4:12 The influence of acetic acid concentration on the efficiency of marinading as a process for tenderizing beef

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Introduction

Marinading is recognised in culinary circles as a means of imparting flavour to meat and improving its tenderness. The technique involves immersing meat in a marinading solution under refrigerated conditions, generally for a time period of between 1 and 24 h prior to cooking. The active tenderizing ingredients are thought to be the organic acids found in typical marinading solutions such as vinegar, wine or fruit juice.

The early work of Griswold (1955a) however, indicated that there was no increase in the tenderness of joints of beef round which were braised after marinading for 48 h in 2.5 percent distilled vinegar. Wenham and Locker (1976) later showed that marinading in 1.5 percent acetic acid for 43 h produced a 3-fold increase in the tenderness of relatively thin strips of beef M. sternomandibularis muscle. However, only marginal benefits were achieved when much thicker beef M. longissimus dorsi steaks were treated under similar conditions. Wenham and Locker (1976) thus concluded that marinading was only effective in tenderizing muscles rich in collagen, claiming that the beneficial effect of marinading was in creating a more acidic meat environment in which the susceptibility of collagen to degradation during cooking was enhanced.

It is clear that under the experimental conditions used by Griswold (1955a, b) and Wenham and Locker (1976), complete penetration of marinade into the meat was never achieved. Consequently, the conclusions reached by these authors do not accurately reflect or explain the potential effectiveness of marinading as a method for tenderizing beef. The present study was therefore planned to investigate the influence of a range of acetic acid concentrations on the efficiency of marinading as a method for tenderizing beef M. longissimus lumborum muscle under standardised conditions which were selected to ensure that penetration of the marinading acid throughout the meat was complete.

Materials and Methods

M. longissimus lumborum muscles from four young steers were obtained commercially three days after slaughter. These were cut transversely on a gravity feed slicer into steaks approximately 1.0 cm thick, from which discs of meat 3.0 cm in diameter (weight 7.5 ± 1.0 g) were prepared using a cork borer. To facilitate slicing and coring, transverse blocks of muscle and steaks were tempered individually at -25°C until the surfaces were rigid.

Acetic acid solutions of the following strength were used as marinades: 0.01 N, 0.025 N, 0.05 N, 0.075 N, 0.10 N, 0.25 N, 0.50 N, 0.75 N, 1.00 N, 1.25 N, 1.50 N, 2.00 N and 3.00 N. Each meat disc was accurately weighed and placed in a 200 ml capacity screw-cap polystyrene jar to which 50 ml chilled (4°C) acetic acid solution was added. Marinading was continued for 48 h at 4°C with continuous swirling at 120 rpm in a Gallenkamp Cooled Orbital Incubator. Untreated meat discs stored under the same conditions were used as controls. Each treatment was replicated four times for each animal.

After marinading, meat discs were reweighed after surface drying with paper towelling. Two discs from each treatment were individually cooked in sealed polythene bags in a water bath at 80°C for 20 min and immediately chilled in an ice-water bath. They were then surface dried as before and reweighed. The weight of each marinaded meat disc, before and after cooking, was divided by the corresponding raw meat weight to express change in weight as a swelling ratio. Cores of meat 0.9 cm in diameter were cut from each meat disc parallel to the muscle fibre direction (where possible) for tenderness assessment on an Instron Model 1122 Universal Testing Instrument fitted with a Warner-Bratzler shear device. The average tenderness value for each meat disc was calculated from the mean of either 4 (control samples and those marinaded in <0.05 N acetic acid) or 6 (samples marinaded in >0.075 N acetic acid) measurements of peak shear force.

The remaining two meat discs from each treatment were individually homogenised and made up to 100 ml with distilled water. The pH of each solution was measured on a Phillips PW 9414 digital ion activity meter fitted with a Pye-Unicam model no. 401/E7 combination glass electrode. Titratable acidity was determined on a 25 ml aliquot of each solution against 0.01 N or 0.1 N NaOH using a phenol phthalein indicator. Total nitrogen was determined on a 10 ml aliquot of the solution by the Kjeldahl method as described by the A.O.A.C. (1980) but incorporating a selenium, rather than mercury-based, catalyst. All marinading solutions were assessed for total nitrogen (25 ml aliquot), titratable acidity (5 ml aliquot) and pH by the methods described above.

Values obtained for titratable acidity were used to calculate the concentration (N) and total weight (g) of acetic acid in the fresh and used marinades, and the total weight of acetic acid in the marinaded meat. The weight of acetic acid was also calculated as a percentage of the used marinade volume and the marinaded meat weight. Values obtained from the nitrogen analyses were used to calculate the percentage total nitrogen content of the raw meat discs present in the used marinades.

Results

Analyses of variance were computed to examine the differences between marinading treatments for each parameter measured. The results shown in Table 1 summarise the effect of each marinading treatment on meat swelling (or shrinkage) before and after cooking, and on its tenderness after cooking. Also included in Table 1 are the mean pH values obtained from homogenates of the uncooked marinaded meat discs.

It is clear that acetic acid concentration had a profound effect on the swelling characteristics of meat discs marinaded under the conditions used in this study. In the uncooked state, control samples and those marinaded in 0.01 N acetic acid showed a slight weight loss. However, there was a marked increase in the weight of meat discs with increasing marinade strength, the maximum swelling achieved in 1.00 N acetic acid corresponding to slightly more than a 100 percent increase in weight. It is also interesting to note that more than an 80 percent weight increase was achieved in meat discs marinaded in acetic acid solutions covering the range 0.25 N to 3.00 N.

Table 1. The influence of acetic acid concentration on the swelling characteristics, tenderness, and pH of marinaded discs of beef M. longissimus lumborum muscle (†8 or ‡16 observations per mean)

	Acetic acid concentration (N) of fresh marinades												
	Cont	0.01	.025	0.05	.075	0.10	0.25	0.50	0.75	1.00	1.25	1.50	2.00	3.00	SEM*
‡RMS	0.94	0.97	1.18	1.38	1.52	1.57	1.80	1.92	1.95	2.04	2.01	1.97	1.92	1.81	.030
†CMS	0.59	0.50	0.64	1.01	1.22	1.34	1.58	1.74	1.76	1.84	1.83	1.84	1.76	1.74	.030
†CMT	6.53	6.62	5.44	2.66	1.40	0.96	0.72	0.45	0.39	0.30	0.33	0.32	0.32	0.36	.040
†pH	5.33	4.61	4.43	4.31	4.19	4.12	3.84	3.65	3.50	3.44	3.34	3.29	3.22	3.15	.021

Note: RMS = raw meat swelling : CMS = cooked meat swelling : CMT = cooked meat tenderness (kg cm^{-2}) * effective standard error of the means

Cooking resulted in a loss of weight from all the marinaded meat discs, with extensive shrinkage in the control samples and those marinaded in 0.01 N and 0.025 N acetic acid solutions. However, swelling was substantially retained after cooking in the remaining samples, weight loss progressively diminishing with an increase in marinade strength. Consequently it is clear that the structural integrity of the meat discs was maintained throughout the concentration range studied, and during cooking.

The influence of marinading on meat tenderness was quite remarkable, a six-fold increase occurring over the relatively narrow concentration range 0.01 N to 0.10 N acetic acid. There was a further three fold increase in tenderness with increasing marinade strength, the maximum benefit being achieved with 1.00 N acetic acid. However, as the marinade strength increased to 3.0 N acetic acid, there was little further change in tenderness.

It can therefore be clearly seen that tenderness is strongly related to the swelling characteristics of the meat and that the maximum swelling and tenderizing benefits of marinading were achieved when the pH of the meat discs had fallen to pH 3.44.

Table 2 summarises those aspects of the marinading conditions of relevance to the extent of penetration of acetic acid into the meat, its distribution between marinading solution and the meat, and the influence such conditions have on the loss of nitrogenous components from the meat discs by leaching and/or solubilization.

A comparison of the acetic acid normalities of the used and fresh marinades indicates that the apparent acetic acid content of the weakest marinades had increased markedly during marinading. An equilibrium situation was reached with the 0.05 N acetic acid marinade, beyond which there was a gradual decrease in the normality of the used compared to the fresh marinades. This comparative decrease reached a limit of approximately 12 percent at an acetic acid concentration of 0.25 N in the fresh marinade, beyond which there was little further change. A similar trend is mirrored if the percentage acetic acid contents of the fresh and used marinades are compared. Such a trend would suggest that approximately 12 percent maximum absorption of acetic acid by the meat discs occurred under the conditions used in this study. However, calculations based on normality are inappropriate in this context because of the large volume decrease of the stronger marinades due to meat swelling.

Consequently, acetic acid content is also expressed in absolute terms to give a more accurate account of its distribution due to marinading. By adding the acetic acid content of the used marinade to that of the marinaded meat, it becomes clear that over the concentration range 0.01 N to 0.10 N, the acetic acid balance consistently exceeds that of the corresponding fresh marinade by a value of approximately 0.06 g which is virtually identical to the apparent acetic acid content of the control samples. It is also clear that the distribution of acetic acid between the used marinades and the marinaded meat increased markedly with increasing marinade strength over the range studied. This is indicative of the proportionately greater apparent absorption of available acetic acid by the meat discs with decreasing marinade strength. This trend is more clearly seen by comparing the percentage acetic acid contents of the marinaded meat discs with those of the used marinades. Here the distribution balance is reached in the 0.50 N acetic acid marinades, beyond which the balance progressively increases in favour of the used marinades.

The remaining results in Table 2 indicate that the pH of the used marinades fell gradually from pH 4.41 to pH 2.71 over the range studied. More than 20 percent of the nitrogen content of the meat discs was found in those marinades covering the range 0.01 N to 0.50 N acetic acid, reaching a maximum of 23.8 percent in the 0.075 N acetic acid marinade. Nevertheless, there was a progressive decrease in the loss of nitrogen from the meat with increasing marinade strength, reaching a minimum of 16.0 percent with the 3.0 N acetic acid marinade.

Table 2 The influence of marinading conditions on the chemical characteristics of used marinade solutions, nitrogen solubility and acetic acid distribution* between meat and marinade (†8 or ‡16 observations per mean)

	Acetic acid concentration (N) of fresh marinades												
	Cont	0.01	.025	0.05	.075	0.10	0.25	0.50	0.75	1.00	1.25	1.50	2.00	3.00	SEM**
‡N^u	-	.018	0.03	0.05	0.07	0.09	0.22	0.44	0.65	0.87	1.10	1.32	1.73	2.60	.06
†pH^u	-	4.41	4.22	3.99	3.90	3.80	3.53	3.29	3.16	3.06	2.97	2.91	2.83	2.71	.03
‡%N^u	-	20.6	21.0	22.1	23.8	23.6	21.9	20.5	19.8	18.7	18.4	17.3	16.4	15.9	.20
‡TA^f	-	.030	.075	.150	.225	.300	.750	1.50	2.25	3.00	3.75	4.50	6.00	9.00	.05
‡TA^u	-	.055	.084	.138	.195	.248	.568	1.12	1.66	2.21	2.79	3.36	4.45	6.81	.05
†TA^m	.059	.036	.050	.071	.091	.114	.221	.393	.604	.806	.967	1.12	1.45	1.87	.02
‡%A^f	-	0.06	0.15	0.30	0.45	0.60	1.50	3.00	4.50	6.00	7.50	9.00	12.0	18.0	.10
‡%A^u	-	0.11	0.17	0.29	0.42	0.55	1.30	2.62	3.89	5.24	6.57	7.89	10.4	15.5	.10
††%A^m	0.81	0.48	0.53	0.67	0.77	0.92	1.62	2.60	3.99	5.11	6.30	7.48	9.82	14.1	.08

Note: Superscripts f, u and m refer to fresh marinade, used marinade and marinaded meat respectively: N = normality of acetic acid : % N = percentage of the total nitrogen content of the fresh meat discs found in the used marinades: TA = total content of acetic acid (g) : %A = percentage acetic acid present on a wt/wt (meat) or wt/vol (marinade) basis: * titratable acidity calculated as acetic acid in all samples, including controls: ** effective standard error of the means

Discussion

The most important aspect of this study is that marinading in relatively weak solutions of acetic acid has been shown to have a profound influence on the tenderness of cooked beef M. longissimus lumborum muscle. It has also been clearly demonstrated that this increase in tenderness is strongly related to an increase in the weight of the meat due to absorption of marinading fluid, and that this is substantially retained during cooking.

Consequently, the conclusions reached by Wenham and Locker (1976), that marinading has no tenderizing effect on beef M. longissimus dorsi muscle, can be justified only in relation to traditional culinary practice where large portions of meat are used, but not under ideal conditions where adequate penetration of the marinade is achieved. A similar opinion can be expressed concerning the work of Griswold (1955a, b). In the present study, problems created by the slow rate of diffusion of acetic acid solution into meat were substantially overcome by using relatively small portions of meat and marinading for a relatively long time under agitated conditions. The benefits of this approach were also achieved to a certain extent by Wenham and Locker (1976) with strips of beef M. sternomandibularis muscle, showing that marinading was effective in tenderising muscles rich in connective tissue. However, when their results are viewed in the light of the present study, where more extensive penetration of the meat by marinade was achieved, it is clear that the beneficial effect observed by Wenham and Locker (1976) was perhaps due more to the general swelling characteristics of beef M. sternomandibularis, rather than the susceptibility of its collagen to breakdown during cooking, particularly since the present study has clearly shown that marinaded M. longissimus lumborum, with an acetic acid content of more than 14 percent and a pH value of 3.15, remains structurally intact after cooking.

Since a substantial proportion of nitrogen was lost from the meat discs during marinading, it would seem that the traditional culinary technique may result in the loss of nutrients and flavour components from the meat by leaching. Nevertheless, in view of the promising results achieved in tenderizing M. longissimus lumborum, marinading of beef may prove attractive to commercial meat processors in the future, particularly if modern technology is adapted to overcome the problems created by the slow diffusion of weak acetic acid solutions into the meat.

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