for even the lowest quality nori products, such as nori tsukudani (a paste normally made with cheaper aonori) or ajitsukenori (flavored nori). When urged to indicate a value anyway, they responded with a price of 6 yen (2½¢) per sheet. The second group was previously judged to be about half the value of the first group (see Table 1).

Because damage related to being frozen with too much water for transport was clearly evident as mentioned above, I pressed for an appraisal assuming that this damage had not occurred. Such an estimate is difficult, but possible from the areas which were alive when dried. These areas retained luster during processing. Without having a complete sheet of glossy nori, they were reluctant, but finally said that such sheets would probably bring no more than twice the price of the sheets in hand, i.e., 12 yen (5¢) per sheet.

The real test would be to process the nori sheets on site in Hawaii. They expected that if this were done, the sheets would retain their luster and be a little harder, but would also be redder (see Table 2).

They also cautioned that the price had increased 50% this year because of bad harvests. Last year the OTEC nori would have been worth somewhat less, perhaps only two-thirds of the above estimates. It would be worth more if bad harvests were to reoccur in Japan and Korea.

Future Prospects

I returned to the Tokyo University of Fisheries on February 19, 1983, to present slides of the culture method and discuss sheet quality with Drs. Miura, Aruga and Oohusa. While they could not add to the evaluation obtained on February 18, they could prognosticate on the prospects for producing a higher quality product than produced this time.

Even though OTEC nori was given a low rating this time, they thought the prospects for a reasonable quality nori were good. They thought that 30 yen per nori sheet (12.8¢) would be a little high to expect, perhaps with refined culture and processing techniques 25 yen (10.6¢, just below the price used in previous economic analysis (Woessner, et al., 1982)) per sheet would be obtainable. They made several suggestions on how to improve quality.

Dr. Aruga suggested that cell strength and color may be improved by periodic drying during early growth stages. Cell strength may also be increased by purposeful, extreme variations in physical conditions, such as temperature or salinity, in the culture system.

Dr. Oohusa speculated that the exposure of nori to the high semi-tropical sunlight intensity may cause the shift to red pigments. This idea concurs with information in NORI SEIHIN KOJO NO TEBIKI (GUIDE TO IMPROVING PORPHYRA QUALITY) by Noda and Iwata (1978). He suggested placing shade screening over the tanks.

Dr. Miura observed that the taste was better than nori produced in indoor cultures probably due to better water exchange rates and higher light intensity. Once seeing the OTEC nori sheets, he became somewhat more optimistic about producing good quality nori in OTEC systems.

They all thought that strain selection holds good potential for quality improvements. Better density control and a different balance of nutrients may also improve quality in an OTEC culture system. Using lower temperatures (15°C used for OTEC nori) would also likely result in higher quality.

On February 23, 1983, Dr. Enomoto invoted Mr. Mori to discuss nori produced in OTEC effluents at the Kobe University Marine Biological Station. He outlined the development of the nori industry in the Awaji Island area. It is important to note that cultivation in this area is conducted mostly on floating nets which remain continuously submerged. Over a ten-year period cultivators developed suitable processing techniques for continuously submerged nori. Awaji Island nori is a very good nori product.

DISCUSSION

OTEC nori quality was less than would be expected from the quality of OTEC water. Even though the water was high in nutrients, clean, disease-free, OTEC nori lacked luster, was too red, lacked cohesiveness, had no aroma, had a flat flavor, was too thick and heavy, and was too fluffy. On the other hand, it was clean and had about the right hardness. Had the nori cells not been damaged, luster and perhaps color would have been improved. Even so, the value of OTEC nori would not have surpassed the price necessary to break even according to previously calculated economic analyses (Woessner, et al., 1982). Since the physical factors can be precisely controlled in an OTEC system, OTEC nori should be of excellent quality. Why was excellent quality not attained?

Analyzing Causes

During the visit to Japan, it became exceedingly clear that much skill and some luck are necessary to cultivate nori and process it into excellent nori sheets. Little mistakes anywhere during the course of producing the product can drastically affect the final quality. For the OTEC nori there were five steps or stages influencing the quality of the final sheets: 1) the seeding and nursing stages conducted in Japan, 2) freezing, transport to Hawaii, and storage prior to thawing, 3) thawing and grow-out in the OTEC-like effluents at NELH, 4) freezing and transport to Japan, and 5) processing into nori sheets in Japan.

The impacts of these stages in different cultivation situations are summarized in Table 3. The different situations include: 1) the present case of nori grown at NELH and processed in Japan, 2) the on-site case where both grow-out and processing would occur at NELH, 3) the traditional case of the way it is done in Japan, and 4) the developed case of the best possible cultivation techniques being used in an OTEC system.

Quality of the final sheets can be no greater than the biological potential of the genetic strains which were seeded to the nets. However, the seeding and nursing stages can greatly affect the final quality of nori products. According to Dr. Aruga, improper handling during the nursing procedure can permanently affect the internal biochemical constituents of later stages and the biochemical balances in the final product. In the experiments at NELH there were no controls over these factors. For future work, strain selection and adapted nursing procedures should improve quality.

Preparation for freezing, freezing, transport to Hawaii and storage were all sources of damage to the stock used in the NELH experiments. Freezing, as long as it does not kill the cells, may not change the biochemical constituents of the final product. However, partial damage of fronds could occur such that only some cells in a frond are killed leaving mostly living cells. The fronds with this mixture of living and dead cells would likely result in wrinkling as mentioned above. Wrinkled fronds affect the surface appearance of the nori sheets and lowers the quality. A future OTEC-related nori production system would probably not require freezing to assure availability of seed stock; thus, problems with wrinkling would likely be avoided.

Table 3. Potential impacts on nori quality according to cultivation situation.

cultivation situation	present OTEC	on-site OTEC	traditional field	developed OTEC
genetic potential	low	low	medium	high
nursing period	high	high	high	high
freezing period	low	none	low	none
grow out	very high	very high	very high	very high
transport	high	low	medium	low
processing	medium	low	low	low
storage	high	high	high	high

Grow-out provides many opportunities for modifying the quality of nori. An OTEC system should be able to provide optimal conditions for producing high quality nori once those conditions are defined. It did not occur in this case for three major reasons: 1) constant conditions bred weak cells, 2) optimal conditions for nori have yet to be determined in OTEC systems, and 3) a convenient mechanism for periodic drying is not yet available for OTEC cultures. Strategies for improving each of these points were discussed by the Japanese experts.

Freezing and transport to Japan probably had the greatest negative impact on the quality of the OTEC nori. The samples were centrifuged, but still contained too much water when frozen. When the water froze, it killed and probably ruptured numerous cells which could then never be processed into acceptable quality sheets. Even though removing more of the water would have improved the prospects for higher quality sheets, transporting raw material long distances increases the time under which the nori is in a stressed state. On-site processing would be a natural part of any future nori production system.

Processing nori into sheets requires much skill. An experienced processor will continually check several variables to assure the highest possible quality from the raw material available. A processor can adjust the washing time and wash water temperature, the type and size of the mincer grid and knives, the water-nori ratio and thus the thickness and consistency, the temperature and humidity in and around the dryer. The quality of the raw material may change midway during processing requiring constant adjustment of any or all of these variables. Future OTEC operations will require experienced, on-site personnel and modern nori equipment.

One conclusion I have portrayed in Table 3 is that grow-out presents the greatest opportunity for improving quality of OTEC nori. The remaining conclusions are based on opinions expressed by the Japanese experts contacted during this trip to Japan.

RECOMMENDATIONS

The Japanee experts believe that there are many ways to improve the quality of OTEC nori. However, that its quality can actually be improved and to what level its quality can be improved, remain in question. Before further production research is pursued, these questions should be clarified by tests and experiments designed to address specific quality problems.

Experiments on improving color and luster of the OTEC nori sheets should be tried first. If color and luster can be improved, taste and other quality factors will likely improve simultaneously. Some of the methods used to improve quality will increase production costs; others will not.

As production techniques are developed, production economics will require more analysis. Particularly, problems related to marketing OTEC nori sheets should be investigated as soon as sufficient sheets are available for test marketing.

While the results of this study do not indicate that OTEC nori will ever be of the highest quality, there is considerable hope of producing nori of at least average quality. If marketing costs are not unexpectedly high, production of such nori would be a commercial enterprise according to preliminary economic feasibility analyses (Woessner, et al., 1982).

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