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Effect of microwave cooking on roasts heated to three different internal temperatures with three different microwave power levels

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세가지의 출력이 다른 전자파를 이용하여 고기의 내부온도를 다르게 조리시 고기에 미치는 물리 화학적인 변화

조 경 희

요 약

본 실험은 1.5 Kg 무게의 고기를 3가지 다른 내부온도(60℃-rare, 70℃-medium, 80℃-well done)에 이르도록 3가지 다른 출력의 전자파(40%, 60%, 100%)로 조리시에 나타나는 고기의 조리조건(조리시간, 대기시간 및 대기시 상승온도)과 고기의 물리 화학적인 변화(수분, 단백질, 지방, vit B_1의 함량, 콜라겐의 용해도, 보수력, texture)를 관찰하였다. 각 처리구 간에 Kg당 조리시간은 유의적인 차이를 나타내었으나 대기시간은 유의적인 차이를 나타내지 않았다. 그러나 고기의 내부온도가 낮은 처리구일수록 긴 대기시간이 요구되었다. 대기시 상승온도도 각 처리구 간에 유의적인 차이를 나타내지 않았으나 거의 모든 처리구에서 10도 이상의 상승온도가 관찰되었다. 고기의 내부온도가 상승할수록 조리시 중량손실도 증가되었고, 수분함량, 수분: 단백질의 비, 보수력, 비타민 B_1의 함량도 감소되었다. Texture를 측정한 항목들에서는 각 처리구간의 유의적인 차이를 나타내지 않았다. 콜라겐의 용해도는 각 처리구간에 유의적인 차이를 나타내지 않았으나 내부온도 60℃와 70℃ 처리구 사이의 용해도는 뚜렷한 증가가 관찰되었다.

I. Introduction

There are many studies (Korschgen *et al.*[1]; Voris and Van Duyne[2]; Zayas and Naewbanij[3]) showing differences in characteristics of roasts between two different cooking methods, microwave and conventional heating. However, there is no information regarding the characteristics of roasts cooked to different internal temperatures with microwave heating. The purpose of this study was to observe the characterisitics of beef roasts cooked to three different internal temperatures (60℃ rare, 70℃-medium, 80℃-well done) with three different) microwave power levels (40%, 60%, 100%).

II. Materials and Methods

1. Preparation of meat cuts

Fifteen whole semimbranosus (SM) beef muscles were purchased from Meat Science Laboratory, University of Illionis, Urbana. All muscles were obtained from USDA Choice Grade carcasses. Each muscle was cut into 2 pieces weighing about 2 kg, was vacuum packed in plastic bags and was frozen in a freezer at −20℃ until needed for experiments. All frozen roasts were thawed in a refrigerator at 4℃ for 3 days until an internal temperature of 4℃ was reached before cooking. After thawing, all visible fat and almost all epimysium was removed. And the muscles were trimmed to approximately the same size and rectangular shape (17×9×10 cm) and weight of 1.5 kg.

2. Microwave oven

The microwave oven which was used in this experiment was Amana Radarange Model RS 458P with nominal power of 700 Watts. The size of interior of the oven was 3.6×10^4 cm^3, 39.4 cm(deep)×34.3 cm(wide)×26.7 cm(high).

3. Cooking method

Each roast was placed in glass roasting pan (33×23×5 cm) and cooked uncovered, using three different power levels (40%, 60% and 100%) in the microwave oven until it reached an internal temperature of 60, 70 and 80℃, including post processing temperature rise (PPTR). Each roast was turned over in the middle of the cooking time. The roast was removed from the oven at a lower temperature, which was determined during preliminary tests, to reach the desired final internal temperature. Internal temperature was measured by a Dickson Temprobe 500 when the roast was removed from the oven.

4. Sample preparation for chemical and physical analysis

Procesure of sample preparation is described in detail on previous study[4].

5. Measurements of cooking time, standing time and post-processing temperature rise, cooking losses.

Procedures of all these measurements are described in detail on previous study[4].

6. Determinations of chemical characteristics (moisture, fat, protein, thiamin and percent solubilized collagen) and physical characteristics (water holding capacity and texture).

Procesures of all these determinations are described in detail on previous study[4].

7. Statistical analysis

Data were subjected to analysis of varience using Statview 512+(Brainpower, Inc., Calabases, CA) on the Macintosh computer. Two-way ANOVAs did not indicate any significant difference ($p<0.05$) due to interaction of power level and internal temperature. Significant differences ($p<0.05$) shown in the tables are based on one-way ANOVAs, which were calculated when two-way ANOVAs showed significant treatment effects but no interaction. Fishers PLSD was used for mean separation.

III. Results and Discussion

1. Cooking time, standing time and PPTR

Table 1 shows final internal temperature, cooking time, standing time and PPTR of roasts. Final internal temperatures of roasts were the highest internal temperatures measured after removing roasts from the microwave oven and allowing them to reach maximum temperature. Most roasts reached the desired temperatures. However, the roasts of internal temperature of 80℃, cooked with 40% microwave power, had lower final internal temperatures than expected.

Cooking time was calculated as min per kg without including standing time. There were significant differences in cooking times temperatures. The lower the

Table 1. Final internal temperature, cooking time, standing time and PPTR of roasts cooked to three different internal temperatures with three different microwave power levels

Characteristics		Internal temperature			
		60℃	70℃	80℃	SF
Final	40%	59.11± 1.89a	69.16± 0.28b	76.67± 0.67Ac	*
Internal	60%	58.74± 2.16a	68.04± 0.28b	81.50± 1.61Bc	*
Temp(℃)	100%	58.22± 0.97a	70.56± 1.41b	80.20± 0.10Bc	*
	SF	ns	ns	*	
Cooking	40%	30.66± 1.61aA	44.16± 2.64bA	45.02± 0.33bA	*
Time	60%	24.77± 1.47aB	29.99± 1.13abB	36.88± 2.24bB	*
(min/kg)	100%	15.79± 1.21aC	23.94± 0.77bC	24.62± 0.95bC	*
	SF	*	*	*	
Standing	40%	17.37± 1.25	17.00± 5.00	17.25± 1.23	ns
time	60%	23.00± 1.16a	17.50± 2.50ab	14.25± 2.38b	*
(min)	100%	23.17± 2.17	16.00± 2.52	19.72± 2.96	ns
	SF	ns	ns	ns	
PPTR*	40%	12.45± 1.45	9.02± 1.06A	7.36± 1.79A	ns
(℃)	60%	14.22± 1.31a	12.60± 0.28ABab	10.09± 0.58Ab	*
	100%	14.52± 0.67	15.87± 1.31B	18.34± 2.78B	ns
	SF	ns	*	*	

SF: Significant difference of F value, *: significant at 0.05 level, ns: not significant.
Small letters show significant differences by different internal temperatures.
Capital letters show significant differences by different microwave power levels.
*PPTR: post processing temperature rise

internal temperature of roast, the shorter the cooking time. The lower the microwave power level of cooking, the longer the cooking time.

Standing time is the time between removal of the food from the oven until it finishes cooking. In preliminary tests, the standing time to reach the desired temperatures (60, 70 and 80℃) was estimated at 14 to 23 min with a average of 18 min. Power level did not significantly affect the standing time, nor did the internal temperature. The standing time of roasts that were cooked to an internal temperature of 60℃ with 60% and 100% microwave power level was a little longer than that of other treatments. The short time needed for cooking to low internal temperatures might result in longer standing times being needed to distribute heat to all areas of the roasts. The published reports showed a wide range of standing time of roasts. Kylen *et al.*[5] showed 20 min of standing time for roasts weighing 1.5 kg to reach an internal temperature of 74.4℃. Korschgen *et al.*[1] showed 40± 11 min of standing time of roasts of 1 kg cooked with 1054 watts of microwave power and 28± 4 min of standing time of roasts of 1 kg cooked with 492 watts of microwave power to an internal temperature of 70℃.

There were some significant differences in PPTR among different microwave power levels at internal temperature of 70℃ and 80℃. A greater increment of PPTR was seen as microwave power level was increased. Sawyer[6] analyzed the duration and extent of PPTR of some products and observed that the quantity and location of PPTR was not consistent within and among batches of the same product and PPTR was product dependent. The literature shows a wide range of PPTR (Kylen *et al.*[5]; Korschgen and Baldwin[7]; Starrak[8]). The results of this study, as well as earlier reports, suggest that the PPTR in roasts can be substantial (up to 20℃ in a 20 min time period). The quality of the final product, therefore, could be affected. Thus, it is essential to monitor meat temperature with a thermometer or probe to produce consistently cooked roasts. Cooking times per kg can only be used as guidelines to approximate amount of time needed.

2. Cooking losses

Table 2 shows total losses, drip losses and evaporation losses of roasts. There were significant differences in total losses of roasts cooked to three different internal temperatures at all microwave power levels. Total losses were increased as internal temperature increased. Most reports compared conventional and micro-

Table 2. Total losses, drip losses, evaporation losses of roasts cooked to three different internal temperatures with three different microwave power levels

Characteristics		Internal temperature			
		60℃	70℃	80℃	SF
Total losses(%)	40%	22.62± 2.38a	33.21± 2.08b	37.56± 1.18b	*
	60%	26.08± 2.40a	33.39± 3.19ab	38.96± 0.03b	*
	100%	28.98± 1.60a	34.06± 1.61ab	39.90± 0.62b	*
	SF	ns	ns	ns	
Drip losses(%)	40%	6.89± 0.93	10.21± 2.09A	10.54± 1.05	ns
	60%	7.41± 0.66	8.59± 0.24AB	7.19± 1.57	ns
	100%	8.59± 0.19a	5.77± 0.54bB	7.24± 1.27ab	*
	SF	ns	*	ns	
Evaporation losses(%)	40%	15.73± 1.54a	22.99± 1.00bA	27.01± 0.79cA	*
	60%	18.67± 1.75a	24.82± 3.28ab	31.77± 1.55bB	*
	100%	20.39± 1.79a	28.29± 1.93bB	32.66± 1.89bB	*
	SF	ns	*	*	
Evaporation ratio*	40%	0.70± 0.02	0.68± 0.10A	0.72± 0.02	ns
	60%	0.72± 0.004a	0.71± 0.02ABab	0.82± 0.04b	*
	100%	0.70± 0.02a	0.83± 0.02Bb	0.82± 0.04b	*
	SF	ns	*	*	

SF: Significant difference of F value, *: significant at 0.05 level, ns: not significant.
Small letters show significant differences by different internal temperatures.
Capital letters show significant differences by different microwave power levels.
*Evaporation ratio: Evaporation losses/Total losses

wave heating methods when meat was cooked to temperature of over 70℃, and showed no differences in these parameters between the two heating methods (Korschgen and Baldwin[7]; Voris and Van Duyne[2]; Payton and Baldwin[9]). However, when Starrak[8] compared the cooking loss of roasts cooked to an internal temperature of 62~65℃ by microwave and conventional methods, there was a significant difference. There are no reports about the comparison of characteristics of microwave cooked roasts of different internal temperatures. Sanderson and Vail[10] reported that total cooking losses were increased when three different beef muscles were cooked to constant internal temperature of 60, 70 and 80℃. Lawrie[11] cited their paper in his book and showed that only part of the increment of cooking losses was due to loss of moisture. This trend is also shown in this study.

Table 3 shows a comparison of Sanderson and Vail[10] study and current study with respect to moisture content, cooking loss and moisture loss of bovine SM muscle cooked to three different internal temperatures. Moisture loss in this table is calculated as the difference between moisture content of raw meat and that of meat cooked with 100% microwave power. If these two studies are used to compare the difference between conventional and microwave heating, it appears that there are differences in cooking loss, moisture loss and moisture content between the two different heating methods at internal temperature of 60℃; however, ther are no differences in these parameters between two different heating at internal temperatures of 70 and 80℃. Therefore, the internal temperature may be a factor to consider when comparing heating methods.

The three different microwave power levels had no effect on total losses at each internal temperature. Although the total losses of roasts cooked to an internal temperature of 60℃ with three different power levels were not significantly different, they tended to increase as microwave power level increased. This trend was also seen in Starrak's report[8], which compared three different microwave power levels in roasting beef top round roasts cooked to an internal temperature of 62~65℃. However, when cooked to an internal temperature of over 70℃ (Korschgen *et al.*[1]; Drew *et al.*[12]), no difference in total losses were observed This phenomenon was also found in the present study. This result might suggest that there is a great change in muscle components between 60 and 70℃ and muscle components could be affected by heating rates and cooking methods.

It is known that meat cooked quickly to a given internal temperature had a lower cooking loss and was more juicy than that cooked slowly to the same temperature because coagulation of the proteins on the surface of meats during roasting inhibited loss of fluid (Andross[13]; Bramblett and Vail[14]). This was not observed in the microwave cooked meat, probably due to the lack of surface browning and different heating patterns in microwave oven as compared to the conventional oven.

Drip losses of roasts showed inconsistent differences among different microwave power levels and different internal temperatures. However, there was a significant difference in evaporation losses among different microwave power levels and different internal temperatures. Evaporation losses were increased as internal temperature of roasts was increased and microwave power level was increased. Bacause total losses depend on the drip losses and evaporation losses, there is a shift

Table 3. Effects of different internal temperature on cooking loss, moisture loss, moisture content of roast cooked with microwaves and conventional heating methods

Cooking Method	Characteristics	Internal temperature(℃)		
		60	70	80
Conventional heating by Sanderson & Vail[10]	Cooking loss(% WB)	10.9	33.7	42.8
	Moisture loss*(% WB)	5.6	9.6	14.0
	Moisture content	68.8	62.2	60.0
Microwave** heating by Current study	Cooking loss(% WB)	29.0	34.1	39.9
	Moisture loss(% WB)	10.6	11.7	16.3
	Moisture content	63.4	62.3	57.7

*: Moisture content of raw muscle-moisture content of cooked roasts
**: Full power

in the kinds of losses and evaporation losses, there is a shift in the kinds of losses that occur at higher internal temperature and power level. Longer cooking time and higher microwave power resulted in greater evaporation from both meat and drippings. the ratio of evaporation losses to total losses of roasts might be another way to compare the drip losses and evaporation losses of roasts. From Table 2, it can be seen that there was no difference in the ratio of evaporation losses to total losses of roasts cooked to an internal temperature of 60℃ among three different microwave power levels. However, the evaporation ratio was increased as microwave power level was increased for the roasts cooked to internal temperatures of 70℃ and 80℃. At 40% microwave power levels, there was no significant difference in the evaporation ratio of roasts cooked to three different internal temperatures.

3. Moisture, fat and protein contents

Table 4 shows the moisture, fat and protein content of roasts cooked to three different internal temperatures with three different microwave power levels. For the moisture content, there was no significant difference among three different power levels at all internal temperatures. However, moisture content in roasts cooked to internal temperature of 60 and 70℃ was significantly higher than in roasts cooked to an internal temperature of 80℃. Kylen[15] found significant differences between moisture content of microwave cooked beef rib roast heated to an internal temperature of 76℃ and conventionally cooked roasts heated to an internal temperature of 64℃; those moisture contents were 49% and 58% respectively. When Baldwin *et al.*[16] compared moisture content of beef cooked by three different cooking methods, high and low microwave

Table 4. Moisture, fat and protein content of roasts cooked to three different internal temperatures with three different microwave power levels

Characteristics		Internal temperature			
		60℃	70℃	80℃	SF
Moisture	40%	64.94± 1.40a	62.83± 0.47a	58.42± 0.68b	*
content	60%	62.60± 0.93a	62.84± 0.78a	57.99± 0.60b	*
(%)	100%	63.52± 0.69	62.34± 1.99	57.71± 1.86	ns
	SF	ns	ns	ns	
Fat[c]	40%	4.24± 0.57	5.43± 0.55	6.94± 1.07	ns
content	60%	5.88± 0.83	3.49± 0.92	6.03± 0.43	ns
(%)	100%	4.37± 0.70	5.88± 0.75	5.60± 1.15	ns
	SF	ns	ns	ns	
Fat[d]	40%	12.01± 1.10	14.57± 1.38	16.61± 3.91	ns
content	60%	15.70± 2.15	9.38± 2.45	14.31± 1.57	ns
(%)	100%	11.91± 1.72	15.47± 1.48	13.05± 4.15	ns
	SF	ns	ns	ns	
Protein[c]	40%	28.41± 1.36a	32.30± 1.05ab	34.49± 1.42ab	*
Content	60%	29.69± 1.34	33.86± 3.46	35.43± 0.83	ns
(%)	100%	31.69± 0.21a	33.27± 1.25ab	35.83± 0.75b	*
	SF	ns	ns	ns	
Protein[e]	40%	81.01± 1.74AB	86.92± 2.87	83.02± 4.14	ns
Content	60%	79.33± 2.26A	89.28± 6.89	84.35± 1.91	ns
(%)	100%	86.94± 2.19B	88.69± 4.83	84.81± 1.96	ns
	SF	*	ns	ns	
Moisture:	40%	2.30± 0.16a	1.95± 0.06ab	1.70± 0.07b	*
Protein	60%	2.12± 0.12a	1.90± 1.20ab	1.64± 0.05b	*
ratio	100%	2.01± 0.01a	1.88± 0.11ab	1.61± 0.09b	*
	SF	ns	ns	ns	

SF: Significant difference of F value, *: significant at 0.05 level, ns: not significant.
Small letters show significant differences by different internal temperatures.
Capital letters show significant differences by different microwave power levels.
c: wet basis, d: moisture free basis. e: moisture and fat free basis.

power and conventional cooking methods, there were significant differences among methods. The percent moisture of high power microwave (1054 watts) cooked roasts and lower power microwave (492 watts) cooked roasts was 52.9 and 53.5% respectively and conventionally cooked roasts of internal temperature of 70℃ was 59.5%. Korschgen and Baldwin[7] reported the moisture content of roasts cooked with microwave and conventional moist heat methods to an internal temperature of 98℃, which were 55.8% and 57.2% respectively and showed no significant difference. Voris and Van Duyne[2] also showed that the moisture contents of the cooked roasts to an internal temperature of 68.3 ℃ with microwave and conventional methods were not significantly different. The mean moisture contents of the roasts were 60.4% and 59.7%. Payton and Baldwin[9] showed no difference in moisture content among three different cooking methods, microwave-convection, forced-air convention and conventional methods. The moisture content of roasts cooked to an internal temperature of 70℃ with three cooking methods were 59 %, 60% and 60% respectively. It seems that the moisture content is not affected by the cooking appliances (e.g., microwave vs. conventional), but it is likely to be influenced by the cooking methods (e.g., roasting and braising).

From the Table 3, it is interesting to observe the changes in cooking loss, moisture loss and moisture content at different internal temperature. It is believed that the increment of cooking loss between 70 and 80℃ is mainly due to moisture loss. However, materials other than moisture were probably solubilized at 60 and 70℃ and contributed to increased cooking losses. In this temperature range, microwave heating might have solubilized more muscle components than conventional heating.

There were no differences in fat content among three different internal temperatures and three different microwave power levels. This result is in consistent with other results (Kylen *et al.*[5]; Baldwin *et al.*[16]; Korschgen and Baldwin[7]; Voris and Van Duyne[2]; Payton and Baldwin[9]).

There was no difference in protein content on the wet basis among the roasts cooked with three different power levels. However, protein content of roasts cooked to three different internal temperatures were significantly different. Baldwin *et al.*[16] found a significant difference in protein content of microwave cooked roasts and conventionally cooked roasts. In contrast, Korschgen and Baldwin[7] did not find any difference in protein contents of roasts cooked with two different cooking methods. Protein content is inversely related to moisture content. The lower the moisture content of the roasts, the higher the protein content. In the present study, protein content was also calculated on moisture free basis and the ratio of moisture to protein content. When protein content was compared with moisture free basis, there is no significant difference in protein content among treatments. However, there is a significant difference is moisture to protein ratio among different internal temperatures. The ratio of moisture to protein tends to decrease as internal temperature is increased.

4. Water holding capacity (WHC)

Table 5 shows WHC of roasts cooked to three different internal temperatures with three different microwave power levels. There was a significant difference in WHC of roasts cooked to an internal temperature of 60℃ among three different microwave power levels. As microwave power level was increased, the WHC was decreased. This trend is also seen in total losses of roasts cooked to an internal temperature of 60℃. However, at internal temperature of 70 and 80℃, the WHC of roasts cooked with three different power levels did not differ. For the roasts cooked to three different internal temperature, there were significant differences in WHC of roast cooked with different microwave power levels except at the 100% microwave power level. The trend is consistent with the findings of Sanderson and Vail[10] and Laakkonen *et al.*[17]. The higher cooking loss and lower WHC of roasts cooked to an internal temperature of 60℃ with full power than at lower microwave power levels is thought to be due to rapid coagulation and disruption of protein and protein network, resulting in the exudation of free water from the muscle. This is not observed at higher internal temperatures because the surface denaturation prevents moisture loss.

5. Thiamin contents and thiamin retention

Table 5 shows thiamin content and retention of roasts cooked to three different internal temperatures with three different microwave power levels. There were no significant differences in thiamin content and retention of roasts cooked with three different microwave power levels to each internal temperature. However, there were significant difference in thiamin content and retention among roasts cooked to internal temperatures of 60, 70 and 80℃ at every microwave

Table 5. WHC and Thiamin content and retention of roasts cooked to three different internal temperatures with three different microwave power levels

Characteristics		Internal temperature 60℃	70℃	80℃	SF
WHC*	40%	0.791± 0.008aA	0.764± 0.003ab	0.739± 0.016b	*
	60%	0.775± 0.009aAB	0.752± 0.009ab	0.740± 0.008b	*
	100%	0.755± 0.008B	0.752± 0.008	0.736± 0.023	ns
	SF	*	ns	ns	
Thiamin^d (mg/100 g)	40%	0.116± 0.007	0.129± 0.006	0.102± 0.003	ns
	60%	0.109± 0.005	0.131± 0.001	0.088± 0.001	ns
	100%	0.117± 0.008	0.122± 0.003	0.093± 0.001	ns
	SF	ns	ns	ns	
Thiamin^e (mg/100 g)	40%	0.375± 0.026a	0.405± 0.020a	0.248± 0.015b	*
	60%	0.330± 0.039a	0.391± 0.003a	0.242± 0.004b	*
	100%	0.362± 0.023a	0.386± 0.020a	0.252± 0.003b	*
	SF	ns	ns	ns	
Thiamin Retention (%)	40%	66.96± 4.60a	64.48± 2.87a	44.19± 2.58b	*
	60%	65.81± 2.06a	60.45± 4.93a	43.21± 0.68b	*
	100%	64.76± 4.10a	66.34± 1.43a	45.09± 0.45b	*
	SF	ns	ns	ns	

SF: Significant difference of F value, *: significant at 0.05 level, ns: not significant.
d: wet basis. e: moisture and fat free basis.
Small letters show significant differences by different internal temperatures.
Capital letters show significant differences by different microwave power levels.
*WHC: Water Holding Capacity

power level. Thomas *et al.*[18] reported the thiamin retention of roats weighing 1.35 kg to 1.80 kg, cooked to an internal temperature of 74℃ by using microwave oven and electric oven. The thiamin retentions of roasts cooked with electronic range and electric range were 63% and 75% respectively. Dawson *et al.*[19] investigated the thiamin retentions of thin cut (3.8 cm thick) of top round beef muscle, which was roasted at 177℃, and thick cut (7.6 cm thick) of top round beef muscle, which was roasted at 149℃. Both roasts were cooked to an internal temperature of 80℃. The thiamin retention of thin cut was 66% and that of thick cut was 72%. They also compared the thiamin retentions of meat cooked by two cooking methods, oven braised and pressure braised, which were cooked to an internal temperature of 100℃. The thiamin retention of oven braised muscle was 31% and that of pressure braised muscle was 28%. Kylen *et al.*[15] compared the thiamin retention of roasts cooked by using electronic range with those of roasts cooked by using gas oven. The thiamin retention of roasts cooked to an internal temperature of 76℃ by microwave oven was 58% and that of roasts cooked to an internal temperature of 64℃ by gas oven was 80%. Baldwin *et al.*[16] compared three different cooking methods in thiamin retention of meat, microwave oven operated with 1054 watts, microwave oven operated with 492 watts and conventional oven at 163℃. Thiamin retention of 1.2 kg longissimus muscles cooked to an internal temperature of 70℃ with the three cooking methods were 61%, 49% and 69% respectively. The thiamin retention of muscles cooked with low power microwave oven was significantly lower. Korschgen and Baldwin[1] showed significant difference in thiamin retention of roasts cooked by moist-heat microwave and by conventional oven to an internal temperature of 98℃, which were 25% and 19% respectively.

The trend of thiamin retention of meat was lower as temperature was increased. Baldwin *et al.*[16] significant differences in thiamin retentions between higher power microwave and lower power microwave. However, present study does not show any difference in thiamin retention of three different microwave power levels. Several reports mention that the vitamin losses between microwave and conventional methods are comparable (Voris and Van Duyne[2]; Gerster[20]). According to the studies of thiamin retention, it is more likely to depend on internal temperature of roast than

Table 6. Shear and compression measurement of roasts cooked to three different internal temperatures with three different microwave power levels

Characteristics		Internal temperature 60℃	70℃	80℃	SF
Shear Cohesiveness (Kg)	40%	9.25± 0.14	9.94± 1.29	8.20± 1.55	ns
	60%	8.49± 1.33	10.74± 1.42	9.59± 0.15	ns
	100%	11.50± 1.24	8.11± 0.78	9.56± 1.24	ns
	SF	ns	ns	ns	
Shear Firmness (Kg/min)	40%	74.20± 4.90	84.04± 6.39	70.62± 13.9	ns
	60%	71.77± 11.75	101.07± 13.45	89.01± 6.80	ns
	100%	82.05± 4.20	68.89± 9.55	99.45± 10.78	ns
	SF	ns	ns	ns	
Compression Hardness (Kg)	40%	25.25± 3.30	37.67± 3.97	36.23± 3.73	ns
	60%	30.55± 0.85	36.23± 3.28	35.63± 2.97	ns
	100%	29.83± 1.99	30.79± 3.09	34.72± 4.78	ns
	SF	ns	ns	ns	
Compression Springiness (min)	40%	0.023± 0.001aA	0.029± 0.002ab	0.032± 0.004b	*
	60%	0.028± 0.001B	0.033± 0.005	0.037± 0.002	ns
	100%	0.026± 0.001aAB	0.036± 0.001b	0.041± 0.001c	*
	SF	*	ns	ns	
Compression Cohesiveness	40%	0.33± 0.04	0.34± 0.02	0.31± 0.01	ns
	60%	0.31± 0.01	0.33± 0.03	0.36± 0.01	ns
	100%	0.32± 0.05	0.37± 0.07	0 37± 0.06	ns
	SF	ns	ns	ns	

SF: Significant difference of F value, *: significant at 0.05 level, ns: not significant.
Small letters show significant differences by different internal temperatures.
Capital letters show significant differences by different microwave power levels.

cooking methods.

6. Shear and compression measurement

Table 6 shows the results of shear cohesiveness, shear firmness, compression hardness, compression springiness and compression cohesiveness of roasts cooked to three different internal temperatures with three different microwave power levels. Except compression cohesiveness, the results did not show any significant difference in the parameters for most treatments.

Sanderson and Vail[10] showed no difference in shear force of LD cooked to internal temperature of 60, 70 or 80℃. However, there was a decreasing trend in the shear force of semitendinosus (ST) and semimembranosus (SM) as internal temperature of meat was increased. They believed that the different reactions of the muscles to cooking was caused by varying connective tissue content. If the reports showing that microwave heating results in more collagen solublization (McCrae and Paul[21]; Zayas and Naewbanij[3]) are correct, then the lack of difference in shear values of roasts of three different internal temperatures in the current study might be attributed to equivalent collagen solublization in microwave heated roasts at all internal temperatures to give comparable shear values even at low internal temperature. Collagen solubility is not significantly different at the three internal temperatures, although there is a trend toward increasing collagen solublization as an internal temperature increases. Davey and Gilbert[22] observed two separated phases of toughening during increasing internal temperature. The first phase, occurring between 40~50℃, was due to the denaturation of the contractile proteins and the second phase, occurring between 65~75℃, was due to fiber shrinkage as collagen denatured. The toughness of muscle diminished above 75℃ as collagen breakdown occurred. Therefore, it showed that collagen solubilization plays some part in tenderness of meat.

Brady and Penfield[23] investigated the textural characteristics of beef semitendinosus cooked conventionally to two different internal temperature (60 and 70℃) with two different heating rates (slow and fast). They

Table 7. Percent solubilized collagen of roasts cooked to three different internal temperatures with three different microwave power levels

Characteristics	Internal temperature			
	60℃	70℃	80℃	SF
40%	20.72± 1.96	27.12± 3.59	25.07± 1.06	ns
60%	20.44± 3.73	24.59± 1.88	27.41± 2.70	ns
100%	20.45± 2.36a	26.85± 0.89b	25.94± 0.16ab	*
SF	ns	ns	ns	

SF: Significant difference of F value, *: significant at 0.05 level, ns: not significant.
Small letters show significant differences by different internal temperatures.

showed no differences in penetration hardness, cohesiveness, and chewiness and shear cohesiveness and firmness of muscles in all treatments. The reports comparing two different heating rates by the microwave power levels did not show any significant difference in shear values (Korschgen *et al.*[1]: Drew *et al.*[12]). This current study shows this trend that there is no significant difference in Instron measured tenderness of roasts cooked with three different microwave power levels to each internal temperature. There are no other reports comparing shear values of meat cooked to different internal temperatures by the microwave heating.

7. Percent solubilized collagen

Table 7 shows percentage of collagen solubility of roasts cooked to three different internal temperatures with three different microwave power levels. The collagen content of raw SM muscle was 10.8 mg/g on wet basis, 44.88 mg/g as dry, fat free basis and 4.5% of total protein. It is well known that different muscles and different ages of muscle differ in collagen content (Goll *et al.*[24]; Bendall[25]; Cross *et al.*[26]; Dransfield[27]). Dransfield[27] showed that the total collagen content of meat from 18 month old steers ranged from 2.2% in psoas major (PM) to 5.6% in complexus muscle, SM muscle had 4.09% of collagen content on a dry, fat free basis. The collagen content of raw SM muscle of this study, which is 4.49% as a dry, fat free basis, is similar. When Bendall[25] estimated the collagen content of different muscle of 18 to 24 months old steers, the collagen content of SM muscle was 2.9% collagen as % dry weight.

There are no differences in solubilized collagen contents of roasts which were cooked with three different microwave power levels at each internal temperature of roast. McCrae and Paul[21] investigated the effect of rate of heating on solubilization of collagen of beef muscles. They showed that microwave heat treatment solubilized more collagen from the muscles than did different conventional heat treatments which had lower heating rates. Zayas and Naewbanij[3] compared conventional heat and microwave heat cooking method in solubilization of collagen of meat. They found microwave energy solubilized more collagen than did conventional heat energy. However, it seems that the different heating rates caused by different microwave power levels did not affect collagen solubilization of roasts in present study. The heating rate of lower microwave power heating is still higher than that of conventional heating.

The solubilized collagen contents increased with increasing internal temperature of roasts at three different power levels. The percentages of solubilized collagen of roasts of internal temperatures of 70℃ and 80℃ were similar. However, the differences in percentages of solubilized collagen of roasts of three different internal temperatures were not significant, even though the percentages of solubilized collagen of roast of internal temperature of 60℃ at full microwave power level was lower than those of roast of internal temperature of 70℃ at the same power level. Zayas and Naewbanij[3] showed that percentages of solubilized collagen of four different internal temperatures (65, 80, 85 and 95℃) ranged from 27 to 31%. Paul *et al.*[28]) made four different internal temperatures comparisons in collagen solubility (58, 67, 75 and 82℃) and ranges of percentages of solubilized collagen of four different internal temperature were 4.25 to 11.03%. Cross *et al.*[26] showed heat soluble collagen of SM muscle was 4.31% when sample was held at 77℃ for 70 min. Dransfield[27] reported 13.7 % of heat soluble collagen of SM muscle when sample was held at 90℃ for three hours. Jeremiah and Martin [29] showed 13.89 to 17.97% heat soluble collagen at 70℃ for 70 min with LD muscle. Burson and Hunt[30] reported that heat soluble collagen at 70℃ for 70 min of LD muscle was 10.2± 1.4% and that at 90℃ for 140 min was 34.7± 1.4%.

Table 8. Correlation of collagen solubility and Instron measurement of roast cooked to three different internal temperatures with three different microwave power levels

℃	power	SC	SF	CH	CS	CC
60	40%	0.962	0.841	−0.656	0.221	0.999
	60%	−0.818	−0.114	−0.998	−0.962	−0.800
	100%	−0.326	0.878	0.402	−0.569	0.311
70	40%	−0.401	−0.165	0.594	0.483	0.646
	60%	−0.054	−0.074	0.127	0.379	0.379
	100%	−0.406	−0.352	−0.033	−0.567	−0.751
80	40%	0.868	0.838	0.805	0.597	−0.703
	60%	−0.730	−0.770	0.794	0.996	−0.026
	100%	−0.858	0.295	−0.042	−0.066	0.992

SC: Shear cohesiveness. SF: Shear firmness. CH: Compression hardness.
CS: Compression springiness. CC: Compression cohesiveness.

The degree of collagen solubility in several studies varies even in the same temperature treatment. Heat soluble collagen can be calculated from soluble fraction of sample by dividing by the amounts of heat soluble plus insoluble collagen. However, the calculation of solubilized collagen is not specified clearly in some reports.

To compare collagen solubility with other studies, guides in collagen solubility calculation are needed. When the collagen content of raw and cooked samples on wet basis were compared, collagen content of cooked samples on wet basis were compared, collagen content of cooked samples was higher than raw sample, because of moisture loss. When the collagen contents of raw and cooked samples on a moisture-and fat-free basis or as collagen N over total N, collagen content of cooked samples might be higher or lower than that of raw muscles. The comparison of collagen contents of raw and cooked muscles is meaningless with respect to solubilized collagen. Alternatively, the sum of collagen contents of drippings and cooked meat can be used as a total collagen. The total collagen of residues of cooked meat can be used as an insolubilized part of collagen. In this method, analysis of drippings is needed and sometimes, it is diffcult to get exact amount of drippings. Therefore, in order to calculate the solubilized collagen content of muscles after cooking, it is suggested that the percentage of solubilized collagen be calculated from total amount of collagen in total residues of cooked muscle divided by total amount of collagen in total raw muscle. Table 8 shows correlations of percent solubilized collagen and Instron measurements, but these were not significant ($p>0.05$).

IV. Conclusion

1. The lower the internal temperature of roast and the higher the microwave power level of cooking, the shorter the cooking time. The standing time of roasts that were cooked to an internal temperature of 60℃ was a little longer than that of other treatments. It seems that the short time needed for cooking to low internal temperatures might result in longer standing times being needed to distribute heat to all areas of the roasts.

2. Total losses and evaporation losses were increased as internal temperature of roast increased from 60℃ to 70℃. There were significant differences in moisture and protein contents among roasts cooked to internal temperatures of 60, 70 and 80℃. As internal temperature of meat was increased, moisture content and water holding capacity of meat was decreased and protein content of meat was increased.

3. There were significant differences in thiamin content and retention among roasts cooked to internal temperatures of 60, 70 and 80℃ at every microwave power level. But there were no difference in thiamin retention among roasts cooked with three different microwave power levels. It shows that thiamin retention is more likely to depend on internal temperature of roast than cooking methods.

4. There were no significant differences in shear and compression measurement of roasts cooked to three different internal temperatures with three different microwave power levels.

5. It seems that the different heating rates caused by different microwave power levels did not affect collagen solubilization of roasts in this study. The solubi-

lized collagen contents increased with increasing internal temperature of roasts at three different power levels.

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