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EFFECT OF HEADSPACE CO_2 CONCENTRATION ON SHELF-LIFE OF COOKED MEAT PRODUCTS

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The shelf-lives of major commercial cooked meat products (i.e., Bologna sausage, Italian-type cooked sausage, and cooked ham) packaged under vacuum or modified atmospheres were tested in this study. Samples were taken from commercial meat processing lines, sliced to 1.2 mm thickness and placed overlapped into polypropylene trays sealed with plastic films. The headspace of modified atmosphere packaged formulations consisted of 30% CO_2 and 70% N_2 or 60% CO_2 and 40% N_2. The samples thus produced were stored under refrigerated conditions. The values of microbiological, chemical, physical or sensory properties were plotted against storage time, and Gompertz curves were fitted to all time series that changed from an initial to a final value during any period of storage. The influence of headspace CO_2 concentration on the properties of sliced cooked meat products varied considerably and, therefore, it was not possible to specify general rules. However, the presence of CO_2 in the packaging atmosphere slowed down the rate of microbial growth, thereby delaying the spoilage of meat products. A CO_2 level of 60% had beneficial effects on both the microbiological and sensory properties of sliced sausages and cooked ham. It was concluded that cooked meat products packaged under modified atmospheres had a shelf-life of 20 days.

Keywords: cooked meat product, shelf-life, carbon dioxide, modified atmosphere packaging, vacuum packaging

Low gas-permeable packaging films do not only protect packaged foods from external contamination but they also delay spoilage when suitable gas mixtures are used (LAKNER, 1994; 1997). In the case of cooked meat products, the exclusion of O_2 is one of the main objectives. Low partial oxygen pressure inhibits the growth of aerobic microbes, which cause a much faster spoilage than do anaerobic micro-organisms (OORAIKUL, 1991). The oxygen content in the packages may be reduced either by vacuum packaging using oxygen scavengers or by flushing the atmosphere of the packages with various gases. The latter system is often referred to as modified atmosphere packaging (MAP). Usually, a proper mixture of N_2 and CO_2 is used for generating the modified atmosphere. Other tested gases such as CO or NO were found to have no beneficial effect on the shelf-life of cooked meat products (CHURCH, 1993).

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The presence of CO_2 in the headspace of packages increases the lag phase of micro-organisms and decreases their maximal growth rate (FARBER, 1991). A mixture of CO_2 and N_2 containing 20 to 30% CO_2 results in residual oxygen levels of below 1%, which also inhibit the growth of yeasts. However, CO_2 contents of over 30% may cause dripping, discolouration, and a sour odour (AHVENAINEN, 1990). Higher CO_2 concentrations (over 50%) suppress the growth of *Listeria monocytogenes*, *Staphylococcus aureus*, *Salmonella* spp., *Escherichia coli* and *Yersinia enterocolitica* (LEFEVRE, 1990).

In this work, the shelf-life of different cooked meat products packaged under modified atmospheres containing various CO_2 levels was examined in an attempt to determine whether the adverse changes known from the literature can also be observed in Hungarian products.

1. Materials and methods

1.1. Products tested

Three types of major commercial cooked meat products were tested in this study. The chemical composition of the products selected is shown in Table 1. Samples were taken from normal meat processing lines.

Table 1. Chemical composition of the products tested

Product	Moisture	Protein	Fat	NaCl	P_2O_5
			content (%)		
Bologna sausage	62.0	10.6	19.5	2.2	0.20
Italian-type cooked sausage	52.7	13.0	28.8	2.3	0.25
Cooked ham	74.6	13.4	5.9	2.9	0.42

1.1.1. Bologna sausage. Pork meat, beef meat and pork fat were homogenized in a cutter with water, nitrite curing salt and spices being added to the meat batter, which was stuffed into artificial casings (9 cm in diameter) and cooked at an internal temperature of 71 °C. The sausages were then kept at this temperature for 10 min, and cooled down.

1.1.2. Italian-type cooked sausage. Pork meat, beef meat and pork fat chopped into approximately 4×4×4 mm cubes were mixed with meat batter, nitrite curing salt and spices. This batter was then stuffed into 7.5-cm diameter artificial casings, cooked at 75 °C for 120 min, and cooled down.

1.1.3. Cooked ham. Pork meat pieces were tumbled in a brine containing nitrite curing salt, sodium polyphosphate and sodium ascorbate, aged, and then stuffed into deep-drawn plastic film packages (9 cm in diameter), which were cooked up to a core temperature of 70 °C, and cooled down.

1.2. Packaging and storage

The outer layer of the samples was frozen, and then the products were sliced to 1.2 mm thickness and placed overlapped into polypropylene trays sealed with plastic films. Darfresh WEB films were used for vacuum packaging and Multibarrier 4 films for MAP. The headspace of modified atmosphere packaged cooked meat products consisted of either 30% CO_2 and 70% N_2 or 60% CO_2 and 40% N_2. The samples thus produced were weighed, placed in cardboard boxes and stored protected from light exposure at 2 to 4 °C.

1.3. Sampling, analyses, and evaluation of results

Samples were taken after 1, 5, 11, 15, 20, 25 and 29 days of storage and microbiological, chemical, physical and sensory analyses were carried out on two samples from each day. The total experimental program was repeated twice.

1.3.1. Enumeration of micro-organisms. The viable counts or presence/absence of the following micro-organisms were determined according to Hungarian and German official methods: total plate count (HUNGARIAN STANDARD, 1986), lactobacilli (DEUTSCHES INSTITUT FÜR NORMUNG, 1991), *Salmonella* spp. (HUNGARIAN STANDARD, 1999), *Staphylococcus aureus* (HUNGARIAN STANDARD, 1985), enterococci (HUNGARIAN STANDARD, 1976), *Escherichia coli* (HUNGARIAN STANDARD, 1979) and mesophilic sulphite-reducing clostridia (HUNGARIAN STANDARD, 1978).

1.3.2. Determination of nitrite content and pH value. The nitrite level of products was determined according to the official method of analysis used in Hungary (HUNGARIAN STANDARD, 1981), and their pH was assessed by means of an ISFET 101 pH meter (Delta TRAK Inc., Pleasanton, CA, USA) and a LanceFET spear tip electrode on a homogenate consisting of 5 g of sample in 50 ml of distilled water.

1.3.3. Colour measurement. The colour of cooked meat products was measured using a Minolta CR-300 chromameter (with aperture diameter and viewing angle set at 8 mm and 0°, respectively) and described numerically by the CIELAB colour space model. L* is a degree of lightness ranging from 0 (black) to 100 (white) along a gray scale. Positive a* values are red and negative a* values are green. Positive b* values are yellow and negative b* values are blue. Chroma $\{[(a^*)^2+(b^*)^2]^{1/2}\}$ is a measure of colour saturation and hue (b*/a*) is the colour angle (COMISSION INTERNATIONALE DE L'ECLAIRAGE, 1978).

1.3.4. Sensory evaluation. Samples from each formulation were randomly assigned for sensory evaluation to a 5-member panel, 2 min after the vacuum or modified atmosphere packages were opened. Properties were assessed using a 5-point rating scale ranging from 0 to 4. A score of 0 from an individual panellist indicated unacceptability for consumption in terms of the organoleptic characteristic tested. The following sensory properties of the cooked meat products were assessed: drip formation, intensity and freshness of odour and flavour, slime formation, stickiness and cohesiveness of slices.

1.3.5. Curve fitting. Gompertz curves were fitted to time series that changed from an initial to a final value during any period of storage (ZWIETERING et al., 1990). The initial value, the initial and final points in time of the fast change, and the final value were determined on the basis of the curve fitted (Fig. 1). Proper polynomials were also fitted to the other time series and the characteristic values were determined based on these polynomials.

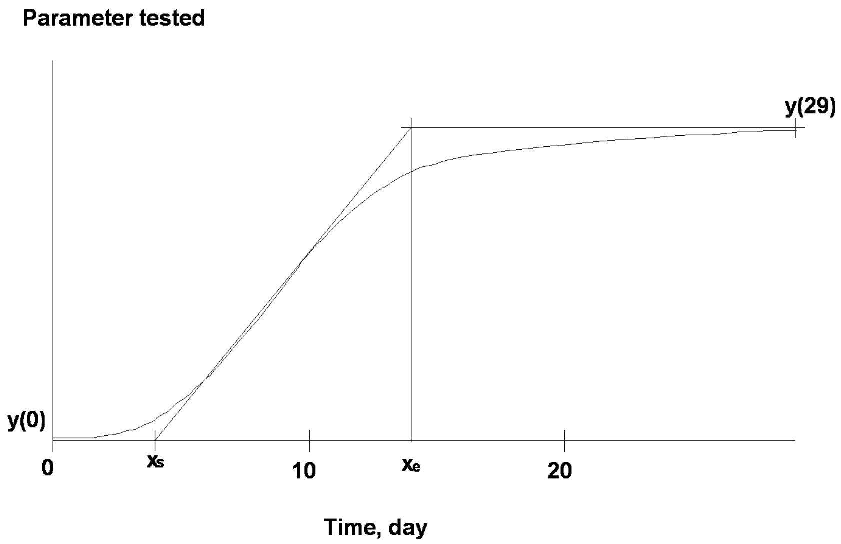

Fig. 1. Characteristic points of curve fitting. y(0): Value of parameter tested on day 0; y(29): value of parameter tested on day 29; x_s: start of change; x_e: end of change

2. Results and discussion

As shown in Table 2, the total plate count (TPC) of Bologna sausage started to increase after 5 to 6 days of storage on average, independently of the headspace CO_2 concentration. The TPC of Italian-type cooked sausage began increasing only on day 11; however, a CO_2 content of 60% put the start of increase off until day 18. The TPC of cooked ham packed under vacuum kept increasing from the beginning of storage, whereas MAP considerably delayed the start of increase.

Because the enumeration of microbial counts in solid samples is not sufficiently accurate below the level of 10^2 CFU g^{-1}, the initial lactobacilli counts presented in Table 3 are not highly reliable. Owing to the low initial counts in Bologna sausage, it was only the packaging atmosphere containing 60% CO_2 that had a slight delaying effect on the growth of lactobacilli. Headspace CO_2 levels decreased the growth rate of lactobacilli in cooked ham and Italian-type cooked sausage. The proportion of lactobacilli in both sausage varieties increased as storage progressed, and in cooked ham the microflora was composed mainly of lactobacilli even at the beginning of the storage period.

Table 2. Changes in total plate counts[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial count (log)	Start of increase (day)	Final count (log)	End of increase (day)
Bologna sausage	0	2.0	5.6	7.0	16.2
	30	2.0	4.9	6.9	21.2
	60	2.0	6.5	7.0	29.0
			SD=0.19		
Italian-type cooked sausage	0	3.0	11.3	6.0	16.8
	30	3.0	10.4	6.0	24.7
	60	3.0	17.7	6.0	28.4
			SD=0.04		
Cooked ham	0	2.0	0	6.3	11.2
	30	2.0	11.9	6.0	28.6
	60	2.0	19.1	6.0	28.4
			SD=0.08		

[a] Values are means based on 4 observations (2 samples, 2 replicates).
SD: standard deviation.

Table 3. Changes in lactobacilli counts[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial count (log)	Start of increase (day)	Final count (log)	End of increase (day)
Bologna sausage	0	1.1	3.7	7.8	23.9
	30	0.8	4.2	6.5	28.2
	60	0.2	11.1	5.9	22.9
			SD=0.21		
Italian-type cooked sausage	0	2.0	9.4	3.5	14.4
	30	1.7	10.2	5.9	27.0
	60	1.0	11.3	5.3	27.8
			SD=0.05		
Cooked ham	0	2.6	8.1	5.4	14.6
	30	2.0	10.8	5.6	27.9
	60	2.0	16.9	5.1	25.3
			SD=0.11		

[a] Values are means based on 4 observations (2 samples, 2 replicates).
SD: standard deviation.

Table 4. Changes in sodium nitrite levels[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial value (mg 100 g^{-1})	Start of change (day)	Final value (mg 100 g^{-1})	End of change (day)
Bologna sausage	0	24.5	0	10.7	29.0
	30	24.3	0	6.7	29.0
	60	24.2	0	13.2	29.0
			SD=1.80		
Italian-type cooked sausage	0	14.4	0	8.7	29.0
	30	14.1	0	11.8	29.0
	60	14.3	0	13.2	29.0
			SD=0.70		
Cooked ham	0	8.7	0	13.4	29.0
	30	11.8	0	13.5	29.0
	60	13.2	0	13.5	29.0
			SD=0.20		

[a] Values are means based on 4 observations (2 samples, 2 replicates).
SD: standard deviation.

Table 5. Changes in pH[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial pH	Final pH	Minimum pH	Time needed to reach minimum pH (day)
Bologna sausage	0	6.23	6.11	6.09	7.1
	30	6.12	5.95	5.89	4.4
	60	6.05	5.92	5.91	18.7
			SD=0.02		
Italian-type cooked sausage	0	6.22	6.11	5.81	22.0
	30	6.10	6.12	5.95	17.4
	60	6.03	6.10	5.91	17.9
			SD=0.05		
Cooked ham	0	6.24	6.16	5.89	22.7
	30	6.11	6.11	6.05	18.9
	60	6.07	6.13	5.94	17.5
			SD=0.04		

[a] Values are means based on 4 observations (2 samples, 2 replicates).
SD: standard deviation.

Table 6. Influence of various CO_2 levels in the packaging atmosphere on colour properties[a] of the products tested

Product	CO_2 (%)			SD
	0	30	60	
Lightness (L*)				
Bologna sausage	61.6	62.3	62.3	0.39
Italian-type cooked sausage	55.0	56.7	56.4	0.91
Cooked ham	57.2	56.2	56.7	1.21
Colour saturation {chroma: $[(a^*)^2+(b^*)^2]^{1/2}$}				
Bologna sausage	20.6	20.3	20.2	0.21
Italian-type cooked sausage	20.0	18.8	19.4	0.74
Cooked ham	13.7	14.9	15.1	1.19
Hue (b*/a*)				
Bologna sausage	0.92	0.91	0.91	0.01
Italian-type cooked sausage	0.94	0.94	0.91	0.06
Cooked ham	0.52	0.48	0.44	0.04

[a] Values for 0%, 30%, and 60% CO_2 levels are means based on 4 observations (2 samples, 2 replicates).
SD: standard deviation.
L*: lightness (0=black; 100=white).
a*: redness (positive values: red, negative values: green).
b*: yellowness (positive values: yellow, negative values: blue).

Table 7. Changes in odour freshness[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	4.0	5.4	0	29.0
	30	4.0	26.3	1.0	29.0
	60	4.0	24.1	0	29.0
	SD=0.14				
Italian-type cooked sausage	0	4.0	16.5	1.0	29.0
	30	4.0	26.0	2.0	29.0
	60	4.0	26.0	2.0	29.0
	SD=0.26				
Cooked ham	0	4.0	16.0	0	29.0
	30	4.0	17.3	0	29.0
	60	4.0	24.1	0	29.0
	SD=0.11				

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

Table 8. Changes in pungent (CO_2) odour[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of improvement (day)	Final score[b]	End of improvement (day)
Bologna sausage	0	4.0	No change	4.0	No change
	30	4.0	No change	4.0	No change
	60	1.9	4.1	4.0	18.8
			SD=0.79		
Italian-type cooked sausage	0	4.0	No change	4.0	No change
	30	4.0	No change	4.0	No change
	60	4.0	No change	4.0	No change
			SD=0.00		
Cooked ham	0	4.0	No change	4.0	No change
	30	3.0	13.4	4.0	16.6
	60	3.0	20.5	4.0	23.6
			SD=0.43		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

As to the other micro-organisms tested, none of the samples contained a detectable count of *E. coli*, enterococci, mesophilic sulphite-reducing clostridia, *S. aureus* or *Salmonella* spp. during the entire storage period.

The initial levels of sodium nitrite were significantly higher in Bologna sausage than in Italian-type cooked sausage or cooked ham (Table 4). However, a gradual decrease occurred in the nitrite content of Bologna sausage during the 4-week storage period, whereas the levels of this component decreased only slightly in Italian-type cooked sausage and even increased in cooked ham and, thus, the final values did not differ considerably. It is clearly seen in Table 4 that the final nitrite concentrations of formulations packed under modified atmosphere containing 60% CO_2 were found to be almost identical.

As illustrated by initial and minimum values in Table 5, both vacuum packaging and MAP had a lowering effect on the pH of products. The pH value of Bologna sausage decreased gradually until day 10 and then remained practically unchanged for the rest of storage. As for the Italian-type cooked sausage and cooked ham, pH fell for approximately 2 weeks and increased afterwards, reaching the initial value by the end of the storage period.

Generally, composition of the packaging atmosphere did not substantially influence the colour properties of cooked meat products (Table 6). However, compared to vacuum packaging, MAP decreased the hue value of cooked ham, thereby slightly increasing the surface redness of this product.

The odour freshness of Bologna sausage packed under vacuum and modified atmospheres started declining after approximately 5 and 25 days, respectively. The final scores in Table 7 indicate that this product developed unpleasant odours by the end of storage irrespective of the packaging atmosphere applied. The Italian-type cooked sausages packed under vacuum and modified atmospheres retained their fresh odour for 16 and 26 days, respectively. It is worth noting that the odour of modified atmosphere packaged samples was satisfactory throughout the storage period. The odour of cooked ham in vacuum packaging or in MAP containing 30% CO_2 retained freshness for 16 days, and the presence of 60% CO_2 in the headspace of packages resulted in extending this period by eight additional days. Similar to what was experienced with Bologna sausage, cooked ham also developed unpleasant off-odours by the end of the storage period regardless of packaging conditions.

The pungent (CO_2) odour of Bologna sausage packed in modified atmosphere containing 60% CO_2 disappeared after 19 days (Table 8). As for cooked ham, no pungent (CO_2) odour was perceived after 17 and 24 days of storage in modified atmosphere packed samples containing 30% and 60% CO_2, respectively. Panellists also indicated a slightly sweet taste in modified atmosphere packaged ham. The Italian-type cooked sausages had no pungent (CO_2) odour at any sampling time throughout the 29-day storage period.

Table 9 shows that vacuum packaging and MAP caused an initial improvement in the characteristic odour of sausages and cooked ham, respectively. However, this sensory attribute deteriorated during subsequent stages of storage. Bologna sausage and cooked ham were highly affected by these adverse changes, whereas the characteristic odour intensity of Italian-type cooked sausage declined only to a lesser extent.

The flavour freshness of Bologna sausage samples began declining around day 6, with MAP having a delaying effect on this undesirable process (Table 10). Italian-type cooked sausage retained its original flavour freshness for 26 days, provided that the packaging atmosphere contained at least 30% CO_2, and a headspace CO_2 concentration of 60% resulted in excellent flavour freshness during the entire storage period. Similarly, cooked ham was also found to have outstanding flavour freshness regardless of sampling time and composition of the packaging atmosphere.

It is clearly visible in Table 11 that the presence of CO_2 in the headspace of packages had a beneficial effect on the characteristic flavour of both sausage varieties. It should also be noted that cooked ham had the highest initial and final scores for characteristic flavour of all three products tested.

As indicated in Table 12, Bologna sausage showed signs of slime formation after 3 weeks in vacuum packaging and after 26 days in MAP, and panellists judged all samples unfit for consumption at the end of the storage period. Vacuum packaging and MAP containing 30% CO_2 led to slime production after approximately 17 and 26 days, respectively, in both the Italian-type cooked sausage and cooked ham samples. In accordance with our aforementioned observations, these products were also perceived to be unpalatable on day 29. In contrast, the presence of 60% CO_2 in the headspace of packages provided complete protection for both cooked ham and Italian-type cooked sausage against slime formation.

Table 9. Changes in characteristic odour intensity[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	2.3	4.8	1.1	15.2
	30	4.0	0	2.1	22.8
	60	4.0	0	2.2	21.6
			SD=0.32		
Italian-type cooked sausage	0	2.3	10.0	2.0	17.5
	30	4.0	No decrease	4.0	29.0
	60	4.0	0	3.0	17.8
			SD=0.17		
Cooked ham	0	4.0	0	1.5	2.1
	30	2.8	14.0	1.9	17.1
	60	3.0	13.3	2.2	22.0
			SD=0.54		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

Table 10. Changes in flavour freshness[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	4.0	5.5	2.0	29.0
	30	4.0	7.9	2.4	29.0
	60	4.0	5.4	3.0	29.0
			SD=0.16		
Italian-type cooked sausage	0	4.0	7.3	1.0	29.0
	30	4.0	26.1	2.0	29.0
	60	4.0	No decrease	4.0	29.0
			SD=0.16		
Cooked ham	0	4.0	No decrease	4.0	29.0
	30	4.0	No decrease	4.0	29.0
	60	4.0	No decrease	4.0	29.0
			SD=0.00		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

Table 11. Changes in characteristic flavour intensity[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	2.0	Poor throughout storage	0	16.0
	30	2.3	4.5	2.0	7.0
	60	3.3	8.7	2.9	23.6
			SD=0.74		
Italian-type cooked sausage	0	2.0	Poor throughout storage	0	17.0
	30	2.8	13.2	2.2	20.3
	60	4.0	0	3.1	22.1
			SD=0.66		
Cooked ham	0	4.0	No decrease	4.0	29.0
	30	4.0	0	3.0	16.5
	60	4.0	0	2.0	23.5
			SD=0.38		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

Table 12. Changes in slime formation[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	4.0	21.5	0	29.0
	30	4.0	25.9	0	29.0
	60	4.0	26.0	1.0	29.0
			SD=0.22		
Italian-type cooked sausage	0	4.0	16.3	0	29.0
	30	4.0	25.9	0	29.0
	60	4.0	No decrease	4.0	29.0
			SD=0.11		
Cooked ham	0	4.0	17.0	0	29.0
	30	4.0	25.9	0	29.0
	60	4.0	No decrease	4.0	29.0
			SD=0.15		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

Table 13. Changes in stickiness and cohesiveness[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	4.0	20.0	1.0	29.0
	30	4.0	26.0	2.0	29.0
	60	4.0	26.0	1.0	29.0
			SD=0.05		
Italian-type cooked sausage	0	2.0	Sticky throughout storage	2.0	29.0
	30	4.0	No decrease	4.0	29.0
	60	4.0	No decrease	4.0	29.0
			SD=0.00		
Cooked ham	0	4.0	No decrease	4.0	29.0
	30	4.0	20.4	1.9	29.0
	60	4.0	20.4	1.9	29.0
			SD=0.10		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

Table 14. Changes in drip formation[a] of products during storage under various packaging atmospheres

Product	CO_2 (%)	Initial score[b]	Start of decrease (day)	Final score[b]	End of decrease (day)
Bologna sausage	0	2.0	Dripping throughout storage	0	29.0
	30	4.0	No drip	4.0	29.0
	60	4.0	26.0	2.0	29.0
			SD=0.10		
Italian-type cooked sausage	0	4.0	No drip	4.0	29.0
	30	4.0	No drip	4.0	29.0
	60	4.0	No drip	4.0	29.0
			SD=0.00		
Cooked ham	0	2.0	Dripping throughout storage	0	29.0
	30	4.0	22.4	2.0	29.0
	60	4.0	26.0	2.0	29.0
			SD=0.10		

[a] Values are means based on 20 observations (5 panellists, 2 samples, 2 replicates).
[b] 4.0=best score, 0=worst score.
SD: standard deviation.

The cohesiveness of Bologna sausage slices declined after 20 days in vacuum packaging and after 26 days in MAP (Table 13). The vacuum packed Italian-type cooked sausage slices were sticky throughout the storage period, whereas their modified atmosphere packaged counterparts were found to be excellent in this respect. The cohesiveness of cooked ham slices packed under modified atmospheres scored 4.0 for 3 weeks and then a decline in scores was observed.

Table 14 shows that severe drip formation was experienced in the vacuum packed Bologna sausage and cooked ham from the beginning to the end of storage, whereas MAP provided some degree of protection against this quality defect. The Italian-type cooked sausage samples showed no sign of dripping over the entire storage period.

3. Conclusions

The influence of headspace CO_2 concentration on the microbiological, chemical, physical and sensory properties of the sliced cooked meat products tested in this study varied considerably and, thus, it is not possible to specify general rules.

MAP reduced the initial pH of samples, especially during the first half of storage, and enhanced their characteristic flavour. The presence of CO_2 in the packaging atmosphere slowed down the rate of microbial growth in each product. These results are consistent with those of ANJANEYULU and SMIDT (1986), who determined that the time of microbial growth inhibition extrapolated to 100% CO_2 concentration was up to 30 days in processed ham. SILLA and SIMONSEN (1985) also demonstrated the inhibitory effect of CO_2 on micro-organisms. In contrast, AHVENAINEN and co-workers (1989; 1990) found no significant difference in this respect between vacuum packaging and MAP containing 43 to 55% CO_2. In our study, a TPC of approximately 6 log cycles resulted in a deterioration of odour and flavour and, therefore, CO_2 delayed the spoilage of meat products. However, high CO_2 concentrations impaired the cohesiveness (i.e., sliceability) of cooked ham. In agreement with the findings of ANDERSEN and co-workers (1990) and in contrast to those of AHVENAINEN (1990), a headspace CO_2 concentration of 60% slightly increased the surface redness of cooked ham. In addition, it also contributed to controlled slime production and the development of a long-lasting, characteristic flavour. Compared to vacuum packaging, MAP reduced drip formation in both Bologna sausage and cooked ham. As opposed to our observations with respect to cooked ham slices, the sour odour of Bologna sausage disappeared quickly during storage, and panellists indicated no sour odour in any of the Italian-type cooked sausage samples tested.

In conclusion, the use of 60% CO_2 in the packaging atmosphere had beneficial effects on the microbiological and sensory properties of sliced sausages and sliced cooked ham. The shelf-life of 28 to 35 days recommended by LEISTNER and GORRIS (1994) for cooked meat products packaged under modified atmosphere containing 20% CO_2 seems to be rather exaggerated; a shelf-life of 20 days would be more realistic instead.

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