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HANDLING AND STORAGE OF BLUE MUSSELS IN SHELL

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Off the coast of Maine more than 20 million pounds of blue mussels (*Mytilus edulis*) in shell have been estimated to exist in commercially exploitable beds (Scattergood and Taylor, 1949a). The average annual harvest for the four year period of 1943 through 1946 was 9.5 million pounds (Scattergood and Taylor, 1949b). In subsequent years production declined rapidly as a result of reduced market demand. One of the reasons responsible for loss of the market was considered to be inferior packs of canned mussels which tended to discourage future sales (Scattergood and Taylor, 1949b). A small, but well established, market for fresh mussels in shell still exists in metropolitan areas. In 1974 the landed volume (in shell) of blue mussels in Maine supplying this market was 1.2 million pounds (Wallace and Dow, 1975). Expansion of the present market appears to be dependent upon increasing the supply through utilization of new mussel beds and/or aquaculture, as well as upon improved quality and extended shelf life through improved handling procedures.

State of Maine agencies have been promoting blue mussels since the early 1900's, and various improvements in harvesting and handling have been implemented during this period (Dow and Wallace, 1954). Pole cultivation of blue mussels was investigated in the late 1940's by the Department of Sea and Shore Fisheries (Wallace and Dow, 1975). At present, the Spanish technique is being evaluated at the University of Maine, Darling Center (Lutz, 1974).

Blue mussels are not commercially cultivated to any extent in the State of Maine, but are pulled, raked, or dredged from existing beds, and placed in one-bushel quantities in burlap or plastic mesh bags. They are then ready for shipment to the market by truck (with or without refrigeration) or are immersed in the sea on rafts for one or more days awaiting shipment. Under existing practices the shelf life of the blue mussel is considered to be about 3 to 4 days—a period of time which limits the market area.

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Freezing mussels in shell and storing at –23.3°C (–10°F) for the purpose of extending the shelf life has proven unsatisfactory (Slabyj, *et al.*, 1974). Such mussels are difficult to shuck upon thawing and steaming, and their meats are tough, especially the adductor muscle.

Storing blue mussels in ice has significantly extended the shelf life of this mollusk and the results of such experiments are presented in this report.

Materials and Methods

All blue mussels used in this research were obtained from a commercial fisherman. They were harvested primarily from muddy flats at low tide or subtidally. The mussels were forked onto a flat bottom skiff and taken to the boat. There the muddy mussels, attached to one another by their byssus threads, were washed until clean and well separated using a grader-washer (drum-cage). Mussels smaller than 2 inches in length were returned to the bed and the remainder packed in one bushel quantities using burlap or plastic mesh bags.

The mussels were then taken directly off the boat to the laboratory or immersed in the sea on rafts for 1 or 3 days before being transported to the laboratory (a distance of 90 miles requiring 2 to 3 hours travel time). To insure low temperatures in transit, especially during the summer months, the mussels contained in burlap or plastic mesh bags were placed in 25 gallon plastic cans and covered with 50 pounds of crushed ice.

At the laboratory the iced mussels in the original containers were placed in a 1.7°C (35°F) room, or with the ice removed, stored at predetermined temperatures of 18.3°C (65°F), 7.2°C (45°F) and 1.7°C (35°F). Relative humidity was not controlled, but was observed to fluctuate between 20 and 40% at 18.3°C, between 55 and 65% at 7.2°C and between 75 and 85% at 1.7°C. During storage, mussels in ice were regularly checked, the water drained, and the melted ice replaced.

Sampling was performed by removing the required number of individuals from the bag. Gapers that did not close when examined were considered dead (Loosanoff and Engle, 1943) and the percent mortality of the sample recorded. Analyses were performed only on mussels that did not gape. These were scrubbed under cold running water using a vegetable brush and shucked. This procedure was accomplished usually in less than 5 minutes.

Preparation for microbiological examination involved homogenizing the mussels (meats and liquor) with an equal weight of phosphate

buffer (American Public Health Assoc., Inc. 1970). Total viable count was obtained by surface inoculation or pour plate technique using Plate Count Agar (Difco). Fungi were detected using Sabouraud Dextrose Agar (BBL).

The volume of liquor associated with mussel meats was determined by shucking the mussels onto a sieve and draining for 10 minutes into a graduated cylinder.

For sensory evaluation, about one dozen mussels were steamed at each sampling for six minutes and the meats removed. These were presented once as a group of coded samples to a panel of seven judges for odor evaluation. Reference samples consisted of steamed meats stored in plastic bags at –23.3°C (–10°F) which were thawed as required. The judges were instructed to record their responses as better than the reference sample (–1), no difference (0), slightly off (+1), off (+2), bad (+3), or very bad (+4). The average response of the seven judges involved was used as the odor score.

Results and Discussion

Blue mussels when harvested from existing mussel beds tend to trap some mud as they close the shell when disturbed. Routine washing does not remove the mud which is trapped in the mantle cavity. Furthermore, tumbling of mussels to break up clumps and to grade not only causes damage to the byssus, but also results in the loss of some body liquor. When such mussels are immersed in the sea for one or three days prior to shipment, they tend to cleanse themselves of the trapped mud and recover lost liquor. During the brief holding in the sea, *Mytilus edulis* will often regenerate damaged or torn byssus threads. Development of these threads generally is not sufficient to detract from the quality of the product. Mollusks, being filter feeders, are known to concentrate biological and chemical pollutants (Clem, 1973). Therefore, mussels, if immersed in the sea in areas other than the harvest area, must have prior approval by the Maine Department of Marine Resources (Hurst, 1972).

The volume of liquor associated with blue mussels is inversely related to the size of the meats. Blue mussel meats are minimal immediately after spawning but continuously increase in weight throughout the year reaching maximum size prior to spawning. Consequently, there is more liquor per unit weight of shucked meats after spawning than before. As mentioned earlier, some of this liquor will be lost during washing and grading, but may be recovered by the blue mussels when held immersed in the sea. Typical results for initial liquor content and its subsequent loss upon storage in ice can be seen in Figure 1. All the ex-

periments for which results are shown were performed using mussels which had been placed in burlap bags (except the July experiment for which plastic mesh bags were used) and had been immersed in the sea for two days (except the June experiment for which the mussels were held in the sea for one day).

The highest initial liquor volume of shell contents (62%) was present in mussels harvested in January and the lowest in those harvested in May (25%). Mussels harvested in July also had relatively high liquor content (55%) since that year initial spawning of most beds took place sometime in May through June. Lower than anticipated liquor content (45%) of the March experiment could be due to failure of the mussels to retain liquor after being immersed in the sea as a result of excessive tumbling during washing and grading. Excessive tumbling during washing and grading has been observed to be detrimental to *Mytilus edulis* (data not shown).

Mason (1972) quotes Wiborg and Bohle (1968) as reporting that mussels cultivated on ropes, are not accustomed to regular opening and closing of the shells with the tide and thus tend to lose water in transit and die within a few days. Drinkwaard (1972) also reported loss of water (3 to 7%) in cultivated mussels when in transit.

Blue mussels in storage were observed to lose their liquor (Figure 1). The liquor loss was rapid in the initial stages of storage for mussels that had maximum liquor volume. This stage was followed by a gradual loss of liquor until death occurred. The loss was more gradual throughout storage in mussels harvested in May, when the meats were at their maximum and the liquor at its minimum. Similar response was observed in the March experiment where the shellfish did not have maximum anticipated liquor content. This perhaps indicates that once the liquor content drops to a certain level the mollusk will tend to conserve the remaining liquor.

Significant mortality (10%) in most experiments occurred when liquor concentration dropped to between 23 and 32% of the shell content except in the May experiment when it reached 14%). Although loss of liquor has been reported to contribute to mortality (Mason, 1972), it does not appear to be the primary factor responsible for death in experiments reported. This is especially evident in an experiment conducted at 7.2°C (45°F). In this instance (Figure 2) one mussel population (with regenerated byssus) exhibited significant mortality at 41% liquor content and another (with byssus not regenerated) at 24%.

It is logical to anticipate more rapid loss of liquor in blue mussels stored at elevated than at lower temperatures. Loosanoff and Engle (1943), observed increased loss in weight with increased temperature for mussels stored at –1.1°C (30°F) to 21.1°C (70°F). To determine

Figure 1. Shell liquor volume of blue mussels harvested at different seasons and stored in ice: (▼) June 3/73, (●) January 17/74, (▲) March 15/74, (♦) May 1/74, (■) July 23/74.

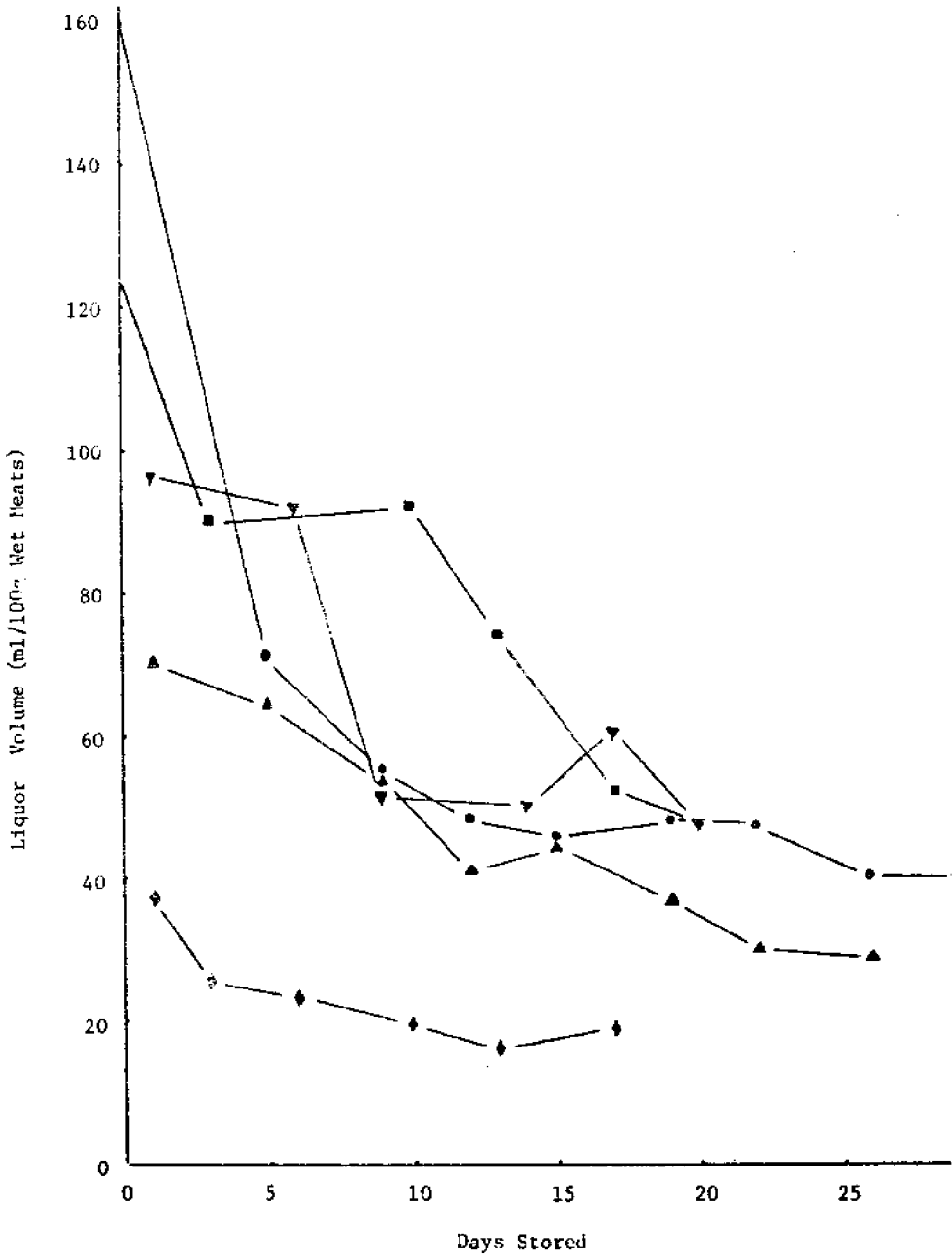
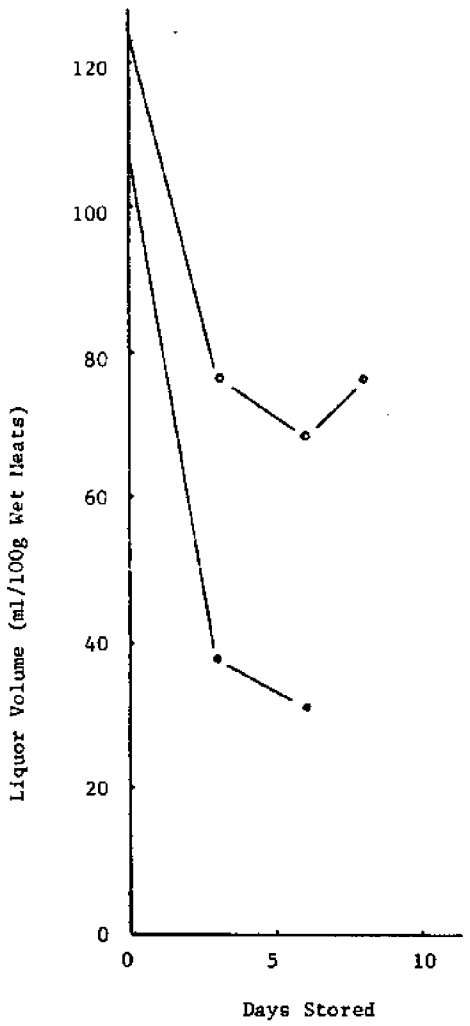


Figure 2. The effect of byssus repair on shell liquor volume of blue mussels harvested July 23/74 and stored at 7.2°C(45°F): (o) byssus regenerated, (●) byssus not regenerated.



the effect of a temperature on liquor retention and effective storage period, mussels in burlap bags immersed in the sea for three days after harvesting were used. Results of these tests (Figure 3) do not indicate a significant difference in liquor volume for mussels stored at temperatures of 7.2°C (45°F), 1.7°C (35°F) or in ice. It is important to note, however, that mussels stored at 7.2°C (45°F) reached significant mortality in 14 days while those stored at 1.7°C (35°F) did not reach the same stage until after 31 days. Liquor loss at 18.3°C (65°F) was noticeably faster than at the lower temperatures examined and sampling was terminated after 7 days. It should be stressed that time-temperature effects are generally cumulative. Thus, holding mussels for 24 hours at 18.3°C (65°F) during transportation would be expected to reduce markedly subsequent shelf life at 0° to 1.7°C (32° to 35°F).

Increased flaccidity of the foot and progressive dehydrated appearance of the meats were observed to be associated with the loss of body liquor. No physical differences in appearance, however, could be noticed upon steaming.

The bacterial count for freshly harvested blue mussels varied between $5x10^2$ and $1x10^4$/ml regardless of season or container used (burlap vs plastic mesh bags), or whether or not the mussels were immersed in the sea after harvesting. Since highest counts were obtained by incubating inoculated plates at room temperature (22°C), as compared to 7° or 35°C (Table 1), room temperature was adopted for routine examination.

Generally, the viable bacterial count increased slowly throughout the storage period at all temperatures examined reaching $2x10^4$ to $2x10^6$/ml at the time the experiments had to be terminated (Tables 1 and 2). This increase in bacterial population is probably related to the multiplication of bacteria on the shell surface which is constantly bathed with liquor that is lost by the mollusk, as well as, in the shell contents. Gross examination of bacterial isolates indicated qualitative changes in population which may be responsible for the off odors in latter stages of storage. Although bacterial multiplication in these tests was minimal, and not apparently related to mortality, it is possible that bacterial activity may contribute to the death of the shellfish. Further investigation into microbial activity in stored mussels is being conducted including organisms of public health significance.

In freshly harvested mussels fungi ranged from below detectable level (<10/ml) to 1,000/ml and showed no tendency to increase in numbers during storage.

When harvesting mussels during periods of sub-zero temperatures, precaution should be taken to prevent freezing of the mollusks. Despite the fact that blue mussels exhibit some resistance to freezing (Williams,

Figure 3. The effect of storage temperature on shell liquor volume of blue mussels harvested December 9/74 and stored under different conditions: (Δ) iced, (▲) 1.7°C(35°F), (●) 7.2°C(45°F), and (■) 18.3°C(65°F).

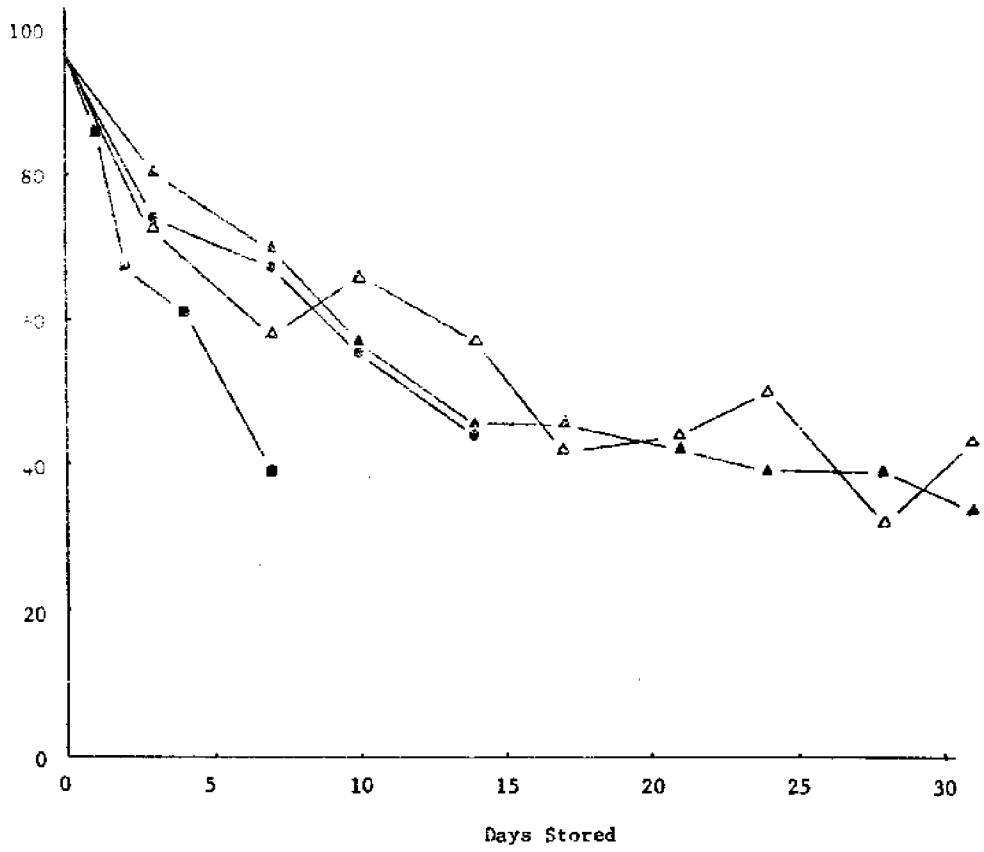


Table 1

Viable bacterial count ($\log_{10}$ ml) of blue mussels harvested in July and stored at 7.2°C (45°F) or in ice.

	Mussels stored in ice					
	Byssus Regenerated			Byssus Not Regenerated		
Days Stored	7°C Count Surf. Inoc.	22°C Count Pour Plate	35°C Count Pour Plate	7°C Count Surf. Inoc.	22°C Count Pour Plate	35°C Count Pour Plate
0	2.9	3.7	3.7	2.9	3.7	3.7
3	3.3	3.3	3.1	3.5	3.3	3.1
6	3.6	4.1	3.9	4.1	4.1	3.2
10	4.0	4.1	3.6	4.9	4.9	3.3
13	4.0	4.2	3.9	4.9	5.1	4.0
17	5.7	5.5	3.9	5.2	5.4	4.7
20	5.9	5.6	4.8	6.3	6.1	3.9
22	6.1	5.8	3.3	—	—	—
	Mussels Stored at 7.2°C (45°F)					
0	2.9	3.7	3.7	2.9	3.7	3.7
3	3.6	3.4	3.1	4.7	4.4	3.1
6	3.5	3.3	3.1	5.2	5.3	3.3
8	4.2	4.8	4.5	—	—	—

1970), mussels harvested at -23.3 C (-10 F) (January 11, Table 3) exhibited high mortality throughout storage. These mussels were also observed to contain relatively little liquor (38%) and remained muddy despite the fact that they were immersed in the sea for two days before being taken to the laboratory. Mussels harvested for the January 17th experiment were also obtained in sub-zero weather (-23.9 C; -11 F), but the fisherman took special precaution to protect his harvest from wind and frost resulting in an apparently improved product.

Fishermen have observed that spawning mussels are very sensitive to handling and when immersed in the sea while confined in bags will succumb very readily. Harvesting spawning mussels is, in fact, prohibited in some countries (Waterman, 1963). It is of interest that mussels harvested July 3, one month after initial spawning, had an acceptable storage period in our laboratory (Table 3). Further investigations are being carried out to define the effect of spawning on quality.

From Table 3 it is apparent that mussels harvested during the winter months did not exhibit significant mortality until after 30 days of storage in ice (0°C; 32°F). The same level of mortality was reached in 17 to 20 days for mussels harvested during the summer months. In other experiments (not shown) 10% mortality was reached in 14 days for summer months. Elevated storage temperature (7.2°C; 45°F) appeared to have a detrimental effect on the effective holding period. In

Table 2

Odor score, total viable count (22°C) and mortality of blue mussels harvested in December and stored at 18.3°, 7.2°, 1.7°C or in ice.

Days Stored	18.3°C (65°F)			7.2°C (45°F)			1.7°C (35°F)			Iced		
	Odor Score	Viable Count log_{10}/ml	% Mortality	Odor Score	Viable Count log_{10}/ml	% Mortality	Odor Score	Viable Count log_{10}/ml	% Mortality	Odor Score	Viable Count log_{10}/ml	% Mortality
0	—	4.0	0	—	4.0	0	—	4.0	0	—	4.0	0
1	0.3	4.1	0	—	—	—	—	—	—	—	—	—
2	0.3	3.8	0	—	—	—	—	—	—	—	—	—
3	0	4.2	0	0.4	4.8	0	0.6	4.3	0	0	4.2	0
4	2.6	4.2	2	—	—	—	—	—	—	—	—	—
7	4.0	4.3	48	0.7	4.0	0	0.7	4.0	0	0.1	3.9	0
10	—	—	—	2.1	4.2	6	0.3	4.2	0	0.3	4.2	2
14	—	—	—	3.2	4.5	16	0.5	4.4	0	0.9	4.4	0
17	—	—	—	—	—	—	—	4.0	0	—	4.3	2
21	—	—	—	—	—	—	1.0	4.4	0	0.2	4.2	2
24	—	—	—	—	—	—	—	4.9	2	—	5.0	0
28	—	—	—	—	—	—	1.7	4.7	3	1.0	4.9	3
31	—	—	—	—	—	—	0.5	4.9	10	1.1	5.0	12
35	—	—	—	—	—	—	2.6	5.0	26	2.3	4.8	13

Table 3

Per cent mortality of blue mussels harvested at different times of year (1974) and stored at 7.2°C (45°F) or in ice.

	Jan 11**	Jan 17	Mar 15	May 1		July 23			
				reg		non		reg	
Days Stored	non* iced	reg* iced	reg* iced	7.2°C	iced	7.2°C	iced	7.2°C	iced
0	—	0	—	0	0	0	0	0	0
1	21	—	0	—	—	—	—	—	—
3	—	—	—	0	0	0	0	0	0
4	15	—	—	—	—	—	—	—	—
5	—	1	2	—	—	—	—	—	—
6	—	—	—	0	0	19	0	9	0
8	10	0	1	0	—	—	—	27	—
10	—	—	—	36	5	—	1	—	1
12	17	4	1	—	—	—	—	—	—
13	—	—	—	—	0	—	2	—	0
15	15	2	3	—	—	—	—	—	—
17	—	—	—	—	17	—	34	—	9
19	20	1	4	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	40
22	28	2	4	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—
26	—	1	8	—	—	—	—	—	—
29	—	6	—	—	—	—	—	—	—

*non - Byssus threads not regenerated
reg - Byssus threads regenerated
**Mussels exposed to freezing temperature during harvesting

fact, an increase of about 5.6°C (10°F) reduced the holding period by more than one-half.

Although mussels stored at 1.7°C (35°F) and those packed in ice did not differ significantly in storage life as judged by mortality or odor score (Table 2), storage in ice generally has a beneficial effect in most experiments with regard to delayed appearance of off odors. This may be due to reduction of bacterial activity on the shell surface which is continuously bathed with water from the melting ice. The higher moisture condition associated with storage in ice may also minimize dehydration of mussels.

It is important to note that loss in quality (occurrence of bad odor) and mortality do not coincide. Strong off odors, at times, can be detected several days before significant mortality is observed (Table 2). Thus stored mussels with low observed mortality will not assure the customer of an acceptable product.

Summary

Significant mortality (10%) of blue mussels held at 0°C (32°F) and 1.7°C (35°F) occurred in about 2 weeks for mussels harvested during the summer months and in about 4 weeks for mussels harvested during the winter months. Best quality and longest shelf life were observed for mussels immersed for a couple of days in sea water prior to further handling and storage. Elevated storage temperatures significantly reduced keeping time.

Blue mussels in shell lost body liquor throughout the storage period. Liquor content, however, varied too much from one experiment to another to be a reliable indicator of imminent death. Bacterial population of commercially harvested mussels was observed to vary between $5x10^2$ and $1x10^4$/ml and increased to between $2x10^4$ and $2x10^6$/ml shell contents at the time the mussel population reached 10% mortality. Although loss of body liquor and bacterial count were not apparently related to mortality, storage temperature appeared to be a critical factor. Thus, increasing storage temperature from 0°C (32°F) to 7.2°C (45°F) or 18.3°C (65°F) reduced shelf life of blue mussels by a factor of about two and four, respectively.

Blue mussels in terminal stages of storage had little body liquor and appeared dehydrated when examined; however, after steaming no difference in physical appearance was observed. Objectionable odors were frequently detected in stored mussels several days before significant mortality occurred. Use of crushed ice appeared to delay appearance of bad odors in storage.

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