DANISH TECHNOLOGICAL INSTITUTE

Guideline

Production of salt reduced bacon

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Aim

Recommendation on production of salt reduced bacon based on:

- Literature study
- Predictive microbiology
- Challenge tests

Conclusion

Microbial shelf life and food safety of bacon with a low salt content (1.5%):

- Reducing the salt level from a high level to a lower level has a smaller impact on shelf life and food safety than reducing the salt level from a low level to an even lower level.
- Predict sensory and microbial shelf life with DMRIPredict. Only temperature, pH, salt and water can be included in the predictions.
- If stabilisation of growth of *Listeria monocytogenes* is needed (bacon is not a ready-to-eat product) use predictive models (e.g., DMRIPredict or FSSP) to find a combination of preservatives suitable for your product.
- If growth of *Listeria monocytogenes* is inhibited during storage at temperatures below 8°C, growth of other pathogens is also inhibited.
- A low salt content will affect the taste. Substitutes might be needed, e.g., more smoke, and/or salt enhancer. On the other hand, frying might result in evaporation of so much water that the salty taste is still acceptable.
- Shelf life will depend on the initial microbial count, storage temperature and preservation. The use of preservation that inhibits growth of *L. monocytogenes* will also prolong the sensory shelf life.

Introduction

Aim

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- Literature study
- Predictive microbiology
- Challenge tests

Bacon production

Bacon production – briefly

Bacon is produced by:

- Curing meat with different amounts of fat
- Curing is injection, drainage and/or dry cure
- Packed in vacuum or modified atmosphere (30/70 CO_2/N_2)
- Bacon is sold as:
  - Whole pieces
  - Sliced bacon

In this guideline, a salt/water concentration between 2.6% and 3.7% (per weight) – 3.9% (per volume) is discussed. 2.6% salt/water concentration corresponds to 1.5% salt in bacon with 57% water.

In this guideline, the pH of bacon is considered to be 5.5-6.5.

Bacon production – Effect on microbes

Curing

Chilling and the use of salt and nitrite will inhibit the growth of bacteria.

Calculations in CombasePredictor have shown that there is no risk of propagation of pathogenic bacteria during curing (minimum 2% salt/water concentration) at max. 7°C and max. 3 days or by equivalent combinations of preservation, temperature and time.

Smoking

Smoking or drying will not introduce bacteria to the meat but will reduce the general number of bacteria on the surface of the product. Bacteria injected into the meat will not be affected by the smoke, temperature and drying on the surface.

Processing temperatures between 50 and 60°C will increase the product temperature to 40-50°C during the process in 2-3 hours. It is important to avoid that the temperature of the products is between 20 and 50°C for too long, as this can lead to a risk of growth.

Storage

During an experiment at DMRI, raw materials for non-smoked bacon (cured in a bag) were inoculated with Salmonella, salted to 3% or 5% salt/water, 150 ppm nitrite, sliced and vacuum packed. This prevented growth at 7°C and 10°C for 6 weeks. Nor did Salmonella grow in products with 3% salt/water + 60 ppm nitrite or 5% salt/water + 60 ppm nitrite.

As bacon is cured but not heated, bacteria present on the raw meat are not inactivated and might grow during storage if preservation and storage temperature do not inhibit growth. If bacon is stored at 5°C, the following pathogenic bacteria might grow depending on the amount of salt, nitrite and organic acid added:

Clostridium botulinum, Listeria monocytogenes and *Yersinia enterocolitica* (for more information, see Svenningsen N.B., 2022). But also lactic acid bacteria, *Pseudomonas* and *Brochotrix* might grow and dominate the product. In conclusion, several different bacteria might grow, who and how fast depend on the storage temperature and amount of preservation.

For further reading consult Hazardanalyse, for example Annex F2-60 and F2-100.

Sensory aspects

Salty taste

Salt and smoke are the two most distinctive taste/smell characteristics of bacon. The salty taste is reduced when less salt is added to the product. To some extent, consumers can adapt to this lower level. Tests at DMRI have shown that the consumer acceptance is not affected by reducing the salt content from 2.8% to 2.1%, but reduction to 1.4% was not accepted by the consumers. See Aaslyng et al., 2014.

Shelf life

Shelf life prediction with DMRI-Predict

Bacon is raw, cured, non-heated meat and not a ready-to-eat product even though some consumers eat bacon non-fried.

The microbial shelf life is based on the initial microbial count, preservation and temperature.

Smoke will to some extend mask the reduced taste of salt in salt reduced bacon, but deterioration caused by microbial growth will also be masked. The shelf life of non-smoked bacon as whole cuts can be predicted with the bacon model at DMRIPredict (vacuum packed whole cuts of non-smoked bacon). The predictions of spoilt odour will be worst case as smoke is not part of the parameters of the model (the smoke smell masks the spoilt odour). The amount of nitrite in the model varies between 60 and 150 ppm; the effect could not be predicted based on the data from the shelf life studies that the model is developed from.

The parameters in the model are:
% salt in the aqueous phase: 2.0-5.5%
Temperatures: -1°C – 7°C
Initial count: 1-5 log cfu/g

Some examples of predictions are shown in Table 1 illustrating that a reduction from 4.2% salt/water to 2% salt/water reduces the sensory shelf life (odour score = 5) at 4°C with 11 days (19%) or 8 days (22%) at 7°C. The shelf life estimated as the time to reach 7 log cfu/g is reduced with 21 days (22%) and 15 days (26%), respectively. In Figure 1, the effect of salt content on sensory shelf life is shown, and in Figure 2 the effect on microbial growth is shown.

Based on DMRIPredict (bacon model), a rough estimate on reduced shelf life at 4°C if the salt/water concentration is lowered with 1% is:

- 2-6 days (time to smell = 5)
- 3-8 days (time to smell = 6)
- 4-14 days (time to log 7)

Based on DMRIPredict (bacon model) a rough estimate on reduced shelf life at 7°C if the salt/water concentration is lowered with 1% is:

- 2-4 days (time to smell = 5)
- 3-6 days (time to smell = 6)
- 2-9 days (time to log 7)

The lower the salt concentration, the more a 1% reduction affects the shelf life. This means that reducing the salt level from a high level to a lower level has a smaller impact on shelf life and food safety than reducing the salt level from a low level to an even lower level.

Table 1. Predicted microbial growth and sensory quality of bacon (DMRIPredict).

Salt/water %	2		2.6		3.0		3.9		4.0		4.2		5	
Temperature °C	4	7	4	7	4	7	4	7	4	7	4	7	4	7
Days until odour score = 5[a)]	47	28	51	31	53	32	57	35	58	35	58	36	60	37
Days until odour score = 6[a)]	57	34	62	38	65	40	70	43	71	43	72	44	74	46
Days until 7 log cfu/g [b)]	76	42	82	50	90	51	96	56	96	56	97	57	100	58

a) The product is no longer sensorially acceptable at scores above 5. 2 = fresh, 4 = acceptable, 6 = unacceptable, 8 = putrefied.

b) Psychrotrophic plate count (initial count: 2 log cfu/g) meaning 5 log growth during storage.

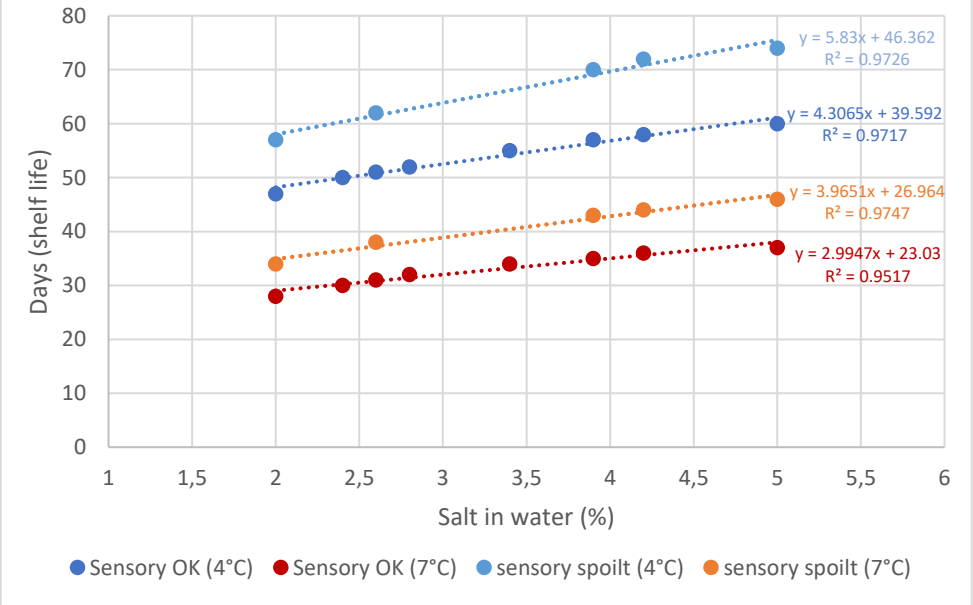

Figure 1. Sensory shelf life of bacon with different salt content stored at 4°C and 7°C. DMRIPredict (bacon model). Sensory OK: smell = 5. Sensory spoilt: smell = 6. Initial count = 2 log cfu/g.

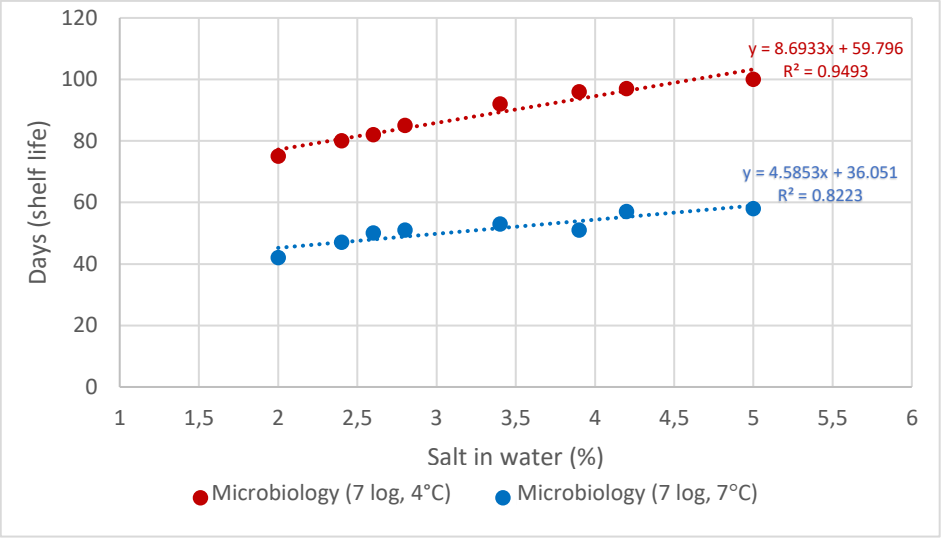

Figure 2. Microbial shelf life of bacon with different salt content stored at 4°C and 7°C. DMRIPredict (bacon model). Initial count = 2 log cfu/g.

Predicted growth of lactic acid bacteria

The shelf life of salt reduced bacon can be improved by:

- Lowering the initial microbial count (process hygiene or decontamination)
- Adding organic acids like acetic acid and/or lactic acid

The effect of organic acids on sensory shelf life cannot be predicted. But the effect on growth of lactic acid bacteria like *Leuconostoc* (DMRI model under development) and *Lactobacillus* (FSSP) can be predicted. Also, different papers from the scientific literature have shown that organic acids can prolong the shelf life of processed meat.

Examples of the effect of organic acids are shown in Table 2. These show that the pH in the bacon is very important for the effect of the organic acids. At pH 6.5, a very high amount of acid must be added, and this might affect the taste of the bacon. More predictions can be made at FSSP (http://fssp.food.dtu.dk/). The predictions can only be used as relative suggestions to obtain the same predicted shelf life for a new salt reduced product compared to a traditional one. The shelf life of traditional bacon is approx. 56 days, which is much longer than the shelf life based on the predicted growth of *Lactobacillus*.

Table 2. Combinations of salt and organic acids with the same shelf life as only salt and nitrite. Initial count = 1 cfu/g. MAP: 30/70% CO_2/N_2 (FSSP). 150 ppm nitrite. Shelf life= time to 7 log cfu/g = 7 log growth.

Temp.	pH	Salt/water	Lactic acid/water (ppm)	Acetic acid/water (ppm)	Shelf life (log 7)
5°C	5.5	4	0	0	20 days
	5.5	2	10,000	0	20 days
	5.5	2	0	2,300	20 days
	6.5	4	0	0	19 days
	6.5	2	67,000	0	18 days
	6.5	2	67,000	2,000	19 days
7°C	5.5	4	0	0	14 days
	5.5	2	10,000	0	14 days
	5.5	2	0	2,300	14 days
	6.5	4	0	0	13 days
	6.5	2	67,000	0	12 days
	6.5	2	67,000	2,000	13 days

10.000 ppm = 1%

Food safety

Bacon is raw, cured, non-heated meat and not a ready-to-eat product, even though some consumers eat bacon non-fried. The microbial food safety is therefore based on only preservation and temperature.

Legislation

At markets where bacon is considered a raw meat product, e.g., in Denmark, there are no legal requirements (anonymous, 2005) regarding the occurrence of *Listeria monocytogenes*. *Salmonella* must not be detectable in 10 g of processed meat (including bacon), which is consumed after heat treatment (food category 1.6; anonymous, 2005).

At some markets, bacon is considered a ready-to-eat product. If growth of *Listeria monocytogenes* within the desired shelf life period (56 days) is ≤ 0.5 log cfu/g, the product is considered stabilised against growth of *L. monocytogenes* (LM-stabilised).

Predicted growth of Listeria monocytogenes

Several combinations of temperature, pH, salt, nitrite, lactic acid and acetic acid can be used to prevent growth of *Listeria monocytogenes* during the wanted shelf life (< 0.5 log growth). Models like DMRIPredict and FSSP can be used to find suitable combinations.

For a shelf life of 56 days, the maximum growth rate (μ max) of *Listeria monocytogenes* should therefore not exceed:

$\frac{0.5 \log cfu/g}{56\ days}$ = 0.00089 log cfu/g/day = 0.00037 log cfu/g/hour

Some examples from predictions in DMRIPredict are:

*Bacon containing **2.2% salt** in the product (= 3.9% salt/water in a product containing 57% water), pH 6, 30% CO_2 in the packaging gas:*

Storage at 8°C with μ_{max} = 0.0003 h^{-1}
- No nitrite, 1.7% L-lactate (2.1% Na-lactate), 0.16% acetate (0.22% Na-acetate)
- 60 ppm nitrite, 1.7% L-lactate (2.1% Na-lactate), 0.12% acetate (0.17% Na-acetate)
- 150 ppm nitrite, 1.7% L-lactate (2.1% Na-lactate), 0.04% acetate (0.06% Na-acetate)

Storage at 5°C with μ_{max} = 0.0003 h^{-1}
- No nitrite, 1.7% L-lactate (2.1% Na-lactate); no acetate
- 60 ppm nitrite; 1.6% L-lactate (2% Na-lactate); no acetate
- 150 ppm nitrite; 1.4% L-lactate (1.8 % Na-lactate); no acetate

*Bacon containing **1.5% salt** in the product (= 2.6% salt/water in a product containing 57% water), pH 6, 30% CO_2 in packaging gas:*

Storage at 8°C
- No nitrite, 1.7% L-lactate (2.1% Na-lactate), 0.17% acetate (0.23% Na-acetate)
- 60 ppm nitrite, 1.7% L-lactate (2.1% Na-lactate), 0.14% acetate (0.19% Na-acetate)
- 150 ppm nitrite, 1.7% L-lactate (2.1% Na-lactate), 0.06% acetate (0.08% Na-acetate)

Storage at 5°C
- No nitrite, 1.7% L-lactate (2.1% Na-lactate); 0.04% acetate (0.05% Na-acetate)
- 60 ppm nitrite; 1.7% L-lactate (2.1% Na-lactate); no acetate
- 150 ppm nitrite; 1.5% L-lactate (1.9% Na-lactate), no acetate

For more predictions, see Svenningsen (2022) or consult DMRIPredict.

Predicted growth of Salmonella, Yersinia, E. coli and Bacillus

The risk assessment by Svenningsen (2022) showed that during cold storage at temperatures below 7°C, the pathogens *Bacillus cereus, Clostridium botulinum (*non-proteolytic), *Listeria monocytogenes, Salmonella, Yersinia enterocolitica* and *E. coli* might grow depending on the amount of preservation.

The predictions showed:
- Organic acid can stabilise bacon against growth of *Listeria monocytogenes*
- Products stabilised against growth of *L. monocytogenes* are also stabilised against growth of *C. botulinum*
- It was not possible to predict if growth of the other pathogens was inhibited in bacon with a low salt content stabilised against growth of *L. monocytogenes*

Challenge tests

Challenge tests by Svenningsen (2023) demonstrated that a cocktail of *Salmonella, Yersinia enterocolitica* and *Bacillus cereus* did not grow in bacon with a low salt content and with organic acids and nitrite added, thus preventing growth of *Listeria monocytogenes* at 5°C and 7°C. The observations are shown in Table 3 and 4.

The variants of bacon included in the challenge tests:

1) Standard product (reference) (approx. 2.6-2.8% salt in the product + nitrite (60 ppm))
2) LM-stabilised (+ nitrite (60 ppm), + lactate (2.18%)/acetate (0.17%)); approx. 2.1% salt in the product
3) Bacon containing 1.3% NaCl in the product (+ nitrite (60 ppm), + lactate (2.18%)/acetate (0.17%))

Table 3. Results from challenge tests in bacon. Observed growth in 11 weeks (77 days) at 5°C and 7°C. 60 ppm of nitrite was added to all products. They were stored in MAP (30% CO_2).

Salt/water*)	L-lactate	Acetate	pH	Stor-age	Listeria	Salmo-nella	Yer-sinia	Bacil-lus
4.9 (=2.4*100/49)	n.d.	n.d.	5.7	5°C	3 log	NG	NG	NG
				7°C	≥4 log	NG	NG	NG
3.9 (=2.05*100/51.9)	1.76	0.17	5.8	5°C	NG	NG	NG	NG
				7°C	NG	NG	NG	NG
2.6 (=1.57*100/59.5)	2.01	0.2	5.8	5°C	NG	NG	NG	NG
				7°C	NG	NG	NG	NG

*) The results are subjected to some uncertainty as the samples were inhomogeneous.
NG = no growth in 11 weeks.
In non-inoculated samples, 7 log cfu/g was detected at week 11. It is not known how fast this number was reached.

Table 4. Results from challenge tests in bacon. Observed growth in 11 weeks (77 days) at 5°C and 7°C. 60 ppm of nitrite was added to all products. They were stored in vacuum.

Salt/water*)	L-lactate	Acetate	pH	Stor-age	Listeria	Salmo-nella	Yer-sinia	Bacil-lus
4.9 (=2.4*100/49)	n.d.	n.d.	5.7	5°C	≥4 log	NG	0-1 log	NG
				7°C	≥4 log	NG	1-2 log	NG
3.9 (=2.05*100/51.9)	1.76	0.17	5.8	5°C	NG	NG	NG	NG
				7°C	NG	NG	NG	NG
2.6 (=1.57*100/59.5)	2.01	0.2	5.8	5°C	NG	NG	NG	NG
				7°C	NG	NG	NG	NG

*) The results are subjected to some uncertainty as the samples were inhomogeneous.
NG = no growth in 11 weeks.
In non-inoculated samples, 7 log cfu/g was detected at week 11. It is not known how fast this number was reached.

Conclusion

Microbial shelf life and food safety of bacon with a low salt content (1.5%):

- Reducing the salt level from a high level to a lower level has a smaller impact on shelf life and food safety than reducing the salt level from a low level to an even lower level.
- Predict sensory and microbial shelf life with DMRIPredict. Only temperature, pH, salt and water can be included in the predictions.
- If stabilisation of growth of *Listeria monocytogenes* is needed (bacon is not a ready-to-eat product) use predictive models (e.g., DMRIPredict or FSSP) to find a combination of preservatives suitable for your product.

- If growth of *Listeria monocytogenes* is inhibited during storage at temperatures below 8°C, growth of other pathogens is also inhibited.
- A low salt content will affect the taste. Substitutes might be needed, e.g., more smoke, and/or salt enhancer. On the other hand, frying might result in evaporation of so much water that the salty taste is still acceptable.
- Shelf life will depend on the initial microbial count, storage temperature and preservation. The use of preservation that inhibits growth of *L. monocytogenes* will also prolong the sensory shelf life.

References

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