SIK-Rapport
1973 Nr 328

THE TIME-TEMPERATURE TOLERANCE
OF FROZEN FOODS

Survey of literature

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This study was sponsored by Food Control AB, Malmö, Sweden, as a part of their development program for a time-temperature indicator.
THE TIME-TEMPERATURE TOLERANCE OF FROZEN FOODS -
SURVEY OF LITERATURE

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SUMMARY

Information found when reviewing the literature regarding the time-temperature tolerance of frozen foods was compiled into tables, noting information about product quality, processing and packaging (PPP factors) and also sensory evaluation techniques. After certain screening of the data, curves for HQL (High Quality Life), and acceptability from these individual investigations were plotted in semilogarithmic time-temperature diagrams. It was then possible to systematize the material into six food groups of different time-temperature tolerance. These groups and their variability were presented in diagrams, including data from investigations with "normal" PPP-conditions only.

The groups so obtained, which partly overlap each other, are the following:

1. Raw lean meat and pre-cooked lean meat packed in gravy.
2. Raw fat meat and pre-cooked foods of fat meat packed in gravy.
3. Pre-cooked foods without gravy. Lean fish.
5. Fruit and berries.
The variability within groups is quite wide, which can be explained by varying PPP-conditions and also by different evaluation techniques being used in different investigations. A finer subdivision into food groups or individual foods has not been considered meaningful, with regard to the great variability in the literature data. The marked influence of raw material-, process- and packaging variables has been illustrated in separate diagrams, which emphasize the fact that these factors must be well defined in order to reduce variability between experiments with a given food material.

The slope and variability are similar for groups 1-4 up to approximately -10°C, where group 2 changes slope, probably because some other quality factor predominates in this temperature range. Groups 5 and 6 (fruit, berries and vegetables) generally show a steeper slope and a wider variation at higher temperatures. Regarding ice-cream and sugared products there is a risk of melting at temperatures exceeding approximately -15°C, and the temperature range exceeding -5°C is altogether very uncertain for all foods.

In the light of the data reviewed possible application areas for a time-temperature indicator are discussed.

1. REVIEWED LITERATURE

Information regarding time-temperature relations for stored frozen food has previously been compiled as a SIK review 1963. This information has, together with the books mentioned below, been considered to cover the literature up to 1965. Up to 1971 the following publications have been systematically scanned. In addition, SIK:s collections of references and reprints have been searched. The below mentioned persons and institutions have also been contacted.
Reviewed books and compendia

Andersen, E., Jul, M. and Riemann, H.
Industriel levnedsmiddelkonservering (Industrial Food Preservation).

van Arsdale, W.B. et al.
Quality and stability of frozen foods.
TTT and its significance.

International Institute of Refrigeration (IIR)
Recommendations for the processing and handling of frozen foods.

The courses in deep freezing of food, arranged by

Reviewed publications

Food Science and Technology Abstracts
Bulletin IIR
BFMIRA Abstracts
Food Science Abstracts
Dairy Science Abstracts
Food Technology
IIR Congresses of refrigeration
Industria Conserve
Journal of Food Science
Journal of Food Science and Technology
Journal of Food Technology
Kulde
Kylteknisk Tidsskrift
Lebensmittel-Wissenschaft + Technologie
Livsmedelsteknik
Quick Frozen Foods
Revue Générale du Froid
Revue Pratique du Froid
Zeitschrift für Lebensmittel-Untersuchung und -Forschung

Contacts
Slagteriernes Forskningsinstitut, Roskilde (The Danish Meat Research Institute, Roskilde), Slagteri- og Konserves-laboratoriet (The Meat and Canning Laboratory), Copenhagen. Fiskeriministeriets Försökslaboratorium (Technological Laboratory, Ministry of Fisheries) Lyngby, Denmark, Professor Frode Bramsnaes, Copenhagen, Professor G. Lorentzen, Trondheim, Djupfrysningsbyrå (The Swedish Bureau for Frozen Foods), Stockholm and Frigoscanbias fryslaboratorium (The Frigoscania Deep-freeze laboratory), Helsingborg.

2. RESULTS

2.1. Reports in the literature

A great number of reports regarding the time-temperature tolerance of frozen stored foods have been found, and are given in the list of references.

van Arsdel's book on "Quality and stability of frozen foods" gives a very good survey of the subject with clear summaries of the TTT- and PPP-data of different products. The book has therefore, together with a previous SIK-review, been used as a basis for systematizing and grouping the complete material. Certain data have then been taken directly from the book without referring back to the source of origin other than by a notation in the list of references.

Information about the time-temperature sensitivity of different foods has been critically investigated and screened with regard to general reliability and the
reputation of the respective researchers, and results showing unexplainably great deviations from the average have in some cases been excluded.

Among noteworthy reports, with reference to meat products may be mentioned those by Dalhoff and Jul, and by Bøgh-Sørensen who have provided the main material for several of the reported TTT-curves, and also Frigoscandia's storage experiments with pre-cooked foods. Extensive work in the field of meat products has also been reported by Gutschmidt, but his values show quite considerably shorter shelf life than other comparable investigations, for which reason they have not been included in our curves. A possible reason for the deviation of Gutschmidt's data could be a difference in raw material quality or possibly a more discriminating and critical taste panel than average.

Regarding fish products, particularly Edhborg, Bramsnaes and Liljemark have supplied valuable information, but apart from this the material is very meagre.

Concerning fruit, berries and vegetables, the work of Guadagni, van Arsdel and coworkers should be emphasized as the pioneering effort in the field of TTT, and only a few investigations have been reported after their extensive experiments during the fifties and the beginning of the sixties.

Apart from these relatively wide investigations several articles giving limited information about a particular product have been found. Among the references are also included some publications listing generally recommended storage times and temperatures, such as those given by the IIR (International Institute of Refrigeration).
2.2. Nomenclature

In the literature, data regarding the time-temperature tolerance of foods (TTT-data) are reported using a number of different definitions. The basic principles of the TTT-concept, as explained in van Arsdel's book, are however, 1) the existence of a linear relationship for most food materials between frozen storage temperature and the logarithm for the time to reach a given reduction of product quality, and 2) that the quality losses resulting from storage periods at a series of different temperatures are additive irrespective of the order between these storage periods.

A list of definitions of the more commonly used concepts is given below.

**TTT** stands for Time-Temperature-Tolerance. In TTT-investigations the rate of quality deterioration at different temperatures is determined.

**PPP** stands for Product-Process-Packaging, and symbolizes that the end quality of a food product in frozen storage is not determined by the time-temperature history only but also, and to a large extent, by the quality of the raw material, as well as the methods of pretreatment, freezing and packaging.

The **Q_{10}-factor** signifies the proportional increase in storage life when the temperature is lowered by 10°C, and is thus a measure of the slope of the TTT-curve. **Q_{2/3}-values** are defined correspondingly.

"Just Noticable Difference" or JND is the first perceptible quality change a trained panel can establish between sample and control sample with a given degree of statistical probability. The most common way to measure JND is by the triangle test, whereby (according to Guadagni) 70-80% correct answers for a trained panel
of given set-up and for a given number of replications is equivalent to JND. When sensory evaluation by scoring scales are used, the change in flavor score, which is equivalent to JND with a certain degree of probability, may be estimated. Usually JND is equivalent to a change of one point in a 10-point scoring scale.

"High Quality Life" or HQL, at a given temperature, indicates the storage time until JND can be determined by sensory evaluation.

"Stability (time)" implies in principle the same as HQL.

Acceptability refers to the time a food product can be stored at a given temperature before a quality level is reached, below which the product is no longer acceptable. It is not as well defined as HQL, different researchers using different definitions and also different names for it. In Danish investigations (Dalhoff, Døgh-Sørensen) the acceptability time indicates the time until the flavor score has reached -2 in a scoring scale from +5 to -5, which is considered equivalent to the limit of consumer acceptability. In Swedish investigations the acceptability time has been indicated, instead, as the time until the flavor score has reached 3 on a 5-point scale, which is considered equivalent to the limit for marketability. The Swedish limit is consequently stricter, and the acceptability time defined in this way is correspondingly shorter than in the Danish investigation.

PSL = "Practical Storage Life" or "Shelf Life", are other expressions of storage capabilities approximately equivalent to consumer acceptability.

Acceptability factor. The ratio between HQL-values and acceptability time is called the acceptability factor. With the aid of this factor HQL-data may be converted into acceptability times. The acceptability factor varies for different foods, and it can sometimes be quite different at different temperatures.
2.3. Outline of the work

Information found regarding time-temperature tolerance of frozen stored foods has been listed in tables\(^1\), divided into different product groups such as beef, pork, pre-cooked food etc., and including available information with regard to PPP-data, method of sensory evaluation etc. It should be pointed out that only storage tests where sensory evaluation was used were included.

Separate lists were prepared for HQL-data, which are relatively uniformly defined, and for acceptability data, which are defined differently in different investigations. From this starting point, the data were plotted on semilogarithmic diagrams and systematized into food groups with different time-temperature tolerance. Separate graphs were prepared for HQL (fig. 2-8) and for acceptability (fig. 2-14), also showing the variability within the individual food groups. The influence of PPP-variations has been illustrated in separate diagrams (fig. 16-18).

2.4. High Quality Life

The HQL-values for individual foods were primarily systematized into the following product groups of different time-temperature tolerance, and TTT-data for all foods within these product groups were drawn up in semilogarithmic diagrams (fig. 2-8):

1. Raw lean meat
2. Raw fat meat
3. Pre-cooked food with gravy
4. Pre-cooked food without gravy
5. Fish
6. Fruit, berries and juice
7. Vegetables

1) Not included with this report.
In the diagrams only data for foods representing "normal" PPP-conditions have been included, that is to say excluding those representing special treatments or qualified packaging. Also data from investigations which are otherwise very much out of line have been left out from the "majority", for instance Gutschmidt's values for meat, as previously mentioned.

With the multitude of curves in fig. 2-8 as a basis, the time-temperature tolerance "bands" of the different product groups have been estimated and summarized in fig. 1. The limit have been chosen so as to include approximately 95% of the experimental values within the "bands".

As seen from fig. 1, the different groups are partially overlapping each other. This is primarily the case with groups 1 and 2 (raw lean and raw fat meat, respectively), which is not surprising, taking into consideration the somewhat vague borderline between what is called lean and fat meat.

The variability is quite wide (broad bands), which can partly be explained by varying PPP-conditions, that is different raw material quality, process techniques and packaging, and also by different sensory evaluation methods being used in different investigations. A finer subdivision into groups or separate foods was therefore not considered meaningful.

As seen from fig. 1, the slopes and variability are rather similar for groups 1-4 up to approximately -10°C; where group 2 changes into a different slope. This change may be caused by different deteriorative reactions predominating at different temperatures for the products in question.
It should be pointed out that most of the individual curves within the respective groups are somewhat curved (consequently no clearly defined Q_{10}-value) even if the curvature, as a rule, is not sufficiently great to prevent them falling within a linear band in fig. 1.

Groups 5 and 6 (fruit, berries and vegetables) show a much steeper slope than the others and also increasing variability with rising temperature.

As is pointed out in fig. 1, the values for the temperature range above -5°C is very uncertain. For ice-cream and sugared products, there is a danger for melting above approximately -15°C, and therefore the complete range above this temperature is very uncertain for frozen storage of such products.

2.5. Acceptability

The acceptability values for different foods have similarly been drawn up in semilogarithmic diagrams, fig. 9-14, for the following product groups:

1. Raw lean meat
2. Raw fat meat
3. Pre-cooked food
4. Freshly ground beef
5. Fish
6. Vegetables

As has been pointed out previously, different definitions for acceptability have been used by different investigators. The acceptability data used in fig. 9-14 correspond to the following definition: the storage time until the flavor score has decreased to point 4 on a 10-degree scale (-2 on the scale -5 to +5). This is equivalent to the limit for consumer acceptability. In fig. 11, 12 and 13,
however, acceptability times are also included, which are equivalent to the limit for marketing acceptability, according to the following definition: frozen storage time until the flavor score has decreased to point 3 on a 5-degree scale, that is to say a considerably stricter judgement. In Livsmedelsteknik (1968) Löndahl; Danielson and Bøgh-Sørensen have discussed the differences between these definitions of acceptability. As an extreme example, storage experiments with minced pork may be mentioned, where Bøgh-Sørensen obtained a consumer acceptability time of 800 days at -18°C, and the Swedes, using a 5-degree scale, reached a marketing acceptability time of 60 days at -18°C, more than 10 times shorter acceptability time than in the previous investigation!

Since there are only a few acceptability investigations reported, with acceptability not uniformly defined, no diagrams have been compiled for such data only. They have instead been combined with converted HQL-data and systematized into product groups or variability "bands" using the abovementioned 10-point scale as shown in fig. 15. For converting HQL-data to acceptability, acceptability factors have been calculated from separate investigations, where both HQL and acceptability have been determined for the same food, or factors reported in the literature have been used. Finally, acceptability factors have been estimated by parallel displacement of the HQL-groups in fig. 1 along the time axis so that they cover the literature values for acceptability (consumer acceptability).

The acceptability "bands" shown in fig. 15 correspond to 2-3 times longer storage times than those for HQL in fig. 1, or an average consumer acceptability factor of 2-3. Spread slope and shape are rather similar for the groups in fig. 1 and fig. 15.
2.6. **Influence of PPP**

The variation observed in time-temperature tolerance for one and the same food material, will to a considerable extent depend on variations in PPP-conditions;

A. The quality of the product or the raw material.
B. Process or pretreatment conditions.
C. Type and manner of packaging.

The HQL- and acceptability values in fig. 1 and 15 have been based on investigations where "normal" PPP-conditions have been used, in other words not highly qualified packaging or special treatment methods but still subject to considerable variation. To what extent PPP-factors may influence time-temperature tolerance is illustrated in fig. 16, 17 and 18, where data from the same storage experiment or reference have been used.

A. **Initial product quality**

In fig. 16 time-temperature tolerance curves have been drawn up for the following products:

1. Calf liver with different bacterial contamination before freezing. As the diagram indicates, the storage time can be nearly doubled (from 470 days to 760 days at a temperature of -20°C), if the raw material is quite fresh and of low bacterial contamination prior to freezing.

2. Pork chops from pigs given different feeds. By feeding the pigs with "good" fodder\(^1\) a firm fat is achieved, while "bad" fodder\(^2\) results in loose fat. Pork chops with firm fat have a considerably longer storage life: 290 days at a temperature of -20°C against 170 days for pork chops with loose fat.

\(^1\) Skimmed milk, barley.
\(^2\) Fish meal, garbage.
3. Hamburgers with or without unconventional protein. By exchanging ingredients in prepared products the keeping quality is affected. By using TVP (textured vegetable protein) in hamburgers, a small keeping quality improvement was obtained (9 months against 7.5 months at a temperature of -18°C).

4. Fish stored in ice for a varying period of time before freezing. A few days ice-storage of fish before freezing had no marked effect on the keeping quality, but if the fish was ice-stored for more than 6 days, the keeping quality was considerably reduced (200 days against 300 days at a temperature of -20°C).

B. **Process**

In fig. 17, the time-temperature tolerance curves are drawn up for the following products:

1. Ground beef, breaded or non-breaded. Breading has, in most cases, a protective effect on the product and increases storage life. This may be attributed to an antioxidative effect of the flour in the breading. The storage life for the breaded beef was 430 days at a temperature of -18°C against 320 days for the un-breaded.

2. Pork sausage, cooked and raw. By heating the sausage up to a temperature of 110°C, a considerably better keeping quality was gained: 440 days at a temperature of -20°C against 260 days for raw sausage.

3. Baltic herring filets, without treatment and treated with Ascorbic acid. Antioxidative treatment of raw Baltic herring filets with Ascorbic acid may increase the acceptability time from 6 months to 9.5 months at a temperature of -18°C, that is to say a considerable increase in shelf life. Similar tests with pork, however, have shown much smaller improvement. (Pap 1968).
C. Packaging

In Fig. 18 the time-temperature tolerance curves are drawn up for the following products:

1. Hamburgers in "Expresso"-cartons and in vacuum-packaging. The acceptability time for hamburgers may be doubled: from 380 days to 800 days at a temperature of -18°C, if they are vacuum-packed.

2. Pork in polyethylene bags and vacuum packed. The storage time could, in this case, be increased from 165 to 200 days at a temperature of -20°C if vacuum packaging was used.

3. Minced meat in cellophane + carton and vacuum packed. Vacuum packaging increased storage time from 135 to 600 days at a temperature of -20°C, a four time increase of storage life.

4. Chicken parts in "good" and "bad" packaging. Also for chicken the keeping quality may be increased considerably by using qualified packaging: from 230 days to 880 days at a temperature of -20°C.

5. Herrings packed in laminated bags with or without vacuum packaging. The keeping time for herrings could be increased approximately three times with vacuum packaging: from 30 to 100 days at a temperature of -20°C.

One other example of qualified packaging is vacuum packaging + glazing. For prawns an acceptability time of 10 months was noted at -18°C using such packaging. Vacuum packaging alone gave 7 months acceptability time and ordinary plastic material only 3.5 months.

All products do not have a simple time-temperature tolerance relationship. As an example bacon can be mentioned, for which the same or even better keeping
quality has been demonstrated at $-6^\circ C$ compared to $-23^\circ C$. This has been observed independently by two Danish investigators (Dalhoff 1965 and Bøgh-Sørensen 1968) and has also been confirmed in later Swedish work. Up to now this is the only case found of reversed time-temperature quality response.

From point C above it appears that qualified packaging (for instance vacuum packaging) can increase shelf life quite considerably. This is primarily of interest with regard to products sensitive to rancidity formation, while vacuum packaging of for instance berries or vegetables does not increase the already considerable shelf life to any considerable extent.

The conclusion of what is said above is that vacuum packaging and other special treatment may more than double the shelf life of many foods. In Fig. 1 and 15 such measures will "lift" group 2 up to group 1 and group 4 to group 3.

3. DISCUSSION

3.1. Variability of literature data. Influence of PPP and other factors.

From our summarized literature values of the time-temperature tolerance of frozen foods in Fig. 1 (HQL-values) and Fig. 15 (acceptability values), it is evident that the time-temperature relationship for the same kind of products show a considerable variability (wide "bands"). This variability may primarily be caused by the following factors:

a. Each group includes data representing varying PPP-conditions, such as different raw material quality, and different processing and packaging conditions, even if extreme conditions have been excluded.
b. In order to determine HQL and acceptability, different sensory evaluation techniques have been used by different investigators, and thus different definitions of JND and limits for acceptability.

a. The influence of PPP-factors on the keeping quality is illustrated in fig. 16, 17 and 18. It seems that raw materials and processing, as a rule, have less influence on the quality of sensitive products than packaging conditions. The influence is strengthened when several P-factors are combined, for instance a product with low raw material quality in poor packaging results in markedly lower shelf life than that for a product of good raw material quality in qualified packaging. Many such combined effects are probably present in our product groups, and these can be said to cover normal variations of PPP-conditions. Raw material quality is probably the factor subject to the largest variability between different investigations within the product groups (or variability bands) in fig. 1 and 15.

The great variability in time-temperature tolerance for pre-cooked foods is noteworthy. In many of these products the ingredients vary considerably from manufacturer to manufacturer and may influence the keeping quality either in a positive or negative direction. Furthermore the range of products in this group is constantly growing and completely new products are appearing on the market.

Qualified packaging, for instance vacuum and inert gas, and special treatment such as use of antioxidants, may increase shelf life more than twofold for sensitive products. The product's TTT-curve is thus moved upwards in fig. 1 and 15, for instance group 4 moves up to group 3 and group 2 to group 1.

b. Regarding sensory evaluations, different methods of measurement and different definitions have been
used, which can also partly explain the considerable variability. HQL, or the storage time to the first noticeable quality change, is reasonably well defined, but JND is sometimes chosen differently, for instance from the difference resulting in 60% correct answers in a triangle test, up to the difference giving 80% correct answers. When using scoring scales, JND is defined as a given small reduction of the flavor score. 10-degree scales are the most common, where JND is considered to correspond to a reduction of 1 point.

The reference used is of great importance when performing a sensory evaluation. The reference sample is commonly stored at a very low temperature and in good packaging. In earlier tests (Guadagni) reference samples stored at a temperature of -29°C (-20°F) were used, which means that changes at low temperatures could not be established. This limitation can partly be avoided by using scoring scales, but instead the demands on panel selection and training increase.

As previously mentioned, the definition for acceptability is varying, which means that the curves of acceptability show even greater variability than those for HQL. The two different definitions "consumer acceptability" limit" and "marketing acceptability limit" have already been discussed. It should however be pointed out that several storage investigations have been made using the latter definition of acceptability, particularly for different kinds of pre-cooked foods. It has not been possible to include these data in Fig. 15 (where the definition "consumer acceptability" or equivalent is used), as there are no constant conversion factors between the two kinds of acceptability times.

Regarding the acceptability diagram in Fig. 15, this has to a considerable extent been constructed with the
aid of chosen acceptability factors and known HQL-values (Fig. 1). The acceptability factors have been derived partly from given literature values and partly from own calculations, and consequently represent a compromise between different sources and methods of calculation, for some food groups based on very limited data (fat fish and pre-cooked food without gravy). The factors chosen are somewhat on the low side, which means that the positions of the acceptability groups are rather too low (too short shelf life) than too high (too long shelf life).

"Föreningen Svenska Konservtillverkare" (The Association of Swedish Canning Manufacturers) has issued a publication concerning recommended storage times for frozen products, which is based on a large number of accomplished storage tests. A comparison between their reported shelf life data and the acceptability values in Fig. 15 of this report show that the recommended storage times for all products fall within the respective groups in the figure. However, the recommended values for fat fish are on the high side of food group 4 (a likely reason is that the Swedish Canning Manufacturers may take for granted some form of oxidation protective treatment or packaging for frozen fat fish), whilst the recommended values for pre-cooked food without gravy are on the low side of our group 3b.

The recommendations concern only products with an estimated maximum shelf life of 9 months, while other products are not considered to be of concern.

3.2. **Other observations of interest**

The fact that log-linear temperature response are not generally obtained is of great interest. This is particularly evident for group 2, where no meaningful $Q_{10}$-value
can be defined. In other cases, individual investigations differ from linearity, but the compiled "band" is still linear. For one product, bacon, the quality is obviously independent of storage temperature in the whole temperature range from -5°C and downwards, or the temperature dependency is even reversed.

3.3. Possible application areas for a time-temperature indicator

As seen from fig. 1 the variability or spread within food groups is quite considerable. As an example the HQL for different groups at -20°C varies as follows:

For fat fish 1 - 3 months
" lean fish 3 - 8.5 months
" fat beef 5 - 16 months
" lean beef 9 - 36 months

This means that the resulting quality of a food material can hardly be estimated with any accuracy from knowledge of the time-temperature exposure of the product. In order to be able to correlate quality and time-temperature exposure sufficiently well, time-temperature tolerance curves must be determined for individual products with sharply reduced variability. This is impossible to do from literature data because of the inherent variation in PPP-conditions used. To reduce variability PPP-conditions must be very carefully specified and tests performed with regard to the influence of all these factors (including interactions) for the whole range of PPP-conditions encountered in practice. Also the pertinent PPP-conditions for a particular market product must be known in considerable detail. Such comprehensive storage investigations would be extremely costly and time consuming, and producers of frozen foods could not be expected to undertake such work other than on a very limited scale.
With regard to the development of time-temperature indicators, it is apparent that an indicator-integrator having the same response curve as the central line of a particular food group, could be very considerably off in predicting the quality loss resulting from a given time-temperature exposure, irrespective of the accuracy of the indicator itself. On the other hand, a combination of two indicators having the response curves for the border-lines of the food group, would presumably be able to indicate with considerable degree of significance that, for example HQL, would not be exceeded when none of the indicators had "changed color", respectively exceeded when both had so.

Taking into account the considerable variability in time-temperature response of product quality, it appears that an accurate time-temperature integrator-indicator would probably be more useful for giving information about the quality of the handling in the freezer chain than about the quality of individual produce. By a combination of several indicators with about the same slope of the response curve as the food group considered, and geared to a series of ordinate intercepts (different time-temperature sensitivity) one could perhaps obtain a rating of the freezer chain that might be of considerable value to those responsible for the various links of the chain, such as processors, importers, custom freezers, wholesalers and retailers.
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Fig. 1a.
Fig. 1b.

Fig. 1. TTT-characteristics (HQL-data) for different foods systematized in groups. The groups are:

1. Raw, lean meats and precooked dishes or lean lean meat in gravy.
2. Raw, fat meats and precooked dishes of fat meat in gravy.
3. Precooked foods without gravy. Lean fish.
4. Fat fish without any qualified protective measures in treatment or packaging.
5. Fruit and berries.
6. Vegetables
High Quality Life

Fig. 3
High Quality Life
Precooked foods
without gravy
Acceptability
Precooked Foods

Fig. 11

11 a: Acceptability for consumption

11 b: Acceptability for marketing

Days

\[ \text{Days} \]

1000

500

200

100

50

20

10

5

-5

-10

-15

-20

-25

-30

-35
Acceptability for marketing

Raw ground meats

Fig. 12
Acceptability for marketing

Fig. 13

Acceptability
Fish (fat: trout, herring; lean: cod, plaice, breaded fish)
Fig. 15a.

Fig. 15b.
Fig. 15c.

**Fig. 15** TTT-characteristics (PSL-data) for different foods systematized in groups. The groups are:

1. Raw, lean meats and precooked dishes or lean meat in gravy.
2. Raw, fat meats and precooked dishes of fat meat in gravy.
3a. Lean fish. 3b. Precooked foods without gravy.
4. Fat fish without any qualified protective measures in treatment or packaging.
5. Fruit and berries.
6. Vegetables
Influence of PEP-factors

1. The significance of product quality.

Fig. 16

1 a. Calf liver
30,000 bacteria/gram
(V a 1)

1 b. Calf liver
600,000 bacteria/gram
(V a 2)

2 a. Pork chops, trim fat,
"good" fodder
(III e 1)

2 b. Pork chops, loose fat,
"bad" fodder
(III e 2)

3 a. Hamburgers with 25 % TVP
(textured vegetable protein) (acceptability)
(IV h h)

4 a. Fish ice-stored 1 day
(VI a 3)

4 b. Ice-stored 3 days before freezing
(VI a 4)

4 c. Ice-stored 6 days
(VI a 5)

4 d. Ice-stored 9 days
(VI a 6)

4 e. Ice-stored 13 days
(VI a 7)
Influence of VPF-factors

1. The significance of packaging.

Fig. 18

1 a. Hamburgers, vacuum-packed (1V ± 1)
1 b. Hamburgers in expresso-carton (1V ± 2)
2 a. Pork, vacuum-packed (1V ± 2)
2 b. Pork in polyethylene bags (1V ± 2)
3 a. Mixed meat, vacuum-packed (1 ± 1)
3 b. Mixed meat in cellophane + carton (1 ± 2)
4 a. Chicken parts, good packing (1 ± 1)
4 b. Chicken parts, bad packing (1 ± 2)
5 a. Herring, vacuum-packed (± 1)
5 b. Herring in laminated bag (± 1)