2. World production and markets for lumpfish eggs and lumpfish caviar

There exists a real world market for salted lumpfish eggs. Some fishing countries have established plants for the production of lumpfish caviar, but it is also produced in many countries that do not catch lumpfish and need therefore to import raw material for their production. Each year before the fishing season starts, the price of the salted eggs is negotiated between buyers and sellers and an opening price is agreed. The price then rises or falls according to the fishing. In contrast, the price for lumpfish caviar varies between the marketing countries, and price changes are usually so slow that there is little difference between seasons.

WORLD PRODUCTION OF SALTED LUMPFISH EGGS

Salted lumpfish eggs are produced by the fishing countries of the North Atlantic. Canada, Greenland, Iceland and Norway are the main producers, but smaller quantities are produced in Denmark and Sweden. Earlier, Denmark was a bigger producer and Greenland a smaller one, but in recent years the situation has reversed. Canada was by far the biggest producer at the end of the 1990s, but catch diminished greatly during 2001–2003. Average world production since 1992 has been 32 000 barrels/year, with production latterly showing a falling trend. In 2003 the catch rose, and world production reached the average world production level for the previous twelve years. (Table 3 and Figure 2).

Supply

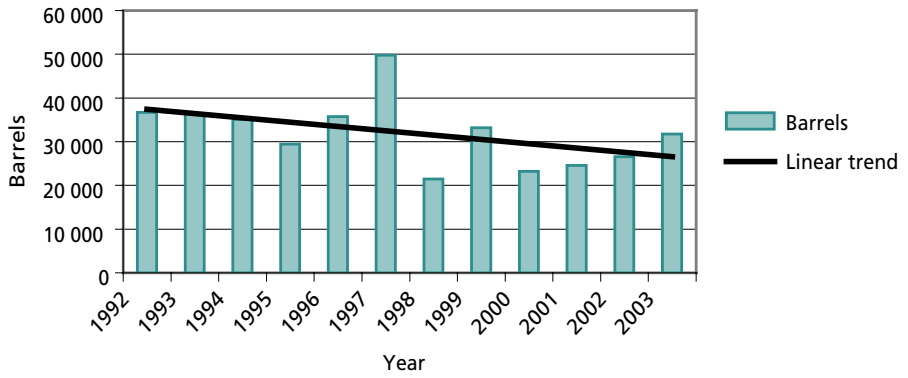
Supply of salted eggs worldwide varies from one year to another, but the average has been 32 000 barrels/year over the past twelve years. The highest catch during this period was 50 000 barrels and the lowest 21 500 barrels. This uneven catch is caused

TABLE 3
Salted lumpfish egg production by country (absolute and relative)

	Iceland	Canada	Norway	Denmark	Greenland	Total
			Absolute production (barrels)			
1992	13 000	15 381	4 528	2 800	1 000	36 709
1993	9 000	17 919	5 720	2 800	1 000	36 439
1994	11 662	12 866	7 058	2 500	1 000	35 086
1995	11 259	10 010	4 657	2 500	1 000	29 426
1996	10 433	9 876	5 300	9 100	1 000	35 709
1997	13 385	17 800	7 300	10 300	1 000	49 785
1998	6 500	10 500	2 000	200	2 300	21 500
1999	6 817	17 700	2 492	3 300	3 200	33 509
2000	4 900	11 000	2 712	1 500	3 100	23 212
2001	6 700	6 500	6 100	1 000	4 300	24 600
2002	10 300	1 050	6 920	1 000	7 000	26 270
2003	13 000	3 500	5 420	1 800	8 000	31 720
2004	11 862	15 500	5 000	--	10 000	42 302
			Relative production			
2003	41%	11%	17%	6%	25%	100%
Over all period	31%	35%	15%	10%	9%	100%

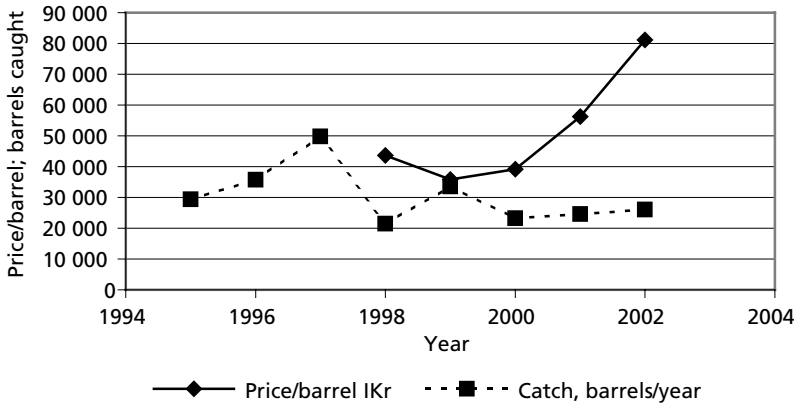
Sources: National Association of Small Boat Owners in Iceland, pers. comm.; Norges Råfisklag, pers. comm.; FAO, 2002.

FIGURE 2
Salted lumpfish eggs in barrels, world production 1992–2003



Sources: National Association of Small Boat Owners in Iceland, pers. comm.; Norges Råfisklag, pers. comm.; FAO, 2002.

FIGURE 3
World catch 1995–2002 (barrels) and Icelandic export prices (Icelandic kronur; IKr) for salted lumpfish eggs in barrels



Sources: Hagstofa Islands – Statistics Iceland; FAO, 2002.

TABLE 4
World catches and export prices per barrel for Icelandic roe

Year	World catch (barrels)	Export price from Iceland per barrel (€)
1995	29 426	
1996	35 707	
1997	49 785	
1998	21 500	506.03
1999	33 509	415.03
2000	23 212	454.24
2001	24 600	652.42
2002	26 000	941.02
2003	31 720	864.21

Sources: Hagstofa Islands – Statistics Iceland; FAO, 2002.

by environmental factors, mainly the weather, and unexplained factors affecting the behaviour of the fish itself. However, the fishing is also influenced by the price fluctuation of salted lumpfish eggs. When carryover stocks are high, the price drops and some fishers, at least in Iceland, will not go fishing until the price rises again. Prices

FIGURE 4
Relative price changes in salted lumpfish eggs compared with the value of the total lumpfish caviar exported and the part of it that is exported from Iceland to Belgium and France. The price of each item is set to unity in 1998

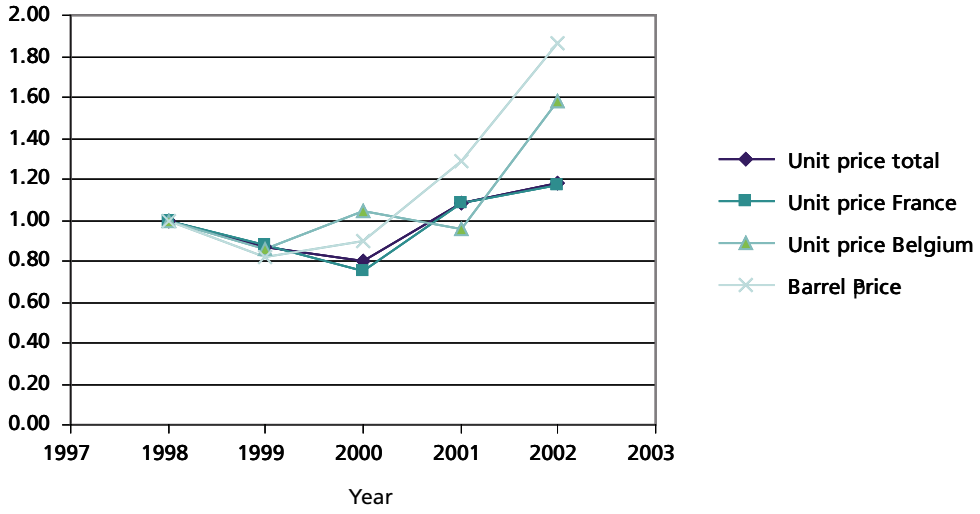


TABLE 5
Unit price and total exports of lumpfish caviar from Iceland and the contemporary unit prices in Belgium and France, based on a unit of a 100-g jar

	Total export (tonne)	**Total unit price** (€)	**France unit price** (€)	**Belgium unit price** (€)
1998	993.0	0.92	0.87	0.83
1999	1154.5	0.80	0.76	0.71
2000	1074.1	0.74	0.65	0.87
2001	873.0	1.00	0.94	0.79
2002	661.1	1.09	1.02	1.31

Source: Hagstofa Islands – Statistics Iceland.

rose considerably between 2000 and 2002, when the world catch of lumpfish was low (Figure 3 and Table 4).

Demand for lumpfish caviar

Demand for lumpfish caviar is relatively constant at between 30 000 and 35 000 barrels/year. Fluctuations in retail prices are limited and do not reflect fully the prices of the salted eggs owing to the power of the European supermarket chains that are the main buyers (Figure 4). Shortage of raw material can however result in higher prices for lumpfish caviar, but the supply shortage can in part be compensated for by use of cheaper capelin eggs.

Trade in salted roe

It is difficult to find information about the quantity of salted lumpfish eggs traded between countries because it is considered a minor item and is not recorded as a separate category in trade statistics (Tables 6 and 7). In some countries, lumpfish fishers are members of associations that keep track of the fishing statistics, but data on trade in the salted product between countries are difficult to find. Lumpfish roe producers in Canada are a part of the Fisheries Association of Newfoundland and Labrador (see www.newfoundlandseafood.com/products). Canada was a big exporter to Europe when the catch was at a maximum at the end of the 1990s, but there are several lumpfish caviar producers in Canada and they absorb most of the catch, leaving little salted roe for export when the catch diminishes, as has occurred in recent years.

TABLE 6
Salted lumpfish egg exports (barrels) exported from the main producer countries

	1998	1999	2000	2001	2002	2003
Canada	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Denmark	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Greenland	2 300	3 200	3 100	4 300	7 000	8 000
Iceland	1 000	2 389	1 860	2 959	4 800	7 130
Norway	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Note: n.d. = no data available.
Sources: Hagstofa Islands – Statistics Iceland; National Association of Small Boat Owners in Iceland.

TABLE 7
Salted lumpfish egg imports (barrels) imported by the main importing countries

	1998	1999	2000	2001	2002	2003
Denmark	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Germany	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Iceland	3 019	2 578	2 340	868	1 290	0
Sweden	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Note: n.d. = no data available.
Source: Hagstofa Islands – Statistics Iceland.

Lumpfish roe producers in Iceland have formed an association and they publish information on their Web site (www.smabatar.is). The association tries to keep statistics on the lumpfish catch worldwide. Many lumpfish caviar producers are in Iceland and salted lumpfish eggs are both imported and exported. The main imports are from Canada, but exports go to many countries, mainly in Europe.

Information on lumpfish egg producers in Norway is available on the Web site of Fiskarlaget (www.fiskarlaget.no). There is one lumpfish caviar plant in Norway, but most of the product is exported. No source of information was found for lumpfish roe producers in Denmark and Sweden. There are many lumpfish caviar producers in both countries.

There are many small producers of salted lumpfish eggs in Greenland, and they have formed a association or central organization. There are, however, no producers of lumpfish caviar in Greenland, and therefore all the salted egg production is exported. It was only possible to obtain information on exports from Greenland and Iceland (Table 6), and information for imports only for Iceland (Table 7).

Price of lumpfish caviar in relation to other roe products (caviar from other species)

There is a great difference in prices of the various fish caviars (Table 8), with true caviar (sturgeon) topping the list at 10 to 40 times that of salmon caviar. The price of lumpfish caviar is one-third that of salmon caviar, but a third to one-half higher than capelin caviar. Capelin eggs are smaller than lumpfish eggs and the texture is sandy. Salmon eggs are bigger than lumpfish eggs, but the salmon caviar is of very variable quality, depending on fish species and processing method. Blended caviar of capelin and lumpfish eggs, or lumpfish and imitation eggs has been seen on supermarket shelves.

TABLE 8
Approximate prices of various caviar products advertised for sale through Internet shops

	Price US$/kg (approx.)	Relative price
Caviar	1300 – 4000	65 +
Salmon caviar	100	5
Lumpfish caviar	36	1.8
Capelin caviar	20	1
Algal caviar	80	4

Source: Gathered from the Internet, November 2002.

There are other types of caviar or caviar imitations on the market; some are made from fish eggs by reconstitution, while vegetable caviar made from algae has recently been introduced. The prices for those products are similar to or even higher than those of lumpfish caviar. None of these have so far been able to supplant lumpfish caviar in the European market.

Trade in lumpfish caviar

Lumpfish caviar is produced in many countries but the major producers are Denmark, Germany, Iceland and Sweden. The home market for Germany is big, but Germany is also a great exporter of lumpfish caviar. The other three countries export most of their production. The main importing countries are France, Germany and the United States of America.

It is very difficult to obtain reliable information about the world consumption of lumpfish caviar, but Table 9 gives an estimate of the consumption as a percentage of world consumption. Europe is the main market for lumpfish caviar, taking about 80 percent, of which France has about 30 percent and and Germany 20 percent. Spain and Italy are significant markets for this product; outside Europe, the United States of America is the biggest market.

The price for lumpfish caviar varies considerably between the marketing countries. The export prices to importing countries for 2001 are given in Table 10. It is interesting to note that the main buyers pay relatively low prices, but the small importers pay very different prices for lumpfish caviar. The price in Japan is three times the price in Spain, even though both are buying in small quantities. The average export price for lumpfish caviar

TABLE 9
Estimated relative consumption of lumpfish caviar

Country or region	Estimated consumption as proportion of the total world market (%)
Europe, of which	80
France	30
Germany	20
Spain	10
Italy	10
Other European countries	10
United States of America	15
Asia	3
Other non-European	2
Total world	100

Sources: Klinkhardt, 2002a; FAO, 2002; author´s estimates.

TABLE 10
Icelandic lumpfish caviar exports and free on board (FOB) price/kg in 2001

	Quantity (tonne)	Value (IKr '000s)	FOB price (IKr/kg)	As proportion of total lumpfish caviar exports (%)
Spain	2.0	1 318	659	0.2
Belgium	57.2	38 899	680	6.6
Sweden	23.3	16 530	709	2.7
Denmark	23.4	18 006	769	2.7
France	481.6	388 923	808	55.2
Germany	116.1	100 349	864	13.3
Italy	68.8	63 546	924	7.9
Other countries (4)	0.6	610	1017	0.1
Poland	5.6	5 973	1067	0.6
United States of America	55.2	63 460	1150	6.3
Netherland	6.6	7 599	1151	0.8
Switzerland	1.5	1 752	1168	0.2
Canada	6.8	8 115	1193	0.8
United Kingdom	2.9	3 835	1322	0.3
Australia	4.6	6 344	1379	0.5
Republic of Korea	13.2	19 835	1503	1.5
Japan	3.7	7 059	1908	0.4
Total	873.0	752 152	862	100.0

Source: Hagstofa Íslands – Statistics Iceland.

increased by 9.4 percent between 2001 and 2002 (Table 8), from IKr 862/kg to IKr 943/kg according to information gathered from Hagstofa Íslands, the official Icelandic statistics bureau.

In 2002, 661 138 kg of Icelandic lumpfish caviar was exported, with an free-on-board (FOB) value of Ikr 623 192 145, implying an average free on board (FOB) price of Ikr 943/kg (Hagstofa Íslands – Statistics Iceland).

3. Catch methods and roe separation

THE FISHING BOATS

Traditionally, in Iceland and Norway, lumpfish was caught using very small fishing boats with only one fisherman. In recent years, however, the boats have become larger, with a crew of two or three persons. The boats now have hydraulic winches for hauling the nets, replacing hand hauling.

THE FISHING GEAR

Lumpfish is hard to catch because its round shape and lack of scales makes it easy for the fish to escape from the net. In Norway, a mesh size (stretched) of 252 mm is used. The average length of the net is 47.3 m, with a fall of 3.4 m (Bertelsen, 1994). In Iceland the mesh size (stretched) is usually between 267 and 286 mm (Thorsteinsson, 1996). This large minimum mesh size is set to protect the fish that is spawning for the first time (Bertelsen, 1994). In Canada, lumpfish is caught using nylon monofilament nets with 10- to 11-inch mesh (256–281 mm) (stretched).They are usually 10 mesh deep and 50 fathoms long (Benson *et al.*, 1988).

The drape of the net, i.e. the length of the web in proportion to the float and foot ropes, is considerable for lumpfish nets, as they are set up so as to develop as much bag as possible. Thus a typical 60-fathom (108 m) roll would be set up on 25–26-fathom (45 m) float and foot lines, with verticals of 0.5–0.7 fathoms (90–125 cm) to maintain the bags and prevent the lumpfish rolling along and out of the net. Lumpfish do not stay easily in the net as they do not entangle as much as other species, such as cod (based on Gudmundsson, 2003).

UTILIZING THE CATCH

Icelandic authorities only allow the use of roe taken from living fish. If the fish is gutted aboard the boat, the roe should be kept in clean and sterilized plastic boxes, protected from sunlight and kept chilled. Indirect icing is preferred to direct icing. Care should be taken not to put the roes in too thick a layer, thus avoiding pressure that can damage the eggs by causing them to burst (Benson *et al.,* 1988).

When a belly cut is made, it is important not to cut through the intestines, in order to hinder contamination from bacteria and parasites (Fiskistofa [Directorate of Fisheries, Iceland], pers. comm., 2003). This procedure is confirmed by Benson *et al.* (1988). There are several different methods in use for belly cutting and none of them can be considered the only correct one. It depends on the craftsmanship of the fishers, who use the method that suits them best.

THE ROE MARKET

In both Iceland and Canada it is recommended that the containers holding the harvested eggs should be allowed to drain while in transit from the fishing grounds to the salting facilities (Benson *et al.,* 1988), but it is easier to separate the eggs from the sac mechanically if some liquid is used together with the roes. This could present difficulties when establishing the price for the roe if the box is draining, because draining will continue for a long time, making it hard to decide the true egg quantity.

A traditional Icelandic fishing boat, typical of the vessels used for the lumpfish fishery

The fishing grounds are close to the shore

Working aboard a modern fishing boat

Hauling the nets

Roe sac being emptied into a barrel. The knife has cut open the roe sac by mistake

This problem was studied in detail by Martinsdóttir (1980), who came to the conclusion that there were three possibilities for evaluating the catch quantitatively:

1. Sell the wet roe. After gutting, the roe and the liquid that follows is put into watertight containers. The percentage of drained eggs, ready for salting, versus undrained roe, are 69.7–70.6 percent, and 150+1 kg of wet roe is needed for each barrel.
2. Sell semi-drained roe. The containers are tilted so the liquid can run over the rim until eggs begin to float with it. There is great variation between containers, making this method a difficult one to standardize and thus open to dispute between buyers and sellers.
3. Sell by count. The roe content per fish differs greatly. Wet roe from a single fish varied from 0.92 to 1.07 kg, so eggs from 145–165 fish were needed for each barrel.

The first method was considered to be the best suited for the purpose of the transaction (Martinsdottir, 1980). However, that method conflicts with the hygiene procedures prescribed by the official governmental body, Fiskistofa [Directorate of Fisheries].

4. Screening, salting and storing lumpfish eggs

After landing, the roe is screened to separate the eggs which are then drained and salted into barrels and the barrels kept under observation until their content is evenly salted and safe to store until processed further. The eggs are of similar size, between 2.2 and 2.6 mm in diameter (Dagbjartsson, 1972a) and augment with increasing age of the fish (Kudriavtseva and Karamushko, 2000). At the same time, the colour of lumpfish eggs can vary from almost colourless to yellow-orange and purple-violet (Basby, 1997). Four different colour shades – orange, blue-red, brown and red – were studied and the eggs were found to be of different strengths, increasing in that order (Dagbjartsson, 1972a). The difference in the colour of the eggs from the same day's catch can clearly be seen in the photograph.

The colour variation in the eggs is the main reason for the artificial colouring of the lumpfish caviar. Besides that, when heavily-salted eggs are stored in barrels the eggs become dull, and without colouring would yield an unappetizing caviar product.

No efforts are made by the industry to grade eggs by colour or size before salting. An exception from this might be that one company claims that it uses specially selected eggs in parts of its products, without explaining in detail how that selection is made.

SCREENING AND SEPARATING EGGS FROM THE SAC

The roe should be processed as soon as possible or on the same day as being landed. The first step in this process is to remove the eggs from the sac and separate them from the connective tissue that surrounds them, by a process called screening. Thereafter the eggs are salted in barrels and stored. They are made into caviar at a subsequent stage.

The eggs can be removed from the sac manually, but trials at the Icelandic Fisheries Laboratories shortly after 1970 led to speeding up the development of mechanized screening. The process was adopted by the industry in the following years. Manual screening is rarely found now in the lumpfish industry; nevertheless a short description of the process is given for the sake of thoroughness.

Manual screening

The roes are screened by rubbing the sac around a screen of 3–4 mm mesh. The eggs fall through the screen but the sac material is retained and discarded. The eggs are then put on a fine screen or cloth to drain overnight (12–18 hours) (Dagbjartsson, 1972b).

SOURCE: PRICE, 2002. PHOTOGRAPH BY STERNIN

Lumpfish eggs come in a range of colours

Manual screening is described in general by Sternin and Doré (1993), mentioning a 5-mm mesh screen size for lumpfish eggs. Canadians (Benson *et al.,* 1988) used a more complicated method by arranging three screens of different mesh sizes one above the other. The first one, of 10 mm mesh, is used to rub the sac to separate it from the eggs. The next screen below is of 5 mm mesh and it retains sac material falling through the first screen while the eggs pass through, and the eggs are then drained on the third screen, of 3 mm mesh.

Salt and water are used to clean the eggs further in a one- or two-step process (Dewar, Lipton and Mack, 1971). The eggs are spread in layers and allowed to drain for several hours. The thickness of the layers should not exceed 25 cm (10 in) as that would result in burst eggs at the bottom, and thicker layers require a longer draining time (Benson *et al.*, 1988).

Mechanical methods

Trials with mechanical screening methods were carried out in the early 1970s in Iceland, using a modified meat-bone separator, namely an Iwema B-1, used earlier in the cod roe industry. The operating speed of the separator was reduced, the alignment of the rubber flaps changed and the hard rubber flaps replaced with softer ones. The results were promising, with an increase in yield and effectiveness. In a report, mechanical and

Screening machine at a demonstration in Drangsnes, Iceland, 2003. Compressed air is used to pump the roes from the landing containers to the screening machine

Cement-type mixer at a demonstration in Drangsnes, Iceland, 2003

manual methods were compared in economic terms (Dagbjartsson, 1972b). Further experiments the next season, however, did not fully confirm the findings and results were not as successful as expected (Dagbjartsson, 1973). No further experimental results could be found, but the industry itself has managed to develop separating machines for this process.

Experiments with washing equipment and a vibrating screen to produce cleaner eggs and drain them more quickly were undertaken at the same time. The results were uncertain and the industry did not follow up. Lumpfish eggs are currently not washed or mechanically screened during separation and draining in Iceland. Benson *et al.* (1998) describe processors in Canada using weak brine (6 percent) to wash the eggs in barrels. Gut material and debris floats to the surface of the brine and is skimmed off. It is concluded in the Benson *et al.* (1998) report that the result is a high quality product. No further information was found on this topic.

TYPE OF SALT

According to the FAO/WHO Codex Alimentarius complete list of current official standards, the type of salt used in the salting of eggs should be vacuum salt for food use, finely divided, fast dissolving and of the highest standard of chemical purity (CAC, 2001).

USE OF PRESERVATIVES

It has long been standard practice to use 200 g of sodium benzoate in each barrel as a preservative. The preservative should be food grade, and a granulated type is easiest to dissolve. This amount is twice the level allowed in some markets for lumpfish caviar, but during the de-salting of the eggs in the lumpfish caviar-making process, the preservative will be diluted as well, and the final level can be adjusted to meet alimentary norms required for the final product. Investigations show that omitting the preservative results in 2 to 4 kg more salt being needed in each barrel to compensate (Magnusson and Martinsdóttir, 1991). The use of sodium benzoate is most effective when pH is 4.0, and the use of it when pH is higher than 4.5 is not recommended by Sternin (1992). At the same time, it is stated that benzoic acid has an antibacterial effect on microbiological growth in lumpfish roe at pH between 5.7 and 6.4 (Petursson and Petursson, 1973) and at pH 5.5 (Petursson, 1973). This topic seems to be controversial and more research is needed to clarify the matter.

Uneven distribution of salt results in over-salting of some eggs, which acquire a lighter shade, while under-salted eggs become darker. The content of a barrel with the salt unevenly distributed will spoil in a short time

THE SALTING PROCEDURE

To avoid uneven distribution of salt in the product, pre-weighing of all ingredients is recommended, if not mandatory. This is to ensure that each barrel contains the correct proportion of ingredients. Uneven content quality will lead to difficulties in the caviar-making process (Petursson, 1972). In Canada, 12–20 percent salt is used for each barrel, and other preservatives are not usually used, but, when used, 100 g is recommended (Benson *et al.,* 1988). If manually stirred, the stirring can be done in several (4–5) portions, but mechanical mixers can manage whole barrels in one load. When eggs and salt are stirred together, liquid is initially released from the eggs and the salt dissolves quickly to make brine. Salting also leads to hardening of the eggs (Basby, 1997), possibly due to transglutaminase activity (Fukuda *et al*., 1998).

Soon after stirring, the eggs will absorb much of the brine, and at this stage it is very important to put all the mixture into the barrels to maintain the correct proportions. It is of the greatest importance not to overdo the stirring so as to avoid mechanical damage to the eggs. Uneven stirring, in contrast, will lead to uneven distribution of salt in the barrel, discoloration of the content and microbiological damage to the eggs.

The duration of stirring depends on the methods used, but excess stirring is to be avoided; stirring for 15–30 minutes is recommended (Sternin, 1992), but that is much longer than is general practice in Iceland. Mixing for 5–8 minutes, waiting for 10 minutes and then mixing again is recommended by Dewar, Lipton and Mack (1971).

It is worth trying a trolley mixer that is capable of mixing the content of one barrel of eggs and salt at a time and can operate under vacuum.

Quantities of ingredients

The final product should contain 105 kg of drained eggs in the barrel when it is received by the buyer. Such a barrel contains:

eggs	105 kg + overweight;
salt	12–20 percent; and
preservative	0.1–0.2 kg.

The brine used for topping up the barrel has a strength of between 12 percent and saturated sodium chloride and is used as needed.

Types of barrel

Traditionally, wooden barrels were used for salted lumpfish eggs but they have been replaced by food grade plastic barrels with a volume of approximately 135 litre. The plastic barrels seem to keep the eggs better, there is less leakage and little work is needed to look after the barrels and top up with brine during the long storage period. The barrels can be tightly closed because a rubber ring is compressed between the lid and the rim of the barrel when closing, thus keeping the contents in and atmospheric oxygen out. It was customary to use the barrel only once for this purpose, but by removing the rubber gasket and washing the barrels they can be reused, renewing the gasket if necessary.

Mixing of ingredients

The salt and sodium benzoate are mixed first to get an even mixture. Thereafter the eggs and the salt-preservative mixture are blended in the correct proportions. This is to ensure a product of even quality. If not blended properly, an unsalted portion of the eggs can clump together and spoil the whole barrel.

THE CURING PROCESS

The blend is put into the barrel until the right amount is reached. Thereafter the barrels are left to stand upright overnight. The next day they are topped up with brine and closed temporarily.

Turning the barrels and filling up with brine

It is general practice for the barrels to be turned or rolled, or both, during the first few days after salting. There is some knowledge based on experience that mechanically mixed eggs do not need as much care as hand mixed eggs, because they are better mixed (Martinsdottir, pers. comm; author's observations). This procedure must be learned by experience based on the situations in each salting facility.

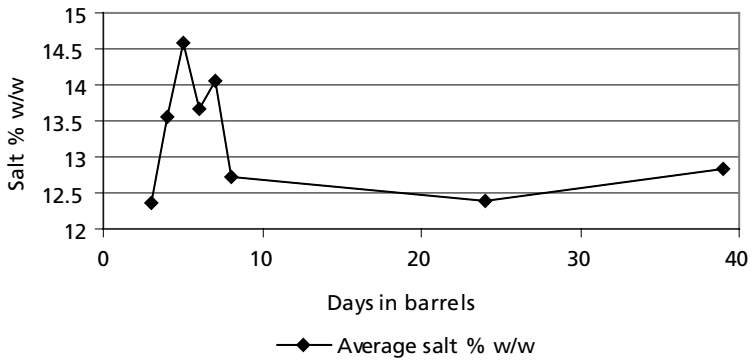
Temperature during maturing

To avoid spoilage of eggs during this work, proper hygiene is needed and the whole process from roe separation to curing should be carried out under chilled conditions.

Changes in water and salt content during maturation

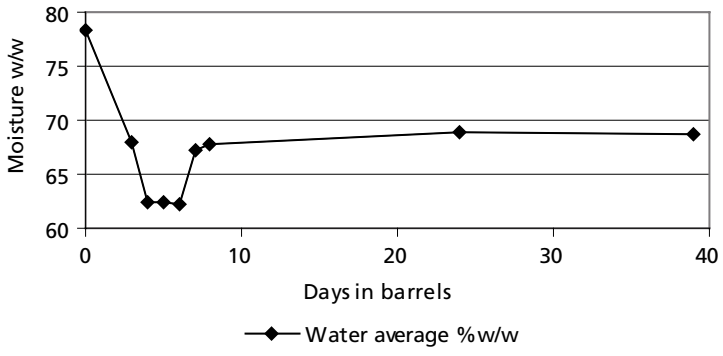
During the first days in the barrel – the curing period – the water and salt content of the eggs changes a lot. The water content decreases from around 80 percent weight by weight in drained eggs to around 60 percent weight by weight after the first week of curing. In the same period, salt content increases from slightly below 1 percent weight by weight to reach its maximum. Equilibrium is achieved within 30 days from the

FIGURE 5
Changes in average salt level in lumpfish eggs during the first few weeks of the curing process



Source: Benson *et al.,* 1988.

FIGURE 6
Average moisture levels in lumpfish eggs during the first few weeks of the curing process (average of two trials)



Source: Data from Benson *et al.,* 1988.

salting date. Measurements of salt can indicate an uneven distribution of salt during the first two weeks, but rolling the barrels or moving them around will hasten the curing process (Benson *et al.,* 1988).

Use of brine for topping up the barrels

At the end of the curing period the barrels are given a final inspection and topped up with brine if air bubbles are forming inside. The brine used can be of various strengths, but 12 percent seems to be the minimum. Brine made of 14 kg salt and 100 litre water is recommended (Peturson, 1972). In Canada, in contrast, it is common practice to use saturated brine (Benson *et al*., 1988).

STORAGE CONDITIONS

Barrels are often stored for many months before being opened again. Therefore care should be taken when sealing the barrels and moving them to the chilled storage room.

Use of pressure rings

It is good manufacturing practice (GMP) to use a pressure ring at the top of the barrel when sealing it. The pressure ring is a perforated plastic ring provided by the producer of the barrel. Its function is to press down the solid content of the barrel to ensure that the solid content is always covered by brine. The perforations are usually too large to block eggs, but putting a cloth of inert material beneath the ring is sufficient to keep the eggs below the surface of the brine (Martinsdóttir and Magnusson, 1983). This will help prevent oxidation and rancidity of eggs during the storage period, which can be longer than a year.

Closing the barrels

Barrels can be closed manually or by using a hydraulic-powered closing machine. The rim of the barrel is cleaned and the lid, fitted with a rubber gasket inside, is pressed onto the barrel, and finally a metal hoop is used to clamp the lid. A bunghole in the lid is used to add more brine if needed. The metal hoop is secured by a lock to prevent it from opening during handling and transport.

Temperature

There are different practices and recommendations for temperatures during the curing process in various countries. In Iceland, the practice is to use temperatures close to 0°C (Magnusson and Martinsdóttir, 1991), but in Denmark a storage temperature of -5°C is used (Basby, Jeppesen and Huss, 1998). In Canada, however, between 0 and 3°C is recommended (Benson *et al.*, 1988), and that is confirmed by Sternin and Doré (1993). No experimental results are available on lumpfish roe, but lowering the temperature below 0°C did hold back the maturing process and prolonged the shelf life of salted cod roe (Hannes Magnusson, pers. comm.).

LONG-TERM STORAGE AND ITS EFFECT ON QUALITY AND YIELD

During long-term storage some changes occur in the barrel of both a chemical and a microbiological nature, and can ultimately spoil the contents, rendering it unusable as a raw material for lumpfish caviar production.

Microbiology

When the roes are still in the fish they are sterile or almost sterile (Ingólfsdóttir, 1987). During gutting and removal of the roe from the fish, and later in screening and salting, a bacterial load is introduced. The initial microbiological flora in newly-salted barrels is similar to that found in other fish but changes during storage. The original *Pseudomonas* spp., *Flavobacterium* spp. and *Moraxella* spp. are replaced by

yeast during nine weeks of storage, while the number of colony-forming units (CFU) increased one hundredfold. Eggs kept at 0°C were unspoiled after 120 weeks, but eggs kept at 5°C and 10°C spoiled in 100–120 and 30–40 weeks, respectively (Martinsdóttir and Magnusson, 1983). Lactic acid bacteria (LAB) and Enterobacteriaceae survived and were found in dewatered lumpfish roe after three months of storage at 5°C under reduced pressure (Basby, 1997). Successful washing of the eggs to lower the bacterial count was effected by using water and changing the brine (Martinsdóttir, 1980).

Chemical changes

The main danger is oxidation caused by atmospheric oxygen, but slow enzymic changes to the proteins will eventually spoil the eggs.

Oxidation

Oxidation occurs when atmospheric oxygen reacts with unsaturated fatty acids in the eggs. This happens if the solid content of the barrel comes in contact with air and leads to deterioration in the contents, usually starting at the top, and is often due to imperfect closure of the barrel and consequent evaporation of the brine. The top layer of eggs in the barrel become yellow or even brown with prolonged exposure, and a rancid smell develops. To avoid the occurrence of such rancidity, the use of pressure rings and secure closure of barrels is of utmost importance (Martinsdóttir and Magnusson, 1983; Basby, 1997).

Tyrosine formation

Autolytically liberated amino acids, mainly tyrosine, will form white crystals if the barrels are kept too long, and there is no remedy if that happens (Sternin, 1992). The rate of enzymatic reaction depends on temperature, but how long it takes is not known and more information is needed on this subject. Dissolved free amino acids are washed out during de-salting (Basby, 1997).

The conclusion is, therefore, to keep the eggs in securely-closed barrels with a pressure ring and inert cloth on top, in a chilled environment, presumably below 0°C, but above the freezing point of the contents (Hannes Magnusson, pers. comm.). During storage for 100 weeks, the pH of eggs stored at 0° was between 5.4 and 5.6 and showed no tendency to change (Martinsdóttir and Magnusson, 1983).

Yield reduction

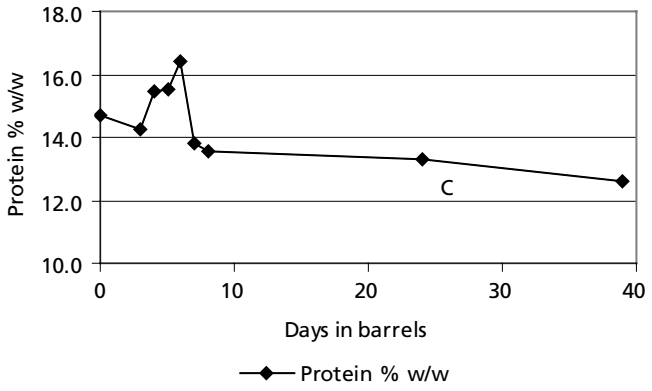
Prolonged storage of salted eggs will lead to reduced yield from the caviar process. Investigations showed that the protein content fell during the first days in the barrel. After some rise and then a rapid drop, the protein level fell steadily during the rest of the period (Figure 7). Egg weight was found to fall during several months of storage (Figure 8). In the lumpfish caviar industry, an increase in product yield is observed when last year's stock is finished and stock from the latest season is taken into production.

OTHER METHODS OF PRESERVING LUMPFISH EGGS

It is a common opinion in the industry that the current method of heavily salting the eggs results in poorer end-product quality, compared with what could be achieved if the caviar were produced in a single step instead of two. By upgrading the product, the producer hopes to gain higher prices (Sternin, 1992). The industry desires a product that is 4 percent water phase salt (WPS) and has a shelf life of three months at 5°C. It is not pasteurized and no chemical preservatives are used (Basby, 1997). The making of lightly-salted lumpfish roes from heavily salted ones is described in great detail by Basby (1997).

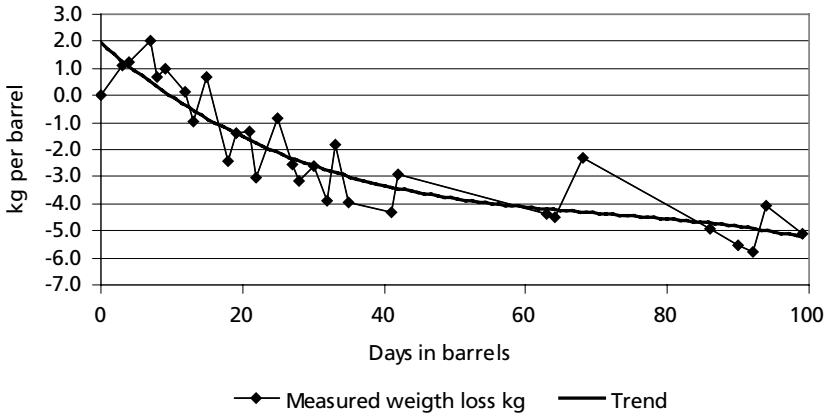
Experiments with less-salted eggs (one-step caviar) showed that it was possible to make unpasteurized lumpfish caviar with 4.5 percent salt content and at least an eight-

FIGURE 7
Changes in protein level during early storage



Source: Benson *et al.,* 1988.

FIGURE 8
Changes in egg weight during 100 days in storage



Source: Data from Martinsdóttir, 1980, 1983.

month shelf life by brine salting and using preservatives (Magnusson *et al.*, 1984). There is an alternative to this model. If freezing and thawing processes could be developed to keep the original characteristics of the eggs little or unchanged during frozen storage and thawing, a new product with short shelf life could be produced year-round. One such product is on the market. The company Bakkavör has marketed lumpfish caviar under the trade name Kavka, in 12 g glass jars, intended for travel catering (airline) use. The company states that the eggs used for that product are of extra high quality and freshness, but the production process knowledge is a trade secret.

FREEZING AND THAWING METHODS

Freezing and thawing eggs has resulted in a high percentage of broken eggs (Martinsdóttir, 1980). To evaluate the process of freezing and thawing, measuring thawing drip loss and counting broken eggs can be used. Thawing drip loss comes partly from the intracellular fluid released by broken eggs, so the methods are in some way interrelated. In an experiment by Jónsdóttir, Thorarinsson and Jónsson (1997) on freezing and thawing lumpfish eggs, the best results were obtained at 5°C compared

with 20°C, with drip loss of less than 1 percent and around 4 percent broken eggs. Eggs were previously salted (4 percent) or unsalted before freezing in a plate freezer and kept in a cold store (-30°C) (Jónsdóttir, Thorarinsson and Jónsson, 1997).

Three thawing methods – in tap water; in 4 percent salt water; in air – were compared. Two temperatures – 5°C and 20°C – were used, and measurement of thawing drip loss and broken egg percentage were used as criteria in evaluating the results.

> *"The main aim of this project was to compare thawing in air, salt water and fresh water at two temperatures, 5°C and 20°C, for salted and unsalted lumpfish roe, and to evaluate the drip and quality of the roe after thawing. The results showed that the best way to thaw unsalted lumpfish roe is to use air at 5°C, and salted lumpfish roe in either air or salt water at 5°C. Thawing unsalted lumpfish [i.e. eggs] roe in air resulted in less drip but thawing it in salt water resulted in lower incidence of broken roe. The difference between thawing salted lumpfish roe in salt water or in air was not significant, so it depends on circumstances which of the two methods give the best result."*
>
> **(English summary in Jónsdóttir, Thorarinsson and Jónsson, 1997).**