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Title: EFFECT OF DIETARY FIBER LEVEL ON THE PROXIMATE COMPOSITION AND WATER-HOLDING CAPACITY OF RABBIT MEAT

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The influence of alfalfa fiber level 28, 54 and 74% in diets on the proximate compositions, pH and water-holding capacity of raw and cooked rabbit meat were investigated.

Preslaughter live weight, percent dress weight and percent abdominal fat of rabbits fed 54% alfalfa fiber diet were significantly higher and total moisture content in raw rabbit meat was significantly less than those of rabbit groups fed 28 and 74% alfalfa fiber diets. The cooked meat from rabbit fed 54% alfalfa fiber diet had a lower protein content and total cooking losses as compared to the other two alfalfa fiber diets. From the results, the 54% was considered as the optimum alfalfa fiber level for rabbits to achieve optimum growth and to produce good quality meat.

Cooking the rabbit meat increased pH, total protein, total lipids, and total cholesterol. However, on a dry weight basis, the total cholesterol content decreased which was caused by heat degradation. Alfalfa fiber level and the sex factor interaction effect was observed on the total cholesterol content on dry weight

basis, and calcium on wet weight basis in raw meat.

On wet weight basis, rabbit meat from all three groups fed alfalfa fiber diets contained an average of 74% total moisture, 21.95% total protein, 13.234 mg/100g calcium, 393 mg/100g potassium, 3.57% total lipids, and 74.93 mg/100g total cholesterol. Compared with other edible meat such as beef and pork, rabbit meat is a good source of edible meat.

Effect of Dietary Fiber Level on the Proximate Composition and Water-Holding Capacity of Rabbit Meat

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TABLE OF CONTENTS

Table of Contents, continued

LIST OF FIGURES

LIST OF TABLES

List of Tables, continued

List of Tables, continued

List of Tables, continued

EFFECT OF DIETARY FIBER LEVEL ON THE PROXIMATE COMPOSITION AND THE WATER-HOLDING CAPACITY OF RABBIT MEAT

INTRODUCTION

As competition between humans and livestock for high quality grains and protein supplements increases, the production emphasis will be on those animals which are least competitive with man. The rabbit, being a nonruminant herbivore, efficiently uses sources of roughage which are less likely to compete with man. The world food supply, particularly that of the protein component, is presently precarious, and both acute and chronic regional shortages are anticipated if the world population continues to increase as predicted (Altschul and Hornstein, 1972). Because rabbits have a rapid rate of growth, a high feed efficiency, an early marketing age (56 days), a good carcass quality, and require a small land area, they can be profitably marketed commercially (Cheeke, 1980). This suggests that the rabbit has practical potential as a livestock species in large scale production and can be one of the sources in supplying protein toward solution of the world's protein needs.

In recent years, the commercial production of rabbit meat for human consumption is being conducted on an international scale. The Hungarians (Holdas and Petohazi, 1975; Holdas, 1978) have two large-scale commercial farms with over 10,000 does per farm. France is the world's largest producer (8-9 million breeding rabbits) and consumer of rabbit meat. In 1975 in France, production was nearly 300,000 metric tons (Balitrand, 1975). Due to the traditional meat

consumption patterns, per capita consumption of rabbit meat in the U.S. is relatively low when compared to other countries (Attifield, 1972). However, there are an estimated 100,000 rabbit producers, and about 13,200 metric tons of rabbit meat consumed annually in the U.S. (Dubbell, 1975).

It is the usual practice that the medium-weight and heavy breeds of rabbits are produced commercially to market the young when about 2 months old. These 8-week-old rabbits weigh about 4 to 5 pounds and are known as fryer rabbits, comprising more than 85% of the domestic rabbits marketed (Hiner, 1962). This project was developed to obtain definitive information on the composition of this type of meat, especially in relation to the recognized market grades. Information on the proximate compositions of rabbit meat is limited, in contrast to that available for other meats. A recent study (Rao et al., 1979) has indicated that some critical nutrients in rabbit meat compare very favorably to most other meat products. The low fat, low cholesterol and low sodium content of rabbit meat may be particular useful in treatment of atherosclerosis patients.

The incidence of atherosclerotic disease, with the clinical phenomena of hyperlipemia, hypertension and hypercholesterolemia, is high in the Western world. In 1970, for example, some 666,000 Americans, of whom about 171,000 were under the age of 65, died of coronary heart disease (AMA, 1972). Dietary lipids intake has been correlated with the high incidence of atherosclerosis. One effective method of decreasing the risk of coronary heart disease is a decrease in the dietary intake of total lipids, saturated fat, and

cholesterol, and an increase in the intake of polyunsaturated fat (Alfin-Slater, 1969). Animal food, such as beef, lamb and pork, is a good source of protein, both in quantity and quality, but it also contains abundant lipids, and moderate amounts of cholesterol (Watt and Merrill, 1963). Rabbit meat contains low fat, low cholesterol and low sodium. This suggests that rabbit meat is a good protein source for coronary heart patients and can be used in diets aimed at the prevention of atherosclerosis.

Concerning the reasons for the economical production of rabbits and rabbit meat as a healthy food source for humans, the effect of rabbit diets on the fat, cholesterol and other components in rabbit meat is of interest. For these reasons, research pursued here is to evaluate the proximate composition and the quality parameter of the raw and cooked thigh meat from rabbits fed 28, 54 and 74% levels of alfalfa meals. The proximate compositions includes total moisture, protein, lipids, cholesterol, calcium and potassium. The water-holding capacity was also determined by a press fluid method. This presents some indication of meat juiciness.

REVIEW OF LITERATURE

Implication of Rabbit Production

Rabbits grow rapidly and achieve early marketing age (56 days). Rabbits have a high reproductive capacity, and are capable of being produced on a large scale (Hiner, 1962). Furthermore, rabbits have an efficient feed efficiency of approximately 2-3.5 pounds feed per pound weight of gain (Cheeke, 1980). These characteristics in association with a good meat to bone ratio (MAFF, 1974) make rabbit production comparable to that of broiler chicken production (Rao et al., 1977; Reddy et al., 1977).

Protein utilization in forage

Rabbit, being herbivorous, can be used to convert forage into meat. A number of studies have compared the protein digestibility of whole plant corn pellets (Schurg, 1977) and alfalfa meal (Slade and Hintz, 1969) for nonruminant animals. Schurg (1977) reported that protein in corn pellets was 80.2% digestible for the rabbit, but only 53.0% for the horse. In another study it was shown that in the pig the digestibility of alfalfa meal protein was less than 50%, while in the rabbit it was about 75% (Slade and Hintz, 1969). When comparing the digestibility of alfalfa protein in the horse, pony

and rabbit the digestibility coefficients were 74.0, 76.2 and 73.7 percent, respectively. Thus, the rabbit has the ability to efficiently digest protein from those leafy forages as well as, if not better than, most monogastric animals.

Fiber utilization in forage

The plant cell is composed of polysaccharides, predominantly cellulose, hemicellulose, lignin and pectin, that are not digested by the endogenous animal secretions (Cumming, 1976). Other indigestible compounds are plant gums, mucilages and algal polysaccharides. These fibrous compounds contribute to the structural integrity of plants. Thus, the fiber fraction of feeds corresponds to the structural carbohydrates of plant materials. This fiber is often fractionated by various methods and may be called crude fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF). These classifications differ in digestibility.

In the past, the term crude fiber (CF) was often used to designate one type of fiber in the diet (Williams and Olmsted, 1935). In the Weende system, crude fiber consists of cellulose, hemicellulose and lignin (Maynard et al., 1979). This fiber has been determined by boiling the sample in dilute acid, then in dilute base (Maynard et al., 1979). However, only 50-90% of the cellulose, 20% of the hemicellulose and 10-40% of the lignin were recovered in the sequence of steps for crude fiber analysis (Van Soest and

McQueen, 1973).

In recent years, the methods of Goering and Van Soest (1975) are generally used to determine fiber in animal forages. They classify fibers as NDF and ADF. Their neutral detergent fiber (NDF) method measures undegraded plant cell wall constituents (CWC) which include cellulose, hemicellulose, lignin and silica. The CWC is another term for NDF. The NDF is determined after dried sample is refluxed with a solution of sodium lauryl sulfate at neutral pH 7. The neutral detergent fiber method produces the most complete estimate of total fiber in the diet. The acid detergent fiber (ADF) method determines the cellulose, lignin and silica when the dried sample was refluxed in acid detergent. The hemicellulose fraction is not determined with acid detergent fiber method.

Scott et al. (1976) reported that the two most prevalent hemicelluloses (xylan and polygluconic acid) can be partially broken down by hydrochloric acid and pepsin in the mammalian stomach. However, microbial enzymes are necessary to break cellulose down into digestible components. Most of the nonruminants lack enzymes necessary to digest cellulose, thus they cannot utilize the cellulose in fiber (Lehninger, 1975). However, Hall (1952) isolated a cellulolytic cocci from the rabbit hindgut. This would indicate fiber digesting bacteria exist in the cecum. Lignin and acid insoluble ash were observed by Hall (1952) to be essentially nondigestible for all animals. On the other hand, the digestibilities of these cell wall constituents of the plant by animals are quite different according to animal species, plant sources, particle size and physical form of diets. The

determination of NDF and ADF in diets is important since it provides information concerning the amount of the digestible fiber component-hemicellulose in diets. Furthermore, determining the digestibility of NDF and ADF by the animal can provide information in choosing the fiber source and in improving the nutritive value of fibrous feeds through processing techniques.

Although some microbial organisms in the rabbit may be capable of breaking down cellulose, the rabbit is not as efficient as ruminants or even other herbivores in the digestion and utilization of fiber. In studying crude fiber digestibility of alfalfa meal in different species, Slade and Hintz (1969) reported values of 18.1% digestibility for the crude fiber in the rabbit, whereas the horse, pony, and guinea pig had a 34.7, 38.1, and 38.2% crude fiber digestibility respectively. Cheeke (1979a) compared the digestibility of the fibrous components (ADF and CWC) in horses and rabbits, using whole corn plant pellets, as feedstuff. The digestibility of acid detergent fiber (ADF) containing cellulose, lignin and silica was 25.0% in rabbits and 47.5% in horses, while the cell wall constituents containing cellulose, lignin, silica as well as hemicellulose were 36.7% in rabbit and 68.9% in horses. Fonnesbeck et al.(1974) compared the digestibility of cellulose and hemicellulose in sheep, swine, chickens, rabbits, and rats. Rabbits had values of 16.1% digestibility of cellulose and 24.7% percent digestibility of hemicellulose. Rats had a digestibility value for cellulose and hemicellulose of 20.7 and 25.9%, respectively. He concluded that fiber digestibility in the rabbit was lower than in the other species.

Digestibility of crude fiber does vary according to plant source. Crude fiber digestibility by the rabbit has been reported to be 18.1% for alfalfa meal (Slade and Hintz, 1969) and 26.6% for barley (Cheeke, 1974). Cheeke (1979b) observed that the digestibility of fibrous ADF component by rabbit was 17.1% for alfalfa meal and 11.2% for comfrey meal while CWC was 35.8 and 18.0% for alfalfa and comfrey meal.

In tropical countries numerous forages can also be considered as potential alternates for alfalfa meal (Owen, 1976). Preliminary work by Eshiett et al. (1980) showed that 45% of cassava root meal can be incorporated in well balanced diets for rabbits without adversely affecting their performance. In 1980, Harris et al., also reported that several tropical forages (such as Spanish clover or butterfly pea) incorporated into a corn-soy diet at a level of 40% gave performance results equal to or exceeding gains attained with alfalfa meal.

Not only does the animal species and plant fiber source affect fiber digestibility, but the digestibility of fiber may also be influenced by reducing the particle size of the fiber through plant grinding or by altering the physical form of feed ingredients. Lebas and Laplace (1977) and Laplace and Lebas (1977) observed improved rabbit growth in ground diet with feeds of smaller particle size. The small particles appeared to be retained longer in the hindgut resulting in better dry matter digestibility. Observation of rabbits indicates that they may prefer a pelleted diet to one in meal form. Chapin (1965) compared the performance of growing rabbits on a commerical pelleted diet (0.48 X 0.63 cm) versus the

same diet in meal form. He found the growth rate and feed efficiency were significantly better with the pelleted diet. Similar findings also have been reported by Lebas and Laplace (1977) and King (1974).

The above studies indicate that rabbits efficiently digest protein in forages, but their ability to digest fiber is low. This may be an advantage in the utilization of roughage for rabbits. The utilization of forage during the production of animal meat has been reviewed by Hintz et al. (1978). They concluded that nonruminant herbivores may be superior the ruminants in the utilization of low quality high fiber roughages. In ruminants, intake of roughage is limited by the rate at which fiber is degraded in the rumen, thus they may be at a disadvantage in the digestion of roughage. In nonruminant herbivores, fibrous feeds have a rapid time of passage, during which nonfiber components are digested and absorbed. Alfalfa contains about 25% crude fiber, therefore it contains 75% nonfibrous constituents which are well utilized by the rabbit. However, the digestibility of roughage is affected by the level of fiber available, in all cases the highest level not necessarily having the most digestibility. Harris et al. (1981) fed levels of 20, 70, 74, 78, 82, 86 and 90% alfalfa to growing rabbits to determine the effect of high alfalfa pelleted diets on growth. Although average daily gains (ADG) were not significantly different among the treatments, ADG was numerically lowest with the 90% alfalfa diet. The results of this study suggest that the optimum alfalfa level for rabbit production is lower than 74%.

Fiber necessary for optimum growth and for preventing enteritis

The weight gain in the rabbit has been directly related to the percent of dry matter digestibility of the forage, rather than dry matter intake (Ingalls et al., 1965). Although crude fiber does not serve as an efficient energy source for rabbits, there is evidence that dietary fiber may have beneficial effects. Non-digestible fiber may be necessary for maintaining optimum growth and normal function of the digestive tract. This was shown by feeding rabbits various levels of alfalfa meal, which increased the rate of weight gain and diminished enteric problems (Cheeke, 1980). The reasons for the beneficial effect of alfalfa fiber has been proposed by Cheeke (1980) to maintain the health of the intestinal lining, preventing the invasion by organisms responsible for enteritis.

Numerous other studies have confirmed the beneficial effects of different levels of fiber on growth and enteritis incidence of weanling rabbits. Heckman and Mehner (1971) found that 8 to 9% crude fiber gave the best results for weight gain and feed efficiency in the growing rabbit. In another study, Cheeke and Patton (1978) fed growing rabbits a diet containing 0, 10, 20, 30 and 40% of sun-cured alfalfa. They reported that the best growth, 38.6 to 44.7 g per day, occurred with 20% alfalfa, containing 7.8% crude fiber. This daily weight gain was about 18-38% higher than the weight gain from any other percent alfalfa diets.

There is no agreement on the minimum level of fiber required in the rabbit diet to prevent enteritis. Davidson and Spreadbury

(1975) observed that in dietary fiber levels of less than 6% fiber, diarrhea occurred in the rabbits. Lebas (1975a,b) noted diarrhea even when the crude fiber level was lower than 12%. Heckman and Mehner (1971) also observed that the mortality rate was highest in a 5% crude fiber groups as opposed to 8% and 9% crude fiber groups. This agreed with work reported by Cheeke and Patton (1978) who found a high mortality rate in groups fed 0 or 10% alfalfa diet containing 2.7 and 5.2% crude fiber, respectively. Those fed 20, 30 and 40% had a lower mortality. In comparison of diet with 28, 54 and 74% alfalfa, Harris et al. (1981) observed again that the incidence of diarrhea was highest in the 28% alfalfa and the mortality was lower on the 54 and 74% alfalfa diets compared to the 28% diet. These findings indicate good prospects for rabbit production in terms of using minimum quantities of grain feeds, i.e. maximizing forage and minimizing grain feeding of rabbits.

The Chemical Constituent of the Edible Portion of Rabbit Meat

Rabbit meat appears to have an average moisture content of 63-73%, total protein 18-24%, total lipids 2-12%, total cholesterol 136 mg/100 g, calcium 12.9 mg/100 g, potassium 205.2 mg/100 g, and sodium 39.3 mg/100 g. A review of the literature has been recorded in Table 1. The chemical constituents of the edible portions of rabbits differs as a result of sex, age, breed, part of muscle and type of diet fed to rabbit.

Table 1. Comparison of the Proximate Composition of Some Edible Meat, on Wet Weight Basis.

	MEAT CHARACTERISTICS					CHEMICAL COMPOSITION OF MEAT						
Reference	Meat Type	Breed	Slaughter Age	Sex	Part of Muscle For Analysis	Total Moisture (%)	Total Protein (%)	Total Lipid (%)	Total Cholesterol (mg/100 g)	Ca (mg/100 g)	K (mg/100 g)	Na (mg/100 g)
Wilson and Morris, 1932	Rabbit Meat	White Angoras	Young (11 months)	Female	Edible flesh	67.32	20.28	5.78				
				Male	(muscle, fat,	69.67	21.12	1.73				
			Adult (24 months)	Female	kidney, liver,	62.98	19.95	9.12				
				Male	and heart)	66.93	21.92	3.30				
Rao et al., 1978		New Zealand White	8 weeks		Edible flesh	71.1	18.7	7.9				
			12 weeks		(muscle only)	70.8	18.6	10.1				
			16 weeks			69.2	19.4	10.9				
Zupka et al., 1978		New Zealand White	9-10 weeks (1.538 Kg slaughter weight)		Forequarter	72.68	20.03	7.18				
					Hindquarter	74.34	22.64	2.34				
			14-16 weeks (2.457 Kg slaughter weight)		Forequarter	69.49	18.85	9.54				
					Hindquarter	73.98	22.06	2.81				
McMillin, 1931		Chinchilla	10 weeks	Male	Edible flesh	70.4	20.48	8.46				
		New Zealand White	13 weeks	Male		67.15	19.70	12.10				
Gauss et al., 1976		New Zealand White			Longissimus dorsi	73.3	23.7	1.5				
					Leg	73.1	21.7	4.1				
		White New Zealand X California hybrid			Longissimus dorsi	73.4	22.1	1.5				
					Legs	72.3	21.2	1.4				
Granát et al., 1977		New Zealand White	12 weeks		Back	75.66	21.36	1.46				
					Thigh	75.04	20.64	2.90				
		California	12 weeks		Back	75.36	21.57	1.32				
					Thigh	75.17	21.06	2.32				
Gilka, 1975		Rabbit meat			Front parts	72.47	--	6.08				
					Back parts	74.40	--	2.71				
Kawinska, 1975		New Zealand White	Young		Forequarter	--	--	4.7				
					Longissimus dorsi	--	--	7.2				
					Hindquarter	--	--	1.9				
Ran et al., 1979		New Zealand White	8 weeks		Arm	72	17.7	7.7	136	12.9	205.2	39.3
					Ribs	70	17.9	8.9				
					Longissimus dorsi	72	18.6	6.5				
					Legs	71	19.8	6.5	91[a]			
Lee and Ahn, 1977		Flemish Giant	10 months (2-3 kg)		Edible flesh, raw	77.8	-	2.9	65.3			
					roasted	65.5	-	2.5	46.1			
Adams, 1975	Beef				Boneless Chuck, raw	70.30	21.28	7.4	91[a]	11.9	340	74
	Pork				Boneless loin, raw	57.2	17.09	24.87	88[a]	9.9	274	59
Posati, 1979	Chicken	Broiler			Breast, raw	74.76	23.09	1.24	58	11	255	65
					Leg, raw	76.13	20.13	3.81	80	11	229	86
					Breast, roasted	65.20	31.02	3.57	85	15	256	74
					Leg, roasted	64.70	27.03	8.43	94	12	242	91
Posati and Orr, 1976	Egg Whole				Raw and hard-cooked (cooked in shell)	74.57	12.14	11.15	548	56	130	138

[a] ADA, 1981. Total cholesterol in cooked meat.

Wilson and Morris (1932) pointed out that rabbits eleven months of age varied in composition depending upon the sex. Females at eleven months of age had about 4% more fat than males. With rabbits averaging 24 months of age, females had about 6% more fat than males. Males, on the other hand, contained more moisture and more protein than females (Table 1). Similar results have been reported by Kawinska et al. (1980).

It was also found by Wilson and Morris (1932) (Table 1) that as the rabbit grows older the moisture content declines. Currently there is a corresponding rise in the fat content of the carcass in both sexes. For female rabbits, the values of total moisture, total protein and total lipids of the average age 24 months group were 62.98, 19.96 and 9.12%, respectively, while those of average age 11 months group were 67.30, 20.27 and 5.8%, respectively. Rao et al. (1978) concluded that the protein content was not influenced by slaughter age, while fat and moisture contents were significantly influenced by slaughter age (Table 1). Similar results were also found by Zupka et al. (1978) (Table 1) and Rudolph et al. (1980).

Slaughter age also significantly influenced the live weight and the feed efficiency. Feed efficiency is defined as the feed consumed over the body weight gain of the rabbit after weaning. As slaughter age increased, feed efficiency increased, furthermore, the value of feeding economics (live rabbit price/feed cost) decreased from 2.19 to 1.51 (Chen et al., 1978). Since early weaning can return the doe for mating for accelerated breeding, it has been recommended that weaning at 4 weeks and slaughtering at 8 weeks is

most economical for rabbit production. Simultaneously, the live weight of this slaughter age (8 weeks) met the requirements for high carcass quality (Fischer and Rudolph, 1979).

In addition to the sex and age of the animal, breed also influenced proximate composition. McMillin (1931) (Table 1) found that total moisture, total protein and total lipids content of the Chinchilla breed were 70.4, 20.48, and 8.46%, respectively, while those of New Zealand White were 67.15, 19.70, and 12.10%, respectively. Effects of breeds (pure bred New Zealand White and New Zealand White X California) on the composition of rabbit meat were also studied by Gauss et al. (1976). As reported in Table 1, meat from the leg muscle of the pure bred tended to have higher protein (21.7% vs 21.2%) and fat content (4.1% vs 1.4%) than that from the cross breeds. Furthermore, the study of Granát et al. (1977) also agreed with the finding that breed does influence the proximate composition of rabbit meat (Table 1).

The proximate composition of rabbit meat varies from muscle to muscle. Generally, arms and ribs are lower in moisture and higher in fat than legs. Gilka (1975) showed the fact that front parts of rabbit carcasses contained significantly less moisture (72.47% vs 74.40%, $p<0.05$) and significantly more fat (6.08% vs 2.71%, $p<0.01$) than back parts of rabbit carcasses (Table 1). Similar results have been reported by Kawinska, et al. (1975) (Table 1) and Gauss et al. (1976)(Table 1). According to Kawinska et al. (1975), the average percent fat in different parts of muscle were: forequarters 4.7%, loin 7.2%, and hindquarter 1.9% (Table 1). However, Gauss et al. (1976) (Table 1) also reported that the fat content of hind leg

muscle was about 4.1% while that of the logissimus dorsi (loin) was about 1.5% in the New Zealand White rabbits. Other studies (Zupka et al., 1978; Granat et al., 1977) (Table 1) also showed this variability. The lipid content of rabbit meat is quite low when compared with other meat such as pork and beef (Table 1). This might suggest that rabbit meat offers the potential for use in low fat diets as far as health is concerned.

In a more detailed study of rabbit meat, Rao et al. (1979) analyzed the nutrient composition of arm, ribs, loin and leg of eight-week old New Zealand white rabbit carcasses. They found that the moisture content of arms, ribs, loin and legs ranged from 70 to 72%, fat content was from 6.5 to 8.9%, crude protein content was from 17.7 to 19.8% (Table 1).

This variability could be due partly to different diets as the proximate composition of rabbit meat is affected by the diet fed to rabbits. Raimondi et al. (1974) evaluated effects of the protein concentration (approximately 17.6% or 20.0%) and energy concentration (approximately 1600 or 1800 kcal/kg) in the diet on the moisture and lipid contents of the meat. Additionally, the fatty acid composition of the meat lipids was evaluated. The results showed that the high-energy diet significantly increased the moisture content and decreased the lipid content in the rabbit meat. The use of a high-energy (1800 kcal/kg) diet significantly altered the fatty acid composition of the fat, increasing C18:2 and C18:3 concentration and decreasing C16:0 and C16:1 concentration in the meat lipids. Protein content of the diet and sex of the rabbits had little or no effect on meat composition or the fatty acid

composition of the lipids.

The fatty acid composition of rabbit fat is characterized by a high level of saturated acid. The saturated fatty acids constitute 56.64% of total fatty acids, with highest contents of palmitic, stearic, and myristic acids. There were 0.95% volatile acids, 43.36% unsaturated fatty acids and 15.36 polyunsaturated fatty acids (Kostenko et al., 1980). When comparing rabbit meat to other animals such as beef cattle and pig, Tsimbalova et al. (1979) reported that the stearic acid and oleic acid concentration are 1.5-5 times lower.

Tsimbalova et al. (1979) also observed that the rabbit has a high proportion of unsaturated fatty acid in the meat with its linoleic and linolenic acid concentration approaching those in vegetable oils. Lee and Ahn (1977) compared the percent of linoleic acid in terms of total fatty acids for rabbit meat, beef, pork and chicken. They were 37.3, 5.9, and 14.5 and 21.9%, respectively. They also discovered that a small amount of short-chain fatty acids was isolated from rabbit meat, but not from the other types of meat. Spreadbury and Davidson (1978) compared the meat composition of rabbit fed high and low fiber diets. In high fiber diets, the body fat and dry matter of the rabbit carcass was lower and the nitrogen content was higher than in the low one.

Rao et al. (1979) showed that rabbit meat is very low in cholesterol with about 136 mg/100g of lyophilized meat (Table 1). In comparing the chemical composition of edible meats (Table 1), the cholesterol content of rabbit flesh is seen to compare favorable with that of chicken flesh, as well as beef and pork used for human

consumption. Reported values of cholesterol in cooked rabbit, beef, pork, chicken leg and egg are 91, 94, 88, 94, and 548 mg/100 g wet sample, respectively (Table 1). However, Lee and Ahn (1977) reported that total cholesterol content in rabbit was similar to other meats.

The mineral content of rabbit meat differs from other kinds of edible meat (Table 1). Rabbit meat has been found to be high in calcium, having approximately 12.9 mg/100 g as compared to 9.9 mg/100 g in pork (Table 1). Rabbit meat appears to have a moderate amount of potassium (205.2 mg/100 g) and a low amount of sodium (39.3 mg/100 g). These mineral elements occur either as separate ions or in a variety of compounds within muscle. Many of the ions influence muscle contraction, water-binding and buffering capacity of the tissue.

Determination of Total Protein, Lipids and Cholesterol in Rabbit Meat

Protein determination

Protein often occurs in foods in physical or chemical combination with carbohydrates or lipids. Thus, protein generally must be extracted from natural sources by maceration, by disruption of cells, digestion by enzymes or by solvent extraction (Pomeranz

and Meloan, 1978). There are numerous methods for analyzing the total protein content in foods. A nitrogen determination for a protein assay is the most commonly used procedure. It is generally assumed that a mixture of pure proteins will contain 16% nitrogen. Thus the protein content of a sample is obtained by multiplying the determined nitrogen by the factor 6.25 = (100/16) for meat (Jones, 1931).

The microkjeldahl method (Horwitz, 1980) is used for the solid and intact-structure samples. Basically, the sample is oxidized, and the protein nitrogen is reduced and transformed into ammonium sulfate. Then the concentrated NaOH is added and the digest heated to drive off the liberated ammonia into a known volume of a standard acid solution. The total nitrogen is determined by titrating the ammonia compounds with a known concentrated acid solution. The Kjeldahl procedure measures total nitrogen and does not distinguish between protein and nonprotein nitrogen (Miller and Johnson, 1954).

The biuret method is another method used for the determination of protein in meats (Torten and Whitaker, 1964). This method was proposed first by Riegler in 1914. It is based on the observation that substances containing two or more peptide bonds form a purple complex with copper salts in alkaline solutions. The biuret procedure is simple, rapid, and inexpensive. It involves a reaction with the peptide linkage and, therefore, furnishes an accurate estimate of protein. However, the color development with various proteins is not identical by using the biuret method. Also, the results may be affected by the presence of lipids and interfering opalescence from components of biological origin such as cell

membranes and tissue fluid, etc. (Kirk, 1947). Thus the biuret procedure is not an absolute method and the color must be standardized against known protein (Kirk, 1947).

Lipids determination

Lipids are usually defined as food components that are insoluble in water and that are soluble in organic fat solvents. These physical properties of lipids reflect their hydrophobic and hydrocarbon nature.

Successful extraction of lipids requires that bonds between lipids and other compounds be broken so that the lipids are freed and solubilized. Nonpolar triglycerides are dissolved in nonpolar solvent such as hexane, ether or chloroform. Polar compounds, such as glycolipids, are soluble in alcohols. The commonly used solvents for extracting fat from meat are anhydrous diethyl ether or petroleum ether. However, since much of the lipid in muscle tissue is complexed with protein, ether does not extract all the lipid from meat (Giam and Dugan, 1965).

A rapid method for lipid extraction was originally proposed by Folch et al. (1957). This method used a process of isolation and purification of total lipids from animal tissues by means of phase partition of a tertiary mixture of chloroform-methanol-water. This method can be used for lipid extraction from rabbit meat. The chloroform layer contains all the lipids, while the methanolic layer contains all the nonlipids. A purified extract is obtained by

isolating the chloroform layer. The nonlipid portions can be removed by partition procedures and centrifugation. Some lipids are appreciably soluble in water, and excessive washing may cause lipid losses.

Bligh and Dyer (1959) studied four procedures for extracting lipids from fish muscle and concluded that the procedure of Folch et al. (1957) extracted more lipid than did the AOAC ether method (Horwitz, 1980). Another advantage of this method is that the mixture of chloroform and methanol (2:1, v/v) are among the most effective and relatively mild extractants. The proteolipids are solubilized with little damage to most proteins, other polar lipids, such as phosphatidyl serine can dissolves in chloroform as well. Also, by using chloroform:methanol extraction method, the change in profile of fatty acids in lipids can be eliminated.

Total cholesterol detemination

Cholesterol, a steroid alcohol with the formula C17H45OH, is the precursor of bile acids, steroid hormones, and provitamin D3. Cholesterol is present primarily in foods of animal origin, whereas plants contain closely related plant sterols such as ergosterol and sitosterol. However, herbivorous animals have both cholesterol and these other sterols in their body tissues (Sweeney and Weihrauch, 1976).

A review of methods in determining cholesterol in food by Sweeney and Weihrauch (1976) indicated that the commonly used

methods of determining cholesterol are far from specific. Thus, the range of cholesterol values reported is often wide. The value of cholesterol in food has been shown to vary with methods used for analysis. Frequently, a proper description of the sample and details of the analytic method used are not given. This makes it very difficult to evaluate the available data.

A review of the literature indicates the Zak et al. method (1954a) is widely used in analyzing the cholesterol content in meat tissue. In this method, generally, the total cholesterol is isolated as the digitonide and then recovered by solution in acetic acid. The total cholesterol gives some reddish-brown color with the ferric choride-acid reagent at 560 mu (Zak et al.,1954b). This method is not only specific to total cholesterol as a series of sterols containing 3-beta-hydroxy group such as cholesterol, beta-sitosterol and ergosterol are included.

Influence of Fiber on Calcium Bioavailability in Rabbits

In live animals, calcium is a major constituent of bone; in addition, calcium has metabolic roles in clotting, in controlling excitability of nerve and muscle tissue, and in the maintenance of acid-base equilibrium (NRC, 1977). Diet has been shown to influence calcium bioavailability in a number of ways.

Phytate hypothesis

The bioavailability of minerals has been correlated with the binding and chelating properties of phytates and fiber and the various forms of calcium in the plant cells. Phytic acid, an organic phosphorous compound, occurs primarily in plant tissues such as seeds and whole grains (deBoland et al., 1975). The large number of phosphoric radicals in the structure of phytic acid allow it to form simple salts with one metal, or mixed salts with several metals in the same molecule. Salts of Ca, Fe, Mg, Zn, and Cu so formed are named phytate and are practically insoluble (deBoland, et el., 1975).

The antinutritional properties of phytic acid stem from its ability to combine with metal ions. Consequently, the minerals become unavailable to the animal. Phytic acid and phytates can be decomposed by prolonged exposures to heat treatment, acid hydrolysis or enzymatic action of phytase. In ruminants, bacterial phytase (in small intestine in particular) degrades the phytate complex, freeing minerals such as calcium for use by the animal. In nonruminants, the mineral availability of plant sources is poor because of the presence of phytate minerals. Intestinal phytase has been observed in some nonruminants. Pileggi (1959) discovered that rats possess an intestinal phytase. Although extensive minerals availability studies have not been conducted with rabbits, a report (Blanco and Gueguen, 1974) confirmed that bacterial action in the cecum and colon renders plant phosphorus in phytate complex available. Thus

calcium will likely be released from phytate complex by bacterial action and made available for absorption by rabbits.

The mineral binding properties of fiber

To test in vitro cation binding capacity of fibers, the work of Reinhold et al. (1976) suggested that absorption involved an ion exchange process that attributed to the presence of free carboxyl groups in fibers (Belford et al., 1959). Branch et al. (1975) found that fiber from plants low in phytate bound calcium in vitro in proportion to its uronic acid content. This suggests that binding by noncellulosic polysaccharides could reduce the availability of calcium for small intestine absorption. Microbial digestion in the colon is believed to liberate this calcium (Harrison and Harrison, 1974). However, the in vivo mineral availability does not necessarily follow the in vitro evidence (Stiles, 1976). Since fiber-mineral complexes may dissociate prior to reaching absorptive sites, it shows no apparent interference with mineral uptake.

Chemical forms of endogenous minerals

The calcium salt of oxalic acid is practically insoluble at neutral or alkaline pH but becomes soluble in acid (Gontzea and Sutzescu, 1968). Oxalates are widely distributed in the plant kingdom. The insolubility of most simple oxalates and the

coprecipitation of other minerals with calcium oxalates (Krishnamurty and Harris, 1961) suggest that minerals in plants containing high amounts of oxalates (e.g. spinach) may not be very readily available.

Jones (1978) has suggested that surface silanol groups of amorphous silica associated with the plant cell wall might also absorb metal cations and impair their availability. However little is known about the exact matrix in which minerals are held in plants. This information would be beneficial in understanding and optimizing the absorption of all minerals.

The calcium level required for the growing rabbit is 0.4% per Kg of diet (NRC, 1977). Although many rabbit rations contain more calcium than required, the absorption is influenced by its level in the diet and the dietary levels of phosphorus and vitamin D. Calcium metabolism in the rabbit is unique. The serum calcium level of the rabbits reflects the dietary calcium level (Chapin and Smith, 1967) rather than being homeostatically regulated to a narrow range as in other species. The rabbit is able to absorb large quantities of calcium and excrete the excess in the urine (Cheeke and Amberg, 1973), while in most other animals biliary excretion is the major route.

The absorbed calcium from the small intestine of the rabbit will increase its serum calcium level. Most animals will secrete calcitonin in response to this raised serum calcium and excrete the excess calcium in feces. However, the less efficient serum calcium homeostasis in the rabbit suggests that its calcitonin secretion rate may be low. Kennedy (1965) suggested a possible role of

vitamin D in stimulating the high urinary calcium excretion in response to the rise in serum calcium. The meaning of this is not fully understood. More research needs to be done to determine how the rabbit is able to metabolize such large quantities without hypercalcemia occurring. In response to the rise in serum calcium, the calcium could deposit in the bone and teeth tissue (Avioli, 1980). Whether excess calcium in the blood is deposited in the soft tissue such as muscle tissue has not been studied.

The Muscle Structure of Rabbit Meat

Slaughter of an animal marks the end of the cellular efficency and the beginning of biochemical and physiological changes in the muscle cell. The molecular basis of muscle organization and theories of contraction and relaxation in the living muscle provide explanations for these changes and their effect on quality characteristics of meat. Many of the same reactions in the muscle form the basis for postmortem changes and further affect the meat quality.

Bailey (1972) and Blanshard and Derbyshire (1975) describe the muscle structure of beef. These, and other reports (Huxley and Hanson, 1960; Smith, 1972; Hultin, 1976; Threadgold, 1976) have extensively reviewed the structure. Work of Paul (1965) and Yang et al. (1974) showed that the basic muscle structure of rabbit meat resembled in general that found in beef, although there were several

exceptions.

Rabbit muscle has approximately 18-24% of crude protein which is close to that of other types of meat (Table 1). Concerning the protein nitrogenous fraction of muscle, Lawrie (1968) has analyzed the relative proportion of the types of protein in a typical mammalian muscle. Of the 18 to 24% protein, about 7-10% is made up of the various proteins of contractile structures (Lobley and Lovie, 1979), 2% is in the connective tissues and 6% is in the sarcoplasm, and subcellular organelles. These three classifications of muscle protein were catagorized according to their differences in extractibility (Goll et al., 1970, 1974). Contractile proteins are those proteins that constitute the myofibril (Bodwell and McClain, 1971; Goll et al., 1970). The sarcoplasmic proteins generally include those proteins found in cytoplasm of the muscle cell (Bodwell and McClain, 1971; Goll et al., 1970). Connective tissue is made up of stroma protein, mainly collagen, elastin and reticulin (Bodwell and McClain, 1971; Goll et al., 1970).

Constituents of myofibril

The myofibril consists of 3 major myofibrillar proteins: the thin filament actin 20-25%, the thick filament myosin 50-55% and 20-25% regulatory proteins. These regulatory proteins regulate adenosine triphosphate-actin myosin complex. Among the regulatory proteins, tropomyosin, troponin, and beta-actinin are associated

with the actin filament; whereas, C-protein is present in the myosin filament; alpha-actinin is a component of the Z-line; and M proteins are believed to be the substances composing the M line.

The thin actin filament contains three major proteins. A two stranded polymer of globular-shaped actin molecules makes up the backbone of the filaments. Tropomyosin lies in the grooves on both sides of the polymers. It is a rod shaped molecule composed of two polypeptide F-actin chains. F-actin is formed from G-actin monomers. Troponin bound to tropomyosin along the thin filament is a calcium-ion-receptive protein and calcium ion sensitive receptor. It is the major fraction in the actomyosin-tropomyosin complex.

The major protein in the thick filaments is myosin. The heads of the myosin molecules extend perpendicularly from the thick filament (Figure 1e and 1). When myosin is subjected to the proteolytic action of the enzyme trypsin, it is split into two different molecular weight fractions; light meromysin and heavy meromysin. In rabbit meat, this heavy meromysin part of the myosin molecule is the site of ATPase activity and actin-myosin interaction (Groschel-Stewart et al., 1973). Another protein, the C protein, is found in the myosin filament. A narrow band of C protein encircles the myosin filament and binds the myosin molecules together into the bundle that forms the thick filament seen in micrographs.

Alpha-actinin is present in the Z-line and constitutes about 2-2.5% of the myofibriller protein (Briskey et al., 1967). Alpha-actinin forms the cementing substance in Z filaments. Beta-actinin, a globular protein, is located at the ends of actin filaments and is believed to regulate their length by maintaining a

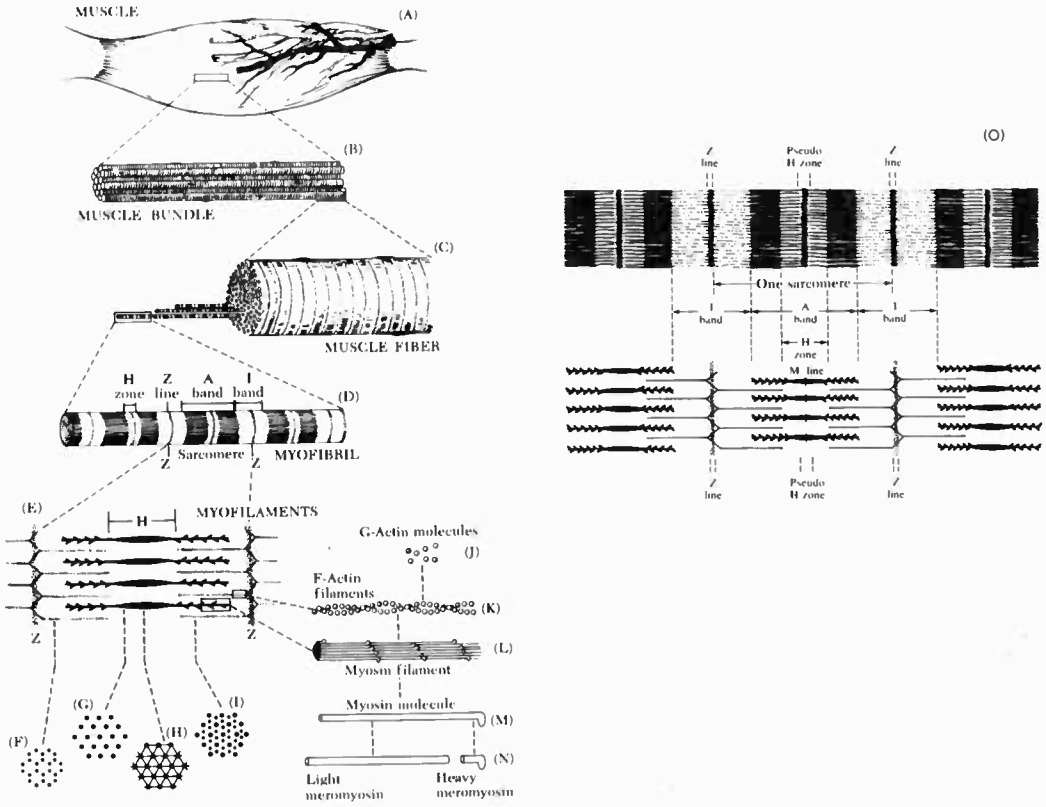

FIGURE 1[1]
Diagram of the organization of skeletal muscle from the gross structure to the molecular level. (A) skeletal muscle, (B) a bundle of muscle fibers, (C) a muscle fiber, showing the myofibrils, (D) a myofibril, showing the sarcomere and its various bands and lines, (E) a sarcomere, showing the position of the myofilaments in the myofibril, (F-I) cross sections showing the arrangement of the myofilaments at various locations in the sarcomere, (J) G-actin molecules, (K) an actin filament, composed of two F-actin chains coiled about each other, (L) a myosin filament, showing the relationship of the heads to the filament, (M) a myosin filament showing the head and tail regions, (N) the light meromyosin (LMM) and heavy meromyosin (HMM) portions of the myosin molecule, and (O) portions of two myofibrils and a sarcomere and a diagram corresponding to the sarcomere, identifying its various bands, zones, and lines. [Modified after Bloom and Fawcett, A Textbook of Histology, 9th ed., W.B. Saunders Company, Philadelphia, p. 273, 1968.]

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[1] Figure 1. Adapted from Forrest, Aberle, Hedricks, Judge and Merkel, Principles of Meat Science, Freeman, San Francisco, California, pp. 32-33, 1975.

constant length of about 1 um in each half sarcomere.

M proteins constitute the substances of the M line that bind the myosin tails together in the myofibril, and thus maintain the arrangement of myosin filaments. Craig (1977) proved that the M-line is necessary for connecting the tails of neighboring thick filaments in correct positions in rabbit meat muscle. However, some invertebrate muscles have been shown by X-ray diffraction to have random thick filament orientation; correspondingly these muscles have no M-line (Millman and Bennett, 1976).

Constituents of sarcoplasmic protein

Sarcoplasmic proteins are the soluble proteins of the sarcoplasm located within the sarcolemma of the cytoplasm of the muscle cell. They constitute a significant portion of the proteins of the cell, usually from 30-35% of the total proteins in skeletal muscles.

Asghar and Pearson (1980) classified the sarcoplasmic protein into four subclasses of structural components: a nuclear fraction, a mitochondrial fraction, a microsomal fraction and a cytoplasmic fraction. The nuclear fraction is composed of nuclear material and lipoproteins. The mitochondrial fraction include the mitochondria, the tricarboxylic acid cycle enzymes and the electron transport chain. The microsomal fraction consists of the microsomes, the sarcoplasmic reticulum, the T-system, and the lysosomes. The cytoplasmic fraction contains the enzymes of the glycolytic pathway

and glucogenesis, myoglobin, and the soluble proteins.

Sarcoplasmic proteins do not contribute significantly to the filamentous organization of muscle. Their function is mainly concerned with the metabolic activities of the cell. Many of the proteins of the sarcoplasm are important in affecting the quality and appearance of meat.

Constituents of connective tissue

Connective tissue is a fibrous protein often referred to as the stromal fraction and it is used to form and support other tissue and to regulate and control the extent of contraction. The connective tissue is held together by a ground substance which acts as a cementing matrix. The ground substance, derived from the plasma, is a firm gel of linear biocolloids that form a very fine meshwork. The connective tissue are comprised mainly of collagen and to a less extent, of another fibrous protein, elastin.

Collagen is the principal structural protein of connective tissues. It constitutes approximately 20-25% of the total protein, which is the most abundant protein in an animal body and significantly influences meat tenderness. The distribution of collagen is not uniform among skeletal muscles, but the amount present generally parallels their physical activity. For example, muscles of the limb contain more collagen than those of the back.

Elastin is responsible for less than 3% of the connective tissue, which is a highly extensible fibrous protein. It has a

completely amorphous structure as the protein chains are randomly coiled kinetically free for most of their length. They are crosslinked at intervals by thermally stable bonds to give it its rubber-like elasticity (Bourne et al., 1966). Aggregation of elastin fibers have a characteristic yellow color. Rabbit muscles appeared to contain little elastin with that present being primarily around the blood vessels except for a few elastin strands in the perimysium of the biceps femoris (Paul, 1965).

Reticulin, another component of connective tissue, consists of small fibers. The small fibers form delicate networks around cells, blood vessels, neutral structures, and epithelium which hold them in place.

Micromolecular structure of muscle

Muscle is composed of a large number of individual fibers whose long axes are oriented in the direction of force development. The contractile force is produced by cylindrical organelles called myofibrils which are bathed by the intracellular colloidal substance named sarcoplasm. The myofibril itself consists of parallel aligned myofilaments, namely thick myosin filaments and thin actin filaments. This is shown in a longitudinal section in Figure 1. These thick and thin filaments complex with each other in such a way that each myosin filament is surrounded by six thin actin filaments. Further, each thin filament is surrounded by three thick filaments (Figure 1) . This arrangement leads to a variation in the density

of the filaments which must obviously change as the muscle contracts and the protein filaments complex. The resulting light and dark bands are visible using light and electron microscopy.

The light band, I band, is bisected by a dark thin band called the Z-line. The Z-line divides the myofibrils into regular units called sarcomere which is the basic contractile unit in rabbit and other animal muscle (Paul, 1965). Huxley and Hanson (1954) proposed that muscle contraction is accomplished by a sliding complexing of thick and thin filaments past one another. The myosin heads constitute the cross-bridges which reach out to complex with the G-actin and cause a sliding of the two kinds of filaments past each other. The complex of actin, myosin, tropomyosin, and troponin formed by this junction is actomyosin which results in a rigid and relatively inextensible condition in the muscle. The myosin and actin chains in the resting muscle are kept separate by the plasticizing action of the magnesium complex of adenosine triphosphate (MgATP). Actomyosin is a transient compound in the contraction cycle of the living animal. Also it is the major form of the myofibril proteins that are found in postmortem muscle. In rabbit muscle fiber, the contraction nodes tended to disappear with longer storage, while in beef they tended to persist (Paul, 1965).

In the central region of the A band there is an area of slightly less density called the H zone (Forrest et al., 1975). Additionally, a narrow dense band known as the M-line, bisects the center of the A band. The thick filaments of the A band contains the myosin of the sarcomere. The thin filaments constitute the I band and extend from the Z-lines to the borders of the H zone,

containing the actin of the sarcomere.

The H zone contains only myosin filaments (Forrest et al.,1975). The width of the H zone varies with the state of contraction of the muscle. Since the I band contains only the thin actin filaments, it is the least dense band of the entire myofibril.

The Z-lines consist of Z filaments which connect with actin filaments on either side of it. Near the Z-line, each actin filament connects to four Z filaments that pass obliquely through the Z-line. In longitudinal sections, this oblique arrangement of the Z filaments results in the characteristic zigzag pattern of the Z-line. These features are evident from cross sections of a sarcomere. Through the H zone, I band and that portion of the A band where the actin and myosin filaments overlap are shown in Figure 1a, h,i and o.

The sarcoplasmic reticulum (SR) is a membranous system of tubules and flat reservoirs for Ca++ to form a closely meshed network around each myofibril. The reticulum is the storage site of Ca++ in a resting muscle, while calsequestrin is the major calcium binding protein of the sarcoplasmic recticulum in rabbit muscle (Caudwell et al., 1978). Ca++ ions are released from the sarcoplasmic reticulum by nerve impulses to start the contraction cycle. This signal is conveyed by means of the transverse tubular system. The transverse tubules are extensions of the external cell membrane and function to transmit the excitatory impulse rapidly from the fiber surface to the cell interior.

The Ca++ ions release ATP from MgATP, and also stimulate the ATPase activity (Greaser, 1976). ATPase splits ATP to ADP,

releasing the energy and permitting the movement of the actin filaments toward the H zone of the A band. Then relaxing factor (Marsh, 1952, 1966) promotes the recapture of the Ca++ ions by the sarcoplasmic reticulum, the MgATP complex is re-formed with new ATP, and this in turn breaks up the actomyosin and permits relaxation. The ATP supply is regenerated by reaction of ADP with creatine phosphate (CP). CP is regenerated by means of reactions utilizing energy supplied by the glycolytic cycle.

Muscle fiber type

Although the basic structure of the muscle fiber is similar to that previously reviewed, they do vary in their physiological states (Gillis and Henrickson, 1967). Investigation of muscle shows that fibers within some muscles are different than adjacent ones in the same muscle. In rabbit meat, this has been reported to be so in the cases of longissimus, semitendinosus, soleus and semimembranosus proprius (Lobley et al., 1977). This type of variability is caused by the construction of muscle from two types of fibers, namely red and white fiber. Earlier anatomical studies have classified muscle fibers as red, white or intermediate, based on their color (Beecher et al., 1965). Physiologically, these muscles are recognized as slow or fast, depending on the speed of contraction. Histochemical studies have led to the classification of three types of muscle fibers, i.e., types A, B, and C (Stein and PadyKula, 1962). Despite the differences in fiber classifications, white fibers can be

equated with type A or fast; red fibers are equivalent to type B or slow, and white type C fibers are intermediate (Goldspink, 1970). In summary, white fibers are generally characterized as being large in diameter, and having a well-developed sarcoplasmic reticulum and T tubule system. This is consistent with their more rapid contraction speed, as compared to that of red fibers. Additionally, white fibers are high in glycogen, creatine phosphate, phosphorylase, but are low in myoglobin and mitochondrial numbers. These features are a reflection of the lower oxidative metabolic activity in white fibers, since those enzymes are associated with mitochondria.

In the rabbit, all these three fiber types (type A, B, C) are found (Groschel-Stewart, et al., 1973). Gilka (1975) reported that rabbit meat has a high proportion of white muscles. Red fibers, because of their metabolism, are less easily fatigued, as long as an oxygen supply is available. These findings supported Paul's (1965) work, showing that rabbit muscle fibers have much less tendency than did beef fibers to granulate with increasing storage.

Muscle organization and construction

Forrest et al. (1975) proposed the concept of muscle organization. In the skeletal muscles, groups of muscle fibers are bound together by connective tissue. The myofibrils are collected into bundles called fibers or muscle cells. Each fiber is contained by a sheath of lipid-protein membrane structure of relatively low

water permeability, namely the sarcolemma or epimysium. The insoluble components of the sarcolemma, mainly reticulin, together with the insoluble components of the extracellular tissue, make up the stroma. The extracellular components include a vascular system, nerve tissue, connective tissue, and the material of the interstitial space.

The number of fibers varies from one bundle to another. The size of the bundles and the thickness of their connective tissue septa (partitions) determines the texture of muscle. Those with small bundles and thin septa have a fine texture (Forrest et al., 1975). The sarcolemma (outer cell membrane) of individual muscle fibers is surrounded by the endomysium, a protein-polysaccharide connective tissue covering. Finally a collection of fibers is enclosed in a muscle sheath or epimysium to form a muscle. These connective tissue septa: endomysium and epimysium, bind the fibers and bundles together and they support the associated nerves and blood vessels.

Postmortem Changes in Rabbit Meat

When rabbit is slaughtered the tissues no longer are supplied with oxygen by the blood stream and undergo irreversible physical and biochemical changes. Howard and Lawrie (1956, 1957) have confirmed Marsh's finding (1954) that general physical and biochemical changes during development of rigor are similar in beef

and in rabbit.

Stiffening and loss of extensibility are the most obvious physical changes which occur with the onset of rigor. Animals of different species appear to develop rigor at different rates. In rabbit muscle, these reactions occurred within the first two hours after death (Stromer et al., 1974; Busch et al., 1972; Paul, 1964), whereas in bovine muscle, this usually takes up to nine hours to occur. In the rigor process, the sarcomere length decreases, crosslinks are formed between the actin and myosin filaments of the myofibril, and the whole system becomes rigid and inextensible.

Concurrent with these physical changes, the following biochemical changes during development of rigor have been noted by Whitaker (1959) in the slaughter of cattle: (1) The start of glycolysis at death and continuation until low pH prevents activity of glycolytic enzymes, (2) pH decrease due to lactic acid build up, (3) a decrease in creatine phosphate, (4) a decrease in ATP level (at about 80% of the initial level the muscle loses extensibility and contracts), (5) ammonia liberation. In the rabbit psoas, rigor onset has also been observed to occur simultaneously with the rapid depletion of ATP (Bendall, 1951). ATP acts as a plasticizer between the actin and myosin filaments to make them into a flexible and easily extensible state (Bendall, 1973). Muscle shortening occurred during this initial phase, with pH falling from about 6.2 and the muscle becoming rigid. This is a condition characteristic of a muscle with low glycogen reserves. Rabbit carcasses take about twelve hours for completion of rigor (Paul, 1964), whereas beef

carcasses take about twenty-four hours (Bodwell et al., 1965) for completion of rigor. Part of the causes of variation in the rate of development and resolution of rigor may be temperature variation due to differences in carcass size and in slaughter procedure (Paul, 1972). Resolution of rigor in rabbit meat may lead to a decline in isometric tension (Busch et al., 1972), Z-line degradation (Penny, 1968), alteration of actin-myosin interaction (Penny, 1968), and degration of myofibrillar proteins, probably due to the action of calcium-activated factor (CAF) and cathepsin (Suzuki and Goll, 1974; Arakawa et al., 1970).

With rabbit meat, the changes in histological appearance and biochemical events during cold storage aging generally resemble those observed in beef, although there were several exceptions (Paul 1965; Dayton et al., 1974). For example, chilled rabbit muscle shows little or no shortening as compared to the massive shortening of chilled beef (Cornforth et al., 1980). Histological appearance of rabbit muscle fibers also shows less tendency to granulate than beef muscle does during cold storage (Paul, 1965). The differences between rabbit meat and beef during cold storage aging have been related to differences in mitochondrial concentration in red and white muscle rather than the differences in the Ca++ accummulating ability of sarcoplasmic reticulum (SR). Buege (1976) hypothesized that at low temperatures SR cannot absorb liberated Ca++, but at high temperatures it can. Since the red muscle in beef contains more mitochondria than the white muscle in rabbit meat, the total Ca++ release is greater in the former, causing a greater extent of cold shortening in beef muscle. Additionally, the smaller muscle

would cool more rapidly than large beef muscle resulting in greater cold shortening. Comparing the structural changes in different types of muscle during postmortem cold storage, Dayton et al. (1974) pointed out that rabbit meat showed faster disintegration of M-lines and Z-lines as compared to beef. This difference was accelerated at 37 C. Similar results also found by Suzuki and Goll (1974) and Davey and Gilbert (1966) showed that a gradual degradation of Z-disk in myofibril happened in rabbit meat. They postulated that calcium-activated protease removed Z-disk from myofibril by means of a very specific proteolytic activity that releases alpha-actinin of rabbit muscle fiber. However, postmortem changes in alpha-actinin and troponin-tropomyosin complex are not the primary cause of postmortem modification in actin-myosin interaction (Arakawa et al., 1970).

Another change in myofibrillar proteins during postmortem storage is the modification of the actin-myosin interaction. In the rabbit meat, this has been revealed by changes in the ATPase activity of myofibril (Goll and Robson, 1967) and changes in dissociability of the actin-myosin complex (Fujimaki et al., 1965). Arakawa et al. (1976) proposed that a cathepetic protease from muscle tissue which is maximally active in the pH range (5.0-5.5) of muscle, cleaves myosin into heavy and light meromyosin which causes the changes in dissociability of the actin-myosin complex.

It is generally agreed that the amount of actomyosin formed during rigor is related to the amount of interdigition of filaments, and, ultimately, to toughness. However, Buck et al. (1970) showed that stretching increases the actomyosin content of rabbit muscle and that increased tenderness is associated with increased amounts

of actomyosin rather than decreased amounts. Since the Z-disk is easy to dissociate during aging (Paul, 1965; Suzuki et al., 1975) the possible reason for this has been suggested by Davey and Gilbert (1966) and Buck et al. (1970). They indicated that the destruction of Z-line material accounts for the freely extracted actomyosin complex during aging with stretched rabbit muscles.

pH of Rabbit Meat and Factors Affect Its pH Changes

As previously indicated, the pH of rabbit meat passes through some changes after slaughtering. Rabbit muscle pH decreases from 6.35 to about 5.5-5.8 during rigor because muscle glycogen at the time of death is converted to lactic acid through the anaerobic glycolytic system (Paul, 1964; Whitaker, 1959). The produced lactic acid cannot proceed on through the citric acid cycle in vivo because the cycle requires oxygen which is no longer available after death. Since the production of lactic acid is dependent on the supply of muscle glycogen, the level of this component at the time of death determines the ultimate pH of meat. The conversion of glycogen to lactic acid will continue until a pH is reached which inactivates the glycolytic enzymes. The final pH obtained is referred to as the ultimate pH (Bendall, 1964).

Paul (1964) reported that the carcass of rabbit passes through the development and resolution of rigor in 12 hours. The ultimate pH for raw and cooked postmortem rabbit meat is 5.8 and 6.11, respectively (Paul, 1964). The variable rate of postmortem

glycolysis and the pH attained in the muscle after slaughter have important implications in the ultimate quality characteristics of muscle as a food (Giffee, 1960). Some intrinsic factors such as species, type of muscle, and the variability between animals, and extrinsic factors such as pre- or post-slaughter practices and the environmental temperature influence glycogen stores in animal carcasses. Consequently, these factors may alter the rate and extent of postmortem glycolysis.

Preslaughter effects

Stress such as exercise prior to slaughter can deplete the glycogen supply whereas feeding may increase the glycogen content of the muscle (Lawrie, 1966). Briskey et al. (1959) showed that severe exercise of hogs immediately antemortem depleted the muscle glycogen and produced high pH meat dark in color and dry in appearance. Asghar (1969) stated that muscles from underfed animals with a lower content of sarcoplasmic and myofibrillar protein and nonprotein nitrogen exhibit relatively rapid rates of pH fall in comparison to those from adequately fed animals. On the other hand, Bate-Smith and Bendall (1956) indicated that the muscle of well-fed rabbit with a high store of glycogen set in rigor slower and had a lower pH as compared to underfed rabbit with low glycogen store.

Postslaughter effects

The decrease in body temperature diminishes chemical reaction rates, influencing the rate of loss of glycogen and ATP (Lawrie, 1974). With most chemical reactions the warmer the environment the faster the reaction and, in this case, the faster the pH decline (Ockerman, 1977). Pale-soft-exudative (PSE) pork is an example of genetic and thermal stress influence. PSE has been associated with high temperatures (30 C) and low tissue pH which leads to a reduction in extractability of sarcoplasmic and myofibrillar proteins (Briskey et al., 1964). Sayre and Briskey (1963) also reported that sarcoplasmic and myofibrillar protein solubilities decreased with low pH and high temperature at the onset of rigor. The protein solubility was also closely related to the juice-retaining properties of muscle. Ikeuchi et al. (1980) have indicated that low pH and high temperature also greatly altered the properties of myofibrillar proteins of rabbit meat.

The postslaughter effects are influenced by the extent of excitement and nervous stimulation of the animal immediately prior to slaughter. The rate of postmortem glycolysis and the ultimate pH attained may be affected. McLoughlin (1965) studied the effect of stunning on the isoelectric pH of the longissimus dorsi of pig muscle (isoelectric pH is the pH measured 30-45 minutes after stunning), stunning either electrically or with CO2 increased the tendency for low isoelectric pH (<6.0) over that found in those

slaughtered without prior stunning Little information is available for effect of preslaughter methods and conditions on rabbit meat.

Postmortem electrical stimulation after slaughter has recently received attention as means for improving meat quality. The results of Bendall (1976) showed that electrical stimulation of rabbit carcass at voltages of 250 v accelerated postmortem pH decline, hastening the rate of pH fall 2-3 times greater than normal. He also reported that ATP level falls in step with the pH: at about pH 6.2, 50% of ATP has disappeared and at pH 5.7, more than 90%.

Type of muscles effects

The individual muscles within the carcass vary in rate and extent of postmortem change, partly depending on the number of red, white or intermediate fibers in the muscle. The rabbit with higher white muscle showed the postmortem influence of muscle type; the white muscles have higher glycolytic activity, less myoglobin, and probably less phospholipid. They develop tension more rapidly and attain lower ultimate pH levels than the red muscles.

Water-Holding Capacity of Rabbit Meat and Factors Affecting Its Water-Holding Capacity Changes

Rabbit muscle which contains about 63-70% water (Table 1) has a pronounced impact on certain quality characteristics of meat as a

result of the water-protein interactions (Fennema, 1973). Water-holding capacity, or the degree of hydration of muscle proteins, appears to be an important factor in influencing quality characteristics of the juiciness of raw or cooked meat as well as moisture content (Deatherage, 1955). The evaluation of the extent of water-binding or -holding to the coagulated and denatured meat has been reported by Hamm (1960). Wierbicki and Deatherage (1958) found lean meat contains about 3.5 g of water per gram of proteins, about ten times as much as the water hydration capacity of commonly known proteins such as egg white protein and casein. For this reason, evaluation of the function of water in binding of meat protein and its influence on quality characteristics is very important.

Scheme of water-binding to meat

Muscle is a complex of membranes, fibers, fibrils, and filaments, cross-bonded in a variety of ways. These provide a highly organized structure with spaces where water is bound. Wismer-Pederson (1971) described the theory of water-binding to protein. The unique geometry of water dipoles permits hydrogen bonding with peptide linkages and with side groups of amides or tyrosine of protein. Formation of the water shell around the charges and polar groups of protein by the water molecules reduces the intensity of the electric field of these groups, and hence stabilizes the protein-water interface by lowering the free energy

of the system. On the other hand, amino acids having hydrophobic side chains repel water dipoles, and hence decrease entropy of the system (Kinsella, 1976).

Many of the types of molecules found in muscle such as myofibrillar, sarcoplasmic and connective tissue proteins have a considerable degree of attraction for water. Myofibrillar proteins account for 70% of the water-binding in muscle. The sarcoplasmic and connective tissue proteins, respectively, bind 20 and 10% of the total water (Hamm, 1960; Scopes, 1970). This three-dimensional network of myofibril forms a lattice type structure to hold water.

Hamm (1960) described the scheme of water-binding (i.e. WHC) to meat proteins using adsorption isotherms with special emphasis on beef. This scheme may be likely transferable to the water binding of muscle protein in rabbits. A first layer, the monomolecular layer, comprising about 4% of muscle water is tightly bound to hydrophilic protein groups. A second layer, the multimolecular layer, with 4 to 6% of muscle water, is formed over the first. These two layers form the bound water. More than 10% of the free water is immobilized in capillary condensation in the small spaces of muscle fibers by ionic linkages, H-bonds, metal groups, Van der Waal forces and by weak but directed bonds with other water dipoles. Free water immobilized in this way is described as water-holding to the muscle tissue, while bound water refers to water actually binding or tightly held on the molecules of muscle tissue. Generally, water-holding and water-binding are used interchangeably to describe the relationship between water and muscle protein.

Fujimaki and Deatherage (1964) confirmed the idea of Hamm

(1960) that changes of the water-holding capacity (WHC) of meat mainly concern actin and myosin or actomyosin. If the muscle fibers are contracted so that the actin and myosin filaments overlap extensively, the lattice spacing diminishes and the WHC is reduced (Bendall, 1964; Goll et al., 1977).

The strong influence of the changes of protein charges and protein structure on the WHC of meat may affect only the free water, which is not bound in mono- and multi-molecular layers. The water retained within the protein structure, perhaps immobilized by "capillary condensation" seems to have a continuous transition to the free water (Hamm, 1960). Tightening the network of proteins decreases immobilized water and increases easily expressible water, whereas loosening the protein structure has the opposite effect. This phenomenon is seen in the muscle contraction and to some extent, in the shrinking of meat during cooking (Bendall, 1964; Goll et al., 1977). A lowering in WHC accompanies the onset of rigor mortis. This was attributed to the depletion of ATP coupled with the formation of actomyosin and a subsequent tightening of muscle structure (Asghar and Yeates, 1978).

Water-holding capacity (WHC) and its determination

The ability of muscle to immobilize water during the application of various stresses such as pressure, heating, grinding, etc. is referred to as water-holding capacity (WHC) (Hamm, 1960). Since the amount of immobilized water determined depends on the

method used, it is not possible to give absolute figures for this water.

Methods appropriate for studying water-holding capacity (WHC) are concerned with differences in the immobilization of free water, and are based on measuring the loose or free water liberated by applying pressure on the muscle tissue. Pressure techniques such as press fluid methods and centrifuged methods are most commonly used.

One modification of the press fluid method of Grau and Hamm (1953) was reported by Wierbicki and Deatherage (1958) in which 400 to 600 mg of fresh beef muscle sample was pressed on Whatman no. 1 filter paper in a specially made press operating under 500 p.s.i. for 1 minute. The muscle and water were subsequently measured with a polar planimeter and the relative amount of expressible water was reported as the ratio of muscle to water areas. The area of the paper wetted in one minute was found to be directly proportional to the amount of water in the expressed juice. Sanderson and Vail (1963) described a similar method in which four 500 mg samples were stacked between individual filter papers and plexiglass plates and pressure of 2000 p.s.i. was applied for 5 minutes with the Carver press. The amount of press fluid was determined by weight difference. This press fluid method may be applied to cooked meat (Asselbergs and Whitaker, 1961). This filter paper press fluid technique can apply to ground and unground tissue, with or without added water, and also to heat denatured meat (Hamm and Deatherage, 1960). This technique requires only a few minutes, a small sample (0.3 g only), and a simple apparatus (Hamm, 1960). However, the large fat content in the meat sample, and more than 100% of water

added for investigations of homogenates, are not suitable for using this technique to study WHC.

Other workers have used centrifugation as the external force. Bouton et al. (1971) used a technique involving centrifugation of muscle tissue to determine WHC. An accurately weighed meat sample of 3 to 4 g was centrifuged at 120,000 G for 30-60 minutes in a polyethylene plastic centrifuge tube. The samples were weighed before centrifuging and again after decanting the centrifugally expressed juice. The centrifugal method was adaptable to the study of meat under pressing conditions (Wierbicki et al., 1957). It is particularly appropriate for measuring changes of WHC of heated meat (Bendall, 1954; Wierbicki et al., 1957). However, there are several disadvantages in the use of this method as compared to press methods. The centrifugal method requires a larger sample (at least 2 g) and the addition of considerable amounts of water. If no water is added, it may not be possible to separate any juice from the tissue even at 14,000 r.p.m.. Adding water is not necessary if the meat is heated to 70 C, but such strong denaturation often masks changes of hydration that one might wish to observe.

Expressible moisture, which can be removed by pressure or centrifuging, may be considered to be "loosely bound" (Hamm, 1960). The method may permit a value of expressible moisture varying as much as from 12 to 30% of total water in beef in one sample. Expressible moisture has been measured and used as the indication of the water-holding capacity of the meat. However, it is not clearly associated with water originally located in any particular part of meat. Howard et al. (1960) reported that the fluid expressed under

pressure is more than is available in the extracellular spaces and it comes from all parts of muscles. The water loss from cooking may or may not be the "same" water as that removed by pressure (Locker and Daines, 1974). The remaining water, some 40-60% of the muscle weight, is described as firmly bound, but its location and the forces which hold it are uncertain.

Water activity (Aw) as a method in determining water-holding capacity of meat

Water activity (Aw) has been related to the water-binding in the meat (Brockmann, 1970). Scott (1957) defined water activity (Aw) as the ratio of the vapor pressure of water above a material (P) and the vapor pressure of pure water (Po) at the same temperature, Aw = P/Po. When the moisture concentration of the system is in equilibrium with the relative humidity (RH) of its environment, Aw is directly related to RH expressed in percent, Aw=RH/100. Hamm (1960) has reported that Aw determines water-binding in that the tightly bound water lowers vapor pressure in meat muscle.

The theory of water activity used in determining the water-binding in meat has been proposed by Brockmann (1970) as follows: "The high degree of polarity within a water molecule results in the formation of low-energy bonds between the hydrogen of one water molecule and the oxygen of another. Based on this property of water, water is bonded to polar sites of the non-aqueous

molecules of food through the hydrogen bonds. These polar sites are primarily hydroxyl, carboxyl, and amino groups. If any bonding of water molecules to polar sites of food molecules exceed that normal to pure water at the same temperature, it will cause a reduction of vapor pressure and consequently a lowering of Aw."

Brockmann (1970) proposed that the geometry of the microporous sorbents, such as represented by the voids and spaces in the fibrillar structure of muscle, affects the vapor pressure of fluid water in sorbents. Such fluid water is commonly designated as held by "capillary condensation". With meat, this capillary condensation water includes a wide range of Aw values, starting between 0.5 and 0.8 and extending to 0.99 of the water activity of fresh mammalian muscle. According to Bull and Breese (1968), binding of free water molecules reduces water vapor pressure and hence water activity. However, Vrchlabsky and Leistner (1970) found that there is no statistical correlation between water-binding and water activity in meat. Similar experimental results were shown by Leistner et al. (1971) in postmortem muscle. Therefore, as Hamm (1960) reported, the proximity of the Aw of fresh muscle and pure water is based solely on vapor pressure and is not to be confused with "loose" water as used in connection with water-holding capacity.

pH influence water-holding capacity (WHC)

Those changes in muscle structure and protein caused by pH, ions and temperature will affect water-binding through capillary

condensation (Hamm, 1960). The water immobilized by capillary condensation appears to have a continuous transition to the loose water. Consequently, the pH, ions, and temperature will alter the water-holding capacity of meat (Hamm, 1960).

Changes in WHC of muscle homogenates has been shown (Hamm, 1958 a, b; 1959) to be closely related to pH, and to be a sensitive indication of variations in the charges and structure of muscle proteins. As the pH approaches the isoelectric point of actomyosin (pH 5.0), WHC is minimum. In 1972 and 1975, Hamm stated that lower pH tightens the network of myofibrillar proteins, and thus less water can be immobilized than in the looser network existing at higher pH values. The result is a decrease in WHC.

During aging the pH of meat rises slowly, but the increase is not strong enough to explain the increase of WHC postrigor (Wierbicki et al., 1956). According to Hamm (1960) after ten days of aging only 23 to 33% of the total increase of the WHC of beef muscle is due to the increased pH. Therefore, other biochemical changes, such as loosening muscle structure during aging, are responsible for the increasing hydration effect of aged meat. The pH of aged beef usually ranges between 5.4 and 5.7. Hamm (1960) also indicated that pH and the WHC are not correlated within the range of pH 5.4 to 5.8. Only at pH values of greater than 5.8 does WHC increase significantly with increasing pH. Thus, with inappropriate slaughter technique, WHC may be higher. On the other hand, in work with pork, Swift et al. (1960) thought that in different muscles of the same animal a highly significant correlation exists between pH and the hydration of beef at pH values

below 5.8. For example, loss of WHC in PSE pork (pale- soft-exudative) parallels the abnormally rapid rate of pH fall postmortem and the resulting low ultimate pH usually attained (Briskey, 1964).

Calcium and potassium influence water-holding capacity (WHC)

The electric field surrounding each muscle protein molecule is influenced by changes in kind and/or concentration of ions present as well as pH changes. Certain ions have the ability to make or break water structure (Sikorski et al., 1976), hence they influence the immobilization of free water in tissues. The ability of an ion to alter the water structure is dependent on its electrical field (Fennema, 1977). Generally, small ions such as Na^+ and OH^-; and multivalent cations such as Ca^{++} and Mg^{++} have strong electrical fields and hence increase viscosity of water. On the other hand, large monovalent ions such as K^+ and Cl^-, having a weak electrical field, are water structure breakers and reduce the viscosity of water (Sikorski et al., 1976). However, the expected influence of ions on water structure is altered when water is involved in hydration of certain proteins (Berendsen, 1975). Swift and Berman (1959) found that calcium and potassium are intracellular components which are inversely associated with water retention.

Deatherage (1963) showed that during postmortem aging the insoluble protein from either heated or unheated beef held more water and concurrently has a net increase in positively charged ions. Some small amounts of sodium and calcium ions tended to be

released from the muscle proteins, yet a small amount of potassium and magnesium are absorbed. Hamm (1960) assured that a relative decrease in hydration capacity of muscle in the pH range 6.0-7.5 is caused by a decrease in negatively charged acidic groups through fixation of cation (Ca++, Zn++, Mg++) especially Ca++, present in the muscle. Thus, calcium content showed an inverse relationship to WHC of beef. Lee and Song's (1977) work with rabbit does agree with Hamm's (1960) finding. However, they pointed out that calcium content had no effect on WHC of rabbit meat. Lee and Song (1977) used a centrifuge method (Wierbicki et al., 1957) to determine WHC. Because of the status of this method, more work needs to be done to determine the role of calcium and its effect on WHC of meat.

Temperature influences water-holding capacity (WHC)

The decrease in body temperature upon slaughter diminishes chemical reaction rates, retards glycolysis and ATP breakdown, and reduces protein denaturation and decreases loss of water-holding capacity (WHC). Bate-Smith and Bendall (1949) found that in rabbit muscle, shortening of the muscles increased with an increase in the temperature at which rigor developed. With shortening of the rabbit muscle, the myofibrillar lattice spacings diminished and then WHC was reduced (Bendall, 1964; Goll et al, 1977).

Heat-Induced Changes in Rabbit Meat

Heating of muscle tissue has a profound effect on the structural, chemical and palatability characteristics of meat. Paul (1972) reported during heat, muscle tissue undergoes progressive physiochemical changes. In general, these changes in meat are due to denaturation and coagulation of proteins, translocation of fat and water, alteration in pH and in water-holding capacity, and chemical changes in heat-labile compounds. The type and extent of changes in meat on heating vary with the composition of the meat and with the method and extent of heating.

Changes in muscle proteins

The most drastic changes in meat during heating are those that involved the muscle proteins (Hamm, 1966). As the muscle is heated, the tissue shrinks and juice is lost due to changes in myofibril protein (Tyszkiewicz et al., 1966). During heating, due to denaturation of sarcoplasmic protein, color changes and loss of muscle enzyme activity also occur. Studies of the heating of rabbit muscle proteins by Cohen (1966) and Paul et al. (1966) showed that the solubility of myrofibrils and sarcoplasmic proteins is reduced during cooking.

The extent of alteration occurring in meat protein is dependent on heating time and temperature. The greatest decrease in the

solubility of myofibrillar proteins during heating of rabbit meat occurs at temperatures between 40°and 60°C. This has been reported by Paul et al. (1966). They found decreases in solubility of myofibrillar proteins after 30 minutes at 45°C. At this temperature, myofibrillar protein unfolds its peptide chains and forms cross-linkages (Hamm, 1960). In general, with increasing temperature or increasing time at a given temperature, the solubility of myofibrillar protein decreased; above 60°C these proteins became almost insoluble and caused disintegration. However, at 45°-55°C after two hours, heating did not cause a complete dissolubilization, conversely the solubility of myofibrillar protein increased. Paul et al. (1966) postulated that the increase in the solubility of myofibrillar protein is the result of increasing the activity of proteolytic enzymes naturally present in the muscle tissue during these temperatures. Among the myofibrillar proteins, alpha-actinin was reported to be the most labile. It became insoluble at 50°C, while actin, tropomyosin and the troponin complex were relatively heat-stable, and became insoluble at about 80°C (Cheng and Parrish, 1979). Martens and Vold (1976) observed that the myosin of bovine M. sternomandibularis muscle becomes insoluble at about 57°C whereas actin at about 80°C. In rabbit meat, Wright et al. (1977) reported that myosin became insoluble at 60°C and actin at 80 C for back muscle of rabbit meat. The larger difference is between red and white muscle types rather than muscles from different animal species (Stabursvik and Martens, 1980). The myofibrillar contraction state will affect the temperature at which the myofibrillar protein becomes insoluble.

Cohen (1966) states that rabbit myosin denatures in solution at 41°-43°C, and actomyosin at 45°-55°C.

The coagulation of sarcoplasmic proteins caused by heating results in the formation of gels which can link structural muscle elements (Davey and Gilbert, 1974). Thus, denaturation of the sarcoplasmic proteins may, to some extent, contribute to the consistency of cooked meat (Hamm, 1977).

Most of the sarcoplasmic proteins coagulate between 40°and 60°C (Hamm, 1966). In rabbit meat, Paul et al. (1966) found decreases in solubility of sarcoplasmic protein of longissimus dorsi muscle after heating two hours at 40°C. She also observed that the sarcoplasmic protein solubility increased at 50°-60°C when heated 2-10 hours. Paul et al. (1966) concluded that the increased solubility of sarcoplasmic protein is due to increased activity of proteolytic enzymes naturally present in muscle tissue. The type and number of protein ionic charges influence protein stability during heating. This has been shown by Lee and Grau (1966). They observed that the sarcoplasmic proteins with the greatest velocity in electric field are denatured most quickly during cooking of meat. This phenomena also explains the strong influence of the pH of meat on the extent of WHC loss by heating.

The heat denaturation of sarcoplasmic heme proteins (mainly myoglobin) is of particular importance because it determines the change of meat color from red to greyish brown during cooking. Myoglobin was altered significantly by holding meat at 60°C (Draudt, 1969). Ledward (1974) had indicated these changes may be due to denaturation of individual myoglobin molecules or denaturation and

interchange of various globin proteins or myoglobin molecules.

Heat also alters the properties of stroma proteins in muscle. The most important thermolabile protein of this type is collagen in connective tissue. The transition of native collagen to an almost irreversibly denaturated state occurs slowly in water with changes occurring over a temperature range of 55° to 65°C (Hormann and Schlebusch, 1968). Within this wide temperature range the following changes happened. First, a product is formed, the molecules of which can easily denature; whereas, prolonged heating leads to a practically irreversible denaturation (Hormann and Schlebusch, 1968) in which a dissociation of the collagen fiber into its alpha, beta and gamma components takes place (Tristram et al., 1965; Grassmann, 1965).

Paul et al. (1966) reported that stroma protein in rabbit meat becomes insoluble with increasing length of time at temperatures of 75°-80°C. This parallels the observations with temperature increase noticed in beef. This is thought to be caused by insolubilization of some protein constituents by extreme heat. These changes in rabbits are similiar to those explained by some of the work done with beef.

According to Mohr and Bendall (1969) the internal connective tissue (endomysium) of beef muscle accounts for about 74% of the muscle collagen. The shrinkage and partial solubilization of the endomysial collagen of bovine muscle is initiated at about 60°C and completed at approximately 70°C. On the other hand, perimysial connective tissue shrinkage requires an initial temperature of 70°C and higher before any significant fiber changes can be observed

(Davey and Gilbert, 1974b; Kopp, 1971).

McClain et al. (1969) found that crosslinks of pork and beef epimysial connective tissue were broken with increasing length of time at 85°C. The degradation of collagen to gelatin involves the rupturing of the crosslinks holding the molecules together into fibrials and fibers (Iyengar et al., 1965).

Heat treatment affects not only the collageneous fibers but also the reticular tissue. At 85°C a decrease in the visible amount of reticular fibers was evident. The elastin fibers, however, were not altered (Deethardt and Tuma, 1971). Elastin is apparently quite resistant to heat change in the temperatures normally used for cooking meat (Lawrie, 1968). In general, it can be concluded that the denaturation of muscle collagen, resulting in shrinkage and solubilization, occurs at higher temperature than the denaturation of myofibrillar proteins.

Changes in microscopic structure of rabbit muscle

The changes in microscopic appearance of rabbit meat in heating resembled in general those found in beef, but there were several exceptions (Paul, 1965). As the beef muscle is heated, the contractile fibers shrink in length and in width and the sarcomeres become shorter (Paul, 1963). Giles (1968) observed that the fine structure of the sarcomere was destroyed at temperature between 50° and 60°C. Hostetler and Landmann (1968) reported that decreases in width of the muscle fibers started soon after heating began, and

were complete at 62°C. Shrinkage in length began at about 55°C, was marked between 55° and 65°C and continued slowly as temperature increased to 80°C. In beef, heating to high temperatures caused fractures occurring increasingly at fiber surfaces and at Z-lines (Jones et al., 1977). They showed that the myofibrillar structure heated to 60°C or above, caused an increase in coagulation and compactness of the A-band portion of the sarcomere and disintegration of the I-band, producing gaps in the sarcomere structure.

Continued heating degrades the collagen from fibrous to granular form. This has been observed in rabbit and in beef muscle (Paul, 1965, 1963). The rabbit muscle fibers showed less tendency to be granulated in heated tissue as compared to beef (Paul, 1965). At longer storage times, heating tended to destroy the granulated structure of collagen, reducing it to an amorphous state. Within the bundles of rabbit muscle, heating appeared to produce some granulation from the muscle fibers themselves, from the fine collagen strands, and from the endomysial reticulum, rather than primarily from the muscle fibers as in beef (Paul, 1965). In the rabbit muscle, some of the collagen lost the granular appearance, becoming an amorphous mass.

Changes in composition

During cooking, meat changes color, becomes firmer in texture, and shrinks. The shrinkage accompanying the loss of appreciable

amount of extractives is mainly responsible for the changes in the composition of meat brought about as a result of cooking. Thus a fall in the moisture content, and an increase in the protein and lipid content are observed during cooking meat.

The water content of meat decreases when the meat is cooked. As the meat is heated, the denaturation and coagulation of the proteins lessens the water-holding capacity (Sherman, 1961). The free water is squeezed out of the tissue as the protein structure shrinks. The water carries with it the water-soluble materials such as salts, sarcoplasmic proteins, and nonprotein nitrogenous compounds.

Cooking losses are determined by measuring the weight change between raw and cooked meat, and are usually expressed as a % of the raw meat. The total cooking loss includes drip losses and evaporation losses. In rabbit meat, Paul (1964) indicated that the percent total cooking losses were significantly related to the change in the percent moisture during cooking. Among the percent of total cooking losses of 12.09-18.84%, Paul (1964) attributed 92.7% of the total cooking loss due to evaporation of moisture from the rabbit. The small amount in the drip portion of the cooking losses agreed with Doty and Pierce's finding (1961). They stated that drip loss consists primarily of fat that is melted out of the meat by heat. It may also include some water, nonvolatile water-soluble materials such as salts and the sarcoplasmic proteins that are heat-coagulated in the pan.

The amount of free water and percent total cooking loss that is lost from the cooked meat depends on the method of cooking,

especially on the internal temperature rise, cooking time, the rate of temperature rise, pH and water-holding capacity to which the meat is heated (Paul, 1972). Cooking losses increase as the internal temperature of the meat increases (Lakkonen et al., 1970). In general, losses increase with longer cooking time for a given cut and cooking method (Rogers and Ritchey, 1969). Taki (1965) collected a large amount of data on cooking bovine longissimus dorsi muscle. He concluded that the faster rate of heating caused the higher weight loss.

Paul (1964), using rabbit meat, noticed that meat of higher pH had lower cooking losses. This may be a reflection of the fact that increasing pH tends to increase the water-holding capacity of meat (Deatherage, 1963). During postrigor aging, the pH of rabbit meat increases slightly, consequently the percent of total cooking losses decreases (Paul, 1964).

A number of studies indicate that cooking often increases the amount of ether extractable material in the lean portion over that found in raw meat, on the dry basis. However, Bramblett et al. (1959) reported increased fat content in some cooked beef samples but decreased amounts in others. Several theories have been suggested to account for this increase in fat in the lean tissue on cooking. When meat is heated, much of the neutral fat is melted out of the fat cells. Wang et al. (1954) noted that the fat from the intramuscular deposits tends to flow in droplets along the path of the heat-degraded collagenous fibers. Also, the heat alteration of the muscle proteins might account for improving the extractibility of the fat in cooked meat. Results of Paul's study (1964) do show

that cooked rabbit meat has a higher fat content than raw.

Changes in the nitrogen content of meat during cooking are usually relatively small. Most of the nitrogen that is lost is found in the drippings with dry heat cooking methods, and in the cooking liquids in moist heat cooking methods. Doty and Pierce (1961) reported that 2.0 to 2.5% of the total nitrogen was found in the drippings from broiled beef steaks, mostly in nonprotein nitrogen-compounds including some free amino acids. No reports on nitrogen changes of cooked rabbit meat were located.

Changes in pH

The heating of muscle tissue as well as of myofibrils results in an increase of pH. This increase depends on the initial pH (Hamm and Deatherage, 1960). In the rabbit, if the pH of the chilled meat was 5.7 or below, the pH usually increased on cooking, while when the pH of the raw meat was above 5.7, the pH decreased on cooking (Paul, 1964). The decrease in pH postmortem muscle is a function of the glycogen supply. If the storage time has not been long enough to complete the production of lactic acid from glycogen, this pH decrease would continue, at least during the early part of the heating period, until the heat had inactivated the glycolytic enzymes which mediate this change.

The pH of the muscle tissues of rabbits increased with heating more rapidly and to a higher level as the heating endpoint temperature increased (Paul et al., 1966). From 45° to 50°C, the

maximum change was between 0.2 and 0.3, while at 70° to 80°C the change was about 0.4 pH unit. A number of other studies have reported an increase of pH on heating meat (Kauffman et al., 1964; Paul, 1964). Hamm and Deatherage (1960) attribute the shift in pH to the loss of free acidic groups by the formation of new stable crosslinkages. However, Hamm (1966) presented the view that some imidazolium groups of histidine, which are masked in the native myofibrils, are exposed by the unfolding of actomyosin molecules on heating (50° to 80° C). This in fact causes a shift in both the pH and isoelectric pH to a higher level.

Changes in water-holding capacity

The decrease of water-holding capacity (WHC) during the heating of meat, which results in the release of juice, is due to a tightening of the myofibrillar network by the heat-denaturation of the proteins. The influence of thermal treatment on the WHC of muscle mainly concerns the "free" water (Hamm, 1966). During coagulation of the myofibrillar proteins, a large part of this water becomes freely movable and is released from the tissue. Many researches concerning heat-induced changes in WHC in beef have been reported, while no studies were found on rabbit meat. According to Hamm (1966), parallel with coagulation of myofibrillar proteins in beef, the decrease in water-holding capacity (WHC) begins at about 35°C and occurs primarily at temperature between 40°and 50°C. It was noticed by Hostetler and Landmann (1968) that a decrease in

width but not in length of the muscle fibers accompany this maximum loss of WHC.

Asselbergs and Whitaker (1961) reported that the free moisture of cooked meat decreased with increased cooking time. Ritchey and Hostetler (1964) investigated the effect on free and bound water of beef longissimus dorsi steak of heating to internal temperatures of 61°, 65°, 74°, and 80°C. Overall losses of free and bound water were evident at each rise in temperature. The largest percentage of change occurred between 74°and 80°C. Ritchey (1965) found that as the internal temperature increased from 68°to 85°C, the rate of loss of free water exceeded the rate of conversion from the bound to free state, so the loss of total moisture increased.

However, a smaller proportion of juice is released between 55° and 90°C as compared to the range of 30°-50°C (Hamm, 1966; Roberts and Lawrie, 1974). This might be partially due to a shortening of muscle fibers by changes in the connective tissue, and also to an increased formation of new cross-linkages in the coagulated myofibrillar system (Hamm, 1966).

In conclusion it can be stated that changes in water-holding capacity of meat on heating occur in two primary phases: the first phase being between 30°and 50°C, and the second between 60°and 90°C (Hamm, 1966; Bouton and Harris, 1972). The temperature range between 50°and 55°C marks the transition from the coagulation process of actomyosin to a closer protein-protein interaction under the formation of new stable crosslinkages within actomyosin. During this temperature range, negligible changes occur. Changes in the first phase are due to the heat coagulation of the actomyosin

system. The second phase seems to be due to denaturation of the collagenous system (shrinking and solubilization of collagen) and/or to the formation of new stable crosslinkages within the coagulated actomyosin system (Hamm, 1966; Bouton and Harris, 1972).

Changes in meat flavor

The flavor of cooked meat arises from water- or fat-soluble precursors present in the raw meat (Dwivedi, 1975). Heating in air promotes reaction among these precursors to produce the flavor and aroma of the cooked meat. Some of these water-soluble precursors are amino acids, peptides, nucleotides and water-soluble components from adipose tissue. The amine-sugar (Maillard) reaction is considered the major reaction system in meat flavor production, but may not be the only mechanism by which flavor is developed (Wilson et al., 1973). He reported that the sulfur-containing amino acids of meat play a predominant role as precursors for meat flavor components. At high temperatures (>120°C) the sulfhydryl groups in beef proteins changed and H2S formed (Bognar, 1971). Pepper and Pearson (1969) attributed 71% of yielded H2S on heating from the water-soluble fraction in meat.

The flavor changes that occur during cooking of meat are influenced by the amount and kind of heat applied. For example, dry-heat cooked meat retained more flavor than moist-heat cooked meat. In moist heat, flavor components in the meat leached into the broth or drippings (Paul, 1972). In dry-heat methods, high

temperature on meat surfaces caused the soluble components to move from the interior to the surface of meat (Paul, 1972). Consequently, the concentration of these flavor materials increased on the surface. The flavor of cooked meat also changes with increasing degree of doneness, finally becoming unpleasant if protein and fat decomposition are carried too far. No studies of heat-induced changes in flavor were located on rabbit meat.

Effects of Heating Method on Constituents of Rabbit Meat

For many years, moist heat cooking was traditionally selected as the method to hydrolyze and soften collagen in connective tissue, whereas dry heat methods were traditionally recommended for tender pieces of meat. Conventional ovens have been employed in roasting meat in the traditional cooking method. Recently electronic or microwave heating has become a newer method. This technique is of interest because the profile of temperature developed is the reverse of that obtained in conventional heating and also heating is faster (Roberts and Lawrie, 1974). With conventional methods of cooking, heat is applied to the outside of the food, principally by conduction (Rosen, 1972). With microwave cooking, food is cooked primarily by the generation of heat within the food itself. As microwaves penetrate the food they cause oscillation of the polar molecules, which converts the electrical energy into molecular motion. The intermolecular friction creates heat that cooks the

food (Copson, 1975). Microwaves heat the entire volume of food simultaneously by conduction and by direct molecular agitation, consequently, heating rates can be increased greatly (Crapuchettes, 1968). On the other hand, for conventional cooking, the rate of heat transfer is proportional to the temperature difference between the outer surface and the inner portion, therefore, it requires a relatively longer time exposure than for comparable cooking with microwave energy. Kierebinski (1968) stated that the rate of rise of temperature is five to ten times greater on the surface and twenty times greater in the interior of beef longissimus dorsi muscle cooked by microwavve at 2450 MHz, than that obtained by boiling (Kierebinski, 1968). Very high heating rates make microwave heating an effective user of electrical power, often requiring only one-third the power consumed by a conventional heater (Crapuchettes, 1968). Hence, application of microwaves can be expected to continue to expand as costs of labor and fuel escalate, and as the shortage of natural gas for heating foods becomes more critical (Schiffmann, 1973).

One of the greatest advantages of microwave cooking is the time saving factor. Meat can be cooked four to five times faster in a microwave oven than in a conventional one (Apgar et al., 1959; Bowers and Heier, 1970). However, some research on cooking meat in a microwave oven indicate greater cooking losses of meat as compared to conventional methods, principally due to evaporation losses (Pollack and Forin, 1960; Headly and Jacobson, 1960). Ruyack and Paul (1972) postulated that the effect of microwaves on polar water molecules within the meat may account for the greater cooking loss

in meat cooked electronically as compared to its conventionally cooked counterpart. The constant change in magnetic field causes the water molecules to oscillate. This may affect the bonding of the bound water and result in greater ease of moisture loss.

As previously reviewed, heating meat causes changes in meat composition. In addition to water-holding capacity and pH, microwaves and conventional heating affect the constituents of meat in different patterns. The study of beef steaks heated by microwave showed significantly more nitrogen per unit of cooked meat (4.738 g/100g muscle) than steaks cooked by the conventional method (4.128 g/100 g muscle) (Baldwin and Tettambel, 1974). The greater amount of nitrogen in the microwave cooked meat appears to support the findings of Gat'Ko (1965). He stated that the greater amount of nitrogen in microwave cooked meat as compared to conventional cooked meat is due to additional water losses with microwave cooking. Janicki and Appledorf (1974) showed that the microwave cooked meat patties had a greater loss of crude fat as compared to conventional cooking. In a comparison of the fatty acid composition of rabbit meat processed by microwave heating and by traditional heating, Nakonechnyi et al. (1978) showed more unsaturated fatty acids in microwave heated meat than in the traditionally heated controls. Microwave cooking also showed the tendency of increasing total cholesterol in cooked beef patties, while decreases in the total cholesterol content were observed in conventional cooking (Janicki and Appledorf, 1974).

Concerning the denaturation of protein in cooked meat, microwave cooking causes less detrimental change in meat than

conventional heating at a given temperature. Roberts and Lawrie (1974) showed that beef cooked by microwaves had little loss of water soluble sarcoplasmic proteins before meat temperatures reached 65°C, while a greater loss of water soluble sarcoplasmic proteins with conventional heating of meat occurred between 45° and 65°C. They gave the reason that, since the heat is generated from the conventional oven and has to penetrate into muscle, it takes longer for a given temperature to be developed in the interior. The total time/temperature combination sustained by the proteins is thus greater and has a correspondingly greater denaturing effect than with microwave heating.

Subjective Sensory Evaluation of meat

Bratzler (1970) emphasized that juiciness, tenderness, flavor, and color are generally accepted as important factors in determining the palatabililty or eating quality of meat. These quality characteristics in rabbit meat, as a muscle food, may be evaluated by either subjective or objective procedures. Bratzler (1970) assigned human judgement as the ultimate test of quality. Many sensory studies have been performed on beef, however, no studies are located for rabbit meat.

In beef, Bouton et al. (1975) suggested that expressible juice measurements were positively correlated with juiciness in cooked meat, if the pH of the raw meat was less than 5.8. Lowe (1949) developed the method of chew count before swallowing as an

assessment of sample tenderness. This method may correlate well with instrumental tenderness measurements, but is not a true indication of tenderness due to variation in force of chew by panel members. The evaluation of flavor in meat is highly subjective in nature. Factors such as feed ingredients in the diet, animal age and sex, meat storage conditions and aging process, as well as, panelist preference, may influence flavor (Bratzler, 1970). The color of fresh meat is objectly measured by a reflectance instrument. The reflectance measurement measures the color on the surface of the meat as observed by the sensory panel and the consumer (Van den Oord and Wesdorp, 1971).

EXPERIMENTAL

Samples and Sampling Procedure

Seven New Zealand White weanling rabbits (4 weeks old) were randomly assigned to either a 28%, 54% or 74% alfalfa fiber diet and fed the experimental diets for 40 days. Diet composition is shown in the Appendix, Table 8. There was no grain in any of the fiber diets except the 28% alfalfa diet which contained 22.36% corn and 28.2% barley. All diets were pelleted and contained at least 16% crude protein, the NRC requirement for rabbit growth (NRC, 1977).

Nine-week old rabbits, reaching the market weight average of 4.48, 5.09, 4.56 pounds for the 28%, 54% and 74% alfalfa diet treatment, were slaughtered, dressed and hung 44 hours (5°C). Upon completion of hanging, carcasses were cut to obtain the left thigh, right thigh and a loin section consisting of both longissimus dorsi muscles. The cuts were subsequently frozen in a home freezer (-15° C) and stored for 1 to 2 weeks until testing.

Individual rabbit sex, live weight, percent of dress weight, and percent of abdominal fat are shown in the Appendix, Table 10 and 11. Also, the age, mortality, average live weight, average daily weight gain, average percent of dress weight and percent of abdominal fat of rabbits for each diet treatment are shown in the Appendix, Table 9 and 11.

Total moisture, pH, expressible moisture index, total protein, total lipids and total cholesterol were determined on the raw left thigh and cooked right thigh muscles. Calcium and potassium content were done on the meat from the raw left thigh muscles.

Frozen meat (-15° C) was defrosted one hour at 25° C (Precision Scientific Low Temperature Incubator Freas 815) and 15 hours at 5° C (General Electric Refrigerator). Total moisture, pH, total protein, total lipids and total cholesterol were done on the powdered excised muscle. The thigh muscles were frozen in liquid nitrogen and ground (Osterizer Cycle Blender) into powder for 30 seconds at "liquify speed". Bottom portion of rabbit tibialis cranialis muscle were used for press fluid determination. The longissiumus dorsi of both loins were used for tenderness and sensory evaluation in the associated portion of the experiment. A sampling schematic graph is shown in Figure 2.

Cooking Methods

The defrosted right thigh was microwave cooked 2.58 minutes. A Sharp Carousel Microwave Oven R-6770 (Sharp Electronics Corp., Paramus, NJ) was used with the variable cooking control on roast. Final internal temperature was recorded in the mid-portion of the semimembranosus muscle. Cooking losses (total, drip, and evaporation) and cooking yield were determined. Heating rate was also calculated. Data are shown in the Appendix, Table 12 to 15.

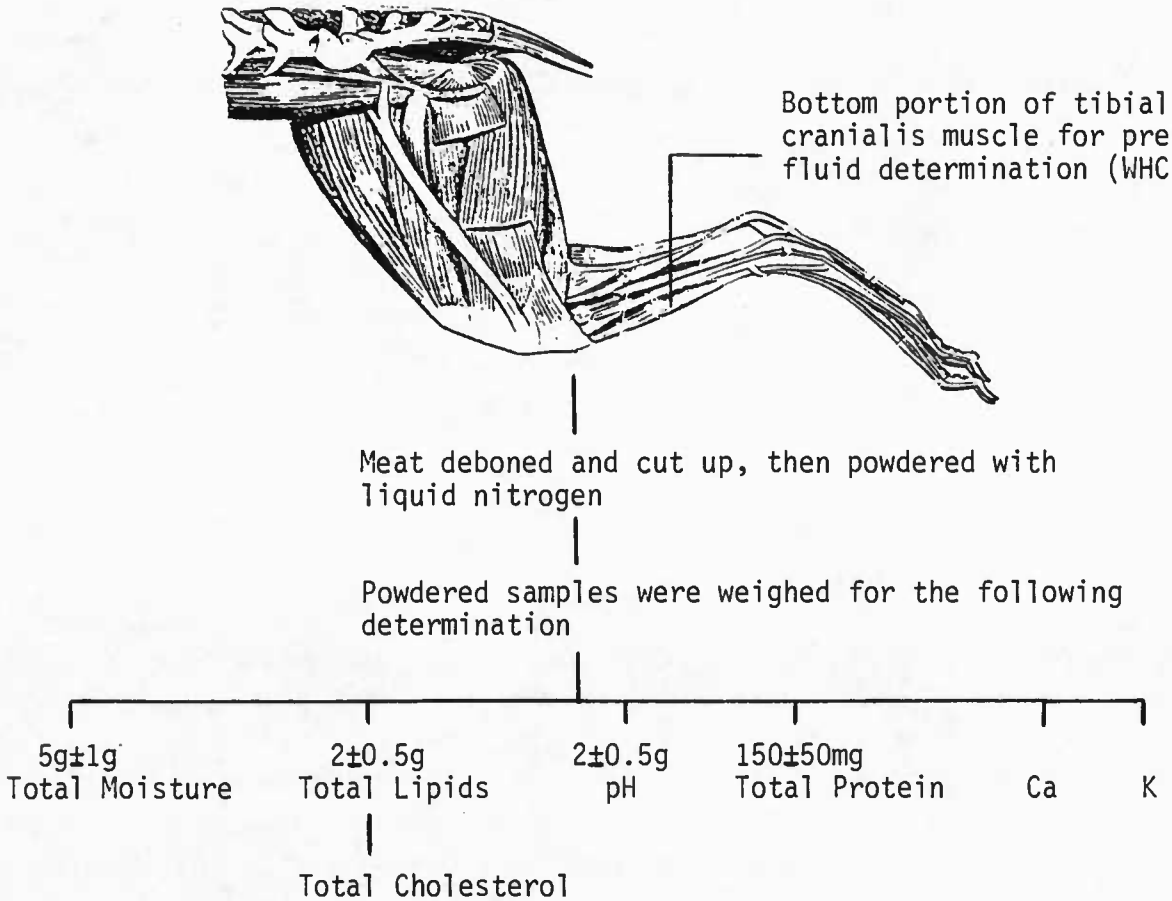

Figure 2. Sampling procedure for the thigh of rabbit meat.

Total Moisture

Moisture content was determined according to the AOAC oven method (Horwitz, 1980). Duplicate 5 g samples from each replication and treatment of liquid nitrogen-powdered rabbit meat were dried (Napco oven, National Appliance Co., Portland, Oregon, linked with Cenco vacuum pump, Central Scientific, Co., Chicago, Illinois). The moisture was calculated as the loss in percent of wet weight (Appendix, Table 16). Weights were determined to the nearest 0.001 gm on a Electronic Mettler PC 180 balance (Mettler Instrument Co., Hightstown, New Jersey).

pH Measurement

Duplicate 2 g liquid nitrogen-powdered rabbit meat were mixed with 10 ml deionized water. pH (Appendix, Table 17) was determined (Orion Research Microprocessor Ionanalyzer/901, Orion Research Inc., Cambridge, Massachusetts) after calibration (buffer pH 6.84 and pH 4.00).

Press Fluid Determination

Press fluid determinations were done on duplicate samples from the lower half of the tibialis cranialis muscle (Figure 2) of the

left raw and right cooked thigh using the method of Sanderson and Vail (1963). A Carver Press (Fred S. Carver, Inc.; W142 N9050 Fountain Blvd., Menomonee Falls, Wisconsin), at a pressure of 2000 lb/in was exerted for 5 minutes. The area wetted by the juices is directly related to the weight of water in the press juice. The water area was subsequently measured with a compensating planimeter (Keuffel and Esser Co., planimeter No. 4234, Serial No. 90789, Hoboken, New Jersey) and the relative amount of expressible water (expressible moisture index) was reported as the ratio of muscle area to juice area (Appendix, Table 18).

Total Protein

Protein content was determined according to the microkjeldahl method (Horwitz, 1980). Duplicate 0.150±0.05 g samples from each replication and treatment of liquid nitrogen-powdered rabbit meat were weighed into half piece of 3"x3" weighing paper and were stored until testing for total nitrogen. Powdered rabbit meat was oxidized in hot concentrated sulfuric acid with a catalyst mixture of HgO and K2SO4. The ammonia sulfate in the digest was then decomposed in NaOH-Na2S2O3 solution, and the ammonia was distilled into 20 ml of 4% boric acid containing methyl red-methylene blue solution as the indicator. The nitrogen content was determined by back titration with 0.02 N HCl solution, and the crude protein concentration was calculated by multiplying the amount of nitrogen by 6.25. Protein was expressed as percent of wet weight and dry weight (Appendix,

Table 19 and 20).

Total Lipids

Total lipids of duplicate samples of the raw left and cooked right excised thigh muscles were extracted by a modification of the Folch et al. (1957) procedure. A detailed schematic is shown in the Appendix, Figure 3. Two to 2.5 g of liquid nitrogen-powdered rabbit meat were weighed into a 25 ml flask and 20 ml of chloroform-methanol (2:1) were added and stoppered with a rubber stopper.

After mixing for 30 seconds, the flask was vortexed with a Deluxe Mixer (Scientific Products Co., Evanston, Illinois) at speed 6 for 2 minutes. The resulting slurry (rabbit meat and chloroform-methanol) was filtered through Whatman #1 filter paper into a 50 ml plastic graduated centrifuge tube. Flasks were rinsed with 24 ml of chloroform-methanol (2:1). The rinsed flasks were shaken 10 times and filtered into the 50 mL plastic graduated centrifuge tube with the initial slurry.

The volume of the filtrate in the graduated centrifuge tubes was measured and 0.05% $CaCl_2 \cdot 2H_2O$ was added (chloroform :methanol:$CaCl_2 \cdot 2H_2O$=8:4:3 v/v). This mixture was stirred 10 times and chloroform-methanol was used to rinse the glass stirring rod.

Centrifuge tubes of the filtrate (the filtrate of rabbit meat slurry:chloroform-methanol:$CaCl_2 \cdot 2H_2O$) were centrifuged (Sorvall Superspeed RCZ-B; Refrigerated Centrifuge, Ivan Sorvall Inc.,

Newtown, Connecticut) for 15 minutes at 3000 rpm (4°C). Total volume of the two layers in the centrifuge tubes was recorded and the upper layer was discarded by aspiration. The volume of this aspirated layer was replaced with a chloroform:methanol:0.05% $CaCl_2 \cdot 2H_2O$ (3:48:47 v/v) mixture and stirred 10 times with a glass stirring rod which was subsequently rinsed with 0.5 ml of additional solution. The centrifuge tubes were centrifuged again (3000 rpm, 15 minutes, 4°C). The upper layer was discarded by aspiration. Chloroform was added to the bottom layer to a certain volume for ease of calculating and total volume of bottom layer was recorded.

The lower layer in the centrifuge tubes were placed in a low temperature freezer (-80°C; Revco Inc., West Columbia, South Carolina) for total cholesterol and fatty acid analysis. Total lipid content was expressed on a wet weight and dry weight basis (Appendix, Table 21 and 22).

Total Cholesterol

Total cholesterol in raw and cooked rabbit thigh was determined by digitonin precipitation (Zak et al., 1954a) and acid iron colorimetry (Zak et al., 1954b). A detailed schematic is shown in the Appendix, Figure 4.

Duplicate 5 ml of the chloroform-fat layer of the lipid extracts were dried under air flow for analysis. The lipid residues were saponified and neutralized with 5 ml 10% KOH solution. The non-saponifiable materials were obtained by extracting the

saponified lipid residues 3 times with hexane and dried. Cholesterol was then precipitated as the digitonide. The digitonide was purified, redissolved in glacial acetic acid, and then treated with ferric chloride ($FeCl_3 \cdot 6H_2O$) color reagent. Thirty minutes later, the absorbance was measured in a Beckman Model DU quartz spectrophotometer (National Technical Laboratories, South Pasadena, California) at 560 mu. Different concentrations of cholesterol standards were carried through the entire procedure for total cholesterol determination. Cholesterol was expressed as mg per 100 g of rabbit meat on a wet weight and dry weight basis (Appendix, Table 23 and 24).

Calcium and Potassium

Calcium and potassium were analyzed according to AOAC 7.091-7.098 (Horwitz, 1980). These analyses were performed by Department of Agriculture Chemistry, Oregon State University, Corvallis, Oregon. Calcium and potassium are reported as mg/100g of wet weight (Appendix, Table 25).

Statistical Analysis

A complete randomized factorial design for the seven replicants of three diet treatments was used (Neter and Wasserman, 1974). Response data for total moisture, pH, expressible moisture index,

total protein, total lipids, and total cholesterol were statistically analyzed with a three-way analysis of variance to determine the prevalence of any treatment or interaction effects among diet, sex and raw/cooked factors.

Response data for live weight, percent dress weight, percent abdominal fat, calcium and potassium in raw sample, and cooking data were statistically analyzed using a two-way analysis of variance to test for significant treatment effects and interaction effects between diet treatment and sex factor. Product-moment correlation coefficients among variables was also performed.

RESULTS AND DISCUSSION

Dietary alfalfa fiber treatments in this experiment tended to have pronounced effect on daily weight gain, preslaughter weight, and carcass characteristics of the percent dress weight and the percent abdominal fat of rabbits. The proximate composition such as total moisture content and calcium content in raw meat, and total protein content on a wet weight basis in cooked meat and total cooking losses of cooked meat were affected by dietary fiber treatments. Furthermore, the interaction effects between alfalfa fiber level and the sex factor are prevalent for both the cholesterol content on dry weight basis and calcium content on wet weight basis in raw meat. Alfalfa fiber level, the sex factor and the cooking factor had significant interaction effects on total cholesterol content on both wet and dry weight basis. These results are summarized in Table 2 to Table 7 and discussed as follows. Detailed replication data and statistical analysis of variance for variables determined are recorded in the Appendix tables.

Average Daily Weight Gain, Feed Conversion and Percent Dress Weight

Average daily weight gain of rabbits fed 28% alfalfa fiber (29.4 g) was significantly lower ($p \leq 0.05$) than those of rabbits fed 54% (38.7 g) and 74% alfalfa fiber (36.1 g) diets (Appendix, Table 9). The average daily intake of diet was also highest in the group

fed a 54% alfalfa diet. Feed conversion values, or grams of weight gain per gram of feed required showed rabbits fed 28% alfalfa fiber had higher conversion values than that of rabbits fed 54 and 74% alfalfa diets. Average individual fryer weights of 68 days were significantly greater ($p \leq 0.05$) for the group fed 54% alfalfa diet than the groups fed either 28 or 74% alfalfa diet. Correlation of initial live weight vs daily weight gain was nonsignificant for overall rabbit groups fed 28, 54, and 74% alfalfa fiber diets. This suggests that although initial live weights were varied in individual rabbits, it had little effect on growth rate with respect to each rabbit group fed 28, 54 and 74% alfalfa fiber diets. This supports work of Harris et al. (1981). Rabbits tended to have heavier live weight as daily weight gain increased. This is again evidenced by the significantly positive correlation ($r = 0.800^{*}$, $p \leq 0.05$) of preslaughter live weights vs daily weight gains (Table 3). As Table 2 indicates, for rabbit groups fed 28, 54 and 74% alfalfa fiber diet, the percent dress weight (dressed weight/live weight) was similar to that found for preslaughter live weights. Results showed average daily gain, preslaughter live weight and the percent dress weight were better with rabbits fed the 54% alfalfa fiber diet compared to the 28 or 74% alfalfa fiber diet. These results suggest that an alfalfa fiber level of 54% approaches optimum level.

Table 2. Mean values for the percent of dress weight (%) and the percent of abdominal fat (%) for rabbits fed 28%, 54% and 74% alfalfa fiber diet, respectively.

Variable	Dietary treatment			Statistical Significance [a]
	28%	54%	74%	
Percent of dress weight	46.7±1.9	48.7±1.7	46.8±1.2	54>74>28 [b]
Percent of abdominal fat	1.77±0.39	2.08±0.56	1.33±0.45	54>28>74 [b]

[a] Values underscored with the same line are not significantly different

[b] Significant at ($p \leq 0.05$)

Table 3. Values of correlation coefficient for all three rabbit groups fed alfalfa fiber diets.

Variables	Correlation Coefficient (r) Raw meat	Cooked meat
Total moisture vs pH	- 0.450*	- 0.485*
Total moisture vs expressible moisture index	- 0.209	- 0.763*
Total moisture vs total protein on wet weight basis	0.457*	- 0.748*
Total moisture vs total protein on dry weight basis	0.825*	0.366
Total moisture vs calcium	- 0.051	---
Total moisture vs potassium	- 0.133	---
Total moisture vs live weight	- 0.355	---
Total moisture vs percent dress weight	- 0.194	---
pH vs expressible moisture index	0.469*	0.323
pH vs total protein on wet weight basis	- 0.044	0.213
pH vs total protein on dry weight basis	- 0.278	- 0.395
pH vs calcium	- 0.041	---
pH vs potassium	0.033	---
Expressible moisture index vs total lipids on wet weight basis	- 0.078	0.352
Expressible moisture index vs total cholesterol on wet weight basis	0.224	- 0.040
Expressible moisture index vs total protein on wet weight basis	- 0.013	0.657*

Variables	Correlation Coefficient (r) Raw meat	Cooked meat
Expressible moisture index vs calcium	-0.029	---
Expressible moisture index vs potassium	- 0.251	---
Expressible moisture index vs live weight	- 0.371	---
Total lipids on wet weight basis vs total cholesterol on wet weight basis	0.121	- 0.58
Total lipids on dry weight basis vs total protein on dry weight basis	- 0.819*	- 0.919*
Total lipids on wet weight basis vs live weight	0.265	---
Total lipids on wet weight basis vs percent dress weight	- 0.151	---
Total lipids on wet weight basis vs percent abdominal fat	0.562*	---
Total cholesterol on dry weight basis vs total lipids on dry weight basis	0.021	- 0.359
Total protein on wet weight basis vs calcium	0.026	---
Total protein on wet weight basis vs potassium	0.207	---
Total protein on wet weight basis vs live weight	- 0.262	---
Total protein on dry weight basis vs percent abdominal fat	- 0.604	---
Live weight vs percent dress weight	0.410	---
Live weight vs abdominal fat	0.537*	___
Percent dress weight vs percent abdominal fat	0.383	--
Raw weight of right thigh vs expressible moisture index	---	- 0.622*
Raw weight of right thigh vs total cooking losses	---	- 0.718*

Variables	Correlation Coefficient (r) Raw meat	Cooked meat
Raw weight of right thigh vs internal temperature	---	- 0.089
Raw weight of right thigh vs heating rate	---	- 0.982*
Cooked weight of right thigh vs expressible moisture index	---	- 0.675*
Total cooking losses vs total moisture in cooked meat	---	- 0.767*
Total cooking losses vs pH in cooked meat	---	0.340
Total cooking losses vs expressible moisture index	---	0.748*
Total cooking losses vs total lipids on wet weight basis	---	0.078
Total cooking losses vs total cholesterol on wet weight basis	---	0.275
Total cooking loss vs cooking yield	---	- 0.999*
Evaporation loss vs total moisture	---	- 0.644*
Evaporation loss vs total lipid on wet weight basis	---	- 0.002
Evaporation loss vs total cholesterol on wet weight	---	- 0.312
Evaporation loss vs total protein on wet weight basis	---	0.818*
Drip loss vs total moisture content	---	- 0.725*
Drip loss vs total lipid on wet weight basis	---	- 0.156
Drip loss vs total cholesterol on wet weight basis	---	0.154
Drip loss vs total protein on wet weight basis	--	0.734*
Initial live weight vs daily weight gain	0.134	---
Live weight vs daily weight gain	0.800	---

* Significant at ($p \leq 0.05$)

Total Moisture, pH and Water-Holding Capacity

Values of the total moisture content, pH and expressible moisture index for raw and cooked rabbit meat are given in Table 4. The total moisture content in raw rabbit meat was significantly greater ($p \leq 0.05$) for the group fed 74% alfalfa fiber diet than for the group fed 54% alfalfa fiber diet. The higher moisture content in raw meat for rabbits fed the highest 74% alfalfa fiber diet confirmed the findings of Spreadbury and Davidson (1978). No significant differences between the groups fed 28 and 54% alfalfa fiber diet and between the groups fed 28 and 74% alfalfa fiber diet in the total moisture content of raw rabbit meat were observed. In cooked rabbit meat of groups fed 28, 54 and 74% alfalfa fiber diets, values obtained for the total moisture content were not statistically different. Cooking reduced the moisture content approximately 4.8 to 6.3% from that in the raw rabbit meat. As Paul (1964) has indicated, total moisture is lost largely through evaporation and to a small amount in drip during heating.

Mean values of total moisture content in raw rabbit meat fell into the range of 73.6 to 74.4% (Table 4). Similar values were reported by other researchers (Table 1). Total moisture content of rabbit meat has been reported to vary with species, age, live weight and diet (Zupka et al., 1978; Spreadbury and Davidson, 1978; Chen et al., 1978). As animal grow older, the live weight increases and total moisture content decreases in the meat. Compared to other edible meats (Table 1), rabbit meat seems to have higher moisture

Table 4. Mean values for total moisture (%), expressible moisture index and pH in both raw and cooked meat.

Variable	Dietary treatment (%)			Statistical Significance [a]
	28%	54%	74%	
Raw meat				
Total moisture	74.0±0.4	73.6±0.6	74.4±0.4	74>28>54 [b]
Expressible moisture index	0.454±0.09	0.400±0.07	0.371±0.043	
pH	5.685±0.038	5.672±0.038	5.612±0.094	
Cooked meat				
Total moisture	67.7±1.3	68.8±1.1	69.2±1.6	
Expressible moisture index	0.502±0.066	0.454±0.051	0.458±0.071	
pH	5.885±0.06	5.918±0.061	5.834±0.079	

[a] Values underscored with the same line are not significantly different

[b] Significant at ($p \leq 0.05$)

content than that of beef or pork and seems to be similar to that of chicken. This may be due to the fact that beef and pork have higher fat deposits than rabbit meat does.

The pH in both the raw and cooked rabbit meat were similar among groups fed 28, 54 and 74% alfalfa fiber diet (Table 4). Mean values of the pH in raw and in cooked rabbit meat for all rabbit groups fed alfalfa fiber diets were 5.656 and 5.879, respectively. Paul (1964) reported that when raw rabbit meat was in cold storage for more than 12 hours, the pH of the meat would be 5.7 or below. She also indicated that the rabbit carcasses would pass through the development and resolution of rigor within 12 hours. It implies that the rabbit carcass used in the current study had passed through rigor when meat was analyzed for composition, pH and water-holding capacity. This would make data from the analysis of rabbit meat comparable with other kinds of postmortem muscle meat. Lee and Song (1977) reported that when meat from the longissimus dorsi muscle of 10 month-old rabbits and 18 month-old crossbreed cattle were removed after storage at 0°-3°C for 24 hours, the pH of rabbit and beef meat were 6.3 and 5.7, respectively. The pH of raw rabbit meat obtained in the current study was different from their study. This is probably due to the difference in diet treatment, animal breed, age and part of muscle used for analysis. The study of Paul (1964) showed that the pH of raw and cooked longissimus muscle from 4 to 5 month-old New Zealand White rabbit were 5.45 and 5.73, respectively. This again showed pH was affected by many intrinsic factors such as animal species and breeds and extrinsic factors such as pre- and post-slaughter conditions.

Hamm and Deatherage (1960) stated that the amount of changes in pH on heating is a function of the initial pH of raw meat. Paul (1964) stated that in rabbit meat, if the pH of the chilled meat was 5.7 or below, the pH usually increased on cooking. A later study of Paul et al. (1966) pointed out that the pH of rabbit meat increased rapidly to high level (pH 6.00) as heating temperature was increased. In the current experiment, the initial pH of 5.61-5.69 of raw meat (left thigh) increased 0.2 pH units (right thigh) after cooking to the temperature range of 72.2° to 73.9°C (Table 4). This result is similiar to that reported by Paul et al. (1966). They reported that at 70°C heating temperature, there was about a 0.25 pH unit increase in cooked rabbit meat from the initial pH 5.69 of raw rabbit meat. Although the initial pH in the current experiment was recorded from raw left thigh meat and the pH of cooked meat was recorded from right thigh meat, the symmetry between meats taken from the left and right thigh on several meat characteristics such as total moisture content, protein, lipids, pH and expressible moisture index has been confirmed by Fischer and Rudolph (1979).

Expressible moisture index (EMI) is expressed as water area pressed out over meat area, which is an indicator of water-holding capacity (WHC). The higher the value of index, the lower the WHC of meat. Mean values of EMI of both raw and cooked rabbit meat for all three rabbit groups fed alfalfa fiber diets were 0.408 and 0.472, respectively. Although there is no significant difference ($p \leq 0.05$) found among the means of the EMI of both raw and cooked meat in each group fed 28, 54 or 74% alfalfa fiber diet, there is a tendency toward a higher EMI in the raw meat of the rabbit group fed the

lower fiber diet (Table 4). Since the WHC determined in different studies varies from method to method, it is difficult to compare values of EMI in this current study to the WHC of rabbit meat and of other meats done by other researchers. However, Lee and Song (1977) compared the WHC between rabbit meat and beef using a centrifuge method (Wierbicki et al., 1957). The longissimus dorsi muscle of both rabbit and beef carcasses was removed after storing them at 0° -3° C for 24 hours. The WHC was expressed as the ratio of total moisture in sample-free water over the total moisture content in the sample meat. The higher the ratio, the lower the WHC. The rabbit meat had lower WHC (ratio = 67.7%) as compared to beef (ratio = 58.9%). Lee and Song (1977) also showed that the pH of meat had direct relationship with the WHC of both beef ($r = 0.64^{*}$, $p \leq 0.05$) and rabbit muscle ($r = 0.71^{*}$, $p \leq 0.01$).

The EMI in cooked rabbit meat is significant higher than in raw rabbit meat. The considerable decreases of water-holding capacity in cooked meat may be due to a tightening of the myofibrillar network by the heat denaturation of muscle proteins at temperature range 72.1° to 73.9° C. At this temperature range (72°-74°C), the myofibrillar proteins of rabbit meat have become insoluble (Wright et al., 1977).

The sex factor did not significantly contribute to the difference among the three rabbit groups fed alfalfa fiber diets in total moisture, pH and expressible moisture index for both raw and cooked rabbit meat (Appendix, Table 31). Also, diet treatments, cooking factor and sex factor did not show interactions for the above parameters.

Correlation

The correlations among live weight, percent dress weight, total moisture, value of pH and expressible moisture index for all rabbit groups fed three alfalfa fiber diet are shown in Table 3. Total moisture showed no significant correlation ($p \leq 0.05$) to live weight and the percent dress weight. It is recognized that as the animal increases in age the moisture content decreases (Zupka et al., 1978). Rao et al. (1978) reported that the moisture content in raw rabbit meat was significantly decreased as slaughter age decreased, furthermore, live weight was significantly increased as the slaughter age increased (Chen et al., 1978). Consequently, the moisture content in rabbit meat decreased as the live weight increased. This contradicted the results of the current study. This contradiction may be explained by the high fiber diet having a stronger influence over the live weight effect on total moisture content in rabbit meat.

For raw rabbit meat, the total moisture content significantly negatively correlates to pH ($r = -0.450^{*}$, $p \leq 0.05$), but not to the expressible moisture index ($r = -0.209$, $p \leq 0.05$) (Table 3). On the other hand, pH is significantly positively correlated to EMI ($r = 0.469^{*}$, $p \leq 0.05$). For the cooked meat, the total moisture content is also significantly negatively correlated to both pH ($r = -0.485^{*}$, $p \leq 0.05$) and EMI ($r = -0.763^{*}$, $p \leq 0.05$). However, with cooked rabbit, pH is not significantly correlated to EMI of cooked meat. Other workers have indicated a relationship of pH and WHC. Deatherage

(1963) indicated that the water-holding capacity (WHC) of beef was minimal at isoelectric pH 5 to 5.5. This is because low pH tightens the network of myofibrillar proteins and thus decreases the WHC of meat (Hamm, 1960). The significant correlation between pH and EMI for raw, but not for cooked rabbit meat, agrees with the findings of Swift et al. (1960) in beef. There exists a high correlation between pH and the WHC of beef at pH value below 5.8. In the current study, raw rabbit meat has an average pH 6.656 for three groups fed alfalfa fiber diet, while cooked rabbit meat has a pH 5.875.

Total Protein and Total Lipids

Mean values for total proteins and total lipids content in both raw and cooked meat are reported on wet and dry weight basis in Table 5. No significant differences for total protein in raw rabbit meat on wet and dry weight basis and in cooked meat on dry weight basis were observed for all three rabbit groups fed alfalfa fiber diet. Yet, cooked meat on wet weight basis did show that the rabbit groups fed higher alfalfa fiber diet (54% and 74%) contained a significantly ($p \leq 0.05$) lower amount of protein than in the group fed lower 28% alfalfa fiber diet.

The total lipid contents (Table 5) of both raw and cooked meat were similar in all three groups fed alfalfa fiber diet, with the highest value for the group fed 54% alfalfa fiber diet and the lowest value for the group fed 28% alfalfa fiber diet (Table 5).

Table 5. Mean values for total protein (%), total lipids (%), and total cholesterol (mg/100g) in both raw and cooked meat on wet and dry weight basis.

Variable	On wet weight basis			Statistical[a] Significance	On dry weight basis			Statistical[a] Significance
	28%	54%	74%		28%	54%	74%	
Raw meat								
Total protein	21.97±0.48	21.89±0.55	21.99±0.71		84.59±2.63	82.97±3.18	85.86±4.00	
Total lipids	3.37±0.77	3.85±0.66	3.50±1.01		12.95±2.83	14.55±2.26	13.60±3.70	
Total cholesterol	76.5±10.3	70.1±7.0	78.2±8.0		294.2±38.2	265.6±24.4	304.9±28.5	
Cooked meat								
Total protein	27.93±1.14	26.01±0.91	26.62±0.79	28>74>54[b]	86.56±1.75	83.47±2.97	86.35±2.58	
Total lipids	4.21±0.65	4.84±0.88	4.08±1.15		13.04±1.82	15.50±2.44	13.11±2.95	
Total cholesterol	78.9±5.4	78.2±7.0	82.7±7.3		244.8±21.0	250.6±18.7	268.6±23.9	

[a] Values underscored with the same line are not significantly different

[b] Significant at ($p \leq 0.05$)

The higher protein and lower fat content in rabbit meat in the high fiber diet confirmed Spreadbury and Davidson's (1978) findings. The higher protein and lower fat content of rabbits fed higher fiber diet may have important market appeal.

The overall mean values (Table 5) for total protein and total lipid in raw meat from rabbits fed three alfalfa fiber diet were, on wet weight basis, 21.95% and 3.57%, respectively. These values were close to those reported by Zupka et al. (1978) who studied 9-10 weeks old New Zealand White rabbit. The rabbits each weighed 1.538 kg with a total protein of 22.64% and total lipids of 2.34% in the hind quarter, while 14-16 weeks old New Zealand White weighed 2.459 kg with total protein content of 22.06% and total lipids of 2.81% (Table 1). On the other hand, Rao et al. (1978) reported that 8 weeks old rabbit have a total protein of 18.7% and total lipids of 7.9% in the edible flesh, while 16 weeks old rabbits have a total protein of 19.4% and total lipids of 10.9% (Table 1). Again, these studies showed the composition in rabbit meat varies depending upon the part of muscle analyzed, age, slaughter live weight, and diet.

Comparing the total protein and total lipids content (Table 5) in raw rabbit meat to other edible meat, it appears that the total protein content in rabbit meat is close to that in chicken meat and slightly higher than in pork (17.09%), while lipid content was quite low as compared to beef (7.4%) and pork (24.87%)(Table 1).

Diet treatment and the cooking factor interaction does exist for total protein in rabbit meat on wet weight basis (Appendix, Table 27). This indicates that cooking increased the protein content in cooked meat of all three groups fed alfalfa fiber diets,

likely due to loss of water by evaporation and drip. No diet treatment by sex factor interaction was observed for protein content in both raw and cooked rabbit meat.

For all three groups fed alfalfa diet, cooked meat does have a significantly larger amount of total lipids than raw meat on wet weight basis (Table 5). However, on the dry weight basis, no significant difference between raw and cooked rabbit meat for all three groups fed alfalfa diet was observed (Table 5). Lowe and Kastelic (1961) also reported no significant difference between raw and cooked samples for total lipids content. Although the current experiment showed no significant difference ($p \leq 0.05$) in the total lipids content between raw and cooked meat for all three alfalfa fiber groups, there is a tendency toward cooked meat having a higher lipid content than raw meat. Many studies (Weir et al., 1962; Woolsey and Paul, 1969) pointed out that it might be due to infiltration of melted fat from the external fat covering during heating and the heat alteration of the muscle proteins improving the extractability of the fat.

Sex difference did not significantly affect the lipids content of either raw or cooked rabbit meat for all three groups fed alfalfa fiber diet (Appendix, Table 33). This agreed with the study of Raimondi et al. (1974) that indicated sex of the rabbit had little effect on meat composition such as lipids content.

Correlation

The correlation of lipids vs live weight, lipid vs the percent abdominal fat, total protein vs live weight, and total protein vs the percent abdominal fat are presented in Table 3. Increases in live weight do not appear to increase the total lipids or decrease the total protein content of rabbit meat. Other factors, such as diet ingredients, have been reported to have a predominant effect on the total protein and lipid content of rabbit meat (Chen et al., 1978; Spreadbury and Davidson, 1978). Raimondi et al. (1974) reported that the high-energy diet significantly increased the moisture content and decreased the lipid content in rabbit meat. This again showed the diet composition effect on meat composition. In the current study, the findings of Raimondi et al. (1974) held true for the group fed 28% alfalfa fiber diet. This diet has the highest energy values and the resulting rabbit meat had the lowest fat and moderate moisture content as compared to groups fed either 54 or 74% alfalfa fiber diet. Other than digestible energy in the diet, the diet fiber level may affect the meat composition. Spreadbury and Davidson (1978) reported that in a high fiber diet, the body fat and dry matter of the carcass were lower than for the lower fiber diet. However, the current experiment did not agree with their findings. The lipids content (Table 5) in the raw meat tended to be 0.13-0.48% higher in the high fiber diet (54% and 74%) than in the low fiber diet (28%). The higher daily weight gain and the heavier preslaughter live weight in the high fiber diet than in

the low fiber diet probably are the reasons.

There is a high correlation of total protein (wet weight basis) vs total moisture content ($r = 0.457^{*}$, raw; $r = -0.748^{*}$, cooked, $p \leq 0.05$), total protein (wet weight basis) vs expressible moisture index ($r = 0.657^{*}$, cooked, $p \leq 0.05$), total protein (dry weight basis) vs total lipids (dry weight basis) ($r = -0.819^{*}$, raw; $r = -0.919^{*}$, cooked, $p \leq 0.05$) (Table 3). The higher the moisture content, the higher the total protein content is in the raw meat. In the current experiment, for the cooked meat, there is a high correlation between EMI and total moisture ($r = -0.763^{*}$) and between EMI and total protein on wet weight basis ($r = 0.657^{*}$). As the total protein in cooked meat decreased, the EMI decreased, its water-holding capacity (WHC) increased, and, consequently, total moisture in meat increased. This is probably due to heating altered muscle protein and reducing the WHC in cooked meat (Table 4), with more moisture being lost through cooking, and, consequently less moisture retained in cooked meat. Thus, moisture loss leads to an increased protein content in cooked meat on wet weight basis. The total protein content in raw and in cooked meat were inversely correlated to total lipids content. It has been recognized that as more lean meat builds up, less fat will be deposited in the animal body during growth.

Total Cholesterol

Mean values of total cholesterol in both raw and cooked rabbit

meat on wet and dry weight basis are shown in Table 5. The total cholesterol values were similar in raw meat for the three groups fed alfalfa fiber diets, with the highest value, 78.2 mg/100g on a wet weight basis (304.9 mg/100g, dry weight basis), for the group fed 74% alfalfa fiber diet. The lowest values, 70.1 mg/100g on wet weight basis (256.6 mg/100g, dry weight basis), were observed in the rabbit group fed 54% alfalfa fiber diet. For the cooked meat, alfalfa fiber level did not have a significant effect on the total cholesterol content, yet the lowest values of total cholesterol content on dry weight basis were associated with the group fed 28% alfalfa fiber diet.

Mean values of total cholesterol in raw and cooked meat for all three groups fed alfalfa fiber were 288.2 mg/100g and 254.7 mg/100g on dry weight basis, respectively (Table 5). These values were close to the study of Lee and Ahn (1977) who reported that raw rabbit meat has 294 $\pm$ 47 mg/100g on dry weight basis (Table 1). However, Rao et al. (1979) reported that rabbit meat has 473 mg/100g total cholesterol on dry weight basis. The reasons for this variation may be due to the analyzing methods, intrinsic factors such as breed and species, and extrinsic factors such as diet composition. Sweeney and Weihrauch (1976) reviewed different analyzing methods on results of total cholesterol content in foods. In the study of Rao et al. (1979), the A.O.A.C. method was used. The Liebermann-Buchard reagent in A.O.A.C. method is relatively lacking specificity which would give colors with other unsaturated compounds and the possible presence of small amounts of sterols other than sitosterol or stigonasterol which could react with

greater intensity. Lee and Ahn (1977) also stated that among animals, the rabbit is known to be most sensitive to dietary changes. Thus different diets fed to animals may affect the amount of total cholesterol content in rabbit meat. Further research in this area needs to be done.

Although cooked rabbit meat has a significantly higher total cholesterol content than raw rabbit meat on a wet weight basis (Table 5), after calibrating for variation in moisture content, the total cholesterol content was higher in raw meat than cooked meat on a dry weight basis for all three groups fed alfalfa fiber diets. This agreed with the work of Lee and Ahn (1977) who compared the effect of different cooking methods on the cholesterol retention in cooked rabbit meat. They concluded that heating reduced the cholesterol in cooked rabbit meat, especially the boiling method. Rabbit meat has been reported as containing a high amount of polyunsaturated fatty acids (Lee and Ahn, 1977; Kostenko et al., 1980). Thus, the cholesterol likely esterifies with these unsaturated fatty acids. This has been shown by evidence of a higher cholesterol ester than free cholesterol in the component of total cholesterol in the rabbit meat (Tu et al., 1967; Lee and Ahn, 1977). During heating, specially dry heat roasting, the polyunsaturated fatty acid has been shown to decrease, the autoxidation of this lipid may cause total cholesterol degradation (Bergstrom and Samuelsson, 1961). Also some loss of cholesterol may be attributed to the transport of the cholesterol in the cooking drips (Tu et al., 1967).

In the current experiment, there is a significant difference

due to the sex factor and diet treatment interaction in the total cholesterol content of raw rabbit meat on a dry weight basis (Appendix, Table 34). In the female rabbits, the total cholesterol content in the group fed 74% alfalfa fiber diet was significantly higher ($p \leq 0.05$) than the other two groups, while in the males, no significant differences were observed for all three groups fed alfalfa fiber diet (Appendix, Figure 8). On the other hand, in group fed low 28% alfalfa fiber diet, the males more easily deposited cholesterol in the meat than that in the females. It appears that not only the alfalfa fiber levels but also the sex difference affects the total cholesterol content in the raw meat. Additionally, heating effects would influence the total cholesterol content of rabbit meat for both sexes of rabbits fed alfalfa fiber diet. Analysis of variance showed that diet treatment, sex factor and heating factor interaction exists for total cholesterol content in cooked rabbit meat on wet and dry weight basis (Appendix, Table 41 and Figure 7 and 8). In the females, total cholesterol is higher in raw meat than in cooked meat for rabbits fed high 74% alfalfa fiber diet on a dry weight basis. In the males, total cholesterol content in meat seems to be more sensitive to heat degradation for rabbits fed 28% alfalfa fiber diet. The reasons for this are not known.

Correlation

The cholesterol of the muscle tissue is an integral part of membranes such as sarcoplasmic membrane of the muscle fibers (Cornwell and Horrocks, 1964). If intramuscular fat contains little or no cholesterol, the total cholesterol content of muscle should decrease appreciably with an increase in lipid concentration (Tu et al., 1967). According to Okey (1945), beef round (medium fat) with 4.6% lipids, contained 125 mg/100g total cholesterol, while a leaner cut (2.1% lipids) possessed 95 mg/100g. This reported data suggests that total cholesterol in beef is related to lipid content. However, Tu et al. (1967) reported that the total cholesterol content in both beef and pork muscle increased slightly with a rise in percent of lipids. Between about 2% and 10% muscle lipid, an increase of 1.7 mg/100g and 0.5 mg/100g in total cholesterol per 1% increase in lipid content was estimated for beef and pork muscle, respectively. An increase of 21 mg/100g in total cholesterol per 1% increase in lipid content was observed for raw rabbit meat on both wet and dry weight bases (Table 5).

Total Calcium and Potassium

The calcium and potassium content of raw rabbit meat on wet weight basis are shown in Table 6. Alfalfa fiber level seems to significantly ($p \leq 0.05$) affect the calcium content of rabbit meat, with the highest content in the group fed 28% alfalfa fiber diet.

Table 6. Mean value for calcium (mg/100g) and potassium (mg/100g) in raw meat on wet weight basis.

Variable	Dietary treatment (%)			Statistical Significance[a]
	28%	54%	74%	
Calcium	18.363±2.548	11.077±8.389	10.263±1.214	28>54>74[b]
Potassium	387±166	397±26	394±48	

[a] Values underscored with the same line are not significantly different

[b] Significant at ($p \leq 0.05$)

Similar calcium content was found in the meat of rabbit fed 54 and 74% alfalfa fiber diets. Branch et al. (1975) found that fiber from plants low in phytate bound calcium in vitro in proportion to its uronic acid content. Since alfalfa contains about 25% of fiber (Cheeke, 1980), the property of fiber chelating with divalent minerals effects may account for the fact found in the current experiment. The data suggests calcium deposited in rabbit meat decreases as alfalfa fiber level fed to rabbits increase, regardless of the increased calcium content in diet with higher alfalfa fiber level. However, if Blanco and Gueguen's (1974) statement about "bacterial action in the cecum and colon rendering plant minerals available to rabbit" is true, the alfalfa fiber level in a diet should not have a significant effect on the calcium content of meat. On the other hand, rabbit has been reported as having a unique metabolic route that absorbs large quantities of calcium and excretes the excess in urine (Cheeke and Amberg, 1973). Whether the absorbed calcium will deposit in soft tissue is still questionable. Thus, more research needs to be done to explain why calcium deposited in rabbit meat decreased as alfalfa fiber level increased. Different levels of alfalfa fiber diets did not show significant ($p \leq 0.05$) effect on the potassium content of raw rabbit meat (Table 6).

The overall mean values for calcium and potassium for all three groups fed alfalfa fiber diets were 13.234 mg/100g and 393 mg/100g, respectively (Table 6). The calcium content in raw rabbit meat was close to that reported by Rao et al. (1979), yet the potassium

content was much higher. As discussed previously, this may be due to the effect of different diets in his study and the current one, since rabbits have been recognized to be sensitive to diet changes (Lee and Song, 1977). No detailed information about the diet composition for raising rabbit in the study of Rao et al. (1979) was reported. It has been reported that alfalfa is high in calcium and potassium (Chapin, 1965 and 1967), which may contribute to the higher content of calcium and potassium in rabbit meat as compared to other kinds of meats such as chicken, beef and pork (Table 1). Chicken, beef and pork have a value of calcium 11 mg/100g and potassium 255 mg/100g, calcium 11.9 mg/100g and potassium 340 mg/100g, and calcium 9.9 mg/100g and potassium 274 mg/100g, respectively.

Diet treatment and sex factor do have significant interaction effect on the calcium content of raw rabbit meat (Appendix, Table 35). In the female, calcium in meat from rabbits fed 28% alfalfa fiber diet was significantly higher ($p \leq 0.05$) than the other two groups fed either 54 or 74% alfalfa fiber diet (Appendix, Figure 9). In the males, percent of alfalfa fiber level has significant effect on calcium content of rabbit meat, with highest calcium content in rabbit meat fed 54% alfalfa fiber diet, with lowest calcium content in the group fed 74% alfalfa fiber diet. On the other hand, for each level of alfalfa fiber diet, only male rabbit meat in the group fed 54% alfalfa fiber diet has significantly higher content of calcium than female rabbit meat does. For the potassium content of raw rabbit meat, sex factor did not have an interaction effect on this parameter (Appendix, Table 35).

Correlation

Correlations of calcium and potassium vs total moisture content, pH, water-holding capacity and total protein, respectively, are shown in Table 3. Although calcium in all three groups fed alfalfa fiber diet did not highly correlate to the total protein content in raw meat, it is recognized that calcium in Ca++ ion form participates in the muscle contraction-relaxation cycle (Bailey, 1972; Goll et al., 1974). Thus the rabbit with high calcium content in meat when fed 28% low alfalfa fiber diet, may have the hyperactive tendency as compared to other groups. No data were collected in the current study to prove above postulation.

Swift and Berman (1959) stated that calcium, as one of the intracellular components, has an effect on water retention in the meat. However, the current study showed little correlation between calcium and expressible moisture index (EMI). These is a slight correlation between calcium and pH. Since pH is a sensitive indication of variations in the charges and structure of muscle proteins, and is closely relate to water-holding capacity (WHC) of meat (Hamm, 1960) this would be expected. The current work agreed with Lee and Song's (1977) findings who found the calcium ion has no effect on WHC of rabbit meat. The current results do contradict relationships reported by other studies using beef as a sample. Detailed studies comparing beef and rabbit meat using the same technique to determine the effect of the calcium ion on WHC of meat

would help to explain the effect of the calcium ion on WHC of rabbit meat.

Potassium is found mainly in the intracellular fluid of mammals (Manery, 1954). Since most of the intracellular fluid is present in the muscular tissue, the higher the proportion of muscular tissue in an animal, the higher the proportion of potassium would be (Anderson, 1959). In the current experiment, potassium did not significantly correlate to the protein content of rabbit meat ($r = 0.209$, $p \leq 0.05$, Table 3). Deatherage (1963) showed that during postmortem aging of beef, the muscle proteins of beef absorbed a much greater amount of potassium and magnesium ions than other ions. These absorbed ions will alter the charge of acidic group of muscle protein, and an increase in pH during aging could account for some increase in WHC.

Total Cooking Losses

Raw and cooked weight of right thigh, internal temperature, cooking rate, total cooking losses (%) and cooking yield (%) are reported in Table 7. The meat from rabbit fed 28% alfalfa fiber diet had significantly ($p \leq 0.05$) higher total cooking losses and lower cooking yield as compared to the group fed either 54 or 74% alfalfa fiber diet. Thus cooking yield (%) is lowest with 28% alfalfa fiber diet group. No significant difference was found in raw weight of right thigh from rabbit groups fed three alfalfa fiber diets. After cooking, the cooked weight of right thigh was

Table 7. Mean values for raw and cooked weight of right thigh sample (g), internal temperature (°C), cooking rate (g/min), total cooking losses (%), and cooking yield (%), on wet weight basis.

Variable	Dietary treatment %			Statistical[a] Significance
	28%	54%	74%	
Raw weight of right thigh	145.6±15.8	168.6±21.0	148.2±16.6	54>74>28[b]
Cooked weight of right thigh	120.8±16.1	148.1±21.3	128.0±17.9	54>74>28[b]
Internal temperature	73.9±6.3	72.5±6.6	72.2±4.4	
Cooking rate	0.018±0.0017	0.016±0.0022	0.018±0.0018	
Total cooking losses	17.22±3.19	12.33±1.88	13.81±3.17	28>74>54[b]
Cooking yield	82.79±3.18	87.67±1.88	86.19±3.17	54>74>28[b]

[a] Values underscored with the same line are not significantly different

[b] Significance at ($p \leq 0.05$)

significantly different among the rabbit groups fed three alfalfa fiber diets. As seen in cooking yield (%) data, cooked weight of right thigh from rabbits fed 28% alfalfa fiber diet is the lowest among three rabbit groups fed different alfalfa fiber diets. Therefore, the higher the total cooking losses, the lower the cooking yield and cooked weight of right thigh.

Heat altered muscle protein frees water previously immobilized in the protein structures. The amount of this freed water that is lost from meat, namely total cooking losses, depends on the method of cooking, especially on the internal temperature and the rate of temperature rise to which the meat is heated. However, in the current study, no significant difference ($p \leq 0.05$) in internal temperature rise (Table 7) and cooking rate were noticed among the cooked meat from the three groups fed different alfalfa fiber diets.

Correlation

It is recognized that total cooking losses may be affected by moisture content, water-holding capacity (WHC), pH, and lipids content of meat and weight of meat cut. Total percent of cooking losses is highly negatively correlated to the total moisture content ($r = -0.767^{*}, p \leq 0.05$) in cooked rabbit meat, and is highly positively correlated to expressible moisture index (EMI, $r = 0.748^{*}$) (Table 3). No significant correlation was found between the total cooking losses and pH of cooked rabbit meat. The total cooking losses were appreciably affected by the total moisture content in cooked meat,

and an average of 72.43% of total cooking losses was due to evaporation (Appendix, Table 14 and 15). This agreed with Paul's (1964) finding; however, she reported that 90% of total cooking losses was due to evaporation. The microwave cooking method used here may account for this difference. Also, the higher the total cooking losses, the higher the EMI and the lower the WHC. As Ritchy (1965) indicated that as the internal temperature increased from 68° to 85° C, the rate of loss of free water exceeded the rate of conversion from the bound to free state, thus the WHC decreased and the total cooking losses increased.

The highly significant correlation of raw weight of right thigh sample versus expressible moisture index ($r = -0.622^{*}$, $p \leq 0.05$) showed that the raw weight of right thigh sample has a significant effect on the total cooking losses ($r = -0.718^{*}$, $p \leq 0.05$) (Table 3). As the raw weight of the right thigh sample increased, the water-holding capacity increased. The increased WHC of rabbit meat corresponded with total cooking losses decrease. In the current study, the pH of cooked meat did not significantly correlate to EMI ($r = 0.323$). pH did not significantly affect the total cooking losses either.

Total cooking losses were not highly affected by fat content in this current study. Since the low total fat content in cooked meat on wet weight basis was slightly related ($r = 0.078$) to total cooking losses and was significantly negatively correlated to the moisture content of cooked meat ($r = -0.767^{*}$, $p \leq 0.05$, Table 3) this lack of fat effect would be expected. These results agreed with Paul's (1964) finding that cooking drip in roasting is largely fat and less than 10% of the total cooking losses was due to drip loss.

SUMMARY

The proximate composition, pH and water-holding capacity of raw and cooked meat from rabbits fed three different alfalfa fiber diets were determined. The three different alfalfa fiber diets contained 28, 54 and 74% alfalfa meal, respectively.

Daily weight gain, preslaughter weight, percent dress weight and percent abdominal fat were significantly ($p \leq 0.05$) affected by alfalfa fiber level treatments. Alfalfa fiber level also significantly ($p \leq 0.05$) influenced the proximate composition of total moisture and calcium in raw rabbit meat, and total protein on wet weight basis in the cooked meat and total cooking losses of cooked meat. Comparing the proximate composition and pH of both raw and cooked rabbit meat, cooked rabbit meat showed higher values than raw meat, except for the total cholesterol content on dry weight basis. Alfalfa fiber level and the sex factor had an interaction effect on the total cholesterol content on dry weight basis, and calcium on wet weight basis in raw meat. The total cholesterol content on both wet and dry weight basis was significantly ($p \leq 0.05$) affected by the interaction effects among alfalfa fiber level, the sex factor and cooking.

In raw meat, the 54% alfalfa fiber diet caused relatively higher preslaughter weight, percent dress weight, and percent abdominal fat, and less total moisture content than the rabbit groups fed the 28 and 74% alfalfa fiber diets. The cooked meat from rabbit fed 54% alfalfa fiber diet had a lower protein content and

total cooking losses as compared to the other two alfalfa fiber diets. It is concluded that the 54% seems to be the optimum alfalfa fiber level for rabbit to maintain optimum growth and to produce good quality characteristics of meat.

Raw rabbit meat, on wet weight basis, is high in total protein (21.95%), calcium (13.234 mg/100g), potassium (393 mg/100g), and low in total lipids (3.57%) and total cholesterol (74.93 mg/100g) averaged for all three alfalfa fiber diets. This suggests that rabbit meat is comparable to other edible meat such as beef and pork, and is a good source of edible meat.

The experimental diets in the current study were planned as practical operational diets. In these practical diets, the grain/legume protein source was not adequately controlled or similar. If repeated one would certainly expect to not complicate the diet in evaluating the influence of alfalfa fiber substitution on rabbit meat quality. If rabbit meat with low cholesterol and lipids content is of use to the dietitian/nutritionist in special diets, further work needs to be done on the influence of rabbit breed, age, diet, and cut of meat. Additionally, from the results of this experiment, mineral content should be particularly investigated.

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APPENDICES

Table 8. Composition of experimental diets[1].

Ingredient	Dietary treatment		
	28%	54%	74%
Alfalfa meal (dehydrated)	28	54	74
Soybean meal	16.62	21	21
Trace mineral salt	0.30	0.5	0.5
Dicalcium phosphate	1.57	0.25	0.25
Molasses	---	3	3
Tallow	---	1.25	1.25
Wheat bran	---	20	---
Barley	28.2	---	---
Yellow corn	22.36	---	---
Bentonite	2	---	---
Limestone	0.45	---	---
Vitamin-mineral premix	0.26	---	---
DL-Methionine	0.24	---	---
Chemical analysis			
Digestible energy[2](kcal/kg feeds)	3072	2583	2531
Crude protein %	15.11	19.60	19.79
ADF (acid detergent fiber) %	13.06	19.71	26.12
CWC (cell wall constituent) %	19.76	28.54	33.82
DM (dry matter)	92.24	92.10	94.29
Ca[2] %	0.92	0.84	1.15
P[2] %	0.62	0.52	0.40

1. The composition of experimental diets are from Dave Harris, Department of Animal Science, Oregeon State University

2. Data were calculated from feed composition table.

Table 9. Performance of rabbit fed three levels of alfalfa meal[1].

Performance	Dietary treatment			Statistical Significance[3]
	28%	54%	74%	
Initial live weight (kg) (3-4 days after weaning)	0.849+0.100	0.910+0.392	0.629+0.071	
Preslaughter live weight (kg) (measured before slaughtering)	2.036+0.218	2.314+0.230	2.072+0.191	54>74>28
Age before slaughter (days)	68	68	68	
Daily gain (g/per day) (40 days daily gain)	29.4+4.79	38.7+4.16	36.1+4.64	54>74>28
Daily feed intakes(g)	119.95	162.93	156.31	
Feed conversion[2]	0.245	0.238	0.231	
Number of litters that were initially put on diets	20	20	60	
Mortality (%)	30	40	60	

1. The data of rabbit performance were determined by Dave Harris, Department of Animal Science, Oregon State University.
2. Feed conversion = body weight gain (kg) / feeds consumed (kg).
3. Significant at ($p \leq 0.05$).
4. Values underscored with the same line are not significantly different.

Table 10. Sex and live weight (kg) of rabbit fed three levels of alfalfa meal[1].

	Dietary treatment					
	28%		54%		74%	
Replication	Sex	Live weight (kg)	Sex	Live weight (kg)	Sex	Live weight (kg)
1	F	2.320	M	2.346	M	2.05
2	M	2.002	F	2.225	F	1.96
3	F	2.205	F	2.506	M	2.005
4	F	2.106	F	2.489	M	1.949
5	M	2.112	F	2.466	M	2.49
6	M	1.707	F	2.319	F	2.077
7	M	1.798	F	1.848	F	1.97
Mean		2.036		2.314		2.072
Standard Deviation		0.218		0.230		0.191

1. The data were determined by Dave Harris, Department of Animal Science, Oregon State University.

Table 11. Carcass characteristics of rabbit fed three levels of alfalfa meal[1]

	Dietary treatment					
	28%		54%		74%	
Replication	Dress Weight[2](%)	Abdominal fat[3](%)	Dress weight[2](%)	Abdominal fat[3](%)	Dress weight[2](%)	Abdominal fat[3](%)
1	48.5	1.32	50.4	1.72	48.2	0.89
2	46.9	2.14	48.0	1.96	46.7	1.71
3	44.3	2.00	48.6	1.81	46.0	2.05
4	46.3	1.58	51.1	3.02	47.5	1.05
5	44.5	1.41	47.1	2.26	48.1	0.96
6	47.2	1.61	49.5	2.46	45.8	1.57
7	49.3	2.34	46.4	1.31	45.1	1.09
Mean	46.7	1.77	48.7	2.08	46.8	1.33
Standard Deviation	1.9	0.39	1.7	0.56	1.2	0.45

1. The data of carcass characteristics were determined by Dave Harris, Department of Animal Science, Oregon State University.
2. Dress weight % is calculated as the ratio of raw carcass weight to live weight.
3. Abdominal fat % is calculated as the ratio of abdominal fat weight to live weight.

Table 12. Raw and cooked weight of the right thigh musclea from rabbits fed three levels of alfalfa meal.

	Dietary treatment					
	28%		54%		74%	
Replication	Raw weight (g)	Cooked Weight (g)	raw weight (g)	Cooked Weight (g)	raw weight (g)	cooked Weight (g)
1	175.30	147.5	180.00	159.4	151.75	134.05
2	146.15	120.8	154.45	132.5	143.35	129.1
3	144.45	118.5	190.10	170.4	132.10	107.9
4	144.60	122.8	189.20	370.5	140.20	119.6
5	144.50	123.8	167.60	146.2	183.50	163.9
6	121.10	92.2	167.70	146.3	143.70	122.9
7	143.20	120.2	130.80	111.3	142.80	118.7
Mean	145.6	120.8	168.6	148.1	148.2	128.0
Standard Deviation	15.8	16.1	21.0	21.3	16.6	17.9

Table 13. Cooking yield[1] (%) and cooking rate[2] of the cooked thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Dietary treatment					
	28%		54%		74%	
	Cooking yield (%)	Cooking rate (min/g)	Cooking yield (%)	Cooking rate (min/g)	Cooking yield (%)	Cooking rate (min/g)
1	84.14	0.015	88.56	0.014	88.34	0.017
2	82.66	0.018	85.79	0.017	90.06	0.018
3	82.04	0.018	89.64	0.014	81.68	0.020
4	84.92	0.018	90.12	0.014	85.31	0.018
5	85.68	0.018	87.23	0.015	89.32	0.014
6	76.14	0.021	87.24	0.015	85.53	0.018
7	83.94	0.018	85.09	0.020	83.12	0.018
Mean	82.79	0.018	87.67	0.016	86.19	0.018
Standard Deviation	3.18	0.0017	1.88	0.0022	3.17	0.0018

1. Cooking yield = (weight of cooked meat/initial weight of meat) X 100%.
2. Cooking rate = time (2.58 minutes)/ initial weight of meat (g).

Table 14. Total cooking losses [1] (%) and drip loss [2] (%) of the cooked thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	28%		54%		74%	
	Total cooking losses (%)	Drip loss (%)	Total cooking losses (%)	Drip loss (%)	Total cooking losses (%)	Drip loss (%)
1	15.86	4.08	11.44	4.39	11.66	3.20
2	17.35	7.42	14.21	4.69	9.94	2.69
3	17.97	5.30	10.36	2.21	18.32	5.53
4	15.08	3.60	9.88	2.06	14.69	3.14
5	14.33	3.88	12.77	4.24	10.68	2.07
6	23.87	8.51	12.76	2.74	14.48	3.27
7	16.06	4.47	14.91	2.60	16.88	4.41
Mean	17.22	5.32	12.33	3.28	13.87	3.47
Standard Deviation	3.19	1.91	1.88	1.12	3.17	1.15

1. Total cooking losses (%) = (weight of raw meat - weight of cooked meat)/(weight of raw meat)

2. Total drip loss (%) = (final pan weight - initial pan weight)/(weight of raw meat)

Table 15. Evaporation loss[1](%) and internal temperature (°C) of the cooked thigh muscles from rabbits fed three levels of alfalfa meal.

	Dietary treatment					
	28%		54%		74%	
Replication	Evaporation loss (%)	Internal temperature (°C)	Evaporation loss (%)	Internal temperature (°C)	Evaporation loss (%)	Internal temperature (°C)
1	11.78	77.0	7.05	71.0	8.46	67.0
2	9.93	82.0	9.52	78.8	7.25	74.0
3	12.67	68.5	8.15	60.0	12.79	77.2
4	11.48	72.0	7.82	76.8	11.55	70.0
5	10.45	65.0	8.53	71.0	8.61	78.5
6	15.36	81.0	10.02	78.8	11.21	70.0
7	11.59	72.0	12.31	71.0	12.47	68.5
Mean	11.89	73.9	9.06	72.5	10.33	72.2
Standard Deviation	1.77	6.3	1.75	6.6	2.19	4.4

1. Evaporation loss (%) = total cooking losses (%) - total drip loss (%).

Table 16. Total moisture (%) of raw and cooked thigh muscles from rabbits fed three levels of alfalfa meal.

	Raw thigh muscle			Cooked thigh muscle		
	Dietary treatment			Dietary treatment		
Replication	28%	54%	74%	28%	54%	74%
1	74.16	73.52	74.33	70.03	69.98	70.80
2	73.79	73.00	74.72	66.58	67.91	70.63
3	74.18	74.33	73.70	67.75	70.45	66.11
4	73.46	72.79	74.76	67.49	69.38	69.01
5	73.63	73.50	74.88	67.73	67.48	70.11
6	74.68	74.02	73.99	65.93	68.42	68.39
7	74.25	74.09	74.23	68.59	68.18	69.06
Mean	74.0	73.6	74.4	67.7	68.8	69.2
Standard Deviation	0.4	0.6	0.4	1.3	1.1	1.6

Table 17. pH of raw and cooked thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Raw thigh muscle			Cooked thigh muscle		
	Dietary treatment			Dietary treatment		
	28%	54%	74%	28%	54%	74%
1	5.674	5.611	5.574	5.875	5.901	5.803
2	5.732	5.670	5.637	5.959	5.994	5.852
3	5.695	5.639	5.692	5.866	5.846	5.891
4	5.654	5.683	5.543	5.873	5.865	5.733
5	5.726	5.677	5.484	5.905	5.903	5.746
6	5.626	5.691	5.589	5.941	5.911	5.865
7	5.688	5.731	5.763	5.775	6.009	5.951
Mean	5.685	5.672	5.612	5.885	5.918	5.834
Standard Deviation	0.038	0.038	0.094	0.060	0.061	0.079

Table 18. Expressible moisture index of raw and cooked thigh muscles from rabbits fed three levels of alfalfa meal.

	Raw thigh muscle			Cooked thigh muscle		
	Dietary treatment			Dietary treatment		
Replication	28%	54%	74%	28%	54%	74%
1	0.3181	0.3255	0.3646	0.4681	0.3595	0.3839
2	0.6102	0.3440	0.3787	0.4762	0.4821	0.4308
3	0.4391	0.3571	0.3387	0.4806	0.4194	0.5307
4	0.4689	0.5019	0.3689	0.5187	0.4452	0.4612
5	0.4050	0.3598	0.3065	0.4349	0.4976	0.3855
6	0.4347	0.4389	0.4422	0.6394	0.4791	0.5707
7	0.4989	0.4708	0.3963	0.4957	0.5015	0.4399
Mean	0.454	0.400	0.371	0.502	0.454	0.458
Standard Deviation	0.090	0.070	0.043	0.066	0.051	0.071

Table 19. Total protein (%) of raw thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Wet weight basis (%)			Dry weight basis (%)		
	Dietary treatment			Dietary treatment		
	28%	54%	74%	28%	54%	74%
1	22.36	21.95	21.89	86.53	82.89	85.28
2	22.00	22.12	22.61	83.94	81.93	89.44
3	21.46	21.62	20.60	83.11	84.22	78.33
4	21.16	21.45	22.03	79.73	78.83	87.28
5	22.43	21.16	22.61	85.06	79.85	90.01
6	22.15	22.06	21.74	87.48	84.90	83.58
7	22.22	22.85	22.44	86.29	88.19	87.08
Mean	21.97	21.89	21.99	84.59	82.97	85.86
Standard Deviation	0.48	0.55	0.71	2.63	3.18	4.00

Table 20. Total protein (%) of cooked thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Wet weight basis (%)			Dry weight basis (%)		
	Dietary treatment			Dietary Treatment		
	28%	54%	74%	28%	54%	74%
1	26.29	25.44	26.35	87.72	84.73	90.24
2	28.67	25.45	25.21	85.79	79.31	85.46
3	28.11	25.51	27.78	87.16	86.33	81.97
4	27.17	25.36	26.84	83.57	82.82	86.61
5	27.55	26.30	26.28	85.37	80.87	87.92
6	29.86	26.07	26.90	87.64	82.55	85.10
7	27.85	27.91	26.96	88.67	87.71	87.14
Mean	27.93	26.01	26.62	86.56	83.47	86.35
Standard Deviation	1.14	0.91	0.79	1.75	2.97	2.58

Table 21. Total lipids (%) of raw thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Wet weight basis (%)			Dry weight basis (%)		
	Dietary treatment			Dietary treatment		
	28%	54%	74%	28%	54%	74%
1	2.52	3.29	2.62	9.75	12.42	10.21
2	3.26	4.19	3.17	12.44	15.52	12.54
3	4.09	3.29	5.47	15.84	12.82	20.80
4	4.52	4.71	3.29	17.03	17.31	13.04
5	3.76	4.38	2.70	14.26	16.53	10.75
6	2.76	4.09	4.17	10.90	15.74	16.03
7	2.68	2.98	3.05	10.41	11.50	11.83
Mean	3.37	3.85	3.50	12.95	14.55	13.60
Standard Deviation	0.77	0.66	1.01	2.83	2.26	3.70

Table 22. Total lipids (%) of cooked thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Wet weight basis (%)			Dry weight basis (%)		
	Dietary treatment			Dietary treatment		
	28%	54%	74%	28%	54%	74%
1	3.38	4.20	3.13	11.28	13.99	10.72
2	4.52	5.75	3.33	13.53	17.92	11.34
3	4.45	4.00	6.29	13.80	13.54	18.56
4	5.07	5.08	4.15	15.60	16.59	13.39
5	4.73	6.08	3.38	14.66	18.70	11.31
6	3.89	4.97	4.89	11.42	15.74	15.47
7	3.45	3.81	3.39	10.98	11.99	10.96
Mean	4.21	4.84	4.08	13.04	15.50	13.11
Standard Deviation	0.65	0.88	1.15	1.82	2.44	2.95

Table 23. Total cholesterol (mg/100g) of raw thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Wet weight basis (mg/100g)			Dry weight basis (mg/100g)		
	Dietary treatment			Dietary Treatment		
	28%	54%	74%	28%	54%	74%
1	71.1	73.5	67.6	275.1	277.5	263.3
2	96.1	83.3	84.9	366.8	308.4	335.9
3	64.4	64.1	87.2	249.5	249.5	332.0
4	71.5	62.9	72.5	269.5	231.3	287.2
5	79.9	70.9	71.2	302.8	267.5	283.3
6	71.7	70.5	86.0	283.3	271.2	330.5
7	80.5	65.8	77.9	312.6	253.9	302.2
Mean	76.5	70.1	78.2	294.2	265.6	304.9
Standard Deviation	10.3	7.0	8.0	38.2	24.4	28.5

Table 24. Total cholesterol (mg/100g) of cooked thigh muscles from rabbits fed three levels of alfalfa meal.

Replication	Wet weight basis (mg/100g)			Dry weight basis (mg/100g)		
	Dietary treatment			Dietary treatment		
	28%	54%	74%	28%	54%	74%
1	79.7	78.5	89.9	265.9	261.3	307.8
2	85.4	77.9	68.1	255.5	242.7	231.9
3	84.6	70.7	87.5	262.3	239.3	258.3
4	73.5	68.1	84.2	226.1	222.2	271.8
5	73.4	79.5	82.3	227.5	244.4	275.3
6	73.4	86.9	80.2	215.3	275.2	253.8
7	82.0	85.7	87.0	261.0	269.2	281.3
Mean	78.9	78.2	82.7	244.8	250.6	268.6
Standard Deviation	5.4	7.0	7.3	21.0	18.7	23.9

Table 25. Calcium (mg/100g) potassium (mg/100g) of raw rabbit thigh muscles from rabbits fed three levels of alfalfa meals.

Replication	Calcium			Potassium		
	Dietary treatment			Dietary treatment		
	28%	54%	74%	28%	54%	74%
1	19.67	24.52	10.40	430	370	410
2	19.22	17.57	11.47	310	400	410
3	14.36	16.85	10.39	370	430	370
4	21.59	4.12	10.54	270	420	360
5	18.09	5.16	11.59	740	390	400
6	15.64	5.06	9.35	330	360	480
7	19.97	4.26	8.10	260	410	330
Mean	18.363	11.077	10.263	387	397	394
Standard Deviation	2.548	8.389	1.214	166	26	48

Table 26. Analysis of variance for moisture content (%), expressible moisture index, pH, associated with diet treatment and cooking factor.

Source of Variance	d.f.	Mean Square	F-value
Moisture Content			
Main effects			
Raw/cooked	1	309.429	292.967*
Diet	2	2.826	2.675
2-way interactions			
Raw/cooked vs. diet	2	2.127	2.014
Error	36	1.056	
Expressible Moisture Index			
Main effects			
Raw/cooked	1	0.042	9.435*
Diet	2	0.016	3.581*
2-way interactions			
Raw/cooked vs. diet	2	0.004	0.337
Error	36		
pH			
Main effects			
Raw/cooked	1	0.523	123.967*
Diet	2	0.021	5.044*
2-way interactions			
Raw/cooked vs. diet	2	0.002	0.456
Error	36	0.004	

* Significant at ($p \leq 0.05$)

Table 27. Analysis of variance for total protein (%), on wet weight and dry weight basis, associated with diet treatment and cooking factor.

Source of Variation	d.f.	Mean Square	F-value
On Wet Weight Basis			
Main effects			
Raw/cooked	1	252.350	400.989*
Diet	2	3.613	5.741*
2-way interactions			
Raw/cooked vs. diet	2	3.164	5.027*
Error	36	0.629	
On Dry Weight Basis			
Main effects			
Raw/cooked	1	10.232	1.192
Diet	2	32.902	3.834*
2-way interactions			
Raw/cooked vs. diet	2	2.528	0.295
Error	36	8.581	

* Significant at ($p \leq 0.05$)

Table 28. Analysis of variance for total lipids (%), on wet weight and dry weight basis, associated with diet treatment and cooking factor.

Source of Variation	d.f.	Mean Square	F-value
On Wet Weight Basis			
Main effects			
Raw/cooked	1	6.841	8.995*
Diet	2	1.436	1.888
2-way interactions			
Raw/cooked vs. diet	2	0.150	0.198
Error	36	0.761	
On Dry Weight Basis			
Main effects			
Raw/cooked	1	0.347	0.047
Diet	2	16.409	2.201
2-way interactions			
Raw/cooked vs. diet	2	1.836	0.246
Error	36	7.454	

* Significant at ($p \leq 0.05$)

Table 29. Analysis of variance for total cholesterol (mg/100 mg), on wet weight and dry weight basis, associated with diet treatment and cooking factor.

Source of Variation	d.f.	Mean Square	F-value
On Wet Weight Basis			
Main effects			
Raw/cooked	1	0.026	4.520*
Diet	2	0.014	2.401
2-way interactions			
Raw/cooked vs diet	2	0.003	0.489
Error	36	0.006	
On Dry Weight Basis			
Main effects			
Raw/cooked	1	1.184	16.783*
Diet	2	0.291	4.127*
2-way interactions			
Raw/cooked vs. diet	2	0.106	1.498
Error	36	0.071	

* Significant at ($p \leq 0.05$)

Table 30. Analysis of variance for percent dress weight (%), percent abdominal fat (%), and live weight (kg) in raw rabbit meat on wet weight basis, associated with diet treatment and sex factor.

Source of variation	d.f.	Mean square	F-value
Percent dress weight			
Main effects			
diet	2	10.450	4.002*
sex	1	7.351	2.816
2-way interactions			
diet vs sex	2	0.658	0.252
Error	15	0.261	
Percent abdominal fat			
Main effects			
diet	2	0.480	1.980
sex	1	0.067	0.275
2-way interactions			
diet vs sex	2	0.154	0.635
Error	15	0.242	
Live weight (kg)			
Main effects			
diet	2	0.098	2.317
sex	1	0.009	0.220
2-way interactions			
diet vs sex	2	0.084	1.982
Error	15	0.042	

* . Significant at ($p<0.05$).

Table 31. Analysis of variance for total moisture (%), pH and expressible moisture content of raw and cooked meat, associated with diet treatment and sex factor.

Source of Variation	d.f.	Mean Square	F-value[1]
Raw Meat			
Total Moisture			
Main effects			
Diet	2	0.738	2.691
Sex	1	0.011	0.038
2-way interactions			
Diet vs. sex	2	0.019	0.071
Error	15	0.274	
pH			
Main effects			
Diet	2	0.007	2.149
Sex	1	0.009	2.509
2-way interactions			
Diet vs. Sex	2	0.005	1.589
Error	15	0.003	
Expressible Moisture Index			
Main effects			
Diet	2	0.012	2.682
Sex	1	0.002	0.474
2-way interactions			
Diet vs. sex	2	0.011	2.654
Error	15	0.004	

(Total Moisture, pH, and Expressible Moisture Content, cont.)

Source of Variation	d.f.	Mean Square	F-value[1]
Cooked Meat			
Total Moisture			
Main effects			
Diet	2	4.107	2.085
Sex	1	0.022	0.011
2-way interactions			
Diet vs. sex	2	1.871	0.950
Error	15	1.970	
pH			
Main effects			
Diet	2	0.006	1.467
Sex	1	0.004	0.860
2-way interactions			
Diet vs. sex	2	0.006	1.453
Error	15	0.004	
Expressible Moisture Index			
Main effects			
Diet	2	0.009	2.273
Sex	1	0.007	1.836
2-way interactions			
Diet vs. sex	2	0.005	1.361
Error	15	0.004	

[1] Significant at ($p \leq 0.05$)

Table 32. Analysis of variance for total protein (%) of raw and cooked meat on wet and dry basis, associated with diet treatment and sex factor.

Source of Variation	d.f.	Mean Square	F-value
Raw Meat			
Total Protein on Wet Weight Basis			
Main effects			
Diet	2	0.020	0.058
Sex	1	0.008	0.021
2-way interactions			
Diet vs. sex	2	0.447	1.276
Error	15	0.351	
Total Protein on Dry Weight Basis			
Main effects			
Diet	2	11.067	0.909
Sex	1	0.426	0.035
2-way interactions			
Diet vs. sex	2	7.151	0.587
Error	15	12.179	
Cooked Meat			
Total Protein on Wet Weight Basis			
Main effects			
Diet	2	5.531	6.430*
Sex	1	0.508	0.590
2-way interactions			
Diet vs. sex	2	1.107	1.287
Error	15	0.860	

(Total Protein, cont.)

Source of Variation	d.f.	Mean Square	F-value
Total Protein on Dry Weight Basis			
Main effects			
Diet	2	8.000	1.117
Sex	1	3.774	0.527
2-way interactions			
Diet vs. sex	2	0.177	0.025
Error	15	7.160	

* Significant at ($p \leq 0.05$)

Table 33. Analysis of variance for total lipids (%) of raw and cooked meat on wet and dry basis, associated with diet treatment and sex factor.

Source of Variation	d.f.	Mean Square	F-value[1]
Raw Meat			
Total Lipids on Wet Weight Basis			
Main effects			
Diet	2	0.047	0.063
Sex	1	0.605	0.805
2-way interactions			
Diet vs. sex	2	0.232	0.308
Error	15	0.752	
Total Lipids on Dry Weight Basis			
Main effects			
Diet	2	0.531	0.054
Sex	1	8.503	0.869
2-way interactions			
Diet vs. sex	2	3.316	0.339
Error	15	9.788	
Cooked Meat			
Total Lipids on Wet Weight Basis			
Main effects			
Diet	2	0.310	0.323
Sex	1	0.122	0.127
2-way interactions			
Diet vs. sex	2	0.367	0.383
Error	15	0.958	

(Total Lipids, cont.)

Source of Variation	d.f.	Mean Square	F-value[1]
Total Lipids on Dry Weight Basis			
Main effects			
Diet	2	4.426	0.649
Sex	1	1.334	0.196
2-way interactions			
Diet vs. sex	2	2.469	0.362
Error	15	6.822	

[1] Significant at ($p \leq 0.05$)

Table 34. Analysis of variance for total cholesterol (mg/100g) of raw and cooked meat on wet and dry basis, associated with diet treatment and sex factor.

Source of Variation	d.f.	Mean Square	F-value
Raw Meat			
Total Cholesterol on Wet Weight Basis			
Main effects			
Diet	2	0.006	1.039
Sex	1	0.003	0.544
2-way interactions			
Diet vs. sex	2	0.020	3.326
Error	15	0.006	
Total Cholesterol on Dry Weight Basis			
Main effects			
Diet	2	0.157	2.183
Sex	1	0.050	0.694
2-way interactions			
Diet vs. sex	2	0.296	4.120*
Error	15	0.072	
Cooked Meat			
Total Cholesterol on Wet Weight Basis			
Main effects			
Diet	2	0.003	0.560
Sex	1	0.002	0.487
2-way interactions			
Diet vs. sex	2	0.003	0.711
Error	15	0.005	

(Total Cholesterol, cont.)

Source of Variation	d.f.	Mean Square	F-value
Total Cholesterol on Dry Weight Basis			
Main effects			
Diet	2	0.078	1.696
Sex	1	0.024	0.512
2-way interactions			
Diet vs. sex	2	0.052	1.123
Error	15	0.046	

* Significant at ($p \leq 0.05$)

Table 35. Analysis of variance for calcium (mg/100g) and potassium (mg/100g) in raw rabbit meat on wet basis, associated with diet treatment and sex factor.

Source of variation	d.f.	Mean square	F-value
Calcium			
Main effects			
diet	2	1231.242	7.185*
sex	1	1161.606	6.778*
2-way interactions			
diet vs sex	2	810.295	4.728*
Error	15	171.367	
Potassium			
Main effects			
diet	2	o.288	0.024
sex	1	0.0001	0.0001
2-way interactions			
diet vs sex	2	3.000	0.270
Error	15	12.000	

*. Significant at ($p<0.05$).

Table 36. Analysis of variance for internal temperature (°C) and cooking rate (g/min.), associated with diet treatment and sex factor.

Source of variation	d.f.	Mean square	F-value [1]
Internal temperature			
Main effects			
diet	2	6.625	0.166
sex	1	4.141	0.104
2-way interactions			
diet vs sex	2	5.927	0.149
Error	15	39.848	
Cooking rate			
Main effects			
diet	2	0.0001	2.859
sex	1	0.0001	0.077
2-way interactions			
diet vs sex	2	0.0001	1.169
Error	15	0.0001	

1. Significant at ($p \leq 0.05$).

Table 37. Analysis of variance for total cooking losses (%), cooking yield (%), and raw and cooked weight of right thigh (g),on wet weight basis, associated with diet treatment and sex factor.

Source of variation	d.f.	Mean square	F-value
Total cooking losses			
Main effects			
diet	2	35.398	3.869*
sex	1	0.169	0.018
2-way interactions			
diet vs sex	2	2.209	0.241
Error	15	9.149	
Cooking yield			
Main effects			
diet	2	35.322	3.863*
sex	1	0.169	0.018
2-way interactions			
diet vs sex	2	2.198	0.240
Error	15	9.143	
Raw weight of right thigh			
Main effects			
diet	2	938.831	2.776
sex	1	15.003	0.044
2-way interactions			
diet vs sex	2	360.420	1.066
Error	15	338.197	
Cooked weight of right thigh			
Main effects			
diet	2	1135.901	3.077
sex	1	13.661	0.037
2-way interactions			
diet vs sex	2	328.417	0.890
Error	15	369.128	

* . Significant at ($p \leq 0.05$).

Table 38. Analysis of variance for total moisture content(%), expressible moisture index, and pH of rabbit meat, associated with diet treatment, cooking factor and sex factor.

Source of variation	d.f.	Mean square	F-value
Moisture content			
Main effects			
raw/cooked	1	209.643	186.844*
diet	2	2.571	2.291
sex	1	0.001	0.001
2-way interactions			
raw/cooked vs diet	2	2.274	2.027
raw/cooked vs sex	1	0.031	0.028
diet vs sex	2	0.758	0.676
3-way interactions			
raw/cooked vs diet vs sex	2	1.132	1.009
Error	30	1.122	
Expressible moisture index			
Main effects			
raw/cooked	1	0.029	7.084*
diet	2	0.019	4.664
sex	1	0.008	2.044
2-way interactiions			
raw/cooked vs diet	2	0.001	0.316
raw/cooked vs sex	1	0.001	0.182
diet vs sex	2	0.015	3.780*
3-way interactions			
raw/cooked vs diet vs sex	2	0.001	0.314
Error	30	0.004	
pH			
Main effects			
raw/cooked	1	0.405	104.827*
diet	2	0.011	2.910
sex	1	0.012	3.054
2-way interactions			
raw/cooked vs diet	2	0.002	0.631
raw/cooked vs sex	1	0.001	0.134
diet vs sex	2	0.011	2.904
3-way interactions			
raw/cooked vs diet vs sex	2	0.0001	0.123
Error	30	0.004	

* . Significant at ($p \leq 0.05$).

Table 39. Analysis of variance for total protein(%) on wet and dry weight basis, associated with diet treatment, cooking factor and sex factor.

Source of variation	d.f.	Mean square	F-value
On wet weight basis			
Main effects			
raw/cooked	1	175.880	290.530
diet	2	2.701	4.462
sex	1	0.319	0.528
2-way interactions			
raw/cooked vs diet	2	2.850	4.708 *
raw/cooked vs sex	1	0.196	0.323
diet vs sex	2	1.120	1.850
3-way interactions			
raw/cooked vs diet vs sex	2	0.434	0.717
Error	30	0.605	
On the dry weight basis			
Main effects			
raw/cooked	1	10.440	1.080
diet	2	16.362	1.692
sex	1	3.369	0.348 *
2-way interactions			
raw/cooked vs diet	2	2.705	0.280
raw/cooked vs sex	1	0.832	0.086
diet vs sex	2	3.390	0.351
3-way interactions			
raw/cooked vs diet vs sex	2	3.939	0.407
Error	30	9.669	

*. Signigiacant at ($p \leq 0.05$).

Table 40. Analysis of variance for total lipids (%), on wet and dry weight basis, associated with diet treatment, cooking factor and sex factor.

Source of variatiton	d.f.	Mean square	F-value
On wet weight basis			
Main effects			
raw/cooked	1	4.663	5.454 *
diet	2	0.253	0.295
sex	1	0.635	0.743
2-way interactions			
raw/cooked vs diet	2	0.104	0.122
raw/cooked vs sex	1	0.092	0.108
diet vs sex	2	0.556	0.651
3-way interations			
raw/cooked vs diet vs sex	2	0.042	0.050
Error	30	0.855	
On dry weight basis			
Main effects			
raw/cooked	1	0.379	0.046
diet	2	3.211	0.387
sex	1	8.286	0.998
2-way interactions			
raw/cooked vs diet	2	1.747	0.210
raw/cooked vs sex	1	1.551	0.187
diet vs sex	2	5.691	0.685
3-way interactions			
raw/cooked vs diet vs sex	2	0.094	0.011
Error	30	8.305	

*. Significant at ($p \leq 0.05$).

Table 41. Analysis of variance for total cholesterol (mg/100g), on wet and dry weight basis, associated with diet treatment, cooking factor and sex factor.

Source of variation	d.f.	Mean square	F-value
On wet weight basis			
Main effects			
raw/cooked	1	0.016	3.024
diet	2	0.008	1.511
sex	1	0.005	1.029
2-way interactions			
raw/cooked vs diet	2	0.001	0.149
raw/cooked vs sex	1	0.0001	0.009
diet vs sex	2	0.004	0.711
3-way interactions			
raw/cooked vs diet vs sex	1	0.019	3.663 *
Error	30	0.005	
On dry weight basis			
Main effects			
raw/cooked	1	0.867	14.680
diet	2	0.183	3.104
sex	1	0.071	1.204
2-way interactions			
raw/cooked vs diet	2	0.052	0.881
raw/cooked vs sex	1	0.002	0.041
diet vs sex	2	0.053	0.899
3-way interactions			
raw/cooked vs diet vs sex	1	0.295	4.997 *
Error	30	0.059	

* . Significant at ($p \leq 0.05$).

Figure 3. Procedure for total lipids determination.

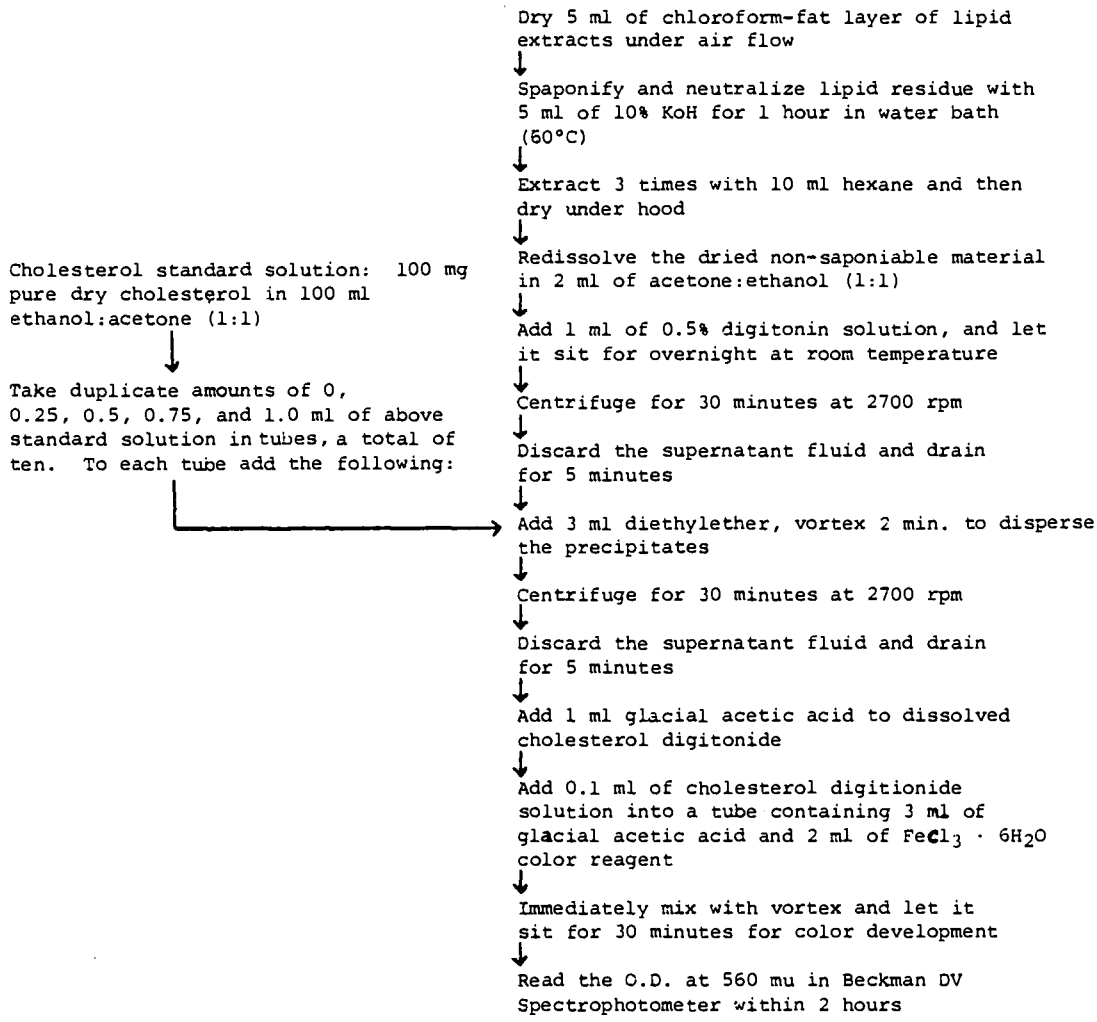

Figure 4. Procedure for total cholesterol determination.

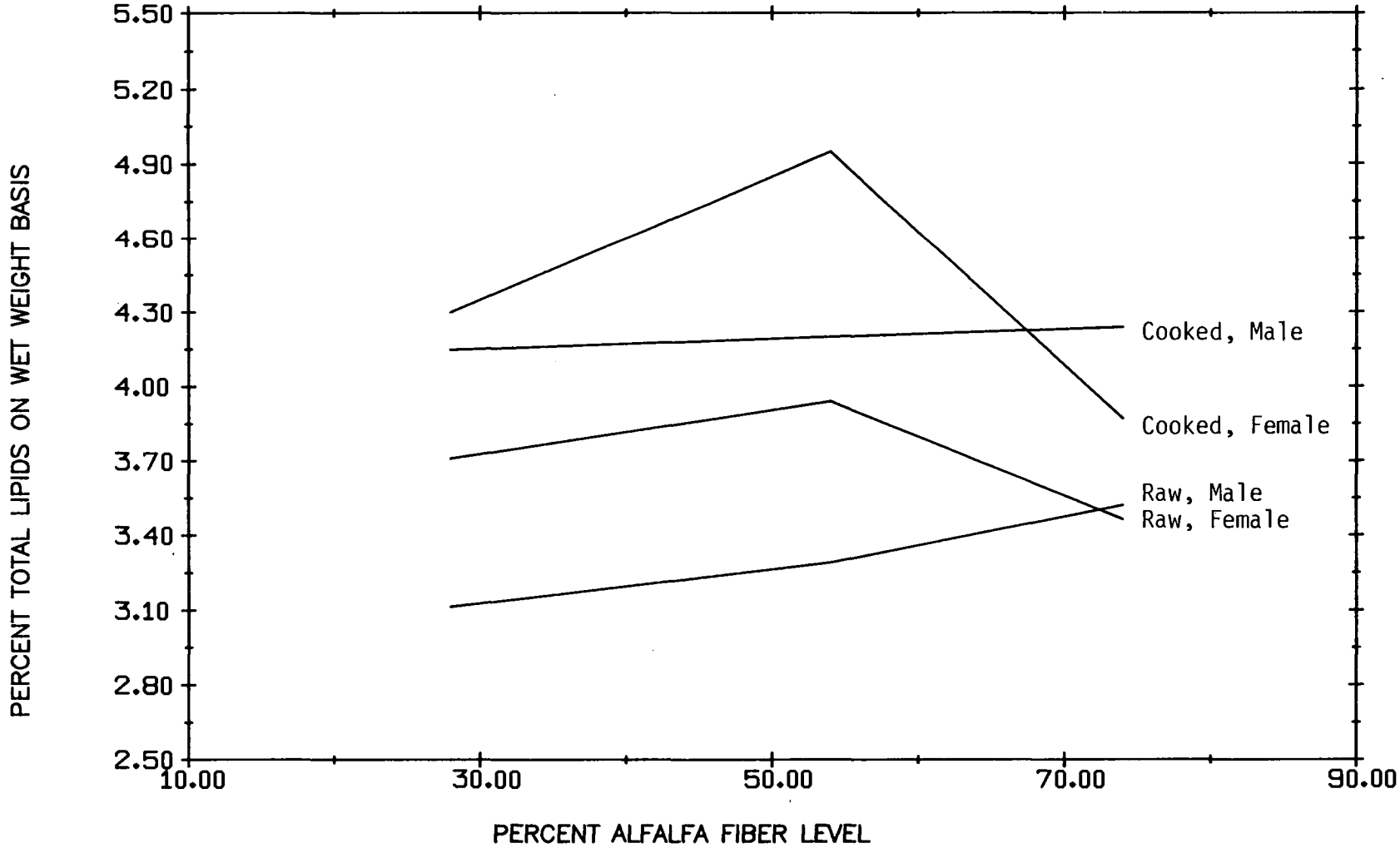

Figure 5. Total lipids content in raw and cooked meat for both male and female rabbits fed 28%, 54% and 74% alfalfa fiber diets, on wet weight basis.

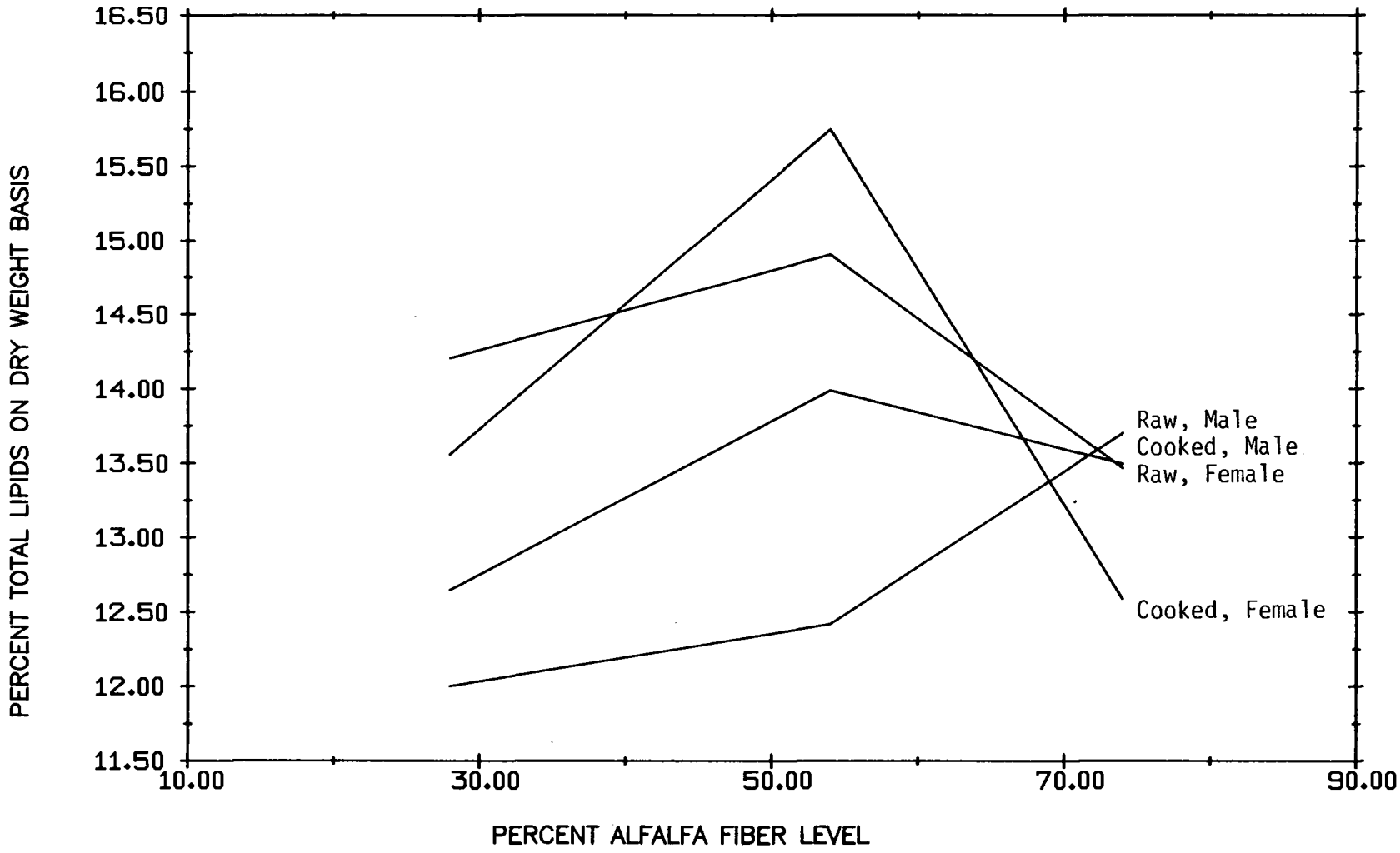

Figure 6. Total lipids content in raw and cooked meat for both male and female rabbits fed 28%, 54% and 74% alfalfa fiber diets, on dry weight basis.

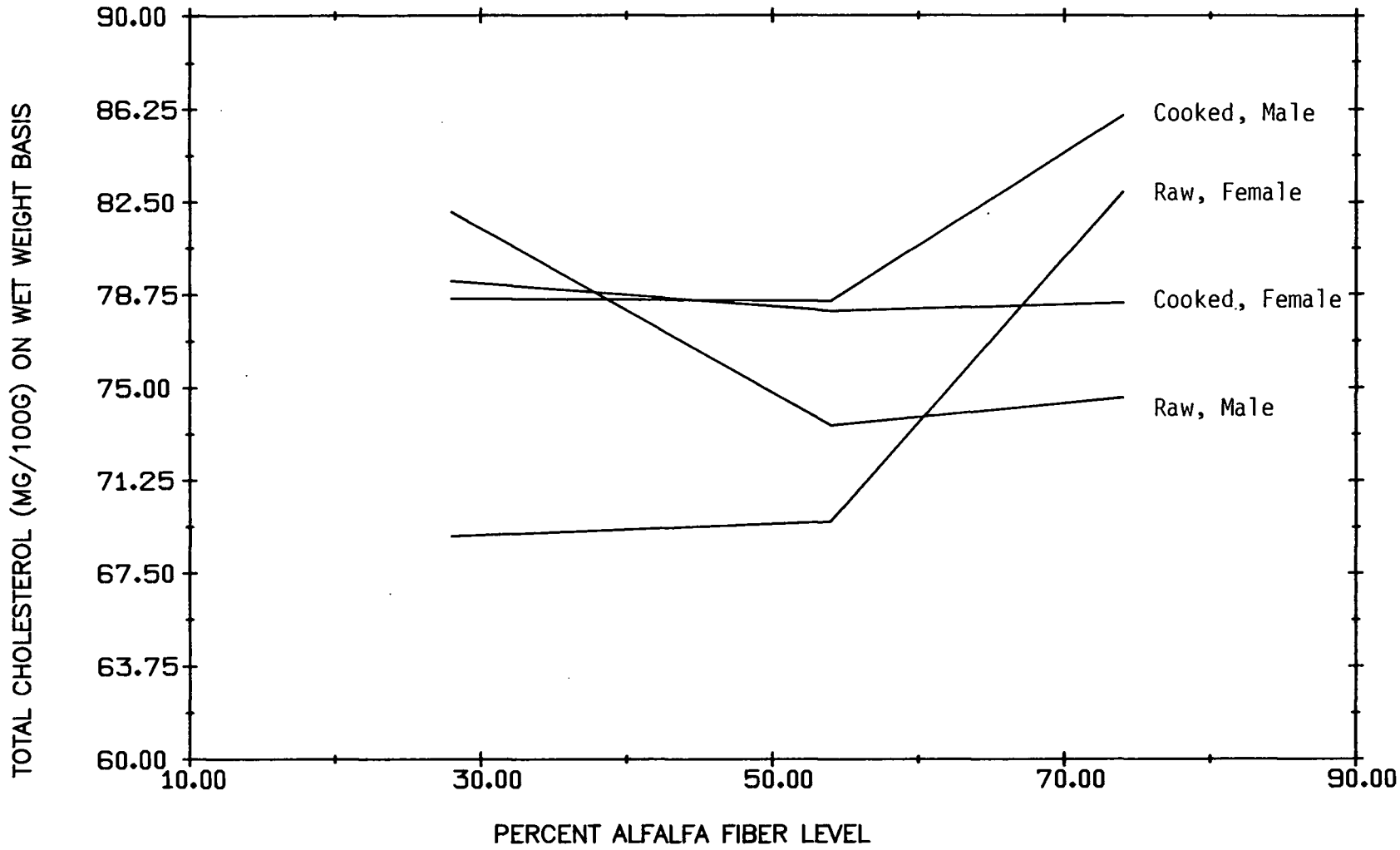

Figure 7. Total cholesterol content in raw and cooked meat for both male and female rabbits fed 28%, 54% and 74% alfalfa fiber diets, on wet weight basis.

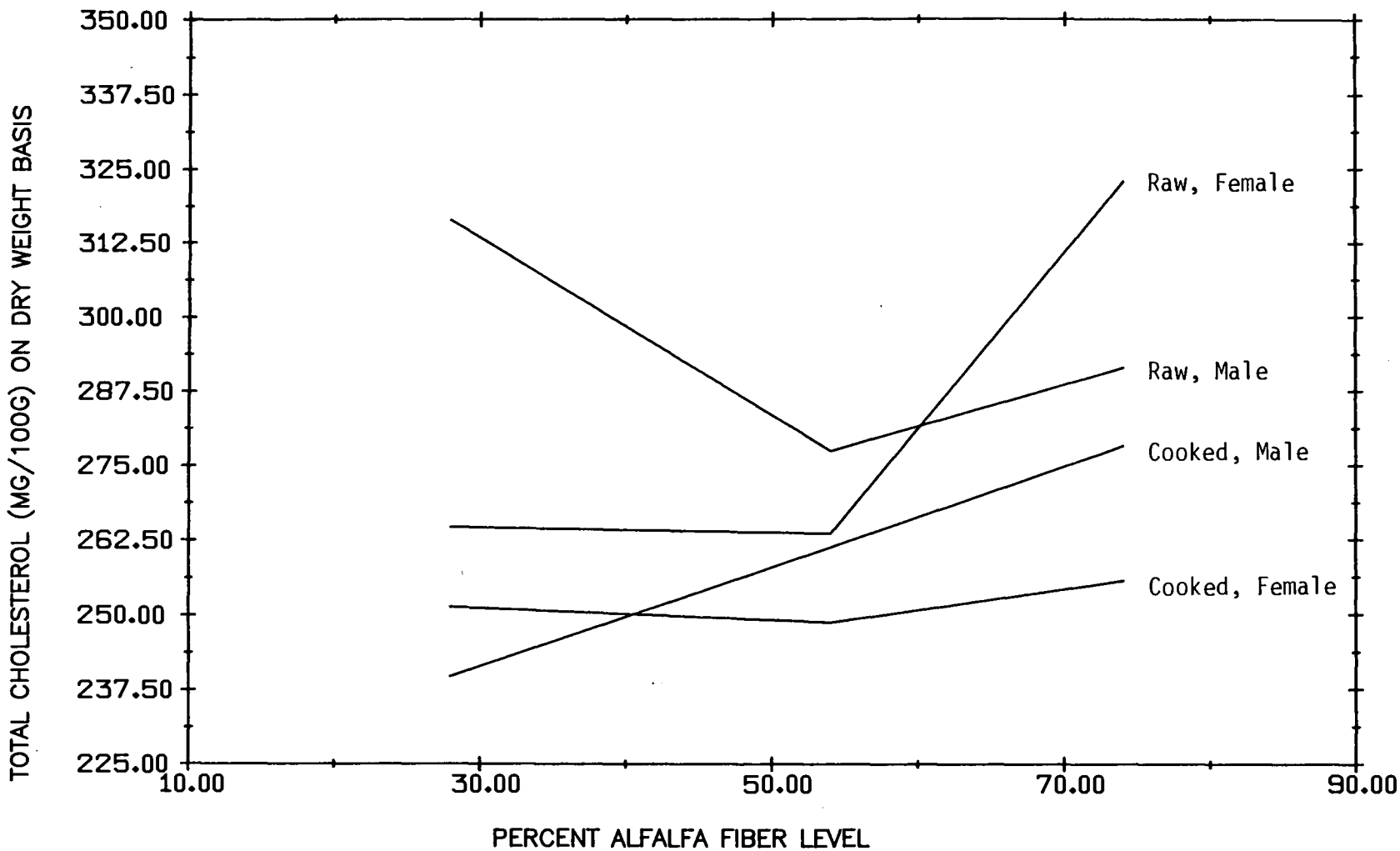

Figure 8. Total cholesterol content in raw and cooked meat for both male and female rabbits fed 28%, 54% and 74% alfalfa fiber diets, on dry weight basis.

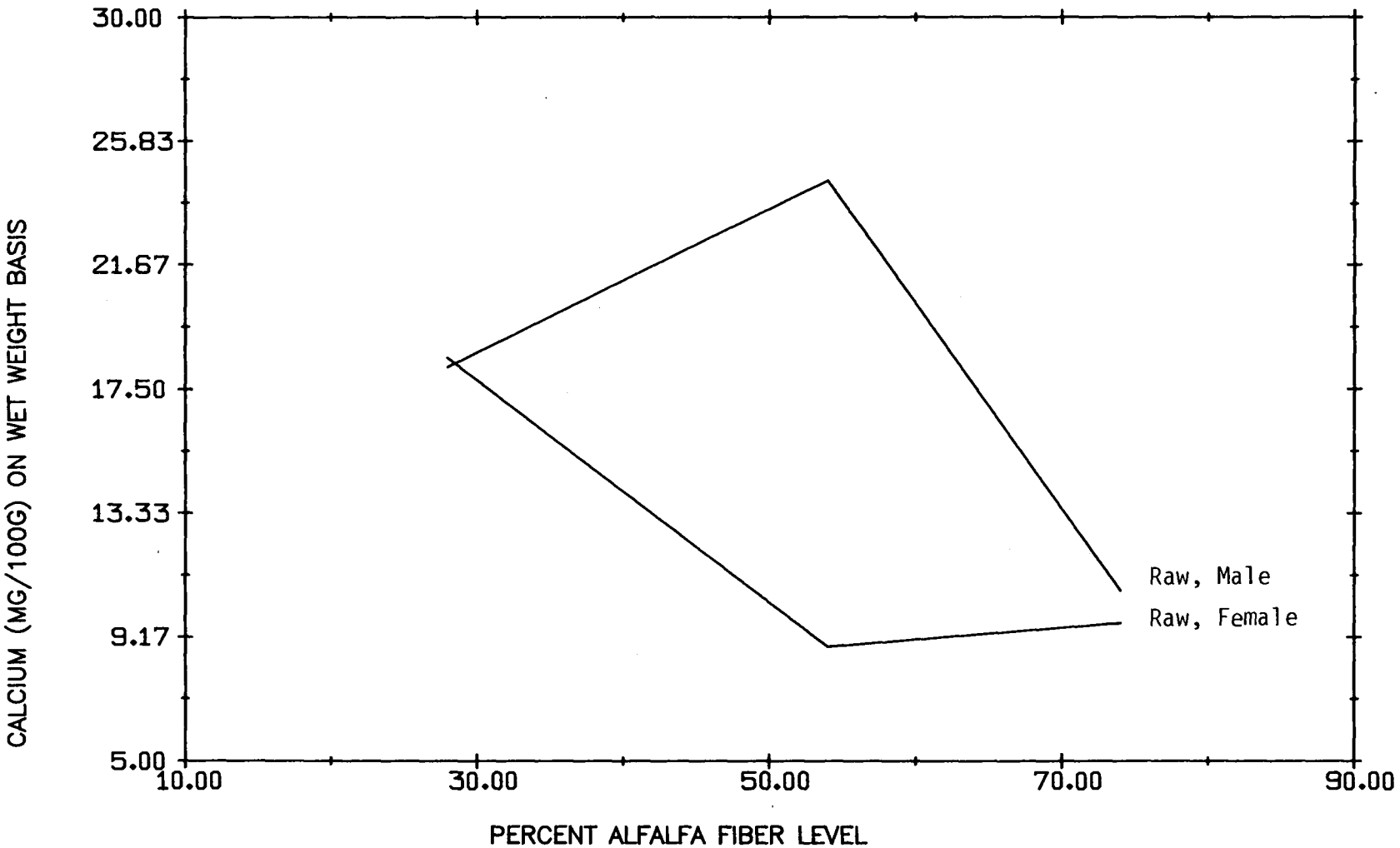

Figure 9. Calcium content in raw and cooked meat for both male and female rabbits fed 28%, 54% and 74% alfalfa fiber diets, on wet weight basis.