CAUSES OF DEVELOPMENT OF SPONGINESS IN ROE PRODUCED FROM FROZEN HERRING

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ABSTRACT

Tsuyuki, H., J. Cheng, S.N. Williscroft and Minh Dieu Huynh. 1977. Causes of development of sponginess in roe produced from frozen herring. Fish. Mar. Serv. Tech. Rep.

The properties of spongy roe and methods of identification from processed roe are described in detail. Two procedures, the hydrogen peroxide treatment and the drying method, used for further identification and confirmation are also described.

A rate of freezing which requires 2-3 days in passing through the critical freezing zone, which is generally between -1°C and -5°C, already results in the development of significant levels of sponginess. Longer times led to progressively increasing incidences. Inadequate cold storage holding temperatures likewise are intimately associated with the development of sponginess. A holding temperature of -10°C still caused considerable sponginess, while at -18°C, the incidence was reduced considerably.

In this study, other factors such as post-mortem age and quality, population differences, and maturity appear to have little, if any, effect. Other often-cited factors associated with freezing such as thawing rates (over 2 days), freeze-thaw cycles, the brining of partially-thawed roe likewise were not involved.

Processed roe stored for 2 months at 2°C, -10°C, -22°C, and -28°C developed low levels of sponginess. Storage temperature of -22°C developed the highest incidence of 5.3%. Storage at 2°C also resulted in the development of milky white opaque areas on the skein in about 25% of the roe.

Key words: roe, herring, processing, spongy, freezing, thawing, rates, development.

RÉSUMÉ

Les auteurs décrivent de façon détaillée les propriétés des oeufs spongieux et les méthodes pour leur détection parmi des oeufs traités. Ils décrivent également deux méthodes (traitement au peroxyde d'hydrogène et sèchage) pour une reconnaissance plus précise et pour confirmation.

La congélation à un rythme tel que la durée du passage de la zone critique de congélation (entre -1 et -5°C) est de deux ou trois jours cause déjà une spongiosité importante; de plus, le nombre d'oeufs atteints augmente avec la durée. De même, des températures inadéquates de conservation au froid sont étroitement liées à l'apparition de la spongiosité. Celle-ci est encore considérable à une témperature de conservation de -10°C mais est réduite fortement à -18°C.

D'après la présente étude, d'autres facteurs comme le temps après la mort et la qualité, les différences entre les populations et la maturité auraient peu d'effets, sinon aucun, non plus que les facteurs de

la congélation souvent cités, comme la vitesse de décongélation (plus de deux jours), le cycle congélation-décongélation et le saumurage d'oeufs partiellement décongelés.

Les oeufs traités et conservés pendant deux mois à 2, -10, -22 et -28°C ont été faiblement atteints, la proportion étant la plus forte à -22°C, soit 5.3%. La conservation à 2°C a également entraîné l'apparition de plaques opaques d'un blanc laiteux sur la peau de 25% des oeufs.

Mots clés: oeufs, hareng, traitement, spongieux, congélation, décongélation, vitesses, apparition.

INTRODUCTION

Following the lifting of the kazunoko (herring roe) import quota in 1972, the Japanese import of this product increased dramatically from 800 m. t. in 1971, to 7,300 m. t. the following year, and to 11,691 m. t. in 1976. The Canadian share of this lucrative market in 1972 amounted to 2,492 m. t. and increased steadily to 7,332 m. t. in 1976. The bulk (about 65% in 1976) of this kazunoko is produced by the British Columbia herring industry.

The fishery to produce this large amount of kazunoko is intensive and in less than a month, most of the quota of upwards to 80,000 m.t. of roe herring is harvested. Both to minimize the proportion of immature roe, which result in soft low quality kazunoko, and to maximize yield, the fishery is monitored closely and harvesting of any particular population is not allowed till a minimum roe content is attained. This past season, this figure was set at 9%. The actual yield for the fishery was 11% resulting in an estimated yield of 8,636 m. t., an all time high.

To cope with this intensive fishery, it has been the practice of industry to process whatever amount possible from fresh herring and to freeze the remainder to be processed at a more convenient pace. Freezing the roe herring results in significant advantages. It firms the roe partially and facilitates retrieval upon thawing and also circumvents the industrial problems created by high salt content in carcasses from fresh fish treated with brine (anywhere from 40^{o} to 100^{o} depending on the processor) to firm the roe for easy removal. Improper freezing, however, also results in the formation of "spongy" roe which is the topic of this report.

While many of the technical problems associated in the processing of herring roe on this scale up to the export stage have been resolved, the upgrading of quality is a continuing problem. One of the more significant is the incidence of sponginess (shibari-Ko) which severely downgrades quality. Industry, Japanese technicians, and we are in unanimous agreement that sponginess is associated with roe processed from once frozen roe herring. While sponginess undoubtedly existed before, more attention has been focussed on the problem in the past few years and particularly during the past season.

Partly as a result of the decrease in the export of roe herring from 25 to 5% of the total harvest, the problem can no longer be exported on as large a scale as before. With the proportional increase in the production of kazunoko from once frozen herring, many buyers are scrutinizing the processed product more stringently for the incidence of sponginess. Their position is understandable as one of the cherished qualities of kazunoko to the consumers of this luxury product is the familiar "crunch" of bursting eggs when the roe is eaten. This characteristic is wholly or partially lost in spongy roe.

Despite the severity of the problem both the criteria of sponginess, its methods of evaluation, as well as the causes of the condition have not been too well understood. Indeed it has been stated by others in the literature that slow freezing and a slow thawing does not lead to the formation of spongy roe. The methods of evaluation are largely subjective leading to considerable variation in the estimation of the degree of sponginess amongst

the buyers' technicians, a fact which causes concern to some producers that the incidence of this condition might be used as an excuse for price-cutting maneuver.

This report describes the condition of sponginess, its methods of evaluation, its chief cause, and its minimization in the freezing process.

MATERIALS AND METHODS

SOURCE OF ROE HERRING

To observe the effect of stock differences, methods of capture, as well as the freezing and thawing rates on the incidence of sponginess, commercial sources of roe herring caught both by gill net and seine from different areas off the coast of British Columbia during March 15 and April 1, 1977, were used. Roe herring less than 10 hours old, obtained from a commercial gill net fisheries of a late stock (May 6, 1977) from Puget Sound in the State of Washington, was also used in this investigation. The post-mortem age ranged, therefore, from within 10 hours to several days and the quality from completely fresh to samples which were decidedly unpleasant in odor and in which the roe was already partially "set".

FREEZING RATES

Fourteen to fifteen kg lots of herring were frozen at various rates in polyethylene bags and in bags placed inside corrugated cartons 4.5 x 2 x 18 inch in size. Unless otherwise indicated, all samples were stored at -28°C till required. Prior to freezing the fish, thermocouples were inserted through the anal opening into the abdominal cavity and held in place with twist ties. The wired fish was then placed in the centre of the 15 kg lots of herring to be frozen under different conditions. Immediately after the samples were placed in the freezers, the thermocouples were connected to a multi-channel recorder (Westronics Inc.) and the freezing, and at the appropriate time, the thawing rates were monitored.

A total of 3100 lbs. of roe herring were frozen at varying rates using different freezers.

(1) Brine freezer: Whole fish was frozen rapidly in saturated brine at -5°F. As established by monitoring, the terminal core temperature was attained in 25 minutes (figure 1).

(2) Dole freezer: 15 kg of fish in 8 mil polyethylene bags closed with staples were placed on horizontal plate freezers and frozen to -30°F. The core temperature of the bags of fish reached -30°F within 3-4 hours (figure 1).

(3) Standard household type chest freezer: 2 rows of 15 kg bags (total of 6) of herring were placed on shelves separated by a 2-3 inch air space for better circulation. Considerable variation is evident in the rate at which the

latent heat of freezing is removed and when the core reached the freezer temperature depending on the bag position. The core of the bags of herring remained at the critical freezing zone of -1° to -5°C for 3-4 days (figure 2).

(4) -28°C walk in freezer: 14 kg lots of fish were frozen in corrugated cartons and stacked 10 high on the floor. The cartons on the bottom, middle, and the second from the top were monitored. The cartons impeded heat transfer to the extent that the average freezing rate was similar to those frozen in the chest freezer in polyethylene bags. The core temperatures remained at the critical zone for about 3 days (figure 3). Ten cartons of roe herring were removed from the walk in freezer while the core temperature was still just above freezing and stored for varying periods at -2°C. This procedure was intended to mimic poor commercial practice.

(5) Extended storage at temperatures ranging from -2 to -28°C: Since facilities were not available for testing the effect on the incidence of sponginess of much slower freezing rates, another lot of herring was stored for various periods at -2°C, -10°, -18°, and the controls at -28°C. The highest temperature of -2°C was selected arbitrarily to prevent excessive deterioration for the duration of the experiments. The freezing rates at each temperature are shown in figure 5.

THAWING RATES

Fast thaw (F) referred to in tables 1-4 was carried out in less than 6 hours by immersing frozen polyethylene bags of fish in slow running warm water. Slow thaw (S) referred to in the same tables was carried out by air thawing at room temperature. (Such thawing was usually completed in about 1-2 days). The rates are shown in figure 4.

HERRING ROE PROCESSING

After thawing, the roe was retrieved in the usual manner. The roe from fast thawed fish tended to be much softer and more care was required for removal. All roe and carcasses were weighed to calculate yield based on females only. The roe was washed 3 times in total with 4% (w/v) NaCl solution over a period of 24 hours and transferred to saturated brine. The first wash was discarded after a short period to avoid prolonged contact with discolored liquor. Excess salt was added to the saturated brine and the processed roe examined for sponginess and other characteristics after at least 2-3 days.

CRITERIA FOR THE EVALUATION OF SPONGINESS

In plant diagnosis of sponginess in herring roe processed to the export stage, that is, up to the step of brightening with hydrogen peroxide which is carred out wholly in Japan, is based on a number of factors valued singly or collectively. General softness, appearance of mottled light colored patches in part or whole of the skein, the ease with which fluids are expressed by squeezing with the fingers or the full grip, the appearance of light colored patches upon the release of pressure are some of the factors considered. The light colored opaque patches result from damaged and/or collapsed eggs partially or wholly devoid of cellular contents. In contrast, grade one kazunoko are more uniformly translucent, the eggs are intact and tend not to release excessive fluids upon squeezing. Even repeated squeezing

short of actual physical damage to the eggs does not usually transform normal kazunoko to the spongy condition. By means of a taste test, spongy roe is softer and depending upon the severity, lacks the familiar "crunch" of bursting intact eggs. All of these indicators of sponginess vary with severity and borderline cases are difficult to classify, leading to variations in grading by different technicians.

Histochemically, in spongy roe the egg cell wall is collapsed and much less stainable material is found within. In normal eggs, the cell wall while not completely spherical is not collapsed and much more stainable material is present. In spongy roe, the cell contents have escaped either through rupture of the walls or by some other process of leakage.

Despite the obvious softness of spongy roe when squeezed with the hand, mechanical compression with the OTMS* resulted in only a slight difference when compared to grade 1 roe. In contrast to a previous report (Yamamoto and Wong, 1976) both spongy and normal grade 1 roe resulted in single and double peaked OTMS chart profiles and a definitive identification cannot be made on this basis.

Prior to marketing, the kazunoko is bleached or "brightened" in Japan with hydrogen peroxide the excess of which is destroyed enzymatically to conform to a certain minimum acceptable level. The process also accentuates the opaque light colored patches in spongy roe. In contrast, normal kazunoko is transformed by the same process to a translucent product uniformly light golden yellow in color. A similar process in a modified form using higher concentrations of hydrogen peroxide to shorten the bleaching time is used to detect spongy roe more effectively. Some plants employ this approach to confirm the extent of sponginess determined at the export stage of processing.

HYDROGEN PEROXIDE TEST FOR SPONGINESS

Brined roe is placed in 1 - 3% hydrogen peroxide in fresh water (or 10^{o} brine) at a ratio of peroxide solution to roe of 3 : 1 at a temperature of about $20^{o}C$. Because of the formation of gas bubbles which become trapped on the surface of the skeins of roe, roe must be kept submerged. After at least several hours, but usually overnight, the peroxide solution is drained and the roe examined for sponginess. As gas bubbles adhering to both normal and spongy roe tend to obscure the opaque light colored patches in the latter, we generally confirmed the extent of sponginess following overnight submersion in saturated brine. This procedure is in fact similar to the one used in Japan.

Immature roe can be readily distinguished from spongy roe by its general light appearance, the softness and fragility of its skein structure, its tendency to crumble easily, and when viewed under a magnifying glass, by its "cataract" like white button that often accompanies an otherwise undamaged spherically shaped egg.

Overmature roe after peroxide treatment is readily distinguishable from spongy roe by the ease with which the skein structure crumbles and separates

* OTMS = Ottawa Texture Measuring System

into individual grains of round intact eggs. Collapsed eggs are not generally found in overmature roe. Like normal roe, the general appearance is translucent beneath the loose ovarian membrane.

Borderline cases of sponginess are still somewhat difficult to detect even following peroxide treatment.

DRYING TEST FOR SPONGINESS

The drying method can be applied to both brined roe and roe leached with fresh water. Sponginess is brought out more clearly in leached roe due to the absence of salt which accumulates on the surface as drying proceeds and obscures the white patches. Brined roe is leached with several changes of fresh water till most of the salt is removed and then dried in circulating air overnight at room temperature. Warm circulating air will hasten the drying process. The completeness of drying is not critical, as the mosaic white patches of damaged eggs become evident after partial drying. Normal roe appears a uniform golden brown in color and while a little shrivelled from drying, it is translucent and the eggs are arranged in uniform rows. White mosaic patches appear on part or all of the skein in spongy roe depending on severity.

PRACTICAL APPLICATION OF SPONGINESS TESTS

Since it is obviously not feasible to test all roe, only the fraction of a day's production which is graded out as "suspect" can be examined further. A precise fraction of the "suspect" roe can be treated with peroxide and the % by weight of truly spongy roe determined. Such a figure can then be applied to the total weight of the "suspect" roe previously set aside.

RESULTS AND DISCUSSIONS

Within the constraints of a laboratory scale investigation on the effect of a multitude of variables on the incidence of sponginess, the quantities of roe herring that can be handled conveniently is necessarily limited. Nevertheless, within these limits valid conclusions can be drawn where sufficiently large quantities of roe are involved or when relatively large and/or reproducible effects are observed.

THE EFFECTS OF 4 HOURS TO 2 - 3 DAYS AT THE CRITICAL FREEZING ZONE ON THE INCIDENCE OF SPONGINESS

Incidences of spongy processed roe from 3 lots of herring differing in post-mortem age, population, and in handling techniques, after various periods of frozen storage are compiled in tables 1 - 3. The storage time varied from 2 - 10 weeks at the indicated temperature. The yield based on females averaged 29%. During the course of this investigation, the proportion of

immature roe was recorded; in the past some uncertainty existed as to what constituted spongy roe. An incidence of immaturity ranging from 0 to 15.4% was found in roe from the different bags of herring examined (tables 1 - 4). Two other categories, the fragile and "daruma-ko" were also recorded in the later stages of this investigation. Although with experience, spongy roe can be distinguished from these two categories, it is of interest to note the incidence of these forms in the normal grades of roe. Fragile roe resembles immature roe by the ease with which the skein structure disintegrates from handling but differs in that the individual grains of eggs appear normal and translucent while lacking the opaque white cataract-like appearance. "Daruma-ko" is a Japanese expression for roe in which both skeins are stuck together in partially or wholly inseparable manner. Speculations on the causes of this condition vary from stacking pressure during harvesting and transportation to biological abnormality.

In general, in these experiments, roe extracted from herring quick frozen in brine or with horizontal plate freezers, tended to be more golden yellow in color with the appearance of distinct vascularization beneath the ovarian sac. In roe from more slowly frozen fish from the same lot, the entire skein appeared more uniformly discolored from diffusion of partially oxidized blood hemoglobin. Black tips from the diffusion of bile pigments was not as common on roe from frozen fish as from fresh with relatively long post-mortem history. Quick freezing resulted in processed roe which tended to be very firm, while slower freezing favored slightly softer, but not spongy, product.

No sponginess was observed in 3.4 kg of roe from brine frozen herring.

Even under the "quick freezing" conditions used (figure 1), the amount of spongy roe from the different bags of frozen herring varied anywhere from 0 to a high of 8.6% (tables 1 - 3). The average of all bags was 1.53% based on 39.7 kg of processed roe.

The slow freezing conditions used in this investigation resulted in a higher average incidence of sponginess of 4.77% (tables 1 - 3) based on 39.9 kg of processed roe. By core temperature monitoring, the centre of the bags of slow frozen herring in corrugated cartons remained at near freezing for up to 3 days before proceeding to equilibrate with the air temperature of the freezer (figure 3). The periphery, however, was frozen solid.

The single high incidence of 22.3% (table 1) was obtained from samples frozen in the standard household chest freezer and stored for 6 weeks at -28°C. Quick frozen samples from the same lot of fish were quite low in sponginess. Wide variations existed in the rate at which the latent heat was removed from the 6 bags of fish in the chest freezer depending upon their position on the shelves (figure 2). This difference may have led to the single high incidence of sponginess observed.

No definite trend in the extent of sponginess was obvious from the different storage times of up to 10 weeks at -28°C. These findings are in marked contrast with a report (Wong, et al., Technical Report No. 604) describing the absence of spongy roe from herring frozen both quickly and at a slower rate. In "slow" freezing method in that study, fish was considered

frozen in 48 hours although core temperatures were not monitored.* The spongy condition, however, is not readily detected by a casual examination and it is doubtful if industry had a very clear definition of sponginess at that time.

Fast or slow thawing rates (figure 4) of herring frozen by either method did not influence the degree of sponginess. Post-mortem quality and age of herring, maturity, and differences in population did not reveal much difference in the incidence of sponginess, at least, by this laboratory scale investigation. A larger scale study might possibly uncover some differences by factors other than freezing although the effect would likely be of relatively minor significance.

To minimize the development of sponginess, therefore, it is essential to remove the latent heat of freezing as quickly as possible to bring the core temperatures well below freezing as fast as possible. Even a 2-3 day delay in the removal of the latent heat during attempts to freeze the fish results in a significant increase in sponginess.

We were unable to detect spongy roe from brine frozen herring under our laboratory conditions. Commercial brine freezing operations have resulted in incidences well below the 1% level.

Clearly much more drastic slow freezing conditions are required to produce higher levels of sponginess. Other factors often cited such as repeated freeze-thaw cycles (in this study, 3 cycles over a 3 day period), thawing rates, or brining of partially thawed roe, did not result in any noticeable increase in the formation of sponginess.

THE EFFECT OF MORE DRASTICALLY SLOWER FREEZING RATES AND DIFFERENT FROZEN STORAGE HOLDING TEMPERATURES ON THE INCIDENCE OF SPONGINESS

So far in the laboratory, only partial simulation was achieved of the extremes in conditions that could occur at times in commercial freezing and storage that may lead to the formation of excessive amounts of spongy roe. Freezing of bags of herring at rates exceeding the freezer capacity and, poor circulation, or defective freezer systems could cause localized "hot spots" and maintain the fish at temperatures near freezing for extended periods of time.

In our initial attempt, cartons of roe herring were first placed in a -28°C walk-in freezer and transferred to another freezer at -2°C when the core temperature just reached near freezing. The peripheral temperatures were probably approaching the air temperature of the walk-in freezer. Three weeks later, the processed roe revealed 47.8 and 52.6% incidence of sponginess (table 4). In 4 weeks, this figure increased to 83.1%. A 6% incidence of sponginess was found in controls from the same lot of fish held at -28°C.

* At the time the earlier work was done, the only concern expressed by the industry was between IQF and good quick freezing. The marginal difference between them is minor compared to "good" versus poor commercial practice.

The roes that were not yet spongy were very soft and certainly of very poor quality compared to the controls. Roe processed from herring stored in chilled 30° brine at 25°F was also found to be soft (Tomlinson et al., 1975). Clearly, the length of time at which the core temperature remains at the critical freezing zone (that is, the freezing rate) has a profound effect on the development of spongy roe.

Next, the effect of different freezing temperatures on the development of sponginess was determined on a lot of gill-net caught herring less than 12 hours post-mortem. Cartons of the fresh fish were held from the beginning at -2°C, -10°C, -18°C, and -28°C for varying periods of time. The freezing rate at these different temperatures are recorded in figure 5. A holding temperature of -2°C for 3 weeks resulted in 52.6% spongy roe, increasing to 93.6% in 5 weeks (table 5). These results not only confirm those in the previous test but also indicate that holding fish at -2°C from the fresh state increases sponginess in proportion to the extent that the periphery of the cartons of herring has not had the advantage of deep freezing. Fish held at -2°C for 3 weeks followed immediately by a 2 week period at -28°C resulted in 82% spongy roe. Once roe becomes spongy, therefore, the condition cannot be reversed by holding fish at a much lower temperature. However, fish frozen at -28°C for 6 weeks and then transferred to -2°C for 3 weeks resulted in an intermediate incidence of sponginess of 15.1% (table 4) indicating that quick freezing to a very low temperature partially protects roe from turning spongy despite subsequently raising the temperature to -2°C for a length of time known to develop the condition to a very high degree.

The next lower holding temperature of -10°C resulted in 18.5% spongy roe after 6 weeks and 29.5% after 9 weeks. While the 4 - 5 days (figure 5) required to pass through the critical freezing zone at this temperature certainly is responsible for the development of sponginess, we have only limited proof that this holding temperature in itself is likewise involved. However, the fact that the longer 9 week storage time increased the incidence of sponginess considerably would indicate that the holding temperature is also intimately involved. A holding temperature of -18°C and -28°C for 9 weeks resulted in an incidence of sponginess which was not more than that observed from quick freezing. After 11 weeks at these temperatures, no further change developed. Freezing rate curves at these holding temperatures, because the cartons of fish were in direct contact with cooling surfaces, show that the core temperatures remained at the critical freezing zone for less than 1.5 days (figure 5) which is shorter than under the earlier slow freeze conditions.

In the freezing process, therefore, the length of time the herring remains at the critical freezing zone as well as the cold storage holding temperatures are extremely relevant to the development of high incidences of sponginess. By these studies, the development of significant amounts of sponginess appears to begin when 2 - 3 days are required to pass through the critical freezing zone and becomes progressively worse with longer times. The slow freezing through this critical zone results from the necessity of removing the latent heat of freezing or the heat liberated when water changes from liquid to ice. Sponginess is reduced progressively with lower cold storage holding temperatures till at -18°C where approximately the normal incidences are observed.

INTERPRETATION

Theories of freezing indicate that large numbers of very small crystals, which do not have time to grow, are formed during rapid freezing (Love, 1966; Dyer, 1971). It is suggested that the ice crystals formed within the eggs during quick freezing are not large enough to destroy the structure or alter the cell wall membranes sufficiently to release cellular contents. In slow freezing, the small crystals grow large enough and may destroy the eggs completely in severe cases, or in less severe instances, alter the permeability enough so that some or all of the cellular contents are lost. In the brining process, fluids which have entered the damaged eggs could readily escape upon the application of pressure, giving rise to the soft, spongy texture and other characteristics associated with eggs in this condition.

EFFECT OF THE STORAGE TEMPERATURE OF PROCESSED ROE ON THE INCIDENCE OF SPONGINESS

Four pails of commercially processed grade 1 roe prepared from frozen herring were examined carefully and all spongy skeins were removed prior to storage. An incidence of 1.87% was found. The roe was placed in saturated brine well fortified with excess sodium chloride and stored at 2°C, -10°C, -22°C, and -28°C in one pail (12 - 14 kg) quantities. Initial examination was carried out at 9 weeks of storage. A storage temperature of 2°C resulted in 3.6% incidence of sponginess, 2.5% at -10°C, 5.3% at -22°C, and 1.0% at -28°C. In about a quarter of the roe stored at 2°C, the grains of eggs in part of the skein turned an opaque white. The condition, however, was not considered spongy. While most of the affected portion was confined to the inner surface of the skein, peripheral edges were also involved. This transformation was rarely observed at the lower storage temperatures. The highest incidence of sponginess was observed at -22°C, a temperature close to the eutectic point* (-21.1°C). The roe stored at this temperature was also not quite as firm as the others. Roe prepared from unfrozen herring (that is, by brining the fish) and stored at 2°C for an even longer period of time showed no evidence of sponginess. Freezing could well be transforming some skeins of roe to the undetectable sub-spongy stage which upon prolonged storage may deteriorate to the detectable category. Depending on the temperature at which they (held roe from frozen fish upon its receipt in Japan), Japanese buyers could experience significant levels of sponginess in roe which was not spongy when exported from Canada.

CONCLUSIONS

Freezing rates and cold storage temperatures are the most important factors in the development of sponginess in roe from once frozen herring. Factors associated with freezing such as freeze-thaw cycles, thawing rates, brining of partially thawed roe, have only a marginal, if any, effect. While post-mortem age and quality, population differences, maturity, and other differences may affect the quality of roe in different ways, these are not the

* That is, the point at which saturated brine will freeze.

crucial contributing factors in the development of spongy roe.

Freezing of roe herring even under the best of methods results in the development of low levels of sponginess. Slower rates of freezing in which the core temperatures of the bags or cartons of herring require 2 - 3 days to pass through the critical freezing zone of -1°C to -5°C already result in a significant increase in the incidence of sponginess. Lengthening this time to 4 - 5 days progressively increases the incidence and after 3 - 5 weeks at -2°C, nearly all the roe become spongy.

A cold storage temperature of up to -10°C also results in a high incidence of sponginess. The temperature must be maintained to at least below -18°C for good results. Therefore, both the rate of freezing and the holding temperature of roe herring are of paramount importance. It is important to realize that the limits stated above for preventing the development of sponginess are minimum conditions under ideally controllable, small scale laboratory operations. For industrial applications, quick freezing and a low cold storage temperature of at least below -18°C are recommended. Freezing techniques such as brine freezing, which greatly shortens the time required to lower the core temperatures to well below the freezing point, are the methods of choice to minimize the incidence of sponginess.

Sponginess of exported roe processed from once frozen herring is expected to increase significantly with storage time. Storage temperatures can also influence its extent. Within certain limits, discrepancies are to be expected in the extent of sponginess from the time the roe leaves the production line and when it is finally brightened for sale to the public after extended storage. Roe processed from unfrozen herring did not develop sponginess following prolonged storage at 2°C.

ACKNOWLEDGEMENTS

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Corrections in the footnotes to the following tables:

Table 1. Δ average increase in weight of processed roe/fresh roe = 2%
Table 2. Δ average increase in weight of processed roe/fresh roe = 8%
Table 3. Δ average increase in weight of processed roe/fresh roe = 16%
Table 4. # average increase in weight of processed roe/fresh roe = 4%
Table 5. # average increase in weight of processed roe/fresh roe = 16%

2	S"	F	2.3	25.5	2.4	0	-	-	2.8	good, yellow, firm
2	S	S	2.4	27.6	2.9	0	-	-	2.1	good, deep yellow, firm
6	F	F	1.8	27.4	1.9	0	-	-	0	good, light yellow, firm
6	F	S	2.0	28.6	2.0	0	-	-	2.0	good, yellow, firm
6	S	F	2.0	31.7	2.1	7.3	-	-	11.9	fair, deep yellow, less firm
6	S	S	1.7	25.4	1.9	0	-	-	22.3	fair/poor, brown yellow, less firm
8	F	F	2.3	33.8	2.5	2.5	-	-	8.6	fair, light yellow, less firm
8	F	S	3.7	29.8	3.8	1.4	-	-	0	good/fair, lighter yellow, firm
8	S	F	3.0	33.0	2.9	14.5	-	-	5.2	fair, yellow, less firm
8	S	S	3.9	26.2	3.2	12.2	-	-	7.3	fair, deep yellow, less firm

* Based on roe from 403 lbs. of seine caught presexed herring of 15/3/77
Δ Increase in yield of processed roe/fresh roe x 100 = 102%
\# In this and succeeding tables F refers to samples frozen quickly in the Dole horizontal plate freezer
" In this and succeeding tables, S refers to samples frozen slowly in the Chest freezer or in corrugated cartons in the walk-in freezer.

TABLE 2. EXPERIMENTAL DEVELOPMENT OF SPONGY ROE*

Storage time(wks) at -28°C	Freeze rate	Thaw rate	Fresh roe wt (kg)	% yield ♀basis	Processed Roe: Total wt(kg) Δ	Im-mature %	Fragile %	Daruma-ko %	Spongy %	Remarks
2	F	F	2.9	27.8	3.1	0	-	-	0	good, light yellow, firm
2	F	S	2.1	30.0	2.3	9.7	-	-	4.4	good, deep yellow, firm
2	S	F	2.5	35.2	2.7	11.0	-	-	0	good, yellow, firm
2	S	S	2.0	32.2	2.3	3.8	-	-	2.6	good, deep yellow, firm
4	F	F	2.4	24.7	2.5	0	-	-	0	good/fair, light yellow, firm
4	F	S	2.3	27.7	2.6	0	-	-	2.2	good/fair, deep yellow, firm
4	S	F	1.5	30.0	1.6	2.9	-	-	3.1	good/fair, yellow, less firm
4	S	S	1.6	32.7	1.6	6.3	-	-	3.2	good/fair, deep yellow, firm
8	F	F	2.6	30.9	2.5	12.9	8.3	2.2	0	fair, yellow, less firm
8	F	S	2.4	30.7	2.8	9.1	6.7	2.3	0	fair, deep yellow brown, less firm
8	S	F	1.4	28.9	1.6	8.4	7.7	0	1.8	fair, yellow, firm
8	S	S	1.4	27.9	1.6	11.0	2.1	0	0	fair, yellow brown, firm

* Based on roe from 590 lbs. of herring caught by seine on 21/3/77

Δ Increase in yield of processed roe/fresh roe x 100 = 108%.

TABLE 3. EXPERIMENTAL DEVELOPMENT OF SPONGY ROE*

Storage time(wks) at -28°C	Freeze rate	Thaw rate	Fresh roe wt (kg)	% yield ♀basis	Processed Roe: Total wt(kg) Δ	Immature %	Fragile %	Daruma-ko %	Spongy %	Remarks
2	F	F	1.2	26.0	1.3	0	-	-	0	good, light yellow, firm
2	F	S	1.4	30.4	1.6	0	-	-	1.0	good, yellow brown, firm
2	S	F	1.1	22.0	1.2	0	-	-	0	good, yellow, firm
2	S	S	1.7	29.9	1.8	3.9	-	-	0	good, deep yellow, firm
4	F	F	2.0	29.4	2.9	6.6	-	-	4.5	good, light yellow, firm
4	F	S	1.5	29.4	1.6	7.2	-	-	8.3	good, yellow, firm
4	S	F	1.2	29.3	1.4	0	-	-	13.7	fair, yellow, firm
4	S	S	1.6	32.7	1.6	4.7	-	-	3.1	good, deep yellow, firm
6	S	F	1.8	29.0	2.1	3.5	0	11.7	7.2	fair, yellow, firm
6	S	S	2.1	27.6	2.5	13.0	4.3	5.8	3.9	good, yellow, less firm
8	S	F	0.8	28.6	1.1	10.2	0	0	3.3	good, yellow, firm
8	S	S	1.2	31.7	1.3	0	0	5.3	5.7	fair, yellow brown, less firm
10	S	F	1.0	28.6	1.1	8.3	0	0	0	fair, yellow, less firm
10	S	S	1.4	29.2	1.6	6.1	0	0	0	fair, yellow brown, firm

* Based on 500 lbs. of roe from herring caught by gill-net on 22-23/3/77

Δ Increase in yield of processed roe/fresh roe x 100 = 116%.

TABLE 4. EXPERIMENTAL DEVELOPMENT OF SPONGY ROE*

Storage time(wks)	Storage T (°C)	Freeze rate	Thaw rate	Processed Roe: Fresh roe wt (kg)	Processed Roe: % yield ♀basis	Processed Roe: Total# wt(kg)	Processed Roe: Immature %	Processed Roe: Fragile %	Processed Roe: Daruma-ko %	Processed Roe: Spongy %	Remarks
3	-2	S	S	2.3	29.1	2.6	10.2	-	-	47.8	fair/poor, dark yellow, firm/soft
3	-2	S	S	3.6	25.6	3.9	1.3	0	1.6	52.6	fair/poor, brown yellow, soft
4	-2	S	S	9.7	30.0	8.2	2.7	-	-	83.1	poor, brown yellow, very soft
6Δ	-28	S	S	10.7	28.7	12.0	15.4	-	-	6.0	good, yellow, firm
6 ↓ 3	-28 ↓ -2	S	S	4.2	28.0	5.0	4.9	0	0	15.1	fair, yellow, firm/soft

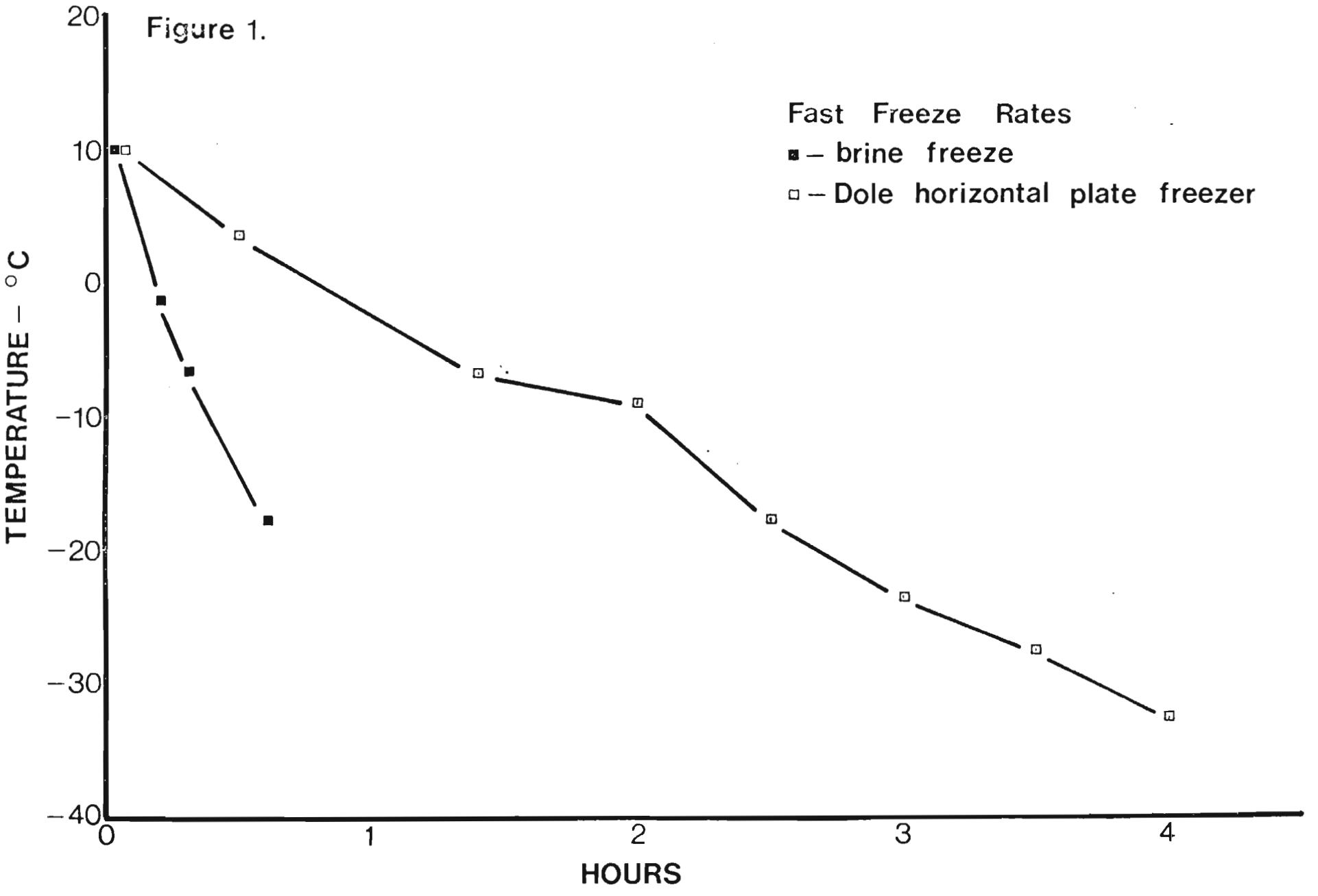
* Based on roe from part of 1500 lbs. of herring caught by seine on 1/4/77
Δ From the same lot of herring used for control
\# Increase in yield of processed roe/fresh roe x 100 = 104%.

TABLE 5. EXPERIMENTAL DEVELOPMENT OF SPONGY ROE*

Storage time(wks)	Storage T (°C)	Freeze rate	Thaw rate	Processed Roe: Fresh roe wt (kg)	Processed Roe: % yield ♀basis	Processed Roe: Total# wt(kg)	Processed Roe: Immature %	Processed Roe: Fragile %	Processed Roe: Daruma-ko %	Processed Roe: Spongy %	Remarks
3	-2	S	S	3.6	25.6	3.9	1.3	0	1.6	52.6	fair/poor, brown yellow, soft
3 ↓ 2	-2 ↓ -28	S	S	1.5	25.0	1.7	3.5	0	0	82.0	fair/poor, brown yellow, soft
5	-2	S	S	3.6	25.5	4.1	2.3	0	0	93.6	poor, brown yellow, soft
6	-10	S	S	3.8	25.5	4.6	1.7	0	0	18.6	fair, light brown yellow, slightly firm
9	-10	S	S	8.0	30.4	8.6	2.9	0	0	29.5	fair, brown yellow, soft
9	-18	S	S	2.6	23.6	3.2	1.3	0	0.9	2.6	good, yellow firm
9	-28	S	S	4.0	25.6	4.5	0.5	0	0	0	good, light yellow firm
11	-18	S	S	5.2	23.7	6.5	3.5	3.2	0	0	good, light yellow firm
11	-28	S	S	5.3	24.0	6.4	3.8	1.3	0	0	good, light yellow firm

* Based on roe from 600 lbs. of herring caught in Puget Sound by gill-net on May 6/77
\# Increase in yield of processed roe/fresh roe x 100 = 116%.

Figure 1.


Fast Freeze Rates
■ – brine freeze
□ – Dole horizontal plate freezer
TEMPERATURE – °C
20
10
0
−10
−20
−30
−40
0
1
2
3
4
HOURS

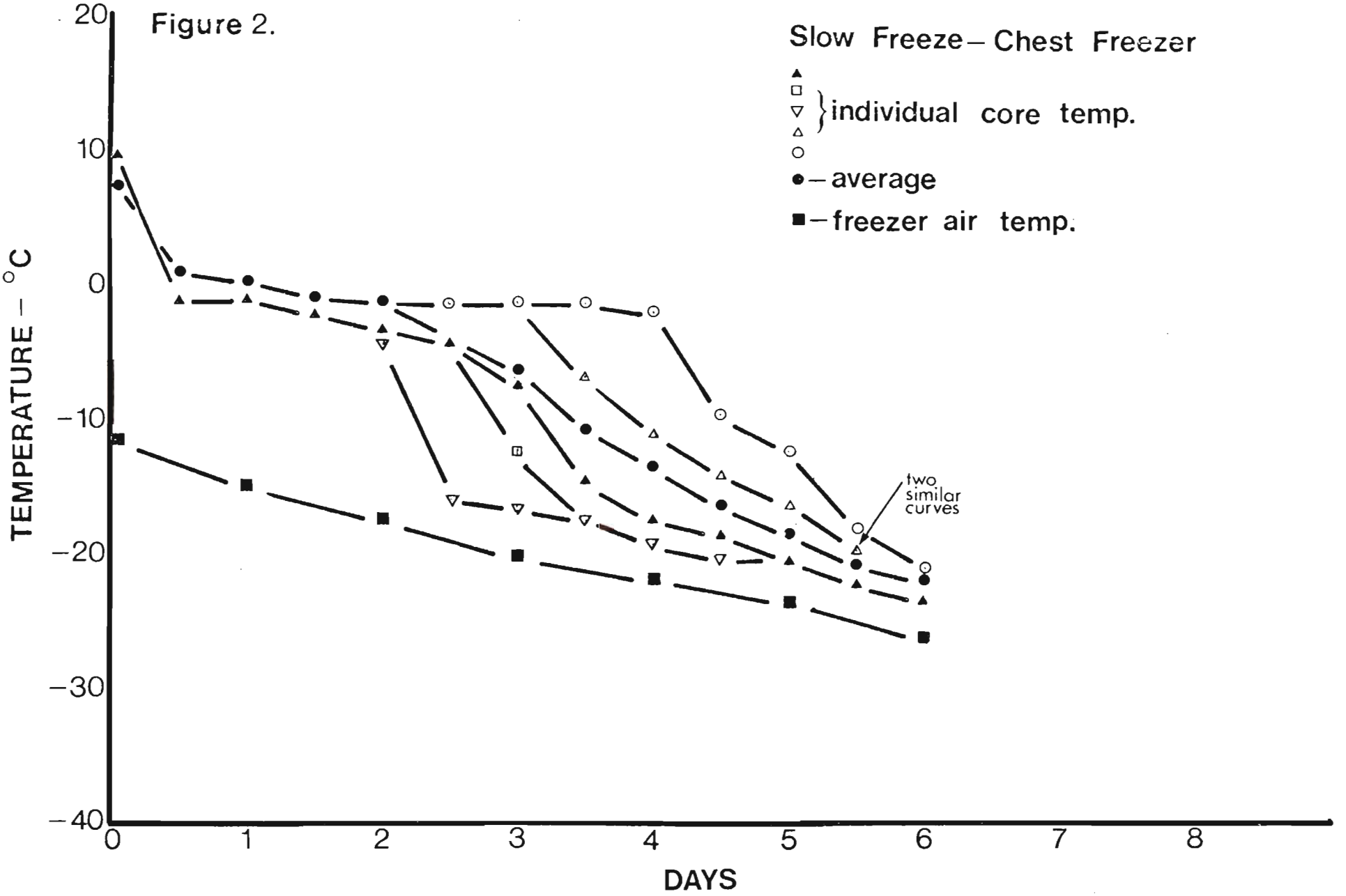


Figure 2.
Slow Freeze – Chest Freezer
individual core temp.
– average
– freezer air temp.
two similar curves
TEMPERATURE – °C
20
10
0
–10
–20
–30
–40
0
1
2
3
4
5
6
7
8
DAYS

Figure 3.

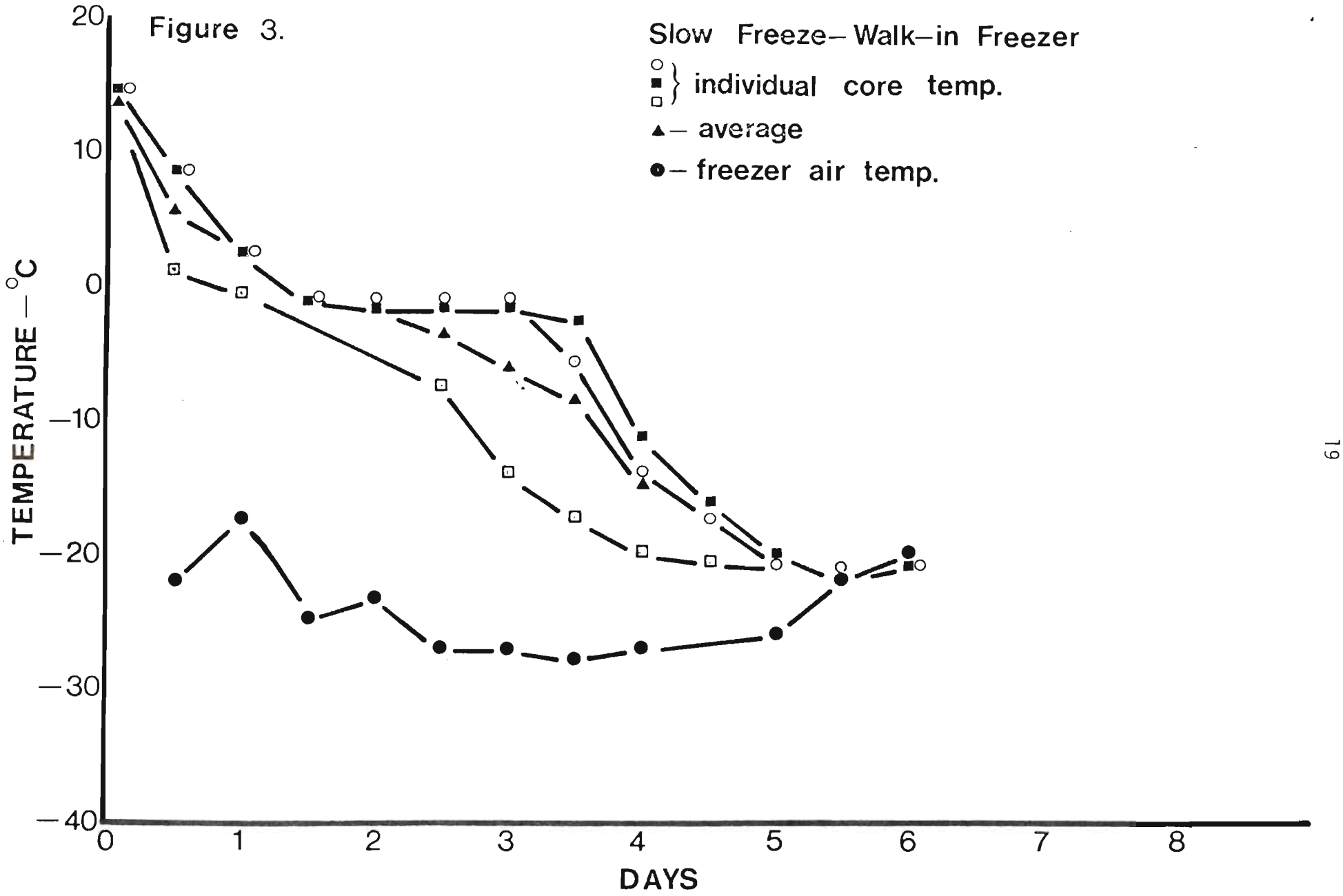

Slow Freeze–Walk–in Freezer
individual core temp.
– average
– freezer air temp.
TEMPERATURE – °C
20
10
0
–10
–20
–30
–40
0
1
2
3
4
5
6
7
8
DAYS

Figure 4.

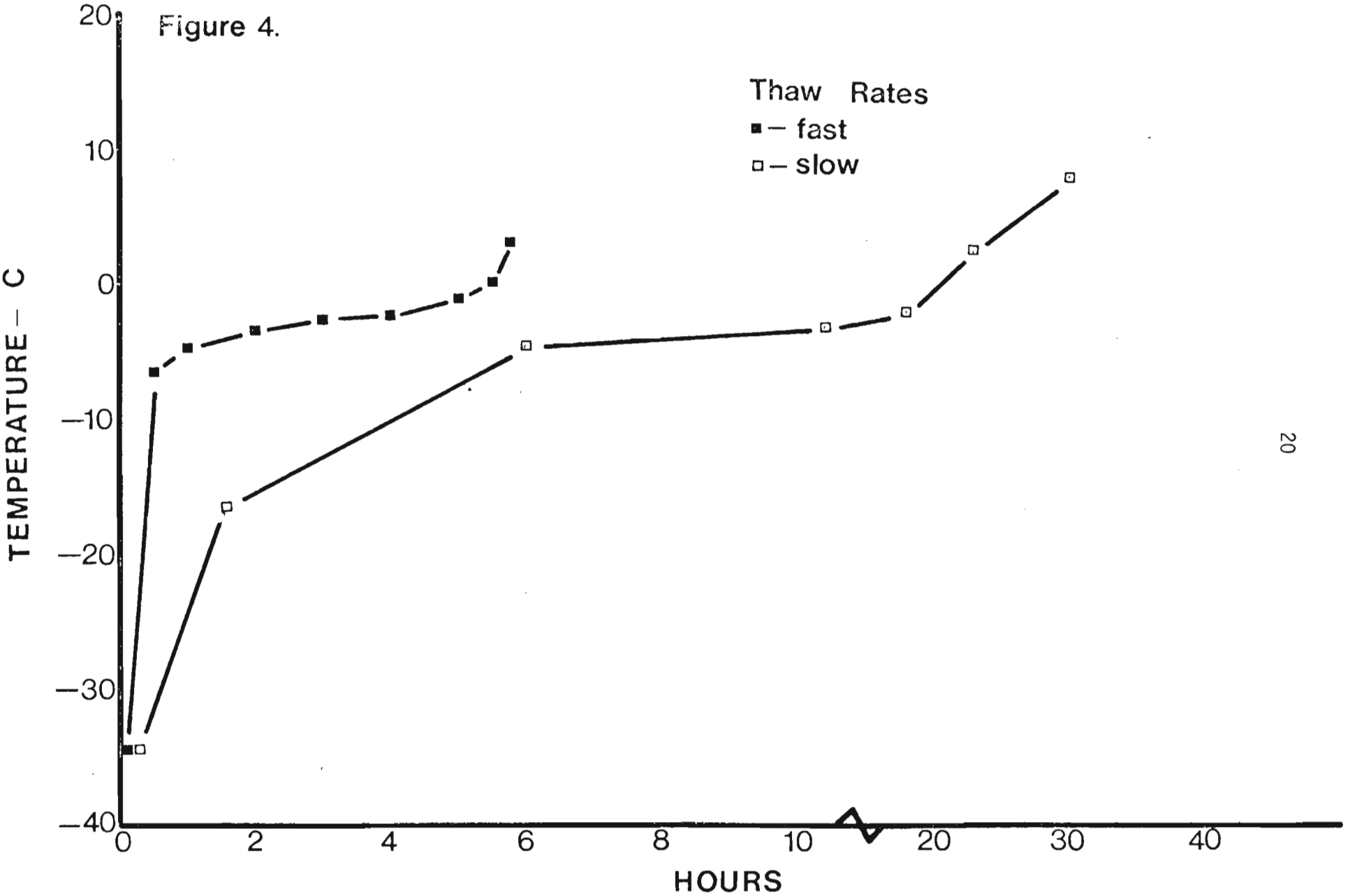
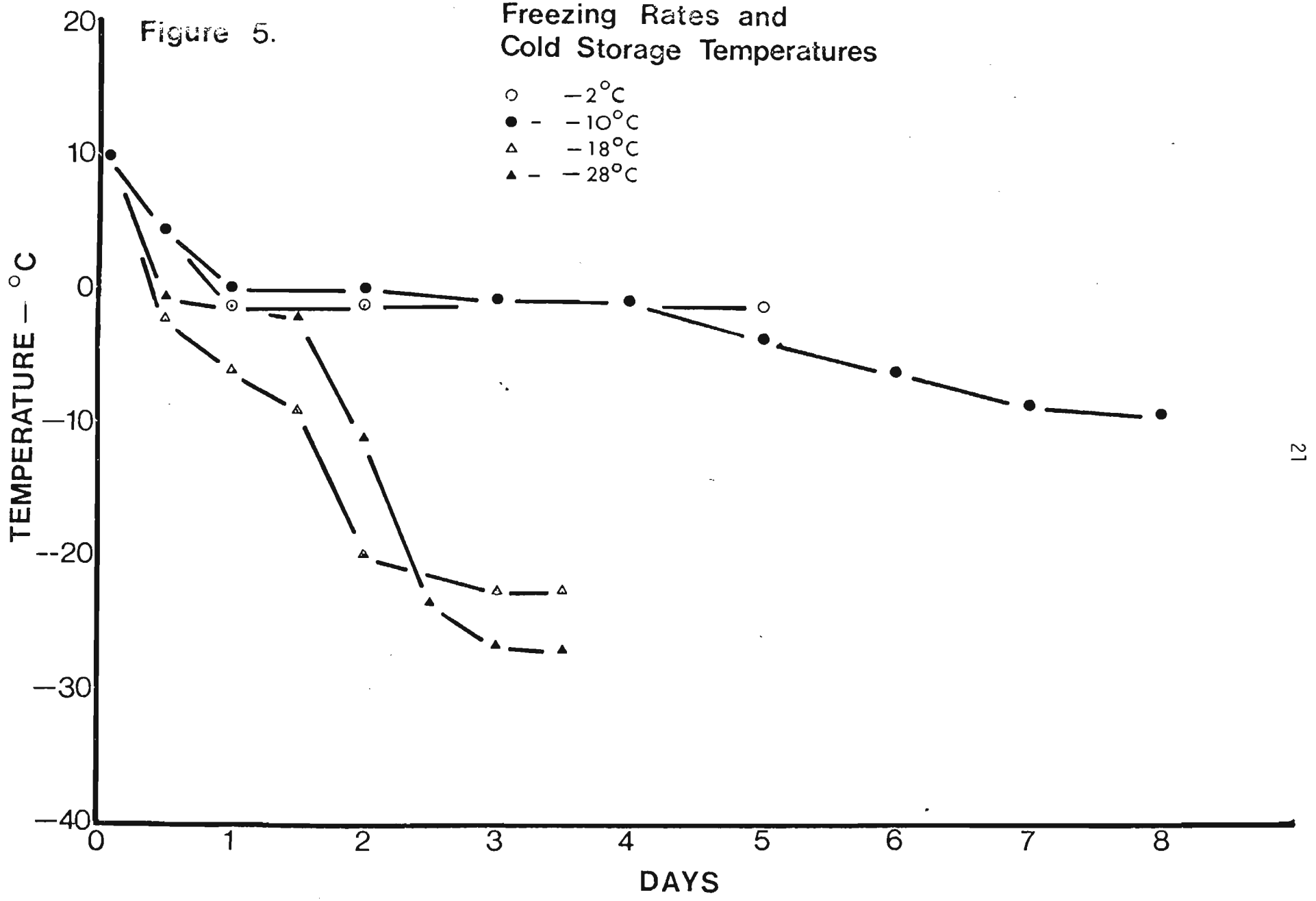

Thaw Rates
■ – fast
□ – slow
TEMPERATURE – °C
20
10
0
–10
–20
–30
–40
0
2
4
6
8
10
20
30
40
HOURS

Figure 5.


Freezing Rates and
Cold Storage Temperatures
○ −2°C
● − −10°C
△ −18°C
▲ − −28°C
20
10
0
−10
--20
−30
−40
TEMPERATURE − °C
0
1
2
3
4
5
6
7
8
DAYS