SHELF LIFE OF IRRADIATED RABBIT MEAT UNDER AEROBIC AND VACUUM PACKAGING

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Thesis submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that this thesis entitled **"SHELF LIFE OF IRRADIATED RABBIT MEAT UNDER AEROBIC AND VACUUM PACKAGING"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis, entitled **"SHELF LIFE OF IRRADIATED RABBIT MEAT UNDER AEROBIC AND VACUUM PACKAGING"** is a record of research work done independently by **SONIKA S.,** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Sonika

Dedicated to my beloved

mother

and

husband...

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Introduction

1. INTRODUCTION

The livestock population is showing a downward trend due to rapid urbanization and nuclear family life style. People are going for rearing small animals like rabbit and goat due to the paucity of land available in their homestead after constructing their house in small land holding. Considering the body size and habit of rabbit, *Oryctolagus* genus, can be reared in small holdings which is an advantage. The census conducted by Animal Husbandry Department in 2003 shows the rabbit population in Kerala as 1,47,275 (AHD Kerala, 2003). Now rabbits are readily available in many localities and there is a gradual momentum in the consumption of rabbit meat among Indian population, which was not considered a meat source in earlier days. Extensive study has not been conducted on preservation technique of rabbit meat including freezing and chilling in tropical climate. The availability of literature on the effect of irradiation, packaging and storage on keeping quality of rabbit meat is scanty.

Rabbit meat is one of the best available white meat. This meat is considered as completely lean and is very tender and juicy. There is no religious taboo or social stigma attached to the consumption of rabbit meat. Among other meats, rabbit meat possesses high percentage of easily digestible protein and contains less fat. It contains high amount of poly unsaturated fatty acids which are not detrimental to consumer's health. Rabbit meat is has low cholesterol compared to all other meats and is preferred among heart patients. Another important aspect of rabbit meat is low sodium and high calcium and phosphorous content so making it suitable to patients with hypertension (ICAR, 2004).

A number of consumers purchase meat in bulk and keep in refrigerators unaware of the quality changes. In recent years, food irradiation has become one of the most discussed technologies for the food safety and the extension of the shelf life. Irradiation has become popular because all other preservation technologies are by adding something to the meat, which may alter the normal appearance or flavour. Irradiation method of preservation kills susceptible microorganisms by direct effect on DNA or indirectly by ionization of water molecules. It is being widely used to increase the shelf life, reduce post harvest losses and to eliminate microorganisms and larvae of parasites, which may result in food infection and intoxication.

Studies with respect to quality changes of various meat and meat products by irradiation preservation has been conducted in various parts of world. On perusal of available literature, it was noted that studies with respect to irradiation of rabbit meat and its quality changes due to irradiation and storage are scanty.

The packaging system has a crucial role in extending the shelf life of meat. The vacuum environment removes the atmospheric oxygen, protecting the food from spoiling by limiting the growth of aerobic bacteria and fungi, and preventing the evaporation of volatile compounds. The vacuum packaging minimizes the oxidation of unsaturated fatty acids and slows the development of rancidity. Thus vacuum packaging is a satisfactory method to prevent colour changes and rancidity in meat during storage.

Wholesome meat production in India is far from satisfactory as a result of unhygienic practices and poor health of animals. There is a need to improve the quality and safety of the meat to enhance the export potential and internal consumption. According to Prevention of Food Adulteration (PFA) Act and its amendments (1998), irradiation is permitted as an approved technique that can be used for the preservation of meat. It permits irradiation of meat and meat products including poultry products at a dose of 2.5 to 4.0 kGy to extend shelf life and to control pathogens.

This study was undertaken to assess the effect of packaging, radiation and storage on rabbit meat qualities, with the following objectives.

- Assess the keeping quality of rabbit meat under aerobic and vacuum packaging in chiller (1 to 4°C) and domestic refrigerator freezer (-6 to -8°C).
- Study the effect of irradiation on rabbit meat qualities on storage.
- Assess the changes in rabbit meat due to irradiation by histological techniques.

Review of Literature

2. REVIEW OF LITERATURE

The World Health Organization defined wholesomeness of food as conducive to health including the aesthetic aspects of food. In order to produce and market any food item, definitely there will be time gap in the marketing channel. The production, processing and marketing which requires handling and delay will lead to addition of contamination and or multiplication of microorganisms. The food, especially the meat produced in surplus seasons are preserved for future use. Preservation of meat dates centuries back right from sun drying and other various methods has been used for preservation from time to time. After the introduction of refrigeration, the most common method of preservation of meat and meat products is chilling or freezing which requires high level of energy input. Many of the meat preservation methods except canning doesn't destroy total microbial load present in meat and nobody can say meat is totally wholesome. Considering the wholesomeness of meat, irradiation of meat and meat products was recognized as a method of meat preservation.

2.1. IRRADIATION OF FOOD

The Joint Committee of FAO / IAEA / WHO / on Irradiated Foods at its meeting in Geneva in 1980 came to a conclusion that foods irradiated in the range up to 10 kGy are toxicologically as well as microbiologically safe and nutritionally adequate and that no health hazard results from consuming such irradiated foods (WHO, 1981).

Radiation energy is measured in terms of rads where 1 rad is equal to 100 ergs of energy absorbed in 1 gram of matter. The newly introduced standard irradiation unit is Gray (Gy) where 1 Gy is equal to 100 rads (Dempster, 1985).

The use of ionizing radiation as a method of food preservation had been studied since 1940. The major applications of food irradiation included sterilization, pasteurization, disinfestations, shelf life extension and product development (Nagai and Moy, 1985).

Thayer *et al.* (1986) stated that from 1940 through 1953, exploratory research in food irradiation in United States was sponsored by the Department of Army, the Atomic Energy Commission and some private industries.

The usage of irradiation to control the spoilage of food was demonstrated in the early decades of the 20^{th} century. However, no commercial development occurred due to various reasons (Urbain, 1989).

In 1905, United States and British patents were issued for the use of ionizing radiation to kill bacteria in foods. Many research works were conducted on the physical, chemical and biological effects of ionizing radiation (ACSH, 1998).

Irradiation is safe, efficient and environmentally clean, not tainted with chemical residue, energy efficient process being particularly valuable as end product decontamination procedure (Farkas, 1998).

United States Department of Agriculture (USDA) approved medium dose irradiation (1 to 10 kGy) for decontamination of raw meat and poultry (Olson, 1998).

The Ministry of Health and Family Welfare, Government of India, amended the Prevention of Food Adulteration Act, 1954 through a special Gazette notification in 1998 dated 06/04/1998 and, permitting irradiation of meat and meat products including poultry products at a dose of 2.5 to 4.0 kGy to extend shelf life and to control pathogens (PFA, 1998).

In December 1997, FDA approved irradiation of red meat to control food borne pathogens and to extend shelf life. In February USDA allowed the proposal of irradiation of raw meat and meat products (Buzby and Morrison, 1999).

A joint FAO/ IAEA/ WHO study group on high dose irradiation meat in Geneva from 15^{th} to 20^{th} September 1997, concluded and established the wholesomeness of any food irradiated up to an overall average dose of 10.0 kGy

(WHO, 1999). As far as India is concerned, even now the PFA act has not amended and dose rate of 2.5 to 4 kGy and is continuing.

About 55 countries have approved and are using food irradiation technologies to ensure food safety and 29 countries have given clearance for irradiation of raw meat and poultry. Countries such as Belgium, China, France, Indonesia, Netherlands, Thailand and United States have implemented irradiation of meat commercially (http://nucleaus.iaea.org., 2003).

2.2 DRESSING PERCENTAGE

Forrest *et al.* (1975) reported that there would be about two percent decrease in dressing percentage when calculated on chilled carcass basis than of hot carcass basis.

Kuttinarayanan and Nandakumar (1989) reported a dressing percentage of 53.10 per cent and 52.72 per cent in Soviet chinchilla and New Zealand white rabbits respectively.

According to Zotte (2002) rabbit carcass quality mainly concerns carcass weight which varies mainly from 1.0 to 1.8 kg, according to the various regions and the slaughter yield was 55–61 percentage of live weight.

Pascual and Pla (2007) stated that selection for growth rate in rabbit and the consequent decrease in degree of maturity of the animals at slaughter weight caused some relevant changes in some carcass composition variables such as higher percentages of viscera (kidneys and liver) and higher percentages of dissectible fat and as a result a higher dressed out percentage.

2.3. PACKAGING

A doubling in the shelf life in vacuum packaged beef cuts irradiated at 2 kGy was observed when compared to non irradiated samples by Niemand *et al.* (1981). The control samples have an acceptable shelf life of approximately 3 weeks, whereas that of irradiated samples was more than 11 weeks at 4^0C storage.

Smith *et al.* (1983) stated that vacuum packaging was superior to modified atmospheric packaging for maintaining desirable appearance of wholesale loins, particularly if the atmosphere contained a high CO_2 concentration.

In a study conducted by Thayer (1993), it was found that shelf life of poultry and beef could be significantly extended by irradiation in combination with vacuum packaging or modified atmospheric packaging.

Vacuum packaging was better than aerobic packaging for irradiation and subsequent storage of meat, as it minimized oxidative changes in turkey patties and produced minimal amounts of volatile compounds that might be responsible for irradiation off-odour during storage (Ahn *et al.*, 2000).

Apple *et al.* (2001) stated that chops from vacuum packaged pork loins stored for 4 and 8 weeks were more tender than chops from loins packaged and stored for only 48 hours.

Vacuum packaging reduced lipid oxidation in rabbit meat and extended its shelf life at chill temperatures (Zotte, 2002).

Salke Dinkar Babanrao (2007) reported that vacuum packaging along with irradiation had significantly increased the shelf life of beef cutlet to three fold at chiller temperature compared to that of control.

2.4. SHELF LIFE

According to Dempster (1985) low dose irradiation could destroy microorganisms of public health significance and extend the shelf life of meat products.

Irradiation treatments with or without elevated carbon dioxide-modified atmospheric packaging significantly reduced the bacterial load and extended shelf life from 5 to 7 days to between 20 and 30 days (Przybylski *et al.*, 1989).

Paul *et al.* (1990) reported that the lamb meat chunks irradiated at 1.0 kGy and 2.5 kGy remained in acceptable condition for 3 and 5 weeks respectively, and the shelf life of irradiated minced meat at 1.0 kGy and 2.5 kGy was acceptable for 2 and 4 weeks respectively at 0 to 3°C storage. In contrast, non-irradiated meat chunks and mince were spoiled within one week at the same storage condition.

Extended chiller storage was observed for ground beef patties for 14, 21 and 42 days when irradiated at 1.0, 3.0 and 5.0 kGy, respectively (Roberts and Weese, 1998).

Irradiation doses of 1.5 and 3.0 kGy reduced the counts of aerobic mesophilic bacteria, psychrophilic bacteria, yeast and mould and prolonged the shelf life of refrigerated rabbit meat samples from 12 to 21 days at chiller storage (Badr, 2004).

Irradiated spices, packaging material (10.0 kGy) and luncheon meat (2.0 kGy) kept in refrigerator (1-4°C) for 12 months showed that gamma irradiation increased the shelf life, decreased the microbial count of spices, packaging material and packed products. However, taste, odour, appearance and texture scores of irradiated product were significantly lower than non-irradiated samples (Al-Bachir, 2005).

Kanatt *et al.* (2005) found that 3.0 kGy was optimal for shelf life extension of some ethnic Indian meat products like chicken chilly, mutton shammi kababs and pork salami. The shelf life was extended by more than 2 weeks at 0 to 3°C compared to corresponding non-irradiated samples.

Jenifer (2006) found that irradiation of minced beef at 1.0, 2.0 and 3.0 kGy had increased the keeping quality up to 10, 25 and 33 days respectively at chiller temperature.

The keeping quality of irradiated beef fry was studied by Kuttinarayanan *et al.* (2006b) and reported an enhanced shelf life of 28 to 32 days in irradiated samples, whereas control spoiled organoleptically by 7 to 9 days of storage in the chiller.

2.5. PHYSICAL QUALITIES (COLOUR AND ODOUR)

Beef roast stored in modified atmospheres containing high level of oxygen exhibited a greater incidence of off odour, surface discoloration, lower overall appearance ratings, shorter retail case life and lower overall palatability rating than those stored under vacuum or modified atmosphere containing 20 per cent carbon dioxide and 80 per cent nitrogen (Seideman *et al.*, 1979).

According to Narsimharao and Sreenivasmurty (1986) unacceptable odour in fresh meat was developed by 6 days at refrigerated storage ($4 \pm 1^{o}C$) when the shelf life of meat was assessed by considering sensory parameter such as discolouration and odour.

Paul *et al.* (1990) observed that freshly ground mutton irradiated at 2.5 kGy had a better colour, odour and microbiological acceptability than non-irradiated or irradiated mutton at 1.0 kGy. The meat chunks irradiated at 1.0 and 2.5 kGy remained in acceptable condition for 3 and 5 weeks respectively, and the shelf life of irradiated mince was 2 and 4 weeks. In contrast, non-irradiated meat chunks and mince spoiled within one week of storage.

Rodriguez *et al.* (1993) suggested that low dose gamma irradiation (2.0 kGy) could be a reliable preservation method to obtain an organoleptically stable retail fresh beef products, by reducing naturally occurring spoilage micro flora and enhancing the shelf life under refrigeration.

Badr (2004) reported that panelists preferred both irradiated and non-irradiated rabbit meat, as the samples were having high acceptance as judged by appearance and odour until rejection. Non-irradiated samples were rejected due to appearance of mould growth, slime formation and off odours by day 6 while irradiated sample showed off odour and mould growth by 12 to 21 days of storage. @ what Temp?

2.6. HISTOLOGICAL STUDIES

Collagen shrinked when irradiated in dry stage and became soluble in water when irradiated wet (Perron and Wright, 1950). Irradiation caused softness and tenderness of texture as an immediate effect (Coleby *et al.*, 1961). The hydrothermal shrink temperature of collagen decreased with increased dosage which was probably due to the destruction of some of the hydrogen bonds which hold together the triple helix of collagen (Lawrie, 1998).

Chungath and Kuttinarayanan (2008) reported that when the porcine *longissimus dorsi* muscle irradiated at 3.0 kGy and above lead to collagen swelling and at 4.0 kGy collagen shrinkage was evidenced by the absence of collagen fibres. They concluded that the pre-rigor meat could be made tender by the process of irradiation since the toughness could be lowered by collagen swelling without affecting other qualities.

2.7. PROXIMATE COMPOSITION

Sakala *et al.* (1987) reported minimum changes in carbohydrates, lipids, proteins and amino acids as a result of low to medium dose of irradiation.

Heath *et al.* (1990) showed that there was no difference in moisture content of non-irradiated (65.0%) and irradiated (64.0%) chicken meat at 100, 200 and 300 k rads.

In a study conducted by Katta *et al.* (1991) found that chicken carcass irradiated at various dose levels ranging from zero to 3.0 kGy using gamma radiation and stored in refrigerator conditions did not show any variation in their fatty acid profile.

Wheeler *et al.* (1999) conducted study on the proximate composition of ground beef patties and found that fat and moisture percentage were not affected by irradiation. They did not observe significant difference in the values of proximate composition between irradiated and non-irradiated patties up to 5 weeks in chiller storage.

In a study conducted by Du *et al.* (2001) in cooked chicken patties packed in oxygen permeable or impermeable bags, irradiated at 3 kGy, it was found that the average moisture, fat and pH were not affected by irradiation.

Daoud *et al.* (2002) studied effect of gamma irradiation (0, 3, 5, 7 and 9 kGy) on the chemical and microbial qualities of chilled minced beef and noted that irradiation with different doses resulted in slight changes in chemical composition. Moisture content was decreased, protein content decreased with the progress of storage, whereas fat and ash per cent increased with storage and irradiation doses.

Trace components of food such as essential amino acid, essential fatty acids and minerals were unaffected under practical irradiation conditions although some vitamins such as vitamin C and vitamin B1 were partially lost (Lee, 2004).

Smith and Pillai (2004) reported that macronutrient (protein, lipid and carbohydrate) and mineral content were unaffected by irradiation.

Luncheon meat which was irradiated at 2 kGy and kept for 12 months in refrigerator storage (1-4^{o}C) showed no significant difference in moisture, protein, fat, pH value, total acidity, lipid oxidation and volatiles (Al-Bachir, 2005).

Rana Raj (2006) in pet food, Salke Dinkar Babanrao (2007) in beef cutlet and Shijin (2008) in chicken fry did not observe any significant changes in proximate composition due to either irradiation or packaging.

2.8. PHYSICOCHEMICAL QUALITIES

2.8.1. pH

Niemand *et al.* (1981) reported that a dose of 2.0 kGy had little effect on the lactobacilli and the metabolites produced which lowered the pH.

Lefebvre *et al.* (1994) reported that irradiation contributed to a diminution of pH in ground beef samples at 1.0, 2.5 and 5.0 kGy. Gram-negative bacteria, which increased the pH by the production of ammonia and amines, were more sensitive to irradiation than that of gram-positive bacteria.

Lee *et al.* (1996) observed that the pH values were not different up to seven days of ageing in irradiated (2.0 kGy) and non-irradiated beef samples, irrespective of storage temperature at 15^0C and 30^0C. However, after 14 days pH of the irradiated samples stored at 30^0C was lowest, because of lactic acid bacteria after 7 days.

Irradiation at 1.5 kGy had not shown any significant effect on the pH of vacuum packaged turkey breast meat samples on day 0 but increased slightly after 10 days of storage at 4^0C (Nam and Ahn, 2002b).

2.8.2. Water Holding Capacity

Grau and Hamm (1957) assessed the WHC by calculating the area of water diffused from the meat on to a filter paper under the influence of a standardized but manually applied pressure. The area of the fluid obtained around the meat film was proportional to the amount of free water in the meat.

Irradiation caused some protein denaturation that increased on storage especially at high temperature. The resultant loss in WHC caused considerable exudation (Cain *et al.*, 1958; Schweigert, 1959).

Van Laack and Smulders (1992) suggested that the degree of protein denaturation was an important determinant of the WHC of meat and more protein denaturation generally resulted in lower WHC. They also reported that the temperature would slow down the pH fall and resulted in less protein denaturation and thereby a better WHC.

Roserio *et al.* (1994) opined that a drastic fall in muscle pH decline denatured the sarcoplasmic and myofibrillar proteins and increased the tendency of actomyosin to contract, thus the amount of fluid free to enter extracellular spaces was affected.

Kristensen and Purslow (2001) reported that WHC of pork, which decreased postmortem, was found to be increased during subsequent ageing. The degradation of the cytoskeletal proteins weakened the linkage between the myofibrils allowing inflow of previously expelled water, so that WHC increased in later periods of storage.

Melody *et al.* (2004) reported that variation in WHC was due to differences in postmortem degradation of intermediate filament protein like desmin. They also found that psoas major had more degradation with a lower drip loss compared to *longissimus dorsi* and *semi-membranosus.*

Zhu *et al.* (2004a) reported that irradiation increased the centrifugation loss in pork loins at 1.5and 2.5 kGy. The increase in water loss might be related to structural damage of muscle fibres and denaturation of muscle proteins.

Huff-Lonergan and Lonergan (2005) found out that the early postmortem events including rate and extent of pH decline, proteolysis and even protein oxidation were the key factors in influencing the ability of meat to retain water. Much of the water in the muscle was entrapped in structures of the cell, including the intra and extramyofibrillar spaces; therefore, changes in the intracellular architecture of the cell influence the ability of the muscle cell to retain water.

Karakaya *et al.* (2006) assessed the WHC of different meat in pre rigor and post rigor stages and reported that the WHC values of mutton and chevon in pre and post rigor stages were higher than those of beef and rabbit. These higher values were attributed to the higher pH values.

2.8.3. Drip loss

Van Laack *et al.* (1996) showed that the higher pH as a result of sodium bicarbonate treatment had decreased drip loss in pork.

According to Joo *et al.* (1999) the percentage of drip loss for the smaller pieces decreased over time, whereas that of the larger pieces increased by time.

Miller *et al.* (2000) reported that percentage drip loss increased for animals classified as having either high or moderate glycolytic potential levels compared to those with low glycolytic potential values.

In a study conducted by Vergara *et al.* (2005) it was found that the packaging under high carbon dioxide concentrations can cause an increase in drip loss in fresh meat.

Xiong *et al.* (2007) observed that providing or withholding food in rabbits before slaughter had little effect on drip loss, but withholding water before slaughter significantly increased drip loss.

2.8.4. Cooking loss

Niemand *et al.* (1981) observed that cooking loss of the beef cut irradiated at 2.0 kGy were higher (25.1%) than their controls (24.5%) through out the storage period of 8 weeks at 4°C.

Bendall and Restall (1983) reported that structure of muscle protein was altered according to temperature of heat treatments. Expulsion of water from individual myofibre was slow at 40-53°C, but was rapid at 60°C as the collagen of basement membrane was shrinking. At 64-90°C, shrinkage of the endomysial, perimysial and epimysial collagens were noticed decreasing the myofibre diameter. Prolonged heating converted the collagen to gelatin and concomitant tenderizing occurs.

Hernandez *et al.* (2000) stated that water holding capacity and fat content were negatively correlated with cooking losses in rabbit meat.

Yoon (2003) observed that irradiated chicken breast had more cooking loss (26.4%) than non-irradiated samples (23.81%) throughout the 14 days storage period. Gamma irradiation caused significant textural toughening with contraction of the sarcomere width and physical disruption in myofibrils.

Beef and rabbit meat had higher cooking loss values in the prerigor stage due to low pH and WHC than chevon and mutton (Karakaya *et al.*, 2006)

2.8.5. Thiobarbituric Acid Reactive Substances

Dempster (1985) reported that doses of 1.03 and 1.54 kGy irradiation of vacuum packaged beef burger gave a significantly higher peroxide value than for raw control.

According to Murano *et al.* (1998) ground beef patties irradiated (2 kGy) and stored under air and those irradiated under vacuum and stored under air, showed a higher degree of lipid oxidation (TBA value) compared with samples irradiated and stored under vacuum or non-irradiated.

In aerobically packaged and irradiated meats, turkey leg muscles had higher cholesterol oxidation products value than beef or pork did, which had a positive correlation with TBARS values in turkey leg and pork (Nam *et al.*, 2001)

In a study conducted by Nortje *et al.* (2005) it was reported that the TBARS analysis indicated that irradiation did not induce a great deal of lipid oxidation in moist beef biltong.

Seydim *et al.* (2006) reported that the TBA values were lowest in vacuum packaged meat compared to the meat packed under high oxygen, high nitrogen and ambient air atmospheres.

2.8.6. Tyrosine Value

Proteolysis measured in terms of tyrosine equivalent and total amino acid content, was found to proceed more rapidly in breast muscle of chicken from vacuum packs than from oxygen permeable packs, might be due to difference in proteolytic activity between two types of micro flora (Jones *et al.*, 1982).

In plate frozen buffalo meat cuts and minced meat, tyrosine values were slightly decreased during storage, since the proteolytic reaction due to bacteria or endogenous enzymes was ceased during frozen storage (Ziauddin *et al.*, 1993).

The irradiation of meat at 1 to 10 kGy could be useful in retaining quality since proteolysis by endogenous enzymes would be diminished (Lawrie, 1998).

Higher protein degradation was observed by Karthikeyan *et al.* (2000) in keema when stored at ambient temperature. The unusual higher tyrosine values noted in treated keema was due to proteolysis of added soy protein isolates and skim milk powder when compared to that of untreated keema.

Dushyanthan *et al.* (2001) observed that mutton packed in multilayered films under vacuum revealed lower mean tyrosine values of 20.54 mg and 21.35 mg per 100g of meat, respectively. Anaerobic environment and barrier property of multilayered film for oxygen led to lower proteolysis and hence the lowest tyrosine values.

Kuttinarayanan *et al.* (2005) reported that proteolytic changes as estimated by tyrosine value have not shown any significant change between control and irradiated turkey breast samples initially. As the period enhanced from 0 to 25th day it was noticed a non significant increase with respect to tyrosine value during storage period as normal biochemical change as it is expected in refrigerated meats.

In a study conducted by Balamatsia *et al.* (2006) it was found that volatile amines, both trimethyl amine nitrogen (TMA-N) and total volatile basic nitrogen (TVB-N) values for aerobically packed non-irradiated chicken increased steeply, while aerobically packed irradiated sample showed lower TMA-N and TVB-N values ($P<0.05$) during refrigerated storage of 21 days at 4°C.

Jenifer (2006) reported that irradiation treatment of minced beef had no significant effect on tyrosine values compared to control samples at day zero. As storage days increased, tyrosine value increased with significant change among the treatments.

2.9. MICROBIOLOGICAL ANALYSIS

2.9.1. Aerobic Plate Count

According to Niemand *et al.* (1981) aerobic bacteria were reduced by 99.99 per cent in irradiated vacuum packaged beef cuts at dose of 2 kGy. However, at 4°C storage there was a rapid increase in bacterial numbers in control and radurized samples for 5 weeks and thereafter control samples maintained level of approximate log 8 bacteria/g whilst the number in radurized samples slowly increased until it reached unacceptable by 11 weeks.

Basker *et al.* (1986) showed that irradiation of raw whole chicken carcass by 2 to 4.5 kGy reduced the initial total aerobic mesophilic count by a factor of 10^3 to 10^4, and during subsequent storage at 4°C for 30 days the total count gradually rose to the initial value of non-irradiated samples.

Irradiation dose required for inactivating 90 per cent of the colony forming units (cfu) of common food borne pathogens associated with meat and meat products were in the range of 1.0 to 4.0 kGy (Thayer, 1993).

Mcateer *et al.* (1995) observed that low dose irradiation (2 and 3 kGy) reduced the number of microorganism in the meat to less than 100 per g and microbial growth did not occur during chill storage (2-3°C for 15 days).

Badr (2004) stated that irradiation at 1.5 to 3 kGy significantly reduced the counts of aerobic mesophilic bacteria and prolonged the refrigerated shelf life of samples to 12 and 21 days, respectively, compared to 6 days for non-irradiated controls.

Lee (2004) stated that irradiation processing of food increased microbial safety and enhanced shelf life of food. He also stated that if irradiation is done properly it acts as a safe process for destroying food borne pathogens.

Smith and Pillai (2004) reported that irradiation food was a beneficial technology to control pathogens, increase shelf life and maintain food quality. It could be used in food with out causing any human health hazard.

Chouliara *et al.* (2006) noted that the APC of 6 log cfu per g in meat or fat trimmings used for Greek dry salami was reduced by irradiation at a dose of 2 kGy (4.8 log cfu per g) and 4 kGy (3.9 cfu per g). *Pseudomonas* showed highest sensitivity while yeast were most resistant followed by lactic acid bacteria. Both of these doses reduced population of *Enterobacteria*, *Enterococci* and pathogenic *Staphylococci* to 1, 2 and 2 log cfu per g, respectively while *Listeria* were undetectable.

The combination of irradiation plus frozen storage resulted in greater overall reductions on microbial loads, extending shelf life of chicken meat for commercial application and critical condition (Javanmard *et al.*, 2006).

A significant reduction in Aerobic Plate Count was observed by low dose irradiation by Jenifer (2006) in minced beef, Kuttinarayanan (2007) in buffalo beef, Salke Dinkar Babanrao (2007) in beef cutlet and Shijin (2008) in chicken fry.

Kuttinarayanan *et al.* (2006a) reported that the treatment of meat with ionizing radiation was an effective method to reduce or eliminate several food borne pathogens and larvae of parasites.

Aymerich *et al.* (2008) stated that irradiation might effectively control the presence of all the main food borne pathogens such as *E. coli*, *L. monocytogenes*, *S. aureus*, *Salmonella spp.* and *Trichinella spiralis* also yeast and mould are effectively eliminated from meat and meat products.

Al-Bachir and Zeinou (2009) reported that all doses of gamma irradiation reduced the total mesophilic aerobic plate counts of minced camel meat. They also stated that the microbial shelf life of camel meat was significantly extended from less than 2 weeks (control) to more than six weeks (samples irradiated with 2, 4 or 6 kGy) in refrigerator.

2.9.2. Psychrotrophic Count

According to Lee *et al.* (1983) there was no difference in the number of lactobacilli, psychrotrophs, aerobes and anaerobes between vacuum and nitrogen packed veal during 49 days of storage at 3 and 7°C. The initial psychrotrophs count consisted primarily of *Pseudomonas putida* (>72 per cent) but by day 49 *Lactobacillus* spp., compromised at least 64 per cent of the total count in both atmospheres. Psychotropic counts ranged between log 4.6 to 6.1 cfu per g by 70 days of storage.

Niemand *et al.* (1983) reported that radurization of minced beef at 2.5 kGy completely eliminated *Pseudomonas* spp., *Enterobacteriaceae* and could not be detected throughout the entire storage period.

A study on the influence of gas atmosphere packaging on the microbial growth and succession on steaks showed that atmosphere containing 10% CO_2, 5% O_2 and 85% N_2 was most effective in reducing psychrotrophic growth on steaks. *Pseudomonas* spp., were the dominated micro flora during early storage, *Serratia liquefaciens* increased with storage time and *Enterobacter aerogenes* appeared at late storage period during 12 days of storage (Ahmad and Marchello, 1989).

Irradiation of fresh pork at 1.0 kGy reduced psychrotrophic and mesophilic bacterial populations by two log cycles and inactivated *Enterobacteriaceae*, whereas lactic acid bacteria were largely unaffected regardless of packaging atmosphere (Lambert *et al.*, 1992).

Lacorix *et al.* (2000) reported that psychotropic microorganism was more resistant when irradiation treatment was done under aerobic than under vacuum packaging and started to increase after 10 days in pork loins.

In a study conducted by Gomes *et al.* (2003) found that psychotropic bacterial counts were higher for non-irradiated samples in mechanically deboned chicken meat up to day eight in refrigeration than irradiated samples. However, psychrotrophic bacterial count exceeded the recommended limit of 6.48 log cfu per g after six days in non-irradiated, while in irradiated (3.0 and 4.0 kGy) it was only after 12 days of storage.

Irradiation doses of 1.5 and 3.0 kGy reduced the counts of aerobic mesophilic bacteria, psychrophilic bacteria, yeast and mould and prolonged the shelf life of refrigerated rabbit meat samples from 12 to 21 days at chiller storage (Badr, 2004).

Rodríguez-Calleja *et al.* (2005) reported that *Pseudomonas* spp. accounted for 61.7% of the total psychrotrophic numbers at the end of the storage life. *Pseudomonas* spp. and *B. thermosphacta* were the dominant microorganisms found throughout the shelf life of refrigerated boxed rabbit carcasses.

Salke Dinkar Babanrao (2007) observed a significant reduction (P<0.05) in psychrotrophic count due to irradiation and vacuum packaging of beef cutlets under chiller storage.

The main microbial groups on rabbit carcasses immediately after slaughter were *Pseudomonas spp.*, LAB and *Br.thermosphacta* with *Enterobacteriaceae* present in low numbers (Soultos *et al.*, 2009)

2.10. ORGANOLEPTIC QUALITIES

2.10.1. Colour

Kropf (1980) reported that colour was probably the single greatest appearance that determined whether the meat cut would be purchased.

In a sensory evaluation of irradiated ground beef (1.0, 2.5 and 5.0 kGy) conducted, revealed that odour and flavour of the irradiated cooked ground beef was slightly disliked while no difference was perceived in the colour and texture.

The lower the dose of irradiation, the better the taste appreciated (Lefebvre *et al.*, 1994).

Zhao *et al.* (1996) observed colour of irradiated pork was significantly less desirable than non irradiated samples throughout the storage. Colour of irradiated pork sample in aerobic packaging samples was less desirable immediately after irradiation. Carbon dioxide packaging was less desirable after 2 weeks of storage whereas vacuum packaging retained the colour throughout 4 weeks of storage.

Murano *et al.* (1998) showed that irradiation did not affect colour of ground beef patties, with differences being due to packaging atmosphere. Samples stored under vacuum were darker and redder than aerobically packed samples.

The extent of colour change by irradiation in vacuum packaged cooked pork sausage was lesser than that of raw pork. Irradiation significantly increased the redness of cooked vacuum packaged sausages regardless of storage time (Jo *et al.*, 2000).

Rabbit meat might change appearance with storage and became darker and drier or wet according to packaging systems (Zotte, 2002).

Zhu *et al.* (2003) reported that irradiation up to 2.0 kGy had limited effects on colour and oxidation of vacuum packaged commercial turkey ham.

Smith and Pillai (2004) opined that irradiation at a dose less than 3.0 kGy had no significant effect on flavour, texture or colour of ground beef.

Shijin (2008) reported a significant reduction in colour score in chicken fry under room temperature and chiller storage conditions.

2.10.2. Flavour

A higher ranking was observed for appearance and odour for minced beef by Niemand *et al.* (1981) throughout the storage period in radurized samples. On the day of irradiation, experienced person could detect a faint but typical irradiation odour in radurized samples although it was not found to be objectionable. Radurized samples had a low score in fourth week and higher score at eight week than control when evaluated for aroma and taste.

Hashim *et al.* (1995) reported that irradiating uncooked chicken meat produced a characteristic bloody and sweet aroma that remained even after cooking the meat.

According to Zhao *et al.* (1996) odour of irradiated products was as less desirable than non-irradiated but score did not change during 4 weeks of storage. For non-irradiated pork in air permeable packages, odour score were high initially, then decreased after 2 weeks of storage. Score between irradiated and non-irradiated remained the same after two weeks of storage.

Ahn *et al.* (1998) suggested that irradiation produced many unidentified volatiles products that could be responsible for the off odour in irradiated raw meat.

Ahn *et al.* (2000) did not observe any dose dependant odour preferences of pork patties with vacuum packaging but panelist preferred odour of aerobic-packaged non-irradiated samples to that of irradiated ones at day zero. Non-irradiated patties stored for 1or 2 weeks in vacuum and aerobic packaging showed lower odour preferences than those of the day zero.

For short term storage, irradiation of turkey breast meat in which lipid oxidation was not a great problem, aerobic packaging would be more beneficial than vacuum packaging, because sulphur volatile compounds responsible for the irradiation off odour could be reduced under aerobic conditions (Nam and Ahn, 2002a).

Zhu *et al.* (2003) reported that irradiation had a significant influence on odour and flavour of vacuum packaged turkey ham, but overall quality changes in irradiated turkey ham at 2.0 kGy were less.

Zhu *et al.* (2004b) reported that sulfury odour and flavour of ready-to-eat turkey breast rolls under vacuum packaging conditions irradiated at 2.0 kGy were stronger than those of non-irradiated. But no difference was detected between irradiated (1.0 kGy) and non-irradiated samples. The intensity of metallic oxidation and sweet odour increased with irradiation dose but the increase was not significant.

Ahn and Lee (2005) observed that irradiation of ready-to-eat turkey breast rolls at 3 kGy showed irradiation odour in treated samples twice higher than that of non-irradiated samples and irradiation did not show significant effect on colour and texture of ready-to-eat turkey breast rolls.

Arthur *et al.* (2005) observed no difference in flavour of irradiated (1 kGy) and non-irradiated ground beef patties samples when chilled carcasses were subjected to low dose irradiation.

Kanatt *et al.* (2005) reported that irradiation of Indian ethnic meat product like chilly chicken, mutton shammi kabab and pork salami either at 1, 2 or 3 kGy did not impart any detectable odour.

2.10.3. Juiciness

According to Smith *et al.* (1983), seven days of storage cooked chops from loins that had been vacuum packaged were less juicy than cooked lamb chops from loins that had been packaged in either of the modified atmospheres having 20% CO_2 80% N_2 or 40% CO_2 60% N_2. There was no difference in juiciness, flavor, desirability or overall palatability among cooked chops that were related to the method of packaging.

Luchsinger *et al.* (1996) evaluated acceptance of fresh or frozen irradiated boneless pork chops (1.5, 2.5 and 3.85 kGy) using a trained panelist and consumers. They did not observe any differences in acceptance, meatiness, freshness or juiciness of products irradiated at 2.5 kGy or below.

Abu-Tarboush *et al.* (1997) reported that irradiation doses (2.5 to 10.0 kGy) had little effect on the sensory acceptability (appearance, odour, texture and taste) of both raw and cooked chicken. Moreover juiciness and tenderness of cooked chicken were only slightly affected by irradiation.

Ground beef patties irradiated under vacuum and tasted one day later demonstrated increased juiciness, while those irradiated under vacuum but stored under air showed increased tenderness. Samples evaluated after seven days of storage showed no difference in any sensory attributes (Murano *et al.*, 1998).

Johnson *et al.* (2004) showed that overall acceptance, juiciness and tenderness of non-irradiated diced chicken and frankfurters were significantly lower than irradiated (1, 2, and 3 kGy) at day 18 and day 32, respectively at 4°C.

Shijin (2008) reported a slow and steady decrease in the juiciness scores in chicken fry as storage period advanced from above eight to 7.25 at the end of the study.

2.10.4. Tenderness

Perception of tenderness had been described in terms of following conditions of meat during mastication such as softness to tongue and cheek, persistence to tooth pressure, ease of fragmentation, meatiness, adhesion and residue after chewing (Forrest *et al.*, 1975).

The effect of irradiation on refrigerated and frozen chicken on sensory properties was investigated on skinless boneless breast (white) and leg (dark). It was found that cooked irradiated frozen dark meat had more chicken flavour and cooked irradiated refrigerated dark meat was tender than control (Hashim *et al.*, 1995).

Murano *et al.* (1998) investigated the changes in flavour, texture and juiciness of ground beef patties after either 2 or 7 days storage at 25°C prior to cooking. It was noted that, irradiated, air or vacuum packed samples were more tender, irradiated vacuum packed samples were more moist and irradiated air packed samples had the least taste.

Ohene-Adjei *et al.* (2004) reported that irradiation (1.5 kGy) of loin chops decreased the tenderness, which might be due to weakened texture of meat system due to irradiation that caused loss of moisture through drip or purge loss.

Arthur *et al.* (2005) reported that low dose irradiation (1 kGy) of ground beef patties the tenderness and juiciness were not dose related and ratings decreased with increased frozen storage.

Xiong *et al.* (2007) observed that allowing rabbits *ad libitum* access to water before slaughter can promote the ripe meat ratio and tenderness of meat.

Shijin (2008) reported that initially the non-irradiated samples had a tenderness score of 8.41±0.06 and this was significantly improved by irradiation and chitosan coating followed by irradiation.

2.10.5. Overall acceptability

In a consumer acceptance study of irradiated poultry cooked products based on colour, appearance, flavour, mouth feel and overall acceptability using a nine point hedonic scale, 73 per cent participants gave the product a minimum rating of 7.0. Consumers were willing to purchase irradiated products if provided more information of such products (Hashim *et al.*, 1995).

Sawant (1998) observed the spoilage changes of un-irradiated and irradiated beef burger and beef kabab samples in the form of souring, stickiness and disintegration. Colour and appearance were good but decrease in odour, texture and overall acceptability were noticed in irradiated and non-irradiated kababs on storage.

Johnson *et al.* (2004) reported that overall acceptance of flavour, juiciness, tenderness and mouth feel of non-irradiated diced chicken and frankfurter were significantly lower than irradiated (1, 2 and 3 kGy) at day 18 and 32, respectively. Although quality of the irradiated samples decreased with increasing storage time.

According to Kanatt *et al.* (2005) overall sensory scores for appearance, flavour and texture of irradiated samples (1, 2 and 3 kGy) of various meat products (chicken chilly, mutton shammi kababs and pork salami) were different from its non-irradiated controls and were acceptable immediately after irradiation.

Consumer acceptance study of irradiated cutlet, beef and minced beef by Kuttinarayanan (2005) revealed that 20 to 22 per cent consumer responded, 72.5 per cent liked to purchase irradiated cutlet and 37 per cent were ready to pay more to irradiated product since it could be kept at chiller conditions. Majority of them did not observe any peculiar smell or taste difference in the products due to irradiation.

Significant difference in overall acceptability was not observed due to low dose irradiation by Jenifer (2006) in minced beef, Vivek (2006) in fresh beef, Salke Dinkar Babanrao (2007) in beef cutlet and Shijin (2008) in chicken fry on the day of preparation and subsequent storage periods.

Kuttinarayanan *et al.* (2006b), conducted a study on the keeping quality and organoleptic studies of beef fry preserved by employing gamma radiation and found that physicochemical characters (pH , thiobarbituric acid reacting substance and tyrosine value) and organoleptic evaluation (with respect to colour, flavour, tenderness, juiciness and overall acceptability) using nine point hedonic scale didn't reveal any marked difference between irradiated and non-irradiated sample even after 28 days of storage at chiller temperature.

Materials and methods

3. MATERIALS AND METHODS

The study on the effect of low dose gamma radiation, aerobic and vacuum packaging on shelf life and quality changes of rabbit meat was conducted at the Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Mannuthy during the period of October 2008 to April 2009.

3.1. PREPARATION OF RABBIT MEAT

Seven batches of cross bred rabbits of 1.85 to 2.05 kg were collected from the local farmers and brought to the Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Mannuthy and given sufficient rest prior to slaughter. The rabbits were scientifically and hygienically slaughtered, the carcasses were washed, weighed and cut into small pieces of size 30 mm^3 for further studies.

3.2. DRESSING PERCENTAGE

Dressing percentage was calculated by applying the following formula and expressed as percentage (Forrest *et al.*, 1975).

$$\text{Dressing percentage} = \frac{\text{Dressed weight}}{\text{Live weight}} \times 100$$

3.3. PACKAGING

The prepared rabbit meat cuts were packaged carefully at a rate of 120 g approximately in High Density Polyethylene (HDPE) pouches (50μ) and in Polyamide Polyethylene (PAPE) pouches (80μ, OTR: <52cc/m^2/24h, CO_2 TR: 208cc/m^2 24h, WTR: 5g/cc/m^2/24h at 38°C, 90% RH). Half of the meat packets in each packaging materials were aerobically packaged by using the Quick seal (Sevana, Kochi) and vacuum packaged (740 mm of Hg) by using a single chamber vacuum packaging machine (Sevana, Kochi).

3.4. GAMMA RADIATION

Half of the packets of aerobic and vacuum packaged samples were subjected to gamma radiation at 2.5 kGy at melting ice temperature using Gamma Chamber 5000, (BRIT-DAE, Mumbai) where ^{60}Co was the source of radiation.

Sufficient number of packets in different treatment were kept immediately at chiller temperature (1 to 4°C) and domestic refrigerator freezer conditions (-6 to -8°C) and designated as follows.

1. HDPE NR C - High Density Polyethylene, Non irradiated, Chiller
2. HDPE IR C - High Density Polyethylene, Irradiated, Chiller
3. PAPE NR C - Polyamide Polyethylene, Non irradiated, Chiller
4. PAPE IR C - Polyamide Polyethylene, Irradiated, Chiller
5. HDPE NR F - High Density Polyethylene, Non irradiated, Freezer
6. HDPE IR F - High Density Polyethylene, Irradiated, Freezer
7. PAPE NR F - Polyamide Polyethylene, Non irradiated, Freezer
8. PAPE IR F - Polyamide Polyethylene, Irradiated, Freezer

The samples were analyzed on days 0, 3, 5, 10, 15, 20, 25, 30, 40, 45, 50, 60 and 70 or until spoilage. The proximate composition of different treatment groups were conducted on the day of preparation. The histological studies of the non-irradiated and irradiated samples were also conducted on the day of preparation.

3.5. PHYSICAL QUALITIES AND SHELF LIFE

Rabbit meat stored at chiller and domestic refrigerator freezer temperature were opened and examined on days 0, 3, 5, 10, 15, 20, 25, 30, 40, 45, 50, 60 and 70 of preparation or until spoilage whichever was earlier and examined for signs of spoilage, viz., change in colour, odour, consistency and slime formation and the data were recorded.

3.6. HISTOLOGICAL STUDIES

In order to assess the effect of irradiation in rabbit meat, samples of ***longissimus dorsi*** muscle at the level of 6^{th} lumbar vertebra was collected, packaged in HDPE packets and subjected to irradiation at 2.5 kGy at melting ice temperature. Irradiated and non-irradiated samples of uniform size were fixed using Neutral Buffered Formalin (NBF) 10 per cent. Tissues were processed and sections of 5µm thickness were made. The sections were stained as per Van Gieson's method (Luna, 1968).

3.7. PROXIMATE ANALYSIS

Rabbit meat was analyzed for its proximate composition, viz., moisture, fat, protein and ash content on the day of preparation. The composition was expressed as percentage of the rabbit meat on wet matter basis.

3.7.1. Moisture

The moisture content of rabbit meat was analyzed as per AOAC (1990). About 10.0 g of the meat sample in an evaporating dish was kept in a hot air oven set at 100±2°C for 16 to 18 h. The weight of the dried samples was taken after cooling in a desiccator. The difference in the weight was the moisture content of the sample and expressed as percentage of the rabbit meat.

3.7.2. Fat

Fat content was estimated as per AOAC (1990). Fat content of three g of moisture free sample was extracted in petroleum ether (boiling range 40-60°C) using Socs Plus Solvent Extraction System (Pelican Equipments, India). Ether extract obtained is dried to a constant weight at 100°C, cooled and weighed. The difference in weight is the total fat content of the sample and converted to wet matter basis and expressed as percentage of the rabbit meat.

3.7.3. Protein

The Copper Catalyst Kjeldahl method was used to determine the protein content of the samples (AOAC, 1990). The nitrogen was estimated using Kel Plus Automated Nitrogen Estimation System (Pelican Equipments, India). The total nitrogen estimated was converted to percentage of protein by multiplying with the constant.

Protein % = 6.25 x % Nitrogen

3.7.4. Ash

About five g of the sample in a silica crucible was ashed in a muffle furnace set at 600±20°C for 2.5 h. Then the crucible with white ash was transferred to a desiccator, allowed to cool and weighed. The difference in weight is the total mineral content of the sample (AOAC, 1990) and expressed as percentage of rabbit meat.

3.7.5. Energy Calculation

The energy content of rabbit meat was determined as per FAO (2002) on wet matter basis.

Energy (kcal) = (fat per cent x 9) + (protein per cent x 4) + (carbohydrate per cent x 4)

3.8. PHYSICOCHEMICAL QUALITIES

3.8.1. pH

The pH of the samples was estimated by using a digital pH meter (μ pH system- Systronics, India) as described by O'Halloran *et al.* (1997). About 50.0 g of meat was taken in a glass beaker and was incised with a scalpel blade. The combined glass electrode of the pH meter was inserted approximately 2 inches into the muscle without entrapping any airspace around the bulb of the electrode. The pH was recorded and the probe was thoroughly rinsed with distilled water before each reading. The pH meter was standardized using buffer solutions of pH 4.0 and 7.0.

3.8.2. Water Holding Capacity (WHC)

The Water Holding Capacity was assessed by the centrifugation method as per Wardlaw *et al.* (1973)

Weighed 5.0 g of the sample and was minced in a calibrated centrifuge tube. It was mixed with 7.5 ml of 0.6M NaCl and was stirred for 1 min with a glass rod. After holding for 15 min at 4°C, the meat slurry was again stirred for 1 min. Immediately centrifuged at 6000 rpm for 15 min in a research centrifuge. The supernatant layer was decanted and the volume (v) recorded. The amount of added solution retained by meat is reported as WHC in ml/100 g meat and was calculated as follows.

$$\text{WHC (ml/100g)} = \frac{(7.5 - v)\,100}{5}$$

3.8.3. Drip loss

The drip loss was assessed as per Taylor *et al.* (1990).

The amount of drip in each pack was estimated by weighing the pack of meat before opening and subtracting the weight of meat after blotting plus weight of packing. Drip loss was expressed as percentage of the initial weight of meat.

The percentage of drip loss was assessed as follows,

$$\text{Drip loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

3.8.4. Cooking loss

The cooking loss was determined as per Boccard *et al.* (1981). 70-100 g of meat was placed in a HDPE pouch and sealed in moderate vacuum to remove the trapped air between the sample and the wall of the pouch. The pouch was kept in the water bath at 75^{0}C for 50 min. Then the pouch was placed in running tape water for 40 min, after which the cooked meat was taken out from the bag, mopped, dried and weighed. The percentage of cooking loss was assessed as follows,

$$\text{Cooking loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

3.8.5. Thiobarbituric Acid Reactive Substances (TBARS)

The Thiobarbituric Acid Reactive Substances were estimated as per Alasnier *et al.* (2000).

Four grams of sample were mixed with Butylated Hydroxy Toluene (BHT) in ethanol (10µg BHT/ g of lipids) and 16.0 ml of Trichloroacetic Acid (TCA 5 per cent). Samples were homogenized for 20 s at 20,000 rpm and then filtered through Whatman filter (No.4). Two ml of the filtrate was added to 2 ml Thiobarbituric Acid solution (TBA 20 mM). The tightly closed tubes were heated at 70^{0}C for 30 min and then cooled and centrifuged at 8000 rpm for 10 min to obtain a clear supernatant. The optical density of the pink coloured supernatant was measured at 532 nm against blank containing 2.0 ml distilled water and 2.0 ml 20 mM TBA solution in UV-Vis Spectrophotometer 119 (Systronics, India). The values were expressed as mg of malonaldehyde per kg (mg mal/kg) of the sample.

3.8.5.1. Standard Graph for Thiobarbituric Acid Reactive Substances

Five μl malonaldehyde was dissolved in 5.0 per cent TCA and BHT in ethanol (10μg BHT/g of lipids) in a 500 ml volumetric flask and then the solution was made up to the mark with single distilled water. The following volumes of malonaldehyde solution were then added to a series of 100 ml of volumetric flasks: 0, 2, 3, 4, 5, 6, 7, 8, 9, 10 ml. Each was made up to the mark with single distilled water and mixed. Two ml of each solution were shaken with two ml TBA 20 mM. The tightly closed tubes were heated at 70°C for 30 min then treated as described as for the determination above. The standard graph was prepared by plotting optical density against mg malonaldehyde/ kg of sample (assuming that 4 g were used).

3.8.6. Tyrosine Value (TV)

The Tyrosine Values of the samples were estimated as per the method described by Pearson (1968).

Two g of sample was weighed and 40 ml of 5.0 per cent TCA solution was added. After homogenization for 2 min the sample was filtered and the filtrate was collected. The filtrate, termed TCA extract was used in the estimation of TV. To 2.5 ml of TCA extract, equal quantity of distilled water was added in a test tube and shaken with 10 ml of 0.5 N NaOH and 3.0 ml of diluted Folin and Ciocalteu's phenol (FC) reagent (1.0 ml of concentrated FC reagent and 2.0 ml of distilled water). After mixing, the contents were allowed to stand for 15 min at room temperature, the optical density was measured at 660 nm in UV-Vis Spectrophotometer 119 (Systronics, India) using a blank containing 2.5 ml of 5 per cent TCA, equal quantity of distilled water was added in a test tube and shaken with 10 ml of 0.5 N NaOH and

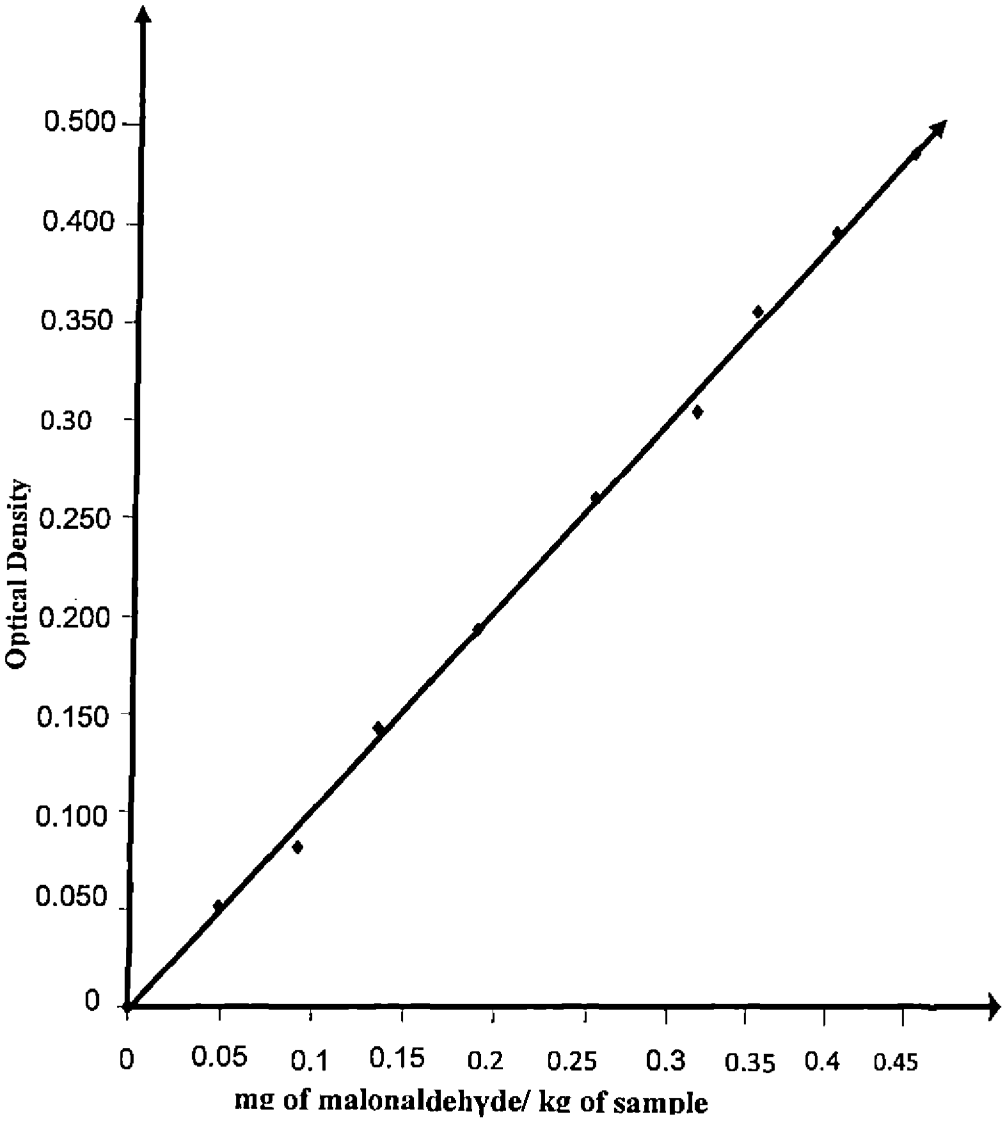

Figure 1. Standard graph for Thiobarbituric Acid Reactive Substances

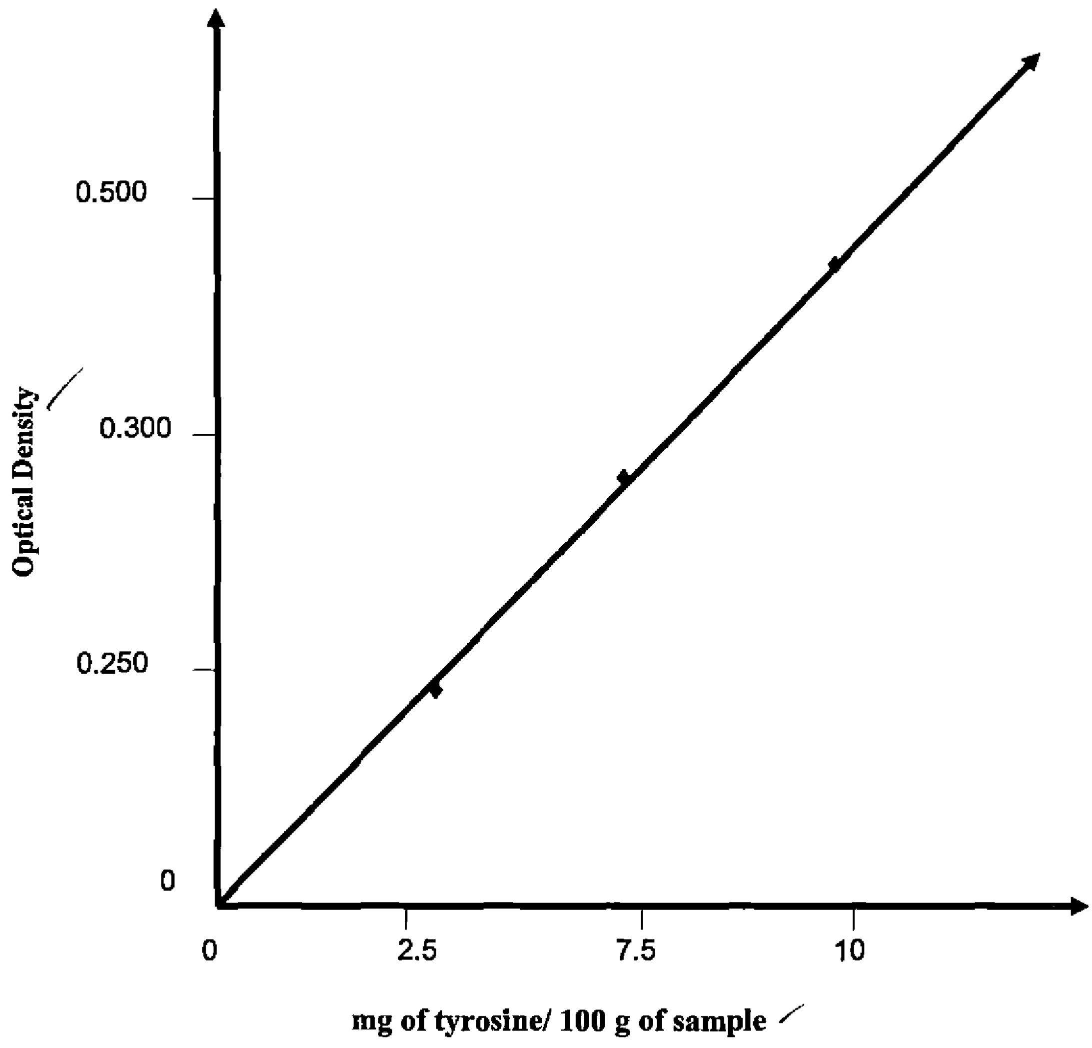

Figure 2. Standard graph for Tyrosine Value

three ml of diluted FC reagent for comparison. By reference to the standard graph the TV was calculated and expressed as mg/100 g of rabbit meat.

3.8.6.1. Standard Graph for Tyrosine Value

Accurately weighed 100 mg tyrosine was dissolved in 5 per cent TCA in a 500 ml volumetric flask and then solution was made up to the mark with water. The following volumes of tyrosine solution were then added to a series of 100 ml volumetric flasks: 0, 1, 3, 5, 7, 10, 12, 15, 20 ml. Each was made up to the mark with single distilled water and mixed. Five ml of each solution was shaken with sodium hydroxide solution and three ml of diluted FC reagent and then treated as described as for the determination above. The standard graph was prepared by plotting optical density against mg tyrosine/100 g sample (assuming that 2.0 g was used). Recoveries were checked by adding known amounts of tyrosine dissolved in TCA solution.

3.9. MICROBIOLOGICAL ANALYSIS

Sealed packets of rabbit meat were opened under aseptic conditions and 25.0 g of the sample was homogenized for 30 sec at 230 rpm with sterile 225 ml of 0.1 per cent peptone water (diluent) in a stomacher (Seward Stomacher® 400 circulator) so as to form one in ten dilution of the sample. Further serial 10 fold dilutions were prepared by transferring one ml of the inoculum into nine ml of the diluent. Selected serial dilutions were used to estimate the number of aerobic bacteria and psychrotrophic bacteria and expressed as $\log_{10}$ cfu/g of sample.

3.9.1. Aerobic Plate Count (APC)

Aerobic Plate Count of each sample was estimated by pour plate technique, as described by Mortan (2001). From the selected dilution of each sample, one ml of inoculum was transferred in labeled duplicate petri dishes of size 100x17mm. To each of these inoculated plates, about 15.0-20.0 ml sterile molten Standard Plate Count Agar (HiMedia, Mumbai) maintained at 45°C was poured and mixed with inoculum by gentle clockwise, anticlockwise, forward and backward movements. The inoculated plates were allowed to solidify at room temperature and incubated at 37°C for 24 h in inverted position. At the end of the incubation period, the plates having colonies between 20 and 200 were selected and counts were taken with the help of digital colony counter (Royal, India). The number of colony forming units (cfu) per gram of sample was calculated by taking the average of duplicate plates and multiplied by the dilution factor and converted to $\log_{10}$ cfu/g of sample.

3.9.2. Psychrotrophic Count (PC)

Psychrotrophic Count was assessed as per Cousin *et al.* (2001). Inoculated agar plates by pour plate method prepared as in case of APC was incubated at 7±1°C for ten days in BOD incubator (Rotec, India). At the end of the incubation period, petri dishes with a bacterial count between 20 and 200 colonies were selected and the colony counts were taken with the help of a digital colony counter (Royal, India). The number of cfu/g of the sample was calculated by taking the average of duplicate plates and multiplied by the dilution factor and expressed as $\log_{10}$ cfu/g of the sample.

3.10. ORGANOLEPTIC QUALITIES

Organoleptic assessment of the non spoiled cooked rabbit meat was conducted on days 0, 3, 5, 10, 15, 20, 25, 30, 40, 45, 50, 60, 70 or until spoilage whichever was earlier. Uniform amount of samples were taken and cooked in HDPE pouch for about 20 minutes in the boiling water (100^0C). The cooked samples were served to trained panelists drawn from the Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Mannuthy. Nine-point Hedonic scale score card (Table 1) was provided to the panelists to assess colour, flavour, juiciness, tenderness and overall acceptability of the cooked product.

3.11. STATISTICAL ANALYSIS

The data obtained with respect to physiochemical, microbiological and sensory evaluation of the samples were analyzed using one way analysis of variance and paired t-tests (Snedecor and Cochran, 1994).

Table 1. SCORE CARD FOR TASTE PANEL EVALUATION

Name of the Product: Cooked rabbit meat Date: Sample No:

	Colour		Flavour		Juiciness		Tenderness		Overall acceptability	
Extremely Appealing	☐ ☐	Delicious	☐ ☐	More Juicy	☐ ☐	Very Tender	☐ ☐	More Acceptable	☐ ☐	9
	☐ ☐		☐ ☐		☐ ☐		☐ ☐		☐ ☐	8
	☐ ☐		☐ ☐		☐ ☐		☐ ☐		☐ ☐	7
Appealing	☐ ☐	Desirable	☐ ☐	Juicy	☐ ☐	Tender	☐ ☐	Acceptable	☐ ☐	6
	☐ ☐		☐ ☐		☐ ☐		☐ ☐		☐ ☐	5
	☐ ☐		☐ ☐		☐ ☐		☐ ☐		☐ ☐	4
Less appealing	☐ ☐	Not so desirable	☐ ☐	Less Juicy	☐ ☐	Tough	☐ ☐	Less Acceptable	☐ ☐	3
	☐ ☐		☐ ☐		☐ ☐		☐ ☐		☐ ☐	2
	☐ ☐		☐ ☐		☐ ☐		☐ ☐		☐ ☐	1

<u>Guide lines for giving judgement</u>: If you feel that the colour of the product given to you for taste panel evaluation is extremely appealing, put a tick mark in any one of the three boxes against colour. Lower box signifies that it is less appealing and a tick in the central box signifies that it is for appealing. Similarly mark for the other characters viz., flavour, juiciness, tenderness and overall acceptability.

Specify comments if any:
Name and designation: Signature:

Results

4. RESULTS

Seven batches of crossbred rabbit comprising of 52 animals were procured and humanely slaughtered under hygienic conditions in Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Mannuthy. The slaughter data were collected. The carcass were uniformly cut and packaged at a rate of 120 g either in HDPE or in PAPE packets. Half of the packets from each groups were subjected to irradiation at 2.5 kGy employing Gamma Chamber 5000, (BRIT-DAE, Mumbai). Sufficient number of the packets were stored under chiller condition (1 to 4°C) and freezer (-6 to -8°C) of a domestic refrigerator. The samples were analyzed on the day of preparation for proximate composition, viz., moisture, protein, fat, ash and carbohydrate. The stored samples were examined for the physical signs of spoilage, viz., changes in colour and odour and slime formation, and spoiled samples were discarded. The non-spoiled samples were assessed for its physical, physicochemical, microbiological and sensory qualities on days 0, 3, 5, 10, 15, 20, 25, 30, 40, 45, 50, 60, and 70 of storage or until spoilage, whichever was earlier.

4.1. DRESSING PERCENTAGE

The dressing percentage of rabbit was calculated using the following formula.

$$\text{Dressing percentage} = \frac{\text{Dressed weight}}{\text{Live weight}} \times 100$$

The data is shown in Table 2. The 52 animals had a total weight of 99.00 kg, averaging 1.90 kg. The carcass yield was 48.86 kg and the average carcass weight was 0.94 kg. The dressing percentage was only 49.35 per cent.

Table 2. Dressing percentage of rabbit

No. of animals	Live weight (kg)	Average weight (kg)	Dressed weight (kg)	Average weight (kg)	Dressing percentage (%)
52	99.00	1.90	48.86	0.94	49.35

4.2. PHYSICAL QUALITIES AND SHELF LIFE

The samples kept both in chiller and freezer was examined for the signs of spoilage like changes in odour, colour, slime formation and mould growth. The spoiled samples were discarded and were not subjected to any further analysis. The shelf life assessed with the help of physical qualities is shown in Table 3 and presented in Figure 3. It was observed that the non-irradiated samples in HDPE packages had the shortest storage life of 5 to 7 days in chiller and an extended storage life of 15 to18 days in irradiated samples. By freezing 3 to 4 times enhancement in shelf life was observed and usage of multilayer film had specific advantage in extending the shelf life both under chiller and freezer conditions.

Table 3. Shelf life of rabbit meat (days) based on physical signs of spoilage

Treatment	Storage	
	Chiller (1 to 4°C)	Freezer (-6 to -8°C)
HDPE NR	5 to 7	25 to 27
HDPE IR	15 to 18	45 to 47
PAPE NR	7 to 9	27 to 29
PAPE IR	17 to 19	47 to 49

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated.

4.3. HISTOLOGICAL STUDIES

The effect of irradiation on the histological architecture of rabbit muscle was conducted on the day of preparation. The sample from *longissimus dorsi* muscle at the region of 6th lumbar vertebra was subjected to irradiation at 2.5 kGy and the histological findings were compared with non-irradiated samples. The stained section of non-irradiated and irradiated muscle fibre is shown in Figure 4 and 5 respectively. Irradiation of the rabbit muscle had not revealed any changes in the striation of the muscle fibre. Whereas, swelling of the collagen was noticed in the irradiated samples.

4.4. PROXIMATE ANALYSIS

Rabbit meat was analyzed for its proximate composition viz., moisture, fat, protein and ash content. The carbohydrate and other contents were arrived by subtracting the sum of these principles from 100, and the energy level of product was arrived. The data is given in Table 4. On an average the product had a moisture percentage of above 76.0. The highest percentage of moisture was recorded in irradiated samples of 76.59±0.18 (HDPE IR) and 76.57±0.21 (PAPE IR). The fat, protein and ash percentages were non significant either by irradiation or by packaging. The carbohydrate of rabbit meat varied from 1.31±0.04 to 1.58±0.09. The energy level was altered due to irradiation and non-irradiated samples had a significantly ($P < 0.05$) high energy level than that of irradiated samples. The percentage composition per 100 g of rabbit meat is shown in Figure 6.

Table 4. Proximate composition of rabbit meat under different treatment groups (on day zero)

Treatment	Parameters					
	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrate (%)	Energy (k cal/ 100g)
HDPE NR	76.09[a] ±0.25	1.81[a] ±0.02	19.57[a] ±0.22	0.95[a] ±0.01	1.58[b] ±0.09	100.89[b] ±0.11
HDPE IR	76.59[ab] ±0.18	1.82[a] ±0.02	19.33[a] ±0.13	0.95[a] ±0.01	1.31[a] ±0.04	98.94[a] ±0.05
PAPE NR	76.18[a] ±0.16	1.76[a] ±0.02	19.48[a] ±0.10	0.96[a] ±0.01	1.55[b] ±0.07	99.96[b] ±0.04
PAPE IR	76.57[b] ±0.21	1.80[a] ±0.02	19.37[a] ±0.13	0.96[a] ±0.01	1.31[a] ±0.07	98.92[a] ±0.05

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).
HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene
NR – Non-irradiated, **IR** – Irradiated.

4.5. PHYSICOCHEMICAL QUALITIES

4.5.1. pH

The pH of rabbit meat analyzed is shown in Table 5 and the trend of change in pH in stored rabbit meat is shown in Figure 7a and Figure 7b. It was observed that irradiation had brought significant ($P < 0.05$) changes in pH where as packaging was

Table 5. pH of rabbit meat on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	5.93^{b} ±0.01	5.88^{cd}* ±0.01	5.83^{bcd}* ±0.01	S	S	S	S	S	S	S
HDPE IR C	5.91^{a} ±0.01	5.85^{a}* ±0.01	5.81^{abc}* ±0.01	5.67^{a}* ±0.04	5.48^{e}* ±0.07	S	S	S	S	S
PAPE NR C	5.93^{b} ±0.01	5.89^{d}* ±0.01	5.84^{de}* ±0.01	S	S	S	S	S	S	S
PAPE IR C	5.91^{a} ±0.01	5.86^{ab}* ±0.01	5.81^{ab}* ±0.01	5.68^{ab}* ±0.02	5.41^{a}* ±0.07	S	S	S	S	S
HDPE NR F	5.93^{b} ±0.01	5.88^{bc}* ±0.004	5.84^{e}* ±0.01	5.74^{bc}* ±0.02	5.63^{b}* ±0.03	5.56^{b}* ±0.03	5.22^{ab}* ±0.04	S	S	S
HDPE IR F	5.91^{a} ±0.01	5.86^{ab}* ±0.01	5.79^{a}* ±0.01	5.71^{ab}* ±0.02	5.54^{ab}* ±0.02	5.43^{a}* ±0.03	5.12^{a}* ±0.04	5.00^{b}* ±0.02	4.88^{b}* ±0.01	4.84^{b}* ±0.02
PAPE NR F	5.93^{b} ±0.01	5.93^{e}* ±0.01	5.85^{e}* ±0.01	5.74^{bc}* ±0.02	5.66^{b}* ±0.02	5.60^{b}* ±0.02	5.28^{b}* ±0.04	S	S	S
PAPE IR F	5.91^{a} ±0.01	5.87^{bc}* ±0.01	5.83^{cde}* ±0.01	5.75^{c}* ±0.02	5.66^{b}* ±0.03	5.59^{b}* ±0.03	5.23^{ab}* ±0.04	5.04^{b}* ±0.02	4.94^{a}* ±0.01	4.88^{a}* ± 0.02

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

not effective in changing the pH. As storage period enhanced the pH has reduced significantly ($P < 0.05$) along with irradiation, where as such a drastic change was not shown by packaging in case of chilled meat either on days 3 or 5 on both chiller and freezer samples separately. The sample on the last day of observation (day 45) under freezer condition had shown significant ($P < 0.05$) difference in pH values of 4.84±0.02 and 4.88±0.02 in HDPE IR F and PAPE IR F samples respectively. Storage in both chiller and freezer had a significant ($P < 0.05$) effect in reducing the pH.

4.5.2. Water Holding Capacity

The WHC of rabbit meat during the storage period is shown in Table 6 as ml/100g of meat. Irradiation on the day of preparation significantly ($P < 0.05$) reduced the WHC both in HDPE and PAPE packaged meat. Storage had a significant ($P < 0.05$) effect in reducing the WHC in all the treatment groups under both storage conditions. Packaging as well as irradiation had an effect in reducing the WHC under chiller as well as freezer condition. As storage period enhanced, about 40 per cent reduction in WHC was noticed in irradiated samples under different packaging system and the lowest value of 17.00±0.44 was noticed on day 45th in HDPE IR F samples as against 30.00±0.58 initially. The trend of reduction of WHC under different packaging system and storage period is shown in Figure 8.

4.5.3. Drip loss

The drip loss of samples under different treatment groups is shown in Table 7. On the day of preparation none of the treatments were significantly influenced the drip loss. Storage had a significant ($P < 0.05$) effect on increasing the drip loss. Chiller storage had significantly ($P < 0.05$) increased the drip loss from day zero while freezer storage has reduced the same significantly ($P < 0.05$). As storage period enhanced (from day three) the drip loss had increased significantly ($P < 0.05$)

Table 6. Water Holding Capacity of rabbit meat (ml/100g) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	31.14^{ab} ±0.46	29.43^{bc}* ±0.29	27.00^{bc}* ±0.31	S	S	S	S	S	S	S
HDPE IR C	30.00^{a} ±0.58	28.43^{a}* ±0.43	25.86^{a}* ±0.34	24.00^{ab}* ±0.76	22.43^{a}* ±0.65	S	S	S	S	S
PAPE NR C	32.14^{b} ±0.34	30.71^{d}* ±0.29	28.57^{de}* ±0.29	S	S	S	S	S	S	S
PAPE IR C	30.14^{a} ±0.40	28.29^{a}* ±0.42	26.43^{ab}* ±0.29	23.86^{a}* ±0.63	22.14^{a}* ±0.59	S	S	S	S	S
HDPE NR F	31.14^{ab} ±0.46	30.14^{bcd}* ±0.26	27.71^{cd}* ±0.29	26.57^{cd}* ±0.20	25.29^{c}* ±0.29	24.00^{ab}* ±0.54	22.57^{a}* ±0.57	S	S	S
HDPE IR F	30.00^{a} ±0.58	28.57^{ab}* ±0.29	26.43^{ab}* ±0.37	25.29^{bc}* ±0.29	23.86^{b}* ±0.34	22.86^{a}* ±0.46	21.29^{a}* ±0.42	19.71^{a}* ±0.42	17.86^{a}* ±0.34	17.00^{a}* ±0.44
PAPE NR F	32.14^{b} ±0.34	30.71^{d}* ±0.29	29.14^{e}* ±0.34	27.71^{d}* ±0.36	26.57^{c}* ±0.37	26.00^{c}* ±0.54	24.43^{b}* ±0.37	S	S	S
PAPE IR F	30.14^{a} ±0.40	29.14^{ab}* ±0.26	27.57^{c}* ±0.29	26.29^{c}* ±0.29	25.29^{c}* ±0.29	24.57^{bc}* ±0.43	22.29^{a}* ±0.57	20.71^{a}* ±0.52	19.00^{a}* ±0.58	18.00^{a}* ±0.58

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

Table 7. Drip loss of rabbit meat (%) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	8.73^{a} ±0.34	9.05^{b*} ±0.20	9.67^{b*} ±0.22	S	S	S	S	S	S	S
HDPE IR C	8.85^{a} ±0.34	9.22^{b*} ±0.29	9.76^{b*} ±0.21	9.99^{b*} ±0.24	10.16^{b*} ±0.24	S	S	S	S	S
PAPE NR C	8.59^{a} ±0.32	8.96^{b*} ±0.21	9.43^{b*} ±0.21	S	S	S	S	S	S	S
PAPE IR C	8.66^{a} ±0.30	9.08^{b*} ±0.23	9.54^{b*} ±0.22	9.83^{b*} ±0.20	10.04^{b*} ±0.22	S	S	S	S	S
HDPE NR F	8.73^{a} ±0.34	1.05^{a*} ±0.01	1.10^{a*} ±0.01	1.29^{a*} ±0.02	1.44^{a*} ±0.03	1.57^{ab*} ±0.04	1.89^{b*} ±0.03	S	S	S
HDPE IR F	8.85^{a} ±0.34	1.07^{a*} ±0.01	1.14^{a*} ±0.01	1.35^{a*} ±0.02	1.49^{a*} ±0.03	1.65^{b*} ±0.04	1.99^{b*} ±0.04	2.13^{a*} ±0.03	2.28^{a*} ±0.03	2.42^{a*} ±0.04
PAPE NR F	8.59^{a} ±0.32	1.02^{a*} ±0.01	1.07^{a*} ±0.01	1.20^{a*} ±0.03	1.36^{a*} ±0.03	1.47^{a*} ±0.06	1.75^{a*} ±0.05	S	S	S
PAPE IR F	8.66^{a} ±0.30	1.05^{a*} ±0.01	1.11^{a*} ±0.01	1.27^{a*} ±0.02	1.41^{a*} ±0.04	1.55^{ab*} ±0.05	1.87^{ab*} ±0.05	2.04^{a*} ±0.04	2.22^{a*} ±0.04	2.34^{a*} ±0.04

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

Drip loss on 0-day. Result possibly should be 24 hrs. clarify.

on day 45^{th} from 1.05±0.01 to 2.34±0.04. The frozen sample on 45^{th} day both HDPE IR F and PAPE IR F samples showed non significant ($P < 0.05$) values of drip loss. The drip loss of rabbit meat on the day of preparation is shown in Figure 9.

4.5.4. Cooking loss

The values of cooking loss in different treatment groups are depicted in Table 8. Irradiation had a significant ($P < 0.05$) effect in enhancing the cooking loss whereas packaging had little effect in this physicochemical parameter of meat. As storage period enhanced there was a change in the cooking loss of meat between chiller stored and frozen meat. The values were significantly ($P < 0.05$) lower in frozen samples. HDPE IR C samples recorded the highest cooking loss of 33.11± 0.34 on day 15^{th}, whereas such a higher value was not noticed in frozen sample even after 45 days of storage. The percentage of cooking loss of rabbit meat on the day of preparation under various treatment conditions is given in Figure 10.

4.5.5. Thiobarbituric Acid Reactive Substances

TBARS values expressed in terms of mg malonaldehyde /kg is shown in Table 9. The non-irradiated samples had a TBARS value of 0.06±0.01 which was increased significantly ($P < 0.05$) to 0.08±0.01 in irradiated samples on the day of preparation. Packaging was not influenced on the day of preparation since there is no time gap between packaging and estimation. As storage period enhanced, the TBARS values have significantly ($P < 0.05$) increased. The trend of increase in TBARS values due to storage is shown in Figure 11a and Figure 11b. From day three onwards, the values of TBARS in frozen samples had a significantly ($P < 0.05$) lower than that of chiller stored samples. In chilled samples, storage had a significant ($P < 0.05$) influence in TBARS values whereas, irradiation of meat in different packages (HDPE and PAPE) results in non significant ($P < 0.05$) values (day ten). The HDPE NR F samples had a significantly ($P < 0.05$) higher value than PAPE NR

Table 8. Cooking loss of rabbit meat (%) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	31.05^{a} ±0.12	31.45^{e*} ±0.14	31.99^{c*} ±0.17	S	S	S	S	S	S	S
HDPE IR C	31.67^{b} ±0.14	32.16^{f*} ±0.15	32.73^{d*} ±0.26	32.93^{c*} ±0.32	33.11^{c*} ±0.34	S	S	S	S	S
PAPE NR C	30.70^{a} ±0.16	31.00^{d*} ±0.13	31.63^{c*} ±0.12	S	S	S	S	S	S	S
PAPE IR C	31.68^{b} ±0.22	32.04^{f*} ±0.17	32.50^{d*} ±0.15	32.70^{c*} ±0.17	32.89^{c*} ±0.19	S	S	S	S	S
HDPE NR F	31.05^{a} ±0.12	29.57^{ab*} ±0.13	30.00^{a*} ±0.09	30.24^{ab*} ±0.10	30.53^{ab*} ±0.13	30.77^{ab*} ±0.16	31.50^{ab*} ±0.19	S	S	S
HDPE IR F	31.67^{b} ±0.14	30.05^{c*} ±0.05	30.49^{b*} ±0.14	30.57^{b*} ±0.14	30.86^{b*} ±0.13	31.24^{b*} ±0.16	32.07^{b*} ±0.22	32.35^{a*} ±0.19	32.78^{a*} ±0.19	33.03^{a*} ±0.23
PAPE NR F	30.70^{a} ±0.16	29.34^{a*} ±0.15	29.72^{a*} ±0.07	29.93^{a*} ±0.04	30.13^{a*} ±0.10	30.39^{a*} ±0.20	31.17^{a*} ±0.18	S	S	S
PAPE IR F	31.68^{b} ±0.22	29.76^{bc*} ±0.09	30.14^{ab*} ±0.10	30.27^{ab*} ±0.12	30.62^{ab*} ±0.10	30.91^{b*} ±0.12	31.58^{ab*} ±0.19	31.98^{a*} ±0.15	32.35^{a*} ±0.18	32.66^{a*} ±0.20

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

Table 9. Thiobarbituric Acid Reactive Substances values of rabbit meat (mg malonaldehyde /kg) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	0.06^{a} ±0.01	0.25^{e}* ±0.01	0.37^{e}* ±0.01	S	S	S	S	S	S	S
HDPE IR C	0.08^{b} ±0.01	0.16^{c}* ±0.02	0.26^{c}* ±0.01	0.34^{d}* ±0.01	0.44^{d}* ±0.01	S	S	S	S	S
PAPE NR C	0.06^{a} ±0.01	0.20^{d}* ±0.01	0.34^{d}* ±0.01	S	S	S	S	S	S	S
PAPE IR C	0.08^{b} ±0.01	0.14^{bc}* ±0.02	0.25^{c}* ±0.01	0.36^{d}* ±0.01	0.43^{d}* ±0.01	S	S	S	S	S
HDPE NR F	0.06^{a} ±0.01	0.11^{ab}* ±0.01	0.22^{b}* ±0.01	0.25^{c}* ±0.01	0.29^{c}* ±0.01	0.32^{d}* ±0.01	0.43^{d}* ±0.01	S	S	S
HDPE IR F	0.08^{b} ±0.01	0.10^{a}* ±0.01	0.18^{a}* ±0.01	0.21^{ab}* ±0.01	0.23^{ab}* ±0.01	0.24^{b}* ±0.01	0.32^{b}* ±0.01	0.38^{a}* ±0.01	0.45^{a}* ±0.01	0.47^{a}* ±0.01
PAPE NR F	0.06^{a} ±0.01	0.10^{a}* ±0.01	0.17^{a}* ±0.01	0.21^{b}* ±0.02	0.25^{b}* ±0.01	0.28^{c}* ±0.01	0.39^{c}* ±0.01	S	S	S
PAPE IR F	0.08^{b} ±0.01	0.09^{a}* ±0.01	0.15^{a}* ±0.01	0.18^{a}* ±0.01	0.20^{a}* ±0.01	0.21^{a}* ±0.01	0.28^{a}* ±0.01	0.35^{a}* ±0.01	0.43^{a}* ±0.01	0.46^{a}* ±0.01

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

F samples indicating PAPE packaging was effective in reducing TBARS values during storage period. Similarly the highest value of 0.47±0.01 recorded on 45th day in case of HDPE IR F samples were not significantly ($P < 0.05$) different from the values of PAPE IR F samples.

4.5.6. Tyrosine Value

Tyrosine Value expressed in mg tyrosine/100g meat is shown in Table 10. Irradiation had a significant ($P < 0.05$) effect in reducing the tyrosine in both type of packaging. Similar to the trend of TBARS, TV had also enhanced due to storage up to 5th day in chiller storage and up to 45th day in irradiated and frozen samples. Packaging had significantly ($P < 0.05$) reduced the TV from day 3rd onwards both in case of chilled and frozen samples. Similarly irradiation right form day zero significantly ($P < 0.05$) decreased the values in different packaging systems. Storage had a significant ($P < 0.05$) effect in enhancing the TV and is shown in Figure 12a and Figure 12b. The non-irradiated control sample which was spoiled on day 5th has shown 3.83±0.03. The highest value of 4.52±0.02 was observed in stored sample under frozen condition on 45th day of storage in case of HDPE packed sample. This was significantly ($P < 0.05$) higher than that of PAPE packaged samples.

4.6. MICROBIOLOGICAL ANALYSIS

4.6.1. Aerobic Plate Count

The count of aerobic organisms expressed in terms of log_{10} cfu/g is given in Table 11. Maintaining strict hygienic production the initial count was substantially low. The initial count of 4.43±0.04 log_{10} cfu/g was significantly ($P < 0.05$) reduced to 1.96±0.03 indicating nearly three log reduction in case of ordinary packed rabbit meat. On the day of preparation packaging had no significant ($P < 0.05$) effect. Under chiller and freezer storage the microbial population in all the samples under

Table 10. Tyrosine Values of rabbit meat (mg/100g) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	1.43^{b} ±0.03	2.70^{g*} ±0.08	3.83^{h*} ±0.03	S	S	S	S	S	S	S
HDPE IR C	1.03^{a} ±0.01	1.82^{e*} ±0.02	2.79^{f*} ±0.02	3.60^{e*} ±0.04	4.11^{f*} ±0.02	S	S	S	S	S
PAPE NR C	1.43^{b} ±0.02	2.59^{f*} ±0.02	3.69^{g*} ±0.02	S	S	S	S	S	S	S
PAPE IR C	1.02^{a} ±0.16	1.68^{d*} ±0.03	2.66^{e*} ±0.02	3.54^{e*} ±0.02	3.92^{e*} ±0.04	S	S	S	S	S
HDPE NR F	1.43^{b} ±0.03	1.61^{d*} ±0.03	2.55^{d*} ±0.02	2.92^{d*} ±0.02	3.45^{d*} ±0.01	3.77^{d*} ±0.02	4.93^{d*} ±0.02	S	S	S
HDPE IR F	1.03^{a} ±0.01	1.30^{b*} ±0.01	1.91^{b*} ±0.02	2.10^{b*} ±0.02	2.39^{b*} ±0.01	2.57^{b*} ±0.02	3.07^{b*} ±0.02	3.96^{b*} ±0.02	4.23^{b*} ±0.02	4.52^{b*} ±0.02
PAPE NR F	1.43^{b} ±0.02	1.51^{c} ±0.01	2.03^{c*} ±0.02	2.73^{c*} ±0.01	2.92^{c*} ±0.02	3.11^{c*} ±0.02	4.22^{c*} ±0.03	S	S	S
PAPE IR F	1.02^{a} ±0.16	1.19^{a*} ±0.01	1.75^{a*} ±0.02	2.03^{a*} ±0.02	2.27^{a*} ±0.02	2.37^{a*} ±0.02	2.86^{a*} ±0.02	3.54^{a*} ±0.02	4.05^{a*} ±0.03	4.39^{a*} ±0.01

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, S – Spoiled.

Table 11. Aerobic Plate Count of rabbit meat ($\log_{10}$ cfu/g) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	4.43^{a} ±0.04	5.61^{f*} ±0.06	6.36^{e*} ±0.04	S	S	S	S	S	S	S
HDPE IR C	1.96^{b} ±0.03	3.15^{c*} ±0.04	4.00^{c*} ±0.01	4.92^{c*} ±0.01	6.98^{e*} ±0.01	S	S	S	S	S
PAPE NR C	4.43^{a} ±0.04	5.60^{f*} ±0.02	6.30^{e*} ±0.05	S	S	S	S	S	S	S
PAPE IR C	1.95^{b} ±0.02	2.83^{b*} ±0.04	3.82^{c*} ±0.02	4.84^{c*} ±0.03	6.93^{c*} ±0.01	S	S	S	S	S
HDPE NR F	4.43^{a} ±0.04	4.50^{e*} ±0.04	5.46^{d*} ±0.11	6.03^{d*} ±0.04	6.29^{d*} ±0.03	6.57^{c*} ±0.04	7.00^{d*} ±0.03	S	S	S
HDPE IR F	1.96^{b} ±0.03	2.86^{b*} ±0.01	3.49^{b*} ±0.07	3.68^{b*} ±0.04	3.90^{b*} ±0.02	4.05^{a*} ±0.02	4.65^{b*} ±0.03	5.01^{b*} ±0.02	6.01^{a*} ±0.04	7.67^{b*} ±0.03
PAPE NR F	4.43^{a} ± 0.04	4.37^{d*} ± 0.05	5.49^{d*} ± 0.09	5.94^{d*} ± 0.03	6.17^{c*} ± 0.04	6.44^{b*} ± 0.06	6.89^{c*} ± 0.03	S	S	S
PAPE IR F	1.95^{b} ±0.02	2.66^{a*} ±0.04	3.29^{a*} ±0.04	3.50^{a*} ±0.05	3.80^{a*} ±0.03	3.95^{a*} ±0.02	4.47^{a*} ±0.04	4.87^{a*} ±0.03	5.90^{a*} ±0.04	7.50^{a*} ±0.03

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

study was increased significantly ($P < 0.05$). Compared to frozen samples chiller samples had higher count especially in non-irradiated samples. In case of irradiated chiller stored meat, packaging was not effective on microbial load from day 5th to 15th. There was a combined effect of irradiation as well as packaging in frozen sample from day 5th onwards. The effect of irradiation compared to non-irradiated samples in chiller and freezer is shown in Figure 13. The maximum count of 7.67±0.03 was noticed on day 45th in HDPE IR F samples and was significantly ($P < 0.05$) higher than PAPE IR F samples indicating the specific advantage of PAPE packaging of meat in reducing bacterial load.

4.6.2. Psychrotrophic Count

The count of psychrotrophic organisms in rabbit meat of different days of storage is given in Table 12. Initially rabbit meat had a count of 3.91±0.02. The irradiation of the samples both in HDPE and PAPE packaging significantly ($P < 0.05$) reduced the count on the day of preparation. As storage period enhanced both in chiller as well as in freezer, the PC had enhanced significantly ($P < 0.05$) indicating storage had a significant ($P < 0.05$) effect through out the study period. Even though packaging had not significantly influenced the PC on the day of preparation, it had significant ($P < 0.05$) effect on days 3, 5 and 15 on chilled samples where a lower count was noticed in PAPE packed samples. Similar trends were noticed in case of frozen samples from day 30th onwards PAPE IR F samples had a significantly ($P < 0.05$) lower count than that of HDPE IR F samples. The trend of psychrotrophic growth in freezer (-6 to -8°C) stored samples is shown in Figure 14, indicating that both irradiation and freezing substantially reduced the psychrotrophic growth and enhanced the shelf life of the product.

Table 12. Psychrotrophic Count of rabbit meat ($\log_{10}$ cfu/g) on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	3.91^{b} ±0.02	4.91^{f*} ±0.01	6.00^{g*} ±0.01	S	S	S	S	S	S	S
HDPE IR C	1.72^{a} ±0.02	2.67^{c*} ±0.02	3.44^{d*} ±0.02	3.83^{b*} ±0.02	4.97^{d*} ±0.03	S	S	S	S	S
PAPE NR C	3.92^{b} ±0.02	4.74^{e*} ±0.03	5.92^{g*} ±0.03	S	S	S	S	S	S	S
PAPE IR C	1.73^{a} ±0.03	2.48^{b*} ±0.02	3.27^{c*} ±0.03	3.78^{b*} ±0.04	4.83^{c*} ±0.02	S	S	S	S	S
HDPE NR F	3.91^{b} ±0.02	3.95^{d*} ±0.01	4.80^{f*} ±0.07	5.01^{c*} ±0.05	5.25^{e*} ±0.02	5.60^{b*} ±0.07	5.97^{c*} ±0.02	S	S	S
HDPE IR F	1.72^{a} ±0.02	2.42^{b*} ±0.05	2.95^{b*} ±0.01	3.27^{a*} ±0.04	3.96^{b*} ±0.02	4.58^{a*} ±0.04	4.97^{a*} ±0.02	5.38^{b*} ±0.03	5.93^{b*} ±0.02	6.98^{b*} ±0.02
PAPE NR F	3.92^{b} ±0.02	3.87^{d*} ±0.02	4.55^{e*} ±0.08	4.88^{c*} ±0.05	5.03^{d*} ±0.02	5.47^{b*} ±0.08	5.86^{b*} ±0.03	S	S	S
PAPE IR F	1.73^{a} ±0.03	2.28^{a*} ±0.06	2.81^{a*} ±0.02	3.38^{a*} ±0.07	3.87^{a*} ±0.03	4.41^{a*} ±0.06	4.88^{a*} ±0.04	5.11^{a*} ±0.06	5.74^{a*} ±0.02	6.92^{a*} ±0.02

Means bearing identical superscripts in the columns do not indicate significant difference ($P < 0.05$).

*Represents significant difference between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

4.7. ORGANOLEPTIC QUALITIES

The sensory evaluation of the cooked rabbit meat with respect to colour, flavour, juiciness, tenderness and overall acceptability were done from day zero until spoilage.

4.7.1. Colour

The colour score of the cooked rabbit meat is shown in Table 13. Initially the non-irradiated meat on the day of preparation had a score of 8.63±0.04 which was improved due to irradiation of meat to 8.90±0.03. As storage period enhanced, both in chiller condition as well as in freezer condition there was a slight decrease in colour score. From day three onwards the score was significantly ($P < 0.05$) reduced due to storage and the meat on the verge of spoilage also maintained a significantly ($P < 0.05$) higher score of 7.37±0.05 in HDPE IR F sample and 7.34±0.05 in PAPE IR F sample indicating the meat was not discarded due to the unattractive colour of the sample. The trend of change in colour score under different treatment conditions and storage period is shown in Figure 15.

4.7.2. Flavour

The flavour score of the cooked sample is given in Table 14. The change in the flavour score of rabbit meat sample is shown in Figure 16. Initial score of 8.77±0.04 was slightly decreased to 8.69±0.03 due to irradiation in HDPE packaged samples. Such a reduction was noticed in PAPE packaged samples also. With an increase in storage period flavour score reduced and reached 7.31±0.04 by day 45th in case of HDPE IR F and 7.23±0.07 in PAPE IR F samples. The flavour score was lower in PAPE packaged samples through out the study period, with lower values in irradiated samples.

Table 13. Colour score of rabbit meat on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	8.63 ±0.04	8.44* ±0.05	8.27* ±0.06	S	S	S	S	S	S	S
HDPE IR C	8.90 ±0.03	8.71* ±0.03	8.56* ±0.02	8.37* ±0.04	8.14* ±0.04	S	S	S	S	S
PAPE NR C	8.63 ±0.03	8.44* ±0.04	8.11* ±0.04	S	S	S	S	S	S	S
PAPE IR C	8.76 ±0.05	8.59* ±0.04	8.46* ±0.04	8.33* ±0.04	8.13* ±0.04	S	S	S	S	S
HDPE NR F	8.63 ±0.04	8.69* ±0.03	8.44* ±0.05	8.14* ±0.07	8.03* ±0.06	7.90* ±0.06	7.80* ±0.05	S	S	S
HDPE IR F	8.90 ±0.03	8.84* ±0.04	8.67* ±0.04	8.46* ±0.03	8.23* ±0.04	8.07* ±0.04	7.87* ±0.04	7.64* ±0.05	7.50* ±0.04	7.37* ±0.05
PAPE NR F	8.63 ±0.03	8.60* ±0.03	8.29* ±0.05	8.11* ±0.04	7.89* ±0.06	7.70* ±0.06	7.50* ±0.06	S	S	S
PAPE IR F	8.76 ±0.05	8.74* ±0.04	8.66* ±0.05	8.47* ±0.04	8.27* ±0.04	8.10* ±0.05	7.90* ±0.05	7.67* ±0.06	7.51* ±0.05	7.34* ±0.05

*Represents significant difference ($P < 0.05$) between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

Table 14. Flavour score of rabbit meat on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	8.77 ±0.04	8.54* ±0.07	8.26. ±0.07	S	S	S	S	S	S	S
HDPE IR C	8.69 ±0.03	8.50* ±0.03	8.30. ±0.04	8.14. ±0.04	7.93. ±0.05	S	S	S	S	S
PAPE NR C	8.66 ±0.04	8.47* ±0.04	8.23. ±0.03	S	S	S	S	S	S	S
PAPE IR C	8.61 ±0.05	8.40* ±0.04	8.23* ±0.06	8.01* ±0.06	7.80* ±0.07	S	S	S	S	S
HDPE NR F	8.77 ±0.04	8.70* ±0.03	8.51. ±0.04	8.33* ±0.06	8.10* ±0.05	7.87* ±0.06	7.63* ±0.04	S	S	S
HDPE IR F	8.69 ±0.03	8.63* ±0.03	8.46* ±0.04	8.29* ±0.03	8.11* ±0.05	7.94* ±0.06	7.77* ±0.06	7.61* ±0.05	7.47* ±0.04	7.31* ±0.04
PAPE NR F	8.66 ±0.04	8.63* ±0.03	8.46* ±0.04	8.27* ±0.04	8.07* ±0.04	7.89* ±0.05	7.67* ±0.06	S	S	S
PAPE IR F	8.61 ±0.05	8.56* ±0.04	8.40* ±0.05	8.20* ±0.04	8.00* ±0.09	7.84* ±0.08	7.69* ±0.08	7.54* ±0.07	7.40* ±0.05	7.23* ±0.07

*Represents significant difference ($P < 0.05$) between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

4.7.3. Juiciness

The juiciness scores of cooked rabbit meat are shown in Table 15. The initial score of 8.74±0.04 was slightly increased due to irradiation as well as packaging. As storage period enhanced similar to that of colour and flavour, juiciness also reduced significantly ($P < 0.05$) either in chiller condition or in freezer condition. Compared to chiller stored samples the frozen samples showed a narrow downward trend (Figure 17) during the storage period. On day 45th it reached to 7.40±0.05 and 7.37±0.07 in HDPE IR F and PAPE IR F samples respectively, which were non-significant ($P < 0.05$), indicating for frozen storage both HDPE and PAPE were of equal in quality.

4.7.4. Tenderness

The tenderness score of cooked rabbit meat is shown in Table 16. Tenderness score of cooked rabbit meat showed a similar trend to that of juiciness score in which irradiation significantly ($P < 0.05$) increased the tenderness score. Between packages, especially in non-irradiated samples, HDPE samples recorded better score both in chiller and frozen storage in many of the storage periods investigated. The tenderness was reduced due to storage in both type of packaging (Figure 18). The initial score of 8.77±0.03 and 8.69±0.03 were reduced to 7.34±0.05 and 7.41±0.05 in HDPE IR F and PAPE IR F samples respectively, by 45 days of storage.

4.7.5. Overall acceptability

The overall acceptability score of the rabbit meat is given in Table 17. Initially the meat had a very good score of 8.51±0.04 which was significantly ($P < 0.05$) improved by irradiation both in HDPE and PAPE packets. Throughout the study period irradiated sample had a better score compared to non-irradiated samples. The PAPE packaged samples had a better score than HDPE packaged samples both in

Table 15. Juiciness score of rabbit meat on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	8.74 ±0.04	8.54* ±0.05	8.29* ±0.05	S	S	S	S	S	S	S
HDPE IR C	8.80 ±0.03	8.63* ±0.04	8.37* ±0.04	8.17* ±0.05	7.96* ±0.37	S	S	S	S	S
PAPE NR C	8.79 ±0.03	8.57* ±0.04	8.30* ±0.05	S	S	S	S	S	S	S
PAPE IR C	8.83 ±0.04	8.66* ±0.04	8.43* ±0.05	8.27* ±0.07	8.09* ±0.15	S	S	S	S	S
HDPE NR F	8.74 ±0.04	8.64* ±0.04	8.47* ±0.05	8.27* ±0.06	8.04* ±0.06	7.84* ±0.08	7.61* ±0.08	S	S	S
HDPE IR F	8.80 ±0.03	8.74* ±0.04	8.59* ±0.04	8.44* ±0.05	8.27* ±0.04	8.10* ±0.05	7.90* ±0.07	7.71* ±0.05	7.54* ±0.06	7.40* ±0.05
PAPE NR F	8.79 ±0.03	8.61* ±0.03	8.44* ±0.04	8.27* ±0.06	8.04* ±0.09	7.89* ±0.08	7.70* ±0.07	S	S	S
PAPE IR F	8.83 ±0.04	8.67* ±0.03	8.50* ±0.06	8.33* ±0.06	8.19* ±0.05	8.00* ±0.06	7.80* ±0.07	7.67* ±0.07	7.50* ±0.07	7.37* ±0.07

*Represents significant difference ($P < 0.05$) between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

Table 16. Tenderness score of rabbit meat on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	8.64 ±0.04	8.40* ±0.03	8.20* ±0.04	S	S	S	S	S	S	S
HDPE IR C	8.77 ±0.03	8.59* ±0.03	8.44* ±0.04	8.26* ±0.06	8.09* ±0.05	S	S	S	S	S
PAPE NR C	8.59 ±0.03	8.43* ±0.04	8.17* ±0.05	S	S	S	S	S	S	S
PAPE IR C	8.69 ±0.03	8.46* ±0.05	8.30* ±0.07	8.11* ±0.06	7.90* ±0.05	S	S	S	S	S
HDPE NR F	8.64 ±0.04	8.59* ±0.04	8.44* ±0.05	8.29* ±0.05	8.16* ±0.05	7.99* ±0.04	7.79* ±0.05	S	S	S
HDPE IR F	8.77 ±0.03	8.71* ±0.03	8.56* ±0.04	8.40* ±0.04	8.24* ±0.04	8.06* ±0.03	7.84* ±0.05	7.63* ±0.06	7.47* ±0.05	7.34* ±0.05
PAPE NR F	8.59 ±0.03	8.59* ±0.06	8.39* ±0.05	8.24* ±0.06	8.03* ±0.06	7.86* ±0.04	7.71* ±0.04	S	S	S
PAPE IR F	8.69 ±0.03	8.81* ±0.03	8.60* ±0.03	8.44* ±0.04	8.24* ±0.04	8.04* ±0.04	7.87* ±0.04	7.70* ±0.05	7.54* ±0.04	7.41* ±0.05

*Represents significant difference ($P < 0.05$) between storage periods.

HDPE – High Density Polyethylene, **PAPE** – Polyamide Polyethylene, **NR** – Non-irradiated, **IR** – Irradiated, **C** – Chiller, **F** – Freezer, **S** – Spoiled.

Table 17. Overall acceptability score of rabbit meat on storage

Treatment	Days of storage									
	0	3	5	10	15	20	25	30	40	45
HDPE NR C	8.51 ±0.04	8.19* ±0.05	7.86* ±0.04	S	S	S	S	S	S	S
HDPE IR C	8.77 ±0.03	8.61* ±0.03	8.46* ±0.02	8.30* ±0.02	8.07* ±0.02	S	S	S	S	S
PAPE NR C	8.66 ±0.03	8.40* ±0.03	8.13* ±0.04	S	S	S	S	S	S	S
PAPE IR C	8.86 ±0.03	8.66* ±0.05	8.49* ±0.06	8.30* ±0.07	8.09* ±0.07	S	S	S	S	S
HDPE NR F	8.51 ±0.04	8.54* ±0.04	8.33* ±0.05	8.17* ±0.05	7.97* ±0.04	7.80* ±0.04	7.60* ±0.03	S	S	S
HDPE IR F	8.77 ±0.03	8.69* ±0.03	8.53* ±0.04	8.41* ±0.03	8.26* ±0.04	8.06* ±0.04	7.91* ±0.03	7.77* ±0.02	7.59* ±0.03	7.43* ±0.02
PAPE NR F	8.66 ±0.03	8.64* ±0.02	8.49* ±0.03	8.31* ±0.03	8.11* ±0.03	7.86* ±0.04	7.67* ±0.04	S	S	S
PAPE IR F	8.86 ±0.03	8.81* ±0.04	8.67* ±0.04	8.53* ±0.04	8.33* ±0.05	8.16* ±0.05	7.97* ±0.04	7.84* ±0.04	7.71* ±0.04	7.59* ±0.05

*Represents significant difference ($P < 0.05$) between storage periods.

HDPE – High Density Polyethylene, PAPE – Polyamide Polyethylene, NR – Non-irradiated, IR – Irradiated, C – Chiller, F – Freezer, S – Spoiled.

irradiated and chiller and freezer stored samples indicating PAPE packaging was advantageous than HDPE packing. The trend of reduction in overall acceptability score is shown in Figure 19. Even after 45th day of storage the sample had a comparatively good score of 7.43±0.02 and 7.59±0.05 in HDPE IR F and PAPE IR F samples respectively. Through out the study period PAPE packaged samples had a higher score than HDPE samples.

The flavor score was reduced due to the process of irradiation, where as the other attributes viz., colour, juiciness, tenderness and overall acceptability were substantially increased due to irradiation. The reduction of the score was more in chiller stored samples compared to freezer stored samples. Similarly some of the attributes were reduced due to the process of irradiation, whereas colour, juiciness, tenderness and overall acceptability were substantially increased due to irradiation. The effect of packaging between HDPE and PAPE showed PAPE packaging was better in many of the attributes including the overall acceptability score of rabbit meat.

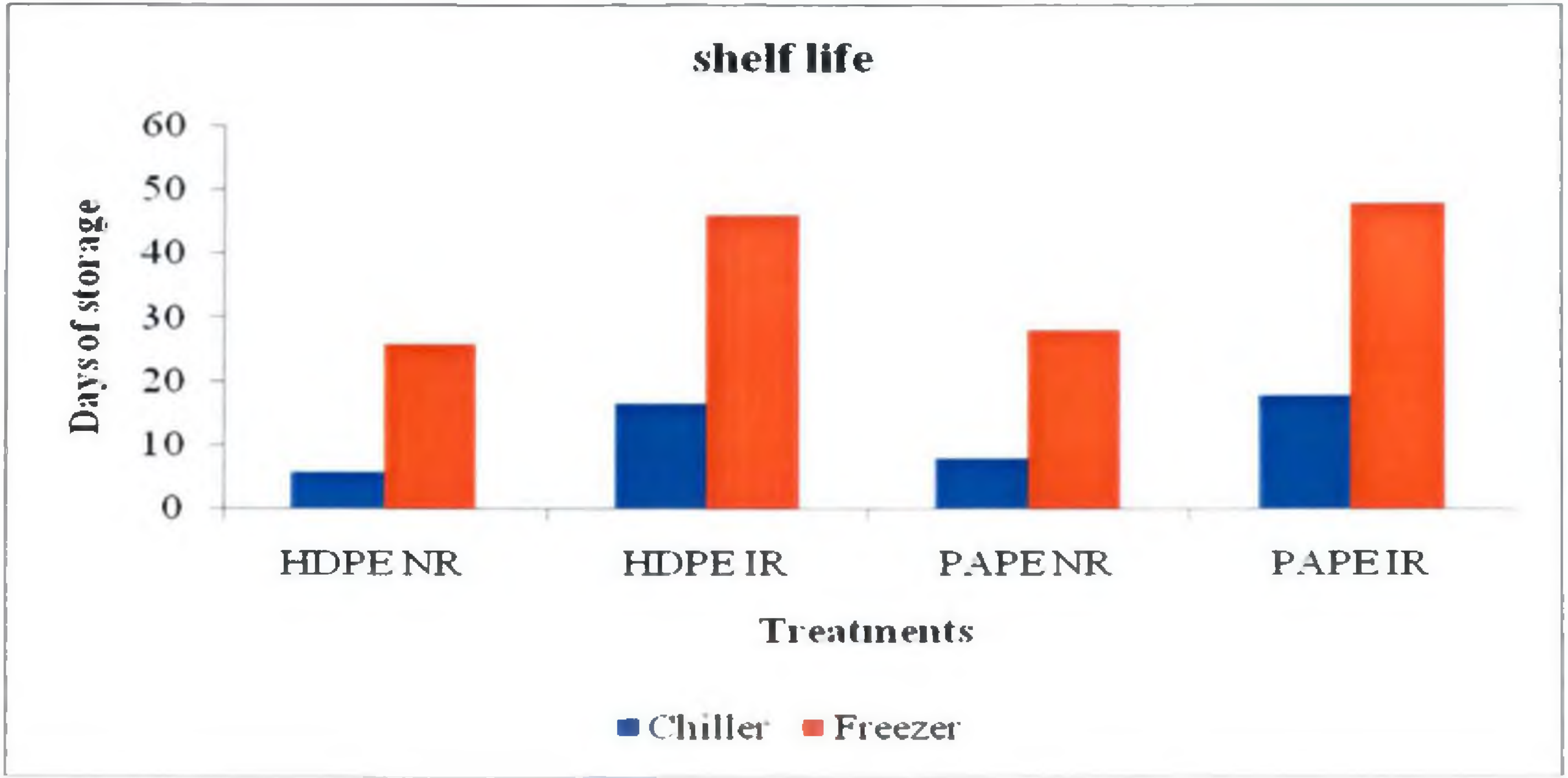

Figure 3. Shelf life of rabbit meat

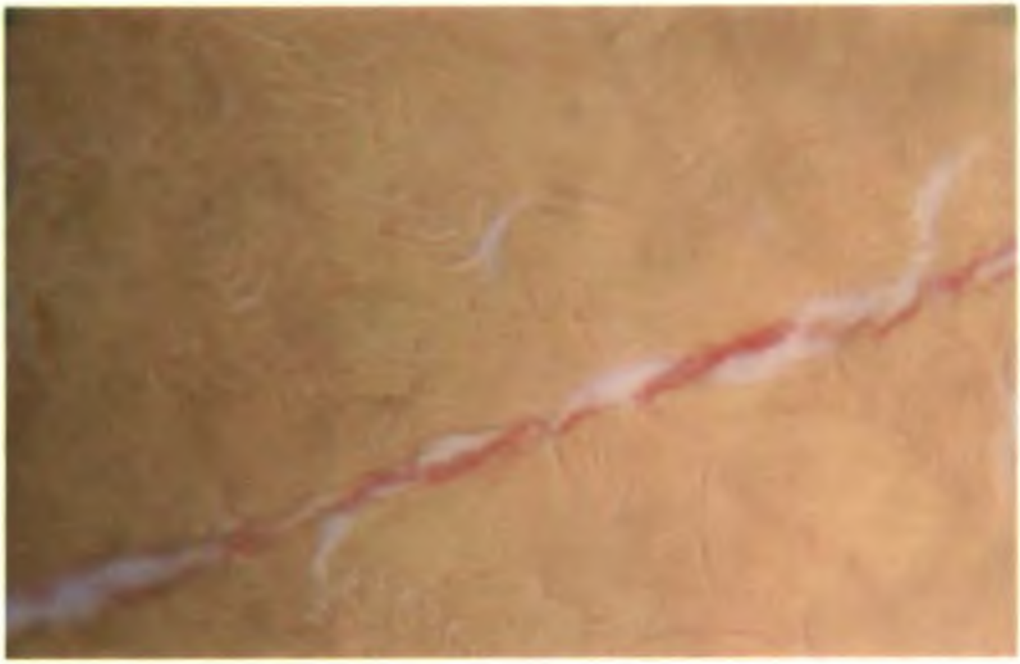

Figure 4. Histological section of non-irradiated rabbit muscle (Van Geison's method) x 100

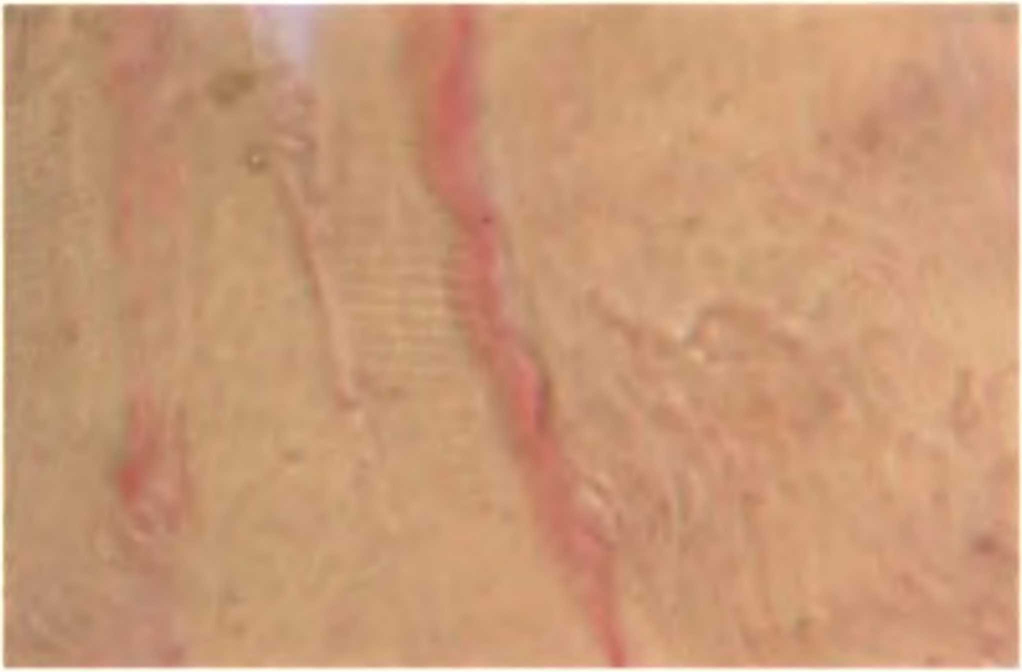

Figure 5. Histological section of irradiated rabbit muscle (Van Geison's method) x 100

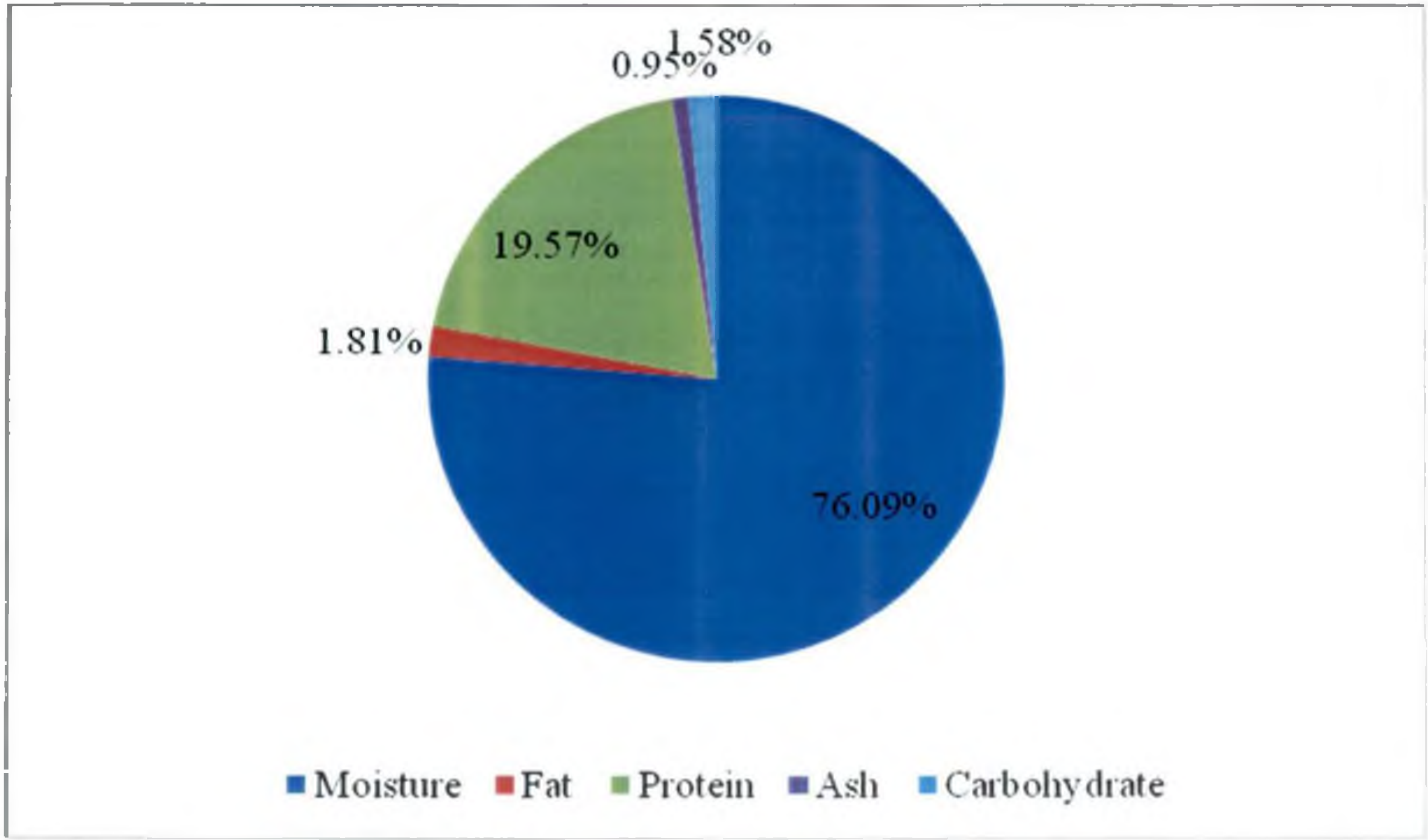

Figure 6. Proximate composition of rabbit meat on day zero

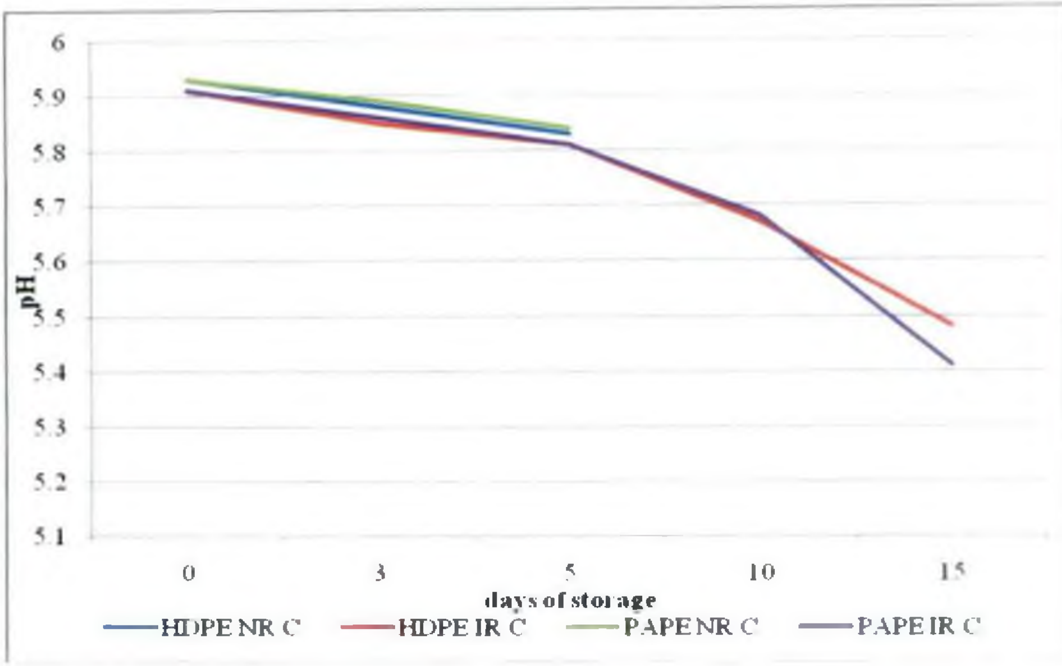

Figure 7a. pH of rabbit meat on chiller storage

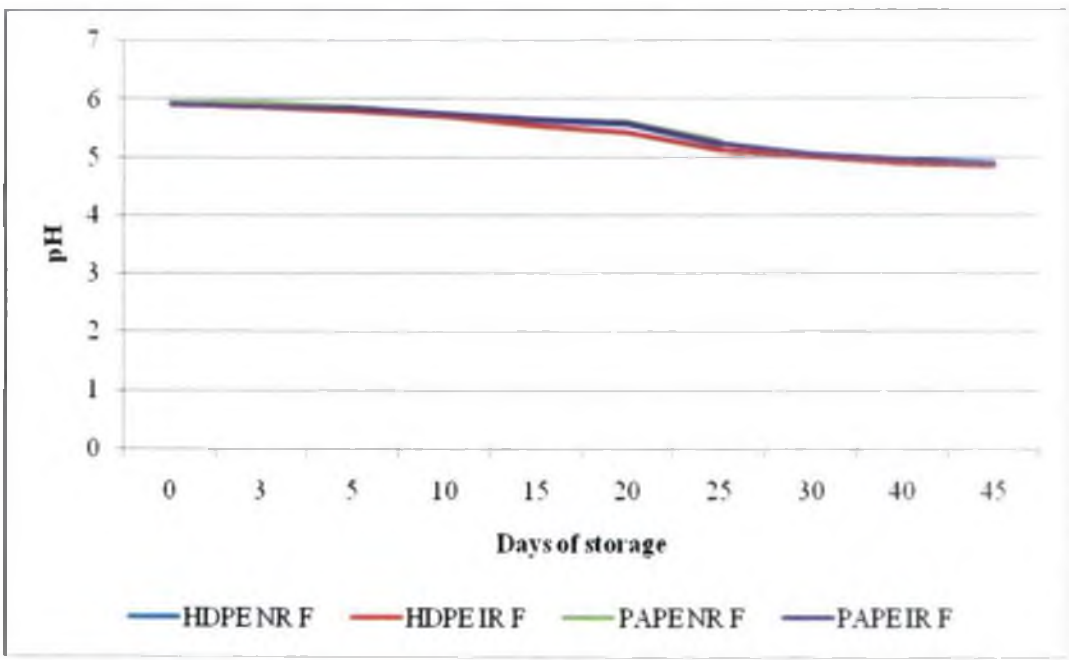

Figure 7b. pH of rabbit meat on freezer storage

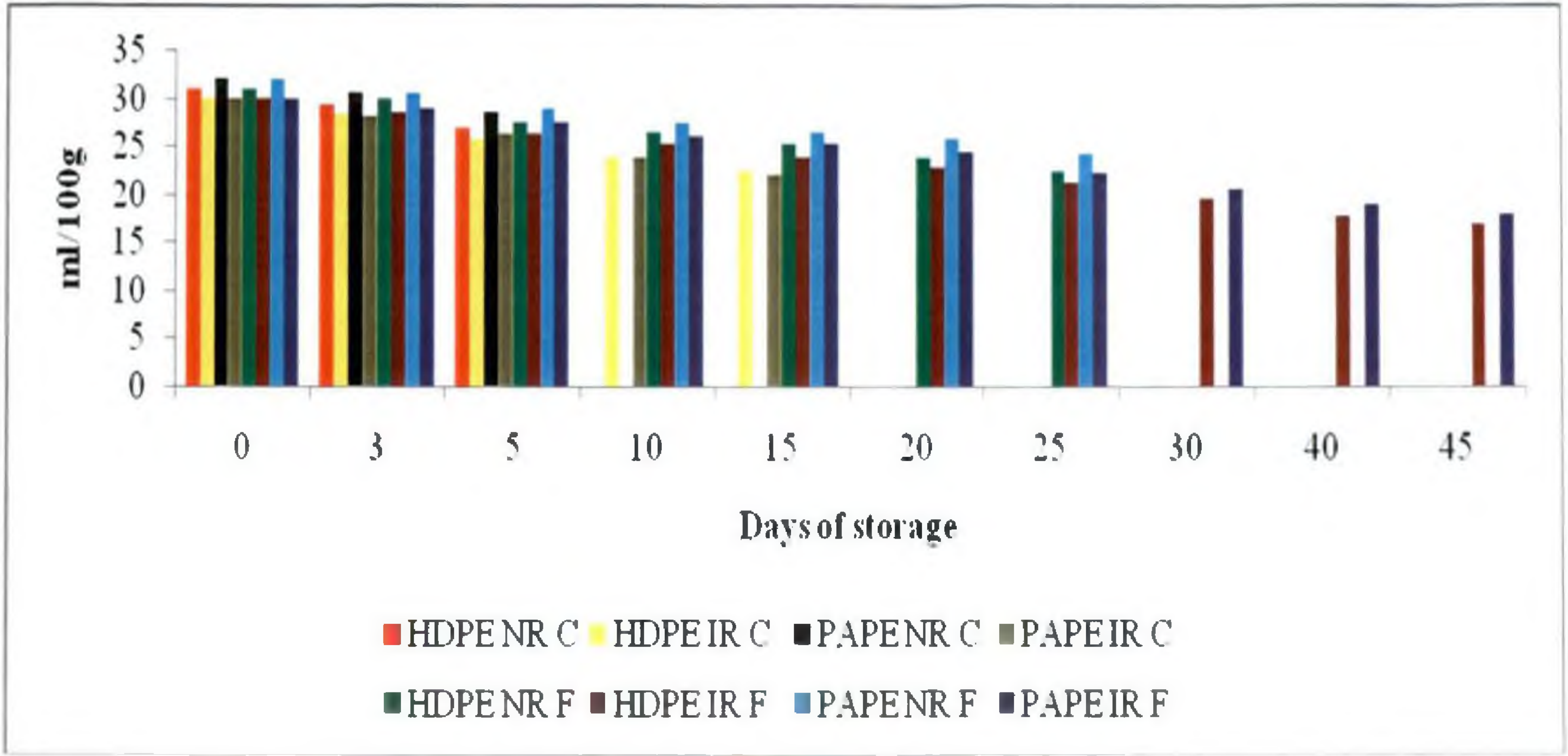

Figure 8. Water Holding Capacity of rabbit meat on storage

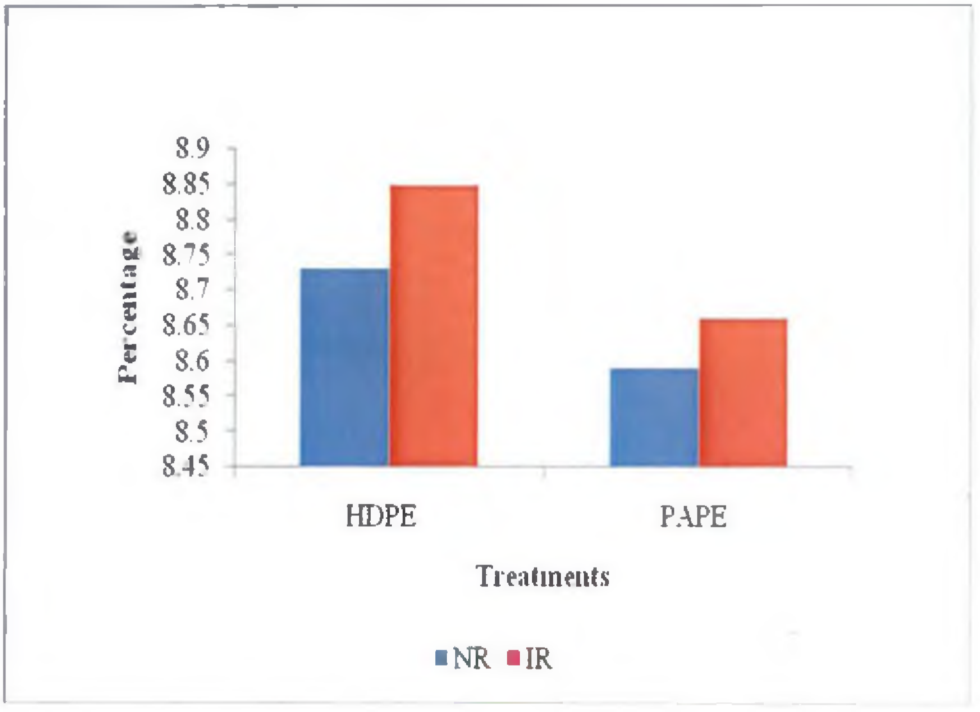

Figure 9. Drip loss of rabbit meat on day zero

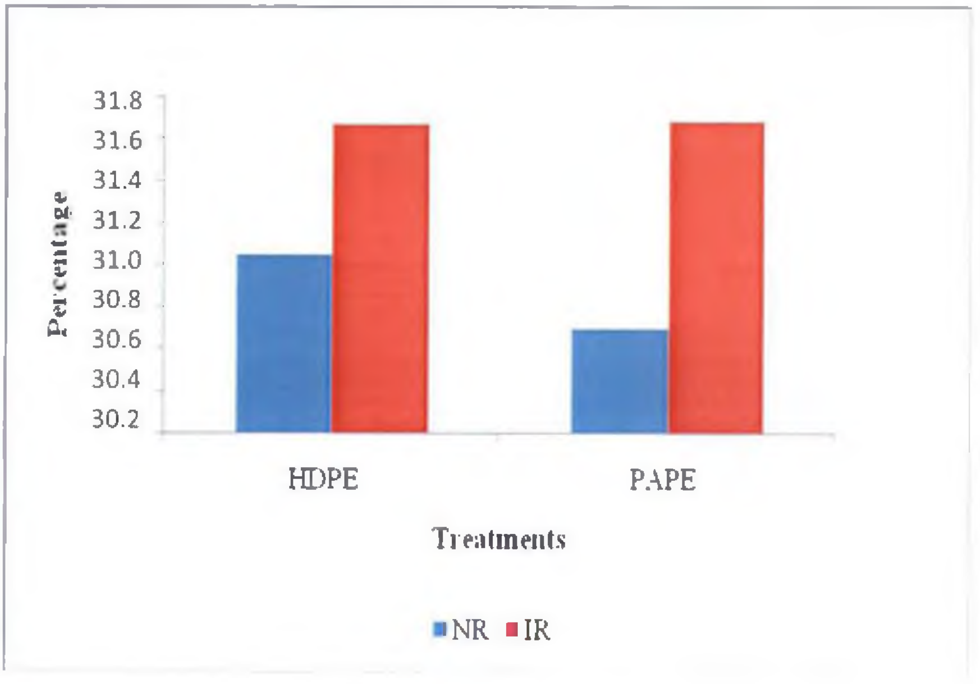

Figure 10. Cooking loss of rabbit meat on day zero

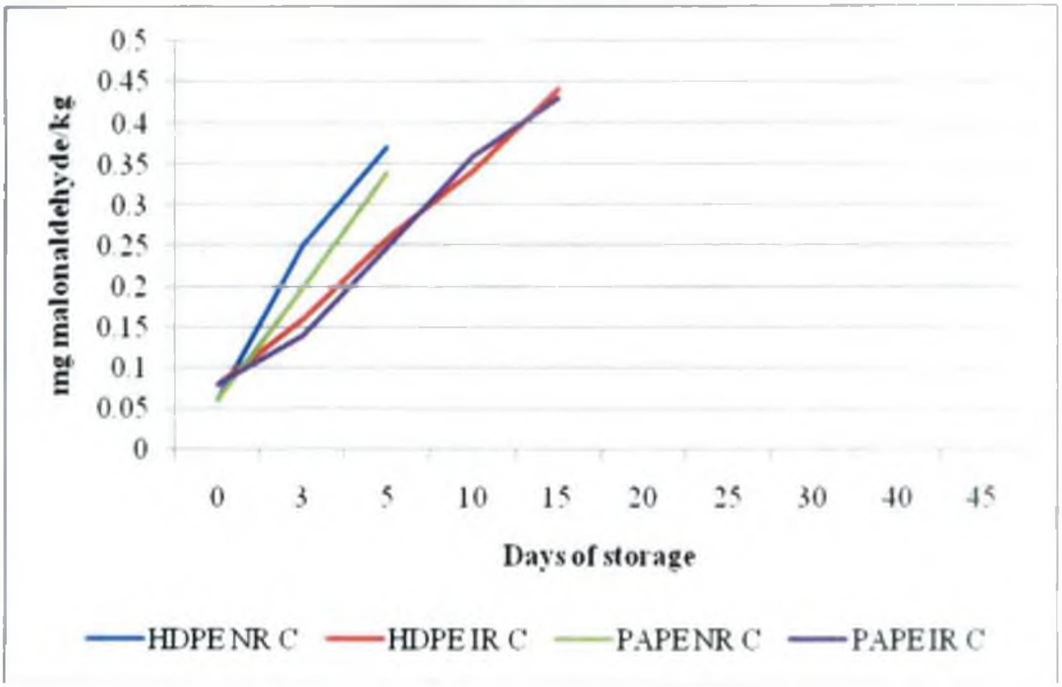

Figure 11a. Thiobarbituric Acid Reactive Substances of rabbit meat on chiller storage

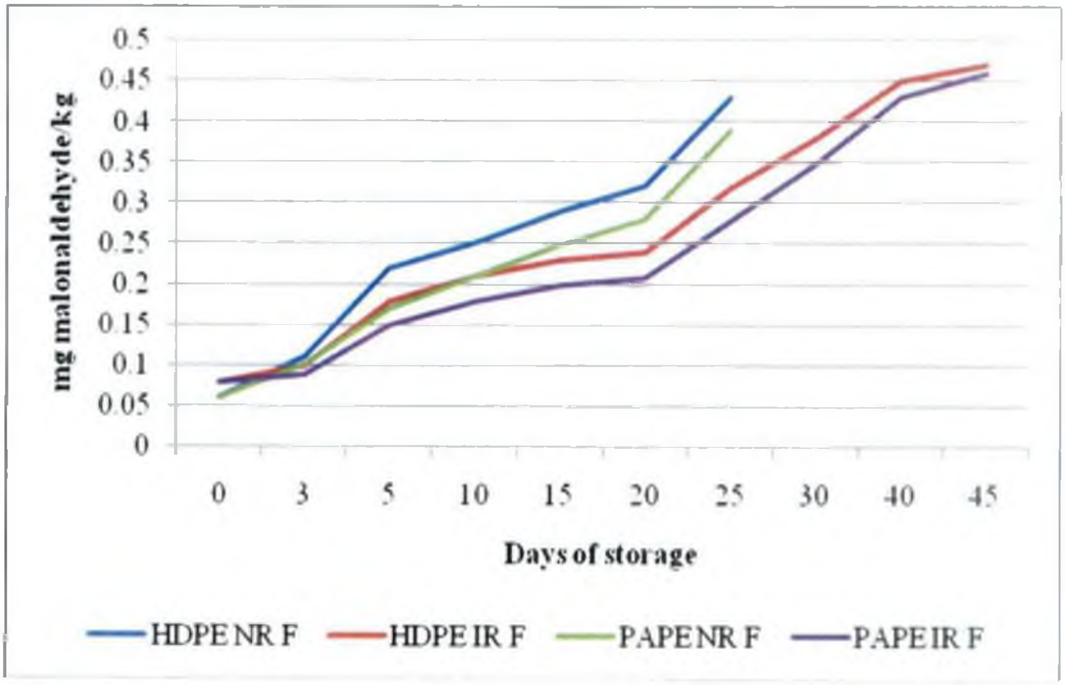

Figure 11b. Thiobarbituric Acid Reactive Substances of rabbit meat on freezer storage

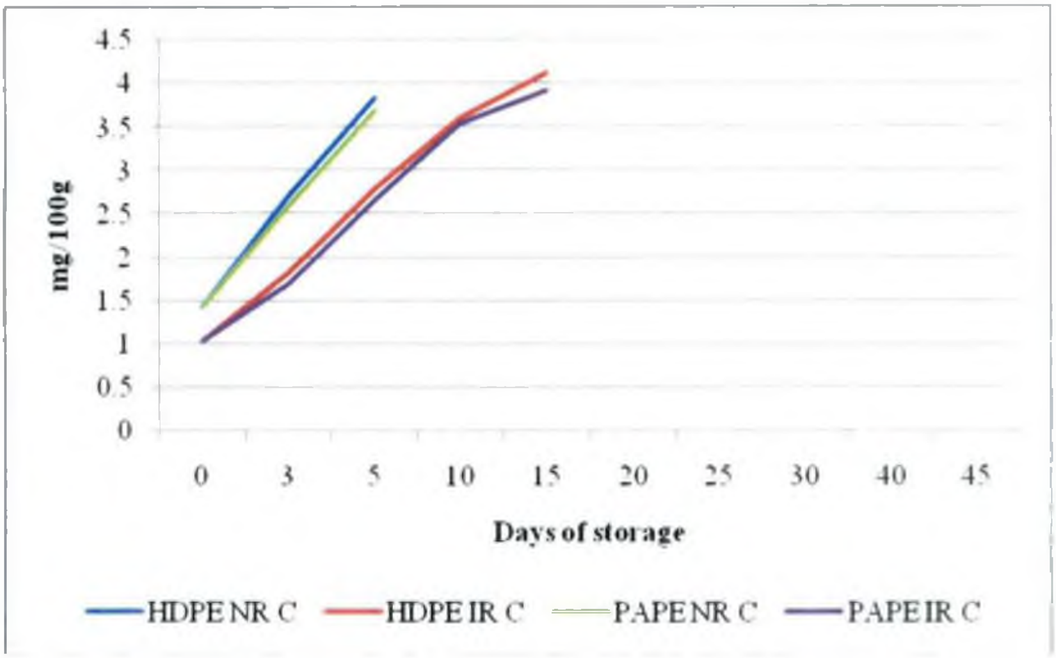

Figure 12a. Tyrosine Value of rabbit meat on chiller storage

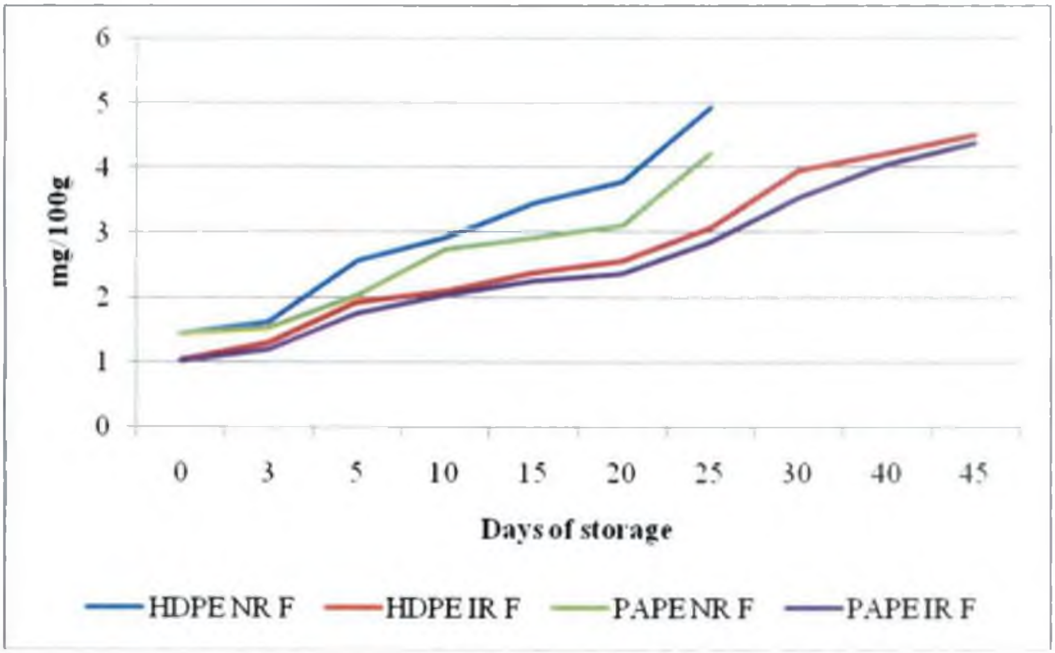

Figure 12b. Tyrosine Value of rabbit meat on freezer storage

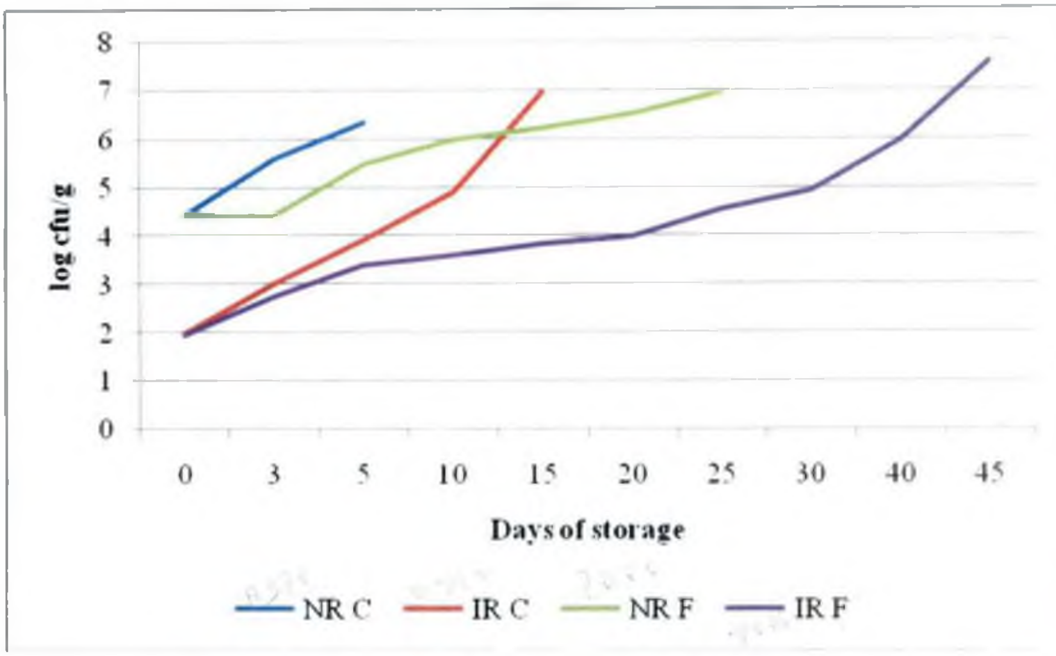

Figure 13. Aerobic Plate Count (averaging HDPE and PAPE packaging) of rabbit meat on storage

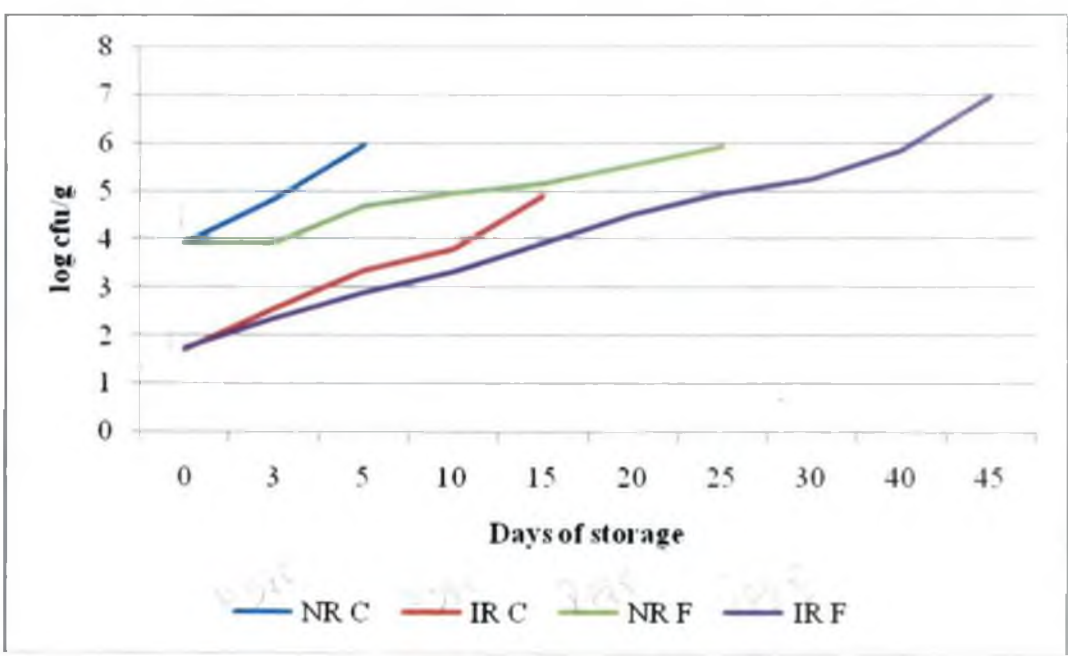

Figure 14. Psychrotrophic Count (averaging HDPE and PAPE packaging) of rabbit meat on storage

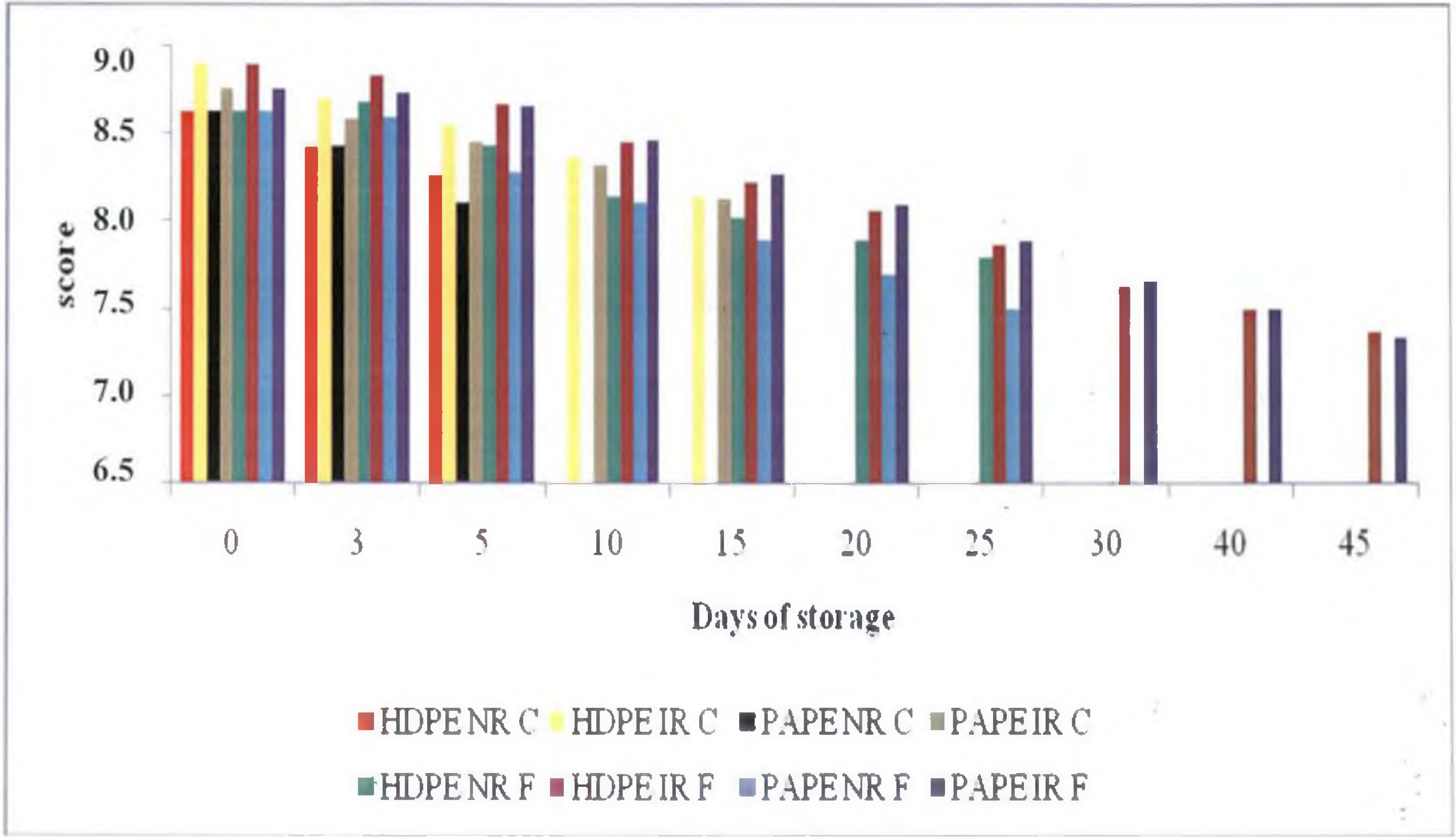

Figure 15. Colour score of rabbit meat on storage

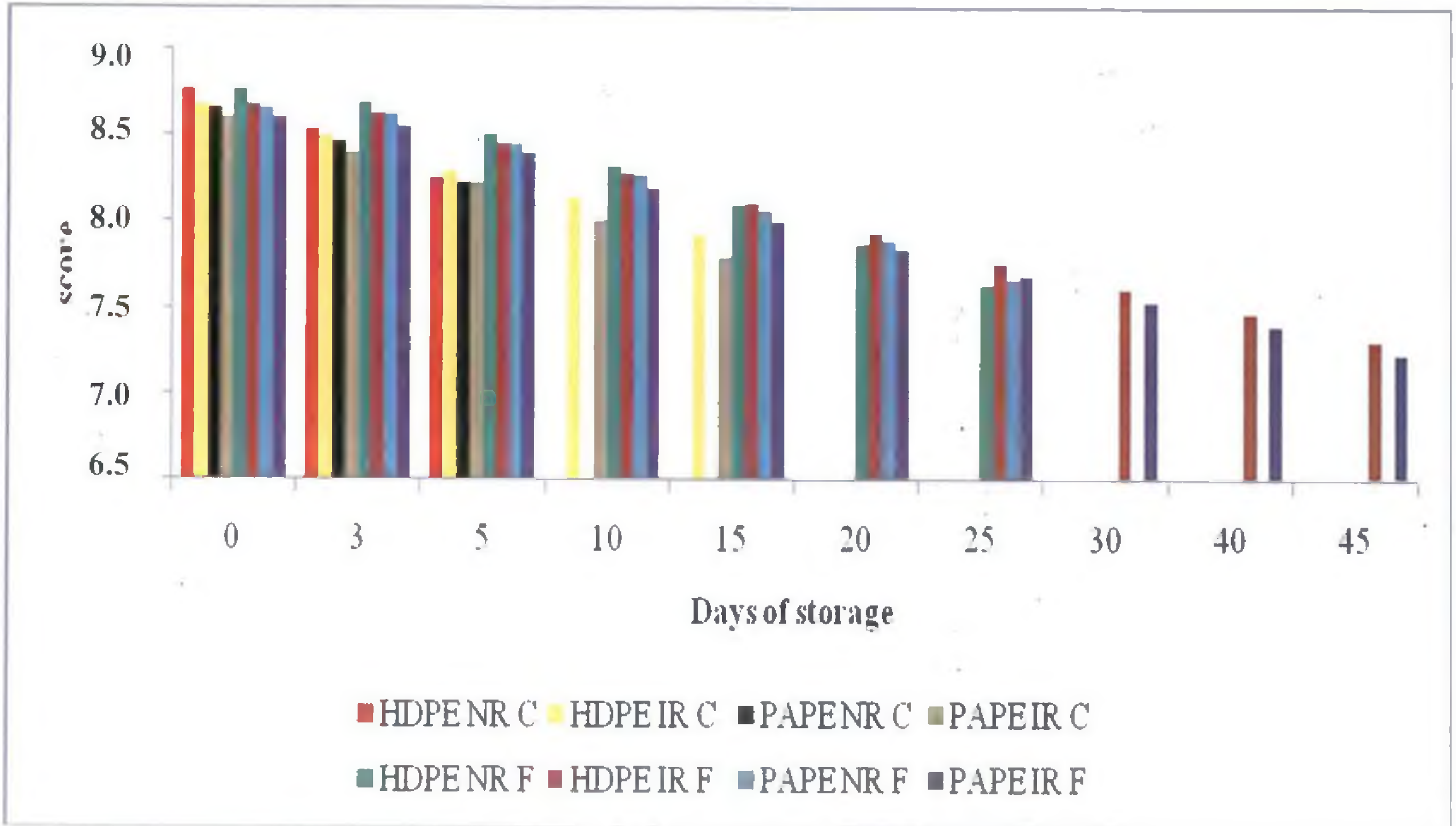

Figure 16. Flavour score of rabbit meat on storage

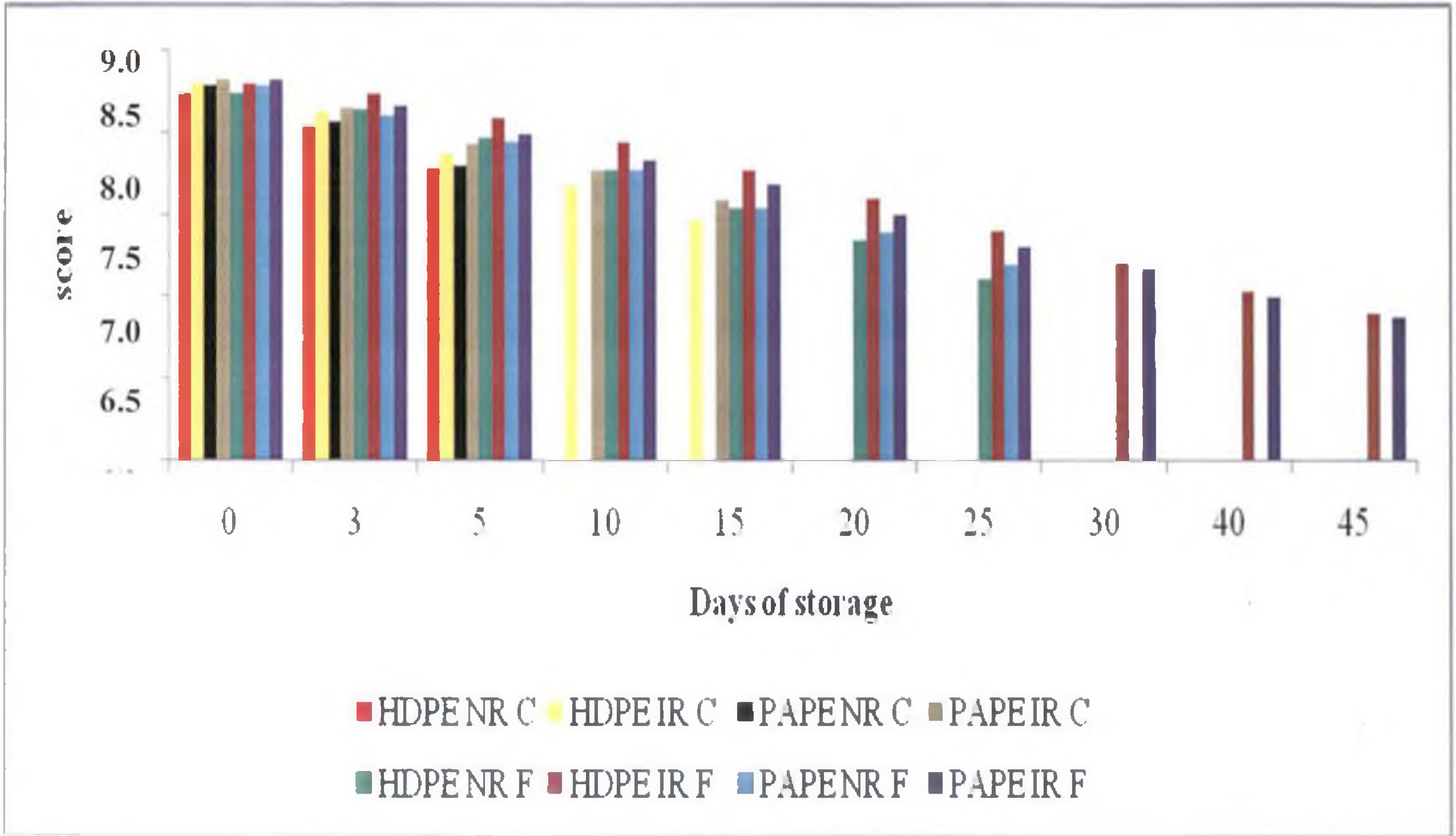

Figure 17. Juiciness score of rabbit meat on storage

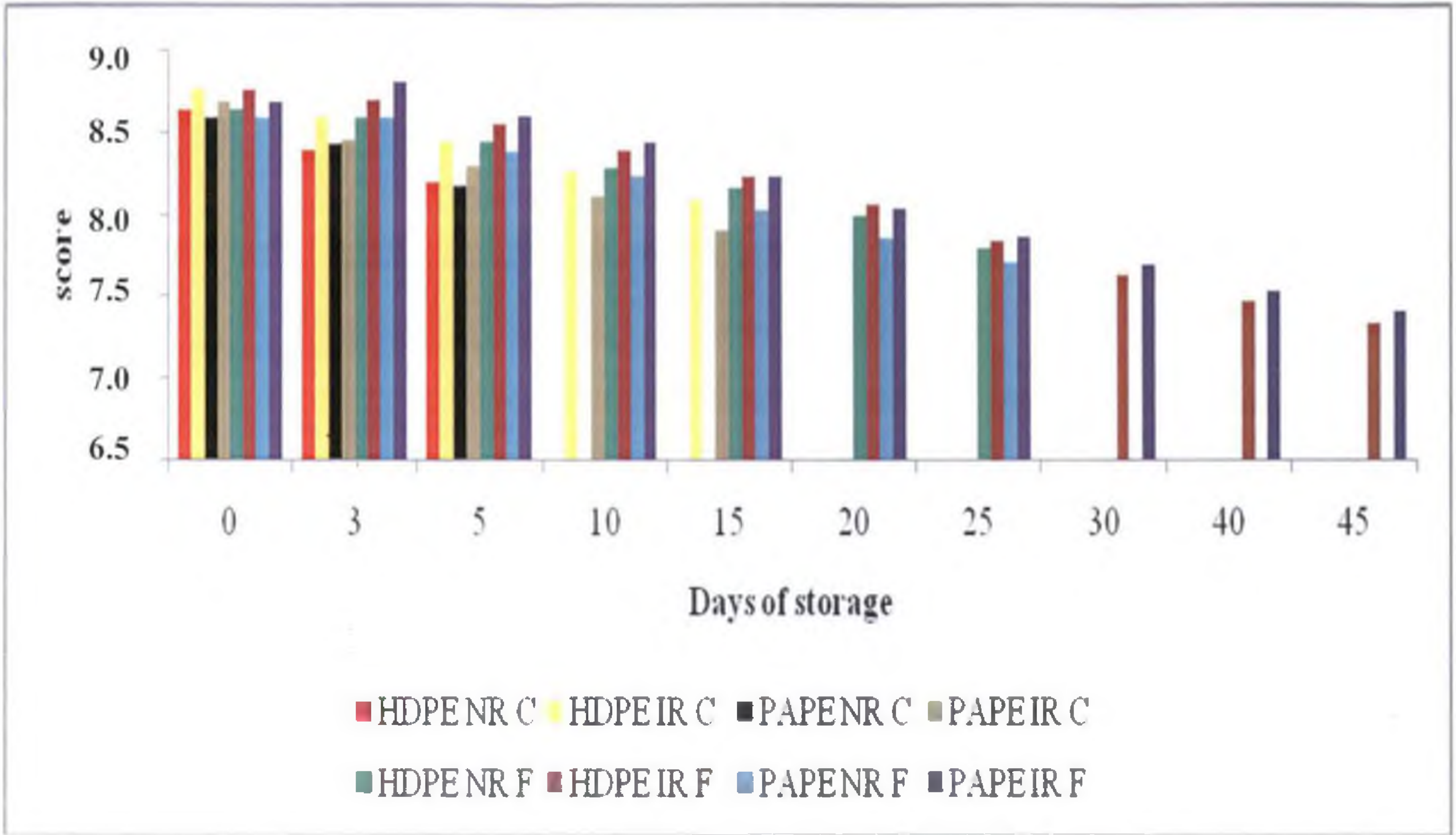

Figure 18. Tenderness score of rabbit meat on storage

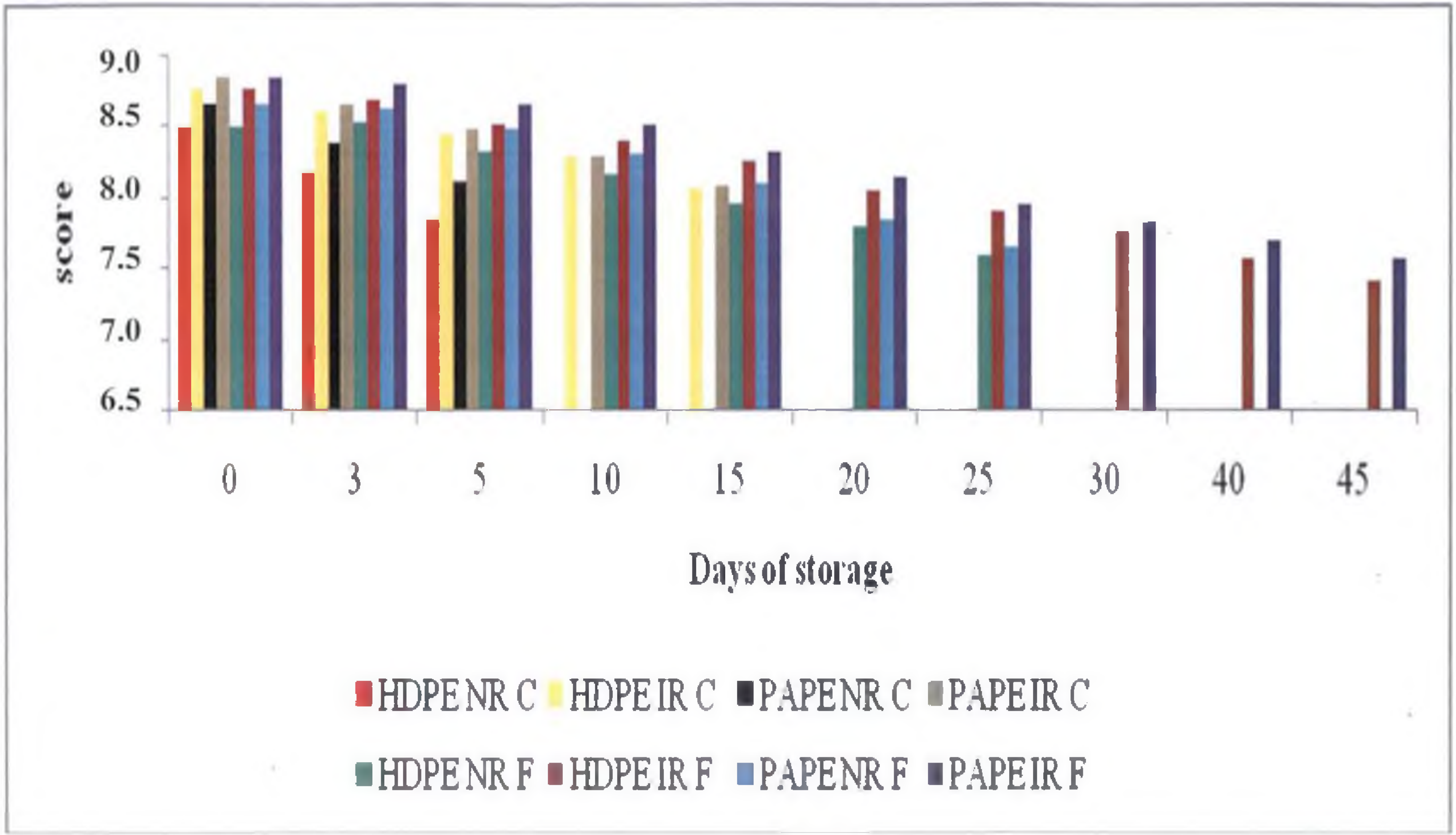

Figure 19. Overall acceptability score of rabbit meat on storage

Discussion

5. DISCUSSION

Seven batches of crossbred rabbits comprising 52 animals were purchased from local market and were slaughtered and dressed under hygienic conditions. The washed carcass after post-mortem inspection were cut into equal size and were packaged at a rate of 120 g each in HDPE or PAPE packages. Half of the samples in each group were irradiated using Gamma Chamber 5000, (BRIT-DAE, Mumbai) at 2.5 kGy. Samples were stored under chiller condition (1 to 4°C) and in freezer condition (-6 to -8°C) in domestic refrigerator and subjected to various quality analysis. The slaughter data of the rabbit were also collected.

5.1. DRESSING PERCENTAGE

The crossbred rabbits which were 52 in number yielded 99 kg and accounted to an average of 1.9 kg. Since the animals were crossbred the dressing percentage (49.35 %) was comparatively lower. Kuttinarayanan and Nandakumar (1989) reported a dressing percentage of 53.10 and 52.72 in Soviet chinchilla and New Zealand white rabbits respectively. Zotte (2002) recorded 55 to 61 percentage slaughter yield and the present study revealed a comparatively low dressing percentage. In the present study the rabbits procured locally had a highly variable genetic make up which might be the reason for a low dressing percentage from that of the earlier observations.

5.2. PHYSICAL QUALITIES AND SHELF LIFE

The non-irradiated sample in HDPE under chiller condition had a shelf life of 5 to 7 days. By the process of irradiation, about three times extension of shelf life was obtained. Almost similar extension was noticed by irradiation in PAPE packaging. Irradiation as well as freezing significantly enhanced the shelf life. Dempster (1985), Przybylski *et al.* (1989) and Paul *et al.* (1990) reported extended storage life by irradiation. Jenifer (2006) reported 25 days of extended shelf life by 2 kGy irradiation in minced beef under chiller condition in HDPE packing. But such an extended shelf life was not observed in present study because of the basic difference in meat type as well as the presence of 2.0 per cent salt in minced beef. Rabbit meat packaged in PAPE and irradiated at 2.5 kGy stored under chiller condition had a keeping quality up to three weeks without affecting much of the quality parameters. Oxygen permeable films like HDPE recorded a still lower keeping quality. Badr (2004) obtained a lower keeping quality with an irradiation dose of 1.5 and 3.0 kGy under chiller storage in case of rabbit meat samples.

Under domestic refrigerator temperature (-6 to -8°C) the shelf life of non-irradiated samples were extended by five times and by the process of irradiation it was nine times. Since this is the most common method of storage of meat at house hold level rabbit meat after irradiation could be kept up to 50 days without compromising the quality parameters especially in PAPE packaging.

5.3. HISTOLOGICAL STUDIES

The rabbit muscle was apparently normal in the muscle structure without any change in the striations of the muscle fibre. A significant result noticed was the swelling of the collagen in the irradiated samples. Lawrie (1998) reported softness and tenderness of muscle and Chungath and Kuttinarayanan (2008) reported collagen swelling in porcine muscle when irradiated at 3.0 kGy. Irradiation at 2.5 kGy in the present study expressed similar results and the irradiated sample was more tender compared to non-irradiated samples were on organoleptic assessment.

5.4. PROXIMATE ANALYSIS

The proximate compositions, viz., moisture, fat, protein, carbohydrate and ash content did not revealed any significant difference in many of the characters. But PAPE irradiated sample values were significantly ($P < 0.05$) different from the non-irradiated groups indicating irradiation had brought certain changes. Daoud *et al.*

(2002) reported gamma irradiation at different doses from 0 to 9.0 kGy resulted in slight changes in chemical composition of minced beef. Rana Raj (2006) in pet food, Salke Dinkar Babanrao (2007) in beef cutlet and Shijin (2008) in chicken fry could not observe any significant ($P < 0.05$) change due to either irradiation or packaging. The difference in the results of the present study might be due to the nature of the freshness of the sample.

5.5. PHYSICOCHEMICAL QUALITIES

5.5.1. pH

The control sample had a comparatively lower pH of 5.93 ±0.01on the day of preparation. Once it was irradiated the value was significantly ($P < 0.05$) reduced indicating irradiation had a significant ($P < 0.05$) effect in reducing the pH of fresh meat. This was true in HDPE as well as in PAPE packaged samples on the day of preparation. Niemand *et al.* (1981) and Lefebvre *et al.* (1994) reported lowering of pH due to irradiation, where as Nam and Ahn (2002b) reported non-significant changes due to irradiation in various meat and meat products. The present study is in agreement with the previous studies in which irradiation had brought about lowering of pH. As storage period enhanced, the storage had a significant ($P < 0.05$) effect in reducing the pH up to the end of the study period. The sample which had the longest shelf life had attained the pH 4.88±0.02 in PAPE IR F and 4.84±0.02 in HDPE IR F. These values were significantly ($P < 0.05$) different among each other as well as from the initial values. The meat was stored in domestic refrigerator which maintained at a comparatively higher temperature might be the reason for reduced pH to the above values. Nam and Ahn (2002b) reported a significant change due to storage as well as irradiation after 10 days at 4°C in vacuum packaged turkey breast meat samples. In the present study right from third day onwards the values were significantly ($P < 0.05$) different at chiller temperature.

5.5.2. Water Holding Capacity

In the present study, on the day of preparation the non-irradiated sample had a significantly ($P < 0.05$) higher WHC of 31.14±0.46 ml/100 g compared to irradiated sample (30.00±0.58) irrespective of packaging. Cain *et al.*, (1958) and Schweigert (1959) reported a considerable decrease in WHC due to irradiation in meat. Zhu *et al.* (2004a) reported an increased centrifugal loss due to irradiation in pork and attributed to the structural damage in membrane. In the present study also irradiation significantly ($P < 0.05$) reduced the WHC and the probable reason might be the structural damage brought to muscle on irradiation.

As storage period enhanced the values were significantly reduced in both HDPE and PAPE packaging as well as chiller and frozen stored samples. Among packaging PAPE had a significantly ($P < 0.05$) better WHC than that of HDPE. Similarly freezing was advantageous over chilling to retain the WHC. As storage period enhanced, the effect of packaging material was not significant ($P < 0.05$) where as storage had a significant ($P < 0.05$) effect. Karakaya *et al.* (2006) also reported significant ($P < 0.05$) difference in pre-rigor and post-rigor WHC in chevon, beef and rabbit and the results of the present study are in agreement with their findings.

5.5.3. Drip loss

Initially the sample had a comparatively low drip loss of 8.73±0.34 per cent in control sample and it was not significantly ($P < 0.05$) affected either by irradiation or by packaging. As storage period enhanced the drip loss had increased where as storage at freezer and chiller had a significant ($P < 0.05$) difference irrespective of treatments. Meat samples stored in freezer had a significantly ($P < 0.05$) lower value than that of chiller stored samples. Between packaging and irradiation there was no significant ($P < 0.05$) effect, where as freezing, chilling and storage had significant ($P < 0.05$) effect in reducing the drip loss. By the verge of spoilage in samples irradiated and stored in chiller condition it was considerably reduced to 10.16±0.24 and

10.04±0.22 compared to 8.85±0.34 and 8.66±0.30 in HDPE IR C and PAPE IR C samples respectively. Where as frozen sample on day 45th the values were only 2.42±0.04 and 2.34±0.04 in HDPE IR F and PAPE IR F samples respectively. Vergara *et al.* (2005) found that packaging under high carbon dioxide concentrations can cause an increase in drip loss in fresh meat. Xiong *et al.* (2007) observed that withholding water before slaughter significantly ($P < 0.05$) increased drip loss in rabbits.

5.5.4. Cooking loss

Initially the control sample had a cooking loss of 31.05±0.12. This was significantly ($P < 0.05$) increased by the process of irradiation in both the type of packaging. Niemand *et al.* (1981) in beef and Yoon (2003) in chicken reported significant ($P < 0.05$) difference in cooking loss due to irradiation and the results of the present study are in agreement with them.

As the storage period enhanced, the cooking loss was significantly ($P < 0.05$) increased indicating that storage had a negative effect in increasing the cooking loss of rabbit meat. During storage period a significant ($P < 0.05$) difference was observed between the packages (HDPE and PAPE) both in irradiated and non-irradiated sample with higher value in irradiated sample throughout the storage period under chiller storage. Under frozen storage the cooking loss was not to that extent of chiller stored sample even though storage had significantly ($P < 0.05$) increased the cooking loss. The effect of packaging was not significant ($P < 0.05$) where as irradiation had increased the cooking loss.

5.5.5. Thiobarbituric Acid Reactive Substances

The TBARS shows the extend of oxidative rancidity changes in meat and meat products. The irradiated sample had a significantly ($P < 0.05$) higher value than that of non-irradiated sample. Packaging in HDPE and PAPE had not affected TBARS values on the day of preparation.

As storage period enhanced, a significant ($P < 0.05$) increase in the TBARS values of rabbit meat were noticed. During the storage period both the packaging as well as storage conditions had significant ($P < 0.05$) effect in TBARS values, with lower values in frozen sample and PAPE packaged samples. Contradictory to the initial increase due to irradiation upon storage, non-irradiated samples had higher values of TBARS. The significant ($P < 0.05$) effect of irradiation on TBARS values were reported by Dempster *et al.* (1985) and Murano *et al.* (1998). Whereas, Nortje *et al.* (2005) reported non-significant ($P < 0.05$) effect on lipid oxidation due to irradiation. Seydim *et al.* (2006) reported the advantages of vacuum packaging in reducing the TBA value. In chiller storage the effect of packaging was significant ($P < 0.05$) both in irradiated as well as in non-irradiated sample, where as an in case of freezing such a packaging effect was not noticed. This might be due to the accelerated biochemical changes in chilled sample compared to that of frozen sample.

5.5.6. Tyrosine Value

The TV indicates the extent of proteolytic changes taking place in meat and meat products. On the day of preparation, the control sample had a significantly ($P < 0.05$) higher value of 1.43±0.03. This initial value was significantly ($P < 0.05$) reduced by the process of irradiation where as packaging had no significant ($P < 0.05$) effect. Lawrie (1998) reported that irradiation of meat could be useful in retaining the quality since proteolysis could be diminished.

As storage period enhanced, the HDPE packaged non-irradiated and chilled sample had the highest value compared to all other treatment groups. Between chiller stored samples PAPE IR sample had the lowest TV. Between chilled sample and frozen sample, frozen sample had a lower value and PAPE IR sample had the lowest through out the storage period. Karthikeyan *et al.* (2000) observed higher percentage of protein denaturation in ambient temperature. Kuttinarayanan *et al.* (2005) reported a non-significant ($P < 0.05$) increase in TV in stored sample as normal biochemical changes in refrigerated meat. Balamatsia *et al.* (2006) reported aerobically packaged and non-irradiated chicken had shown a significant increase in trimethyl amine nitrogen (TMA-N) and total volatile basic nitrogen (TVB-N) during refrigerated storage at chiller storage. These are the end products of tyrosine. Jenifer (2006) reported irradiation had no effect in changing the TV on day zero and an increased value due to storage under chiller condition. In the present study, the storage had a significant ($P < 0.05$) effect in increasing the TV always with lower values in PAPE packed irradiated frozen samples.

5.6. MICROBIOLOGICAL ANALYSIS

5.6.1. Aerobic Plate Count

In India, irradiation of meat and meat products was permitted to destroy the microorganisms and to extend the shelf life as envisaged in Prevention of Food Adulteration Act. The present study employing gamma rays at a dose of 2.5 kGy resulted in three log reduction in APC. Microorganisms are much more sensitive to irradiation in high moisture. Since the initial load was comparatively less, the present study got an excellent result in reducing the bacterial load and making the meat safe for consumption. There were reports of reduction by 100 per cent or above 90 per cent by Niemand *et al.* (1981), Thayer (1993) and Mcateer *et al.* (1995). Lee (2004) reported increased microbial safety and enhanced shelf life of food due to irradiation. On the day of preparation, between packages the effect was not significant ($P < 0.05$). As storage period enhanced, there was an increase in bacterial load both in irradiated and non-irradiated sample with lower values and enhanced keeping quality in frozen sample compared to chiller stored sample. A significant ($P < 0.05$) reduction in APC by low dose gamma irradiation initially and storage had a significant ($P < 0.05$) effect in increasing the count were noticed in minced beef (Jenifer, 2006), in buffalo beef

(Kuttinarayanan, 2007), in beef cutlet (Salke Dinkar Babanrao , 2007) and in chicken fry (Shijin, 2008). The effect of packaging was not significant ($P < 0.05$) in chiller storage, whereas, under frozen condition PAPE was better than that of HDPE packaging in reducing the bacterial load.

5.6.2. Psychrotrophic Count

The PC assessed in rabbit meat on the day of preparation (3.91 ±0.02) was significantly ($P < 0.05$) reduced due to irradiation both in HDPE and PAPE packaged samples. About two log reduction was noticed due to irradiation. Niemand *et al.* (1983) reported complete elimination of *Pseudomonas* spp. by irradiation in minced beef, where as Lambert *et al.* (1992) reported a two log reduction in psychrotrophic count in pork. The present study, irradiation resulted more than two log reduction of count. Lacorix *et al.* (2000) reported psychrotropic organisms were resistant to irradiation in aerobic condition compared to vacuum packaging.

As storage period enhanced there was a significant ($P < 0.05$) increase in the PC both in irradiated and non-irradiated samples with higher count in non-irradiated and chiller stored samples. Under chiller storage, PAPE packaging had a beneficial effect in reducing the count with the lowest count in PAPE samples. Under frozen storage PAPE irradiated samples maintained it's significantly ($P < 0.05$) lower count than that of HDPE irradiated samples. Considering the above factor it could be inferred that samples could be packaged in PAPE and irradiated in chiller for a short term storage and could be frozen for longer storage.

5.7. ORGANOLEPTIC QUALITIES

5.7.1. Colour

The sensory evaluation of the cooked sample was conducted with help of nine-point Hedonic scale. The purchaser always goes for a product by its appearance and colour. In the present study the non-irradiated control meat had a colour score of

8.63±0.04. This was significantly ($P < 0.05$) improved by the process of irradiation on the day of preparation. Initially PAPE packaged samples scored less than that of HDPE samples, especially after irradiation. Murano *et al.* (1998) reported non-significant effect of irradiation on colour of ground beef patties. As storage period enhanced colour score was significantly ($P < 0.05$) reduced. Reduction was more in chiller stored samples than that of frozen stored samples. The effect of irradiation was more as storage period enhanced with higher values in irradiated samples than that of non-irradiated samples. Zhu *et al.* (2003) also reported limited effect on colour due to irradiation. The present study was in agreement with Jo *et al.*, (2000) who reported a better colour in vacuum packed and irradiated sausages. Shijin (2008) reported a significant reduction in colour score both under room temperature and chiller storage conditions and the result of the present study was in agreement with the report. Even after 45^{th} day of storage the rabbit meat maintained a comparatively better score both in HDPE and PAPE irradiated and frozen samples.

5.7.2. Flavour

The flavour score of 8.77±0.04 was observed in non-irradiated rabbit meat on the day of preparation. The combined perception received by the sense of taste and smell was very good as far as the control sample was considered. This was numerically reduced to 8.69±0.03 by irradiation. Contradictory to the colour score, the non-irradiated sample had higher score compared to the irradiated sample in each groups. Zhao *et al.* (1996), Ahn *et al.* (1998), Zhu *et al.* (2003) and Zhu *et al.* (2004b) reported flavour changes due to irradiation in various meat and meat products which was in agreement with the results of present study. Whereas Arthur *et al.* (2005) and Kanatt *et al.* (2005) did not observe any detectable odour or flavour changes in irradiated meat products.

As storage period enhanced, a significant ($P < 0.05$) downward trend in flavour score was noticed in both type of packaging with better score in chilled sample compared to frozen sample. There was no significant ($P < 0.05$) difference between packaging on storage period. Between HDPE and PAPE packaging the HDPE packaged sample obtained a better score. Nam and Ahn, (2002a) reported that aerobic packaging would be more beneficial than vacuum packaging in meat and meat products, where lipid oxidation was not a great problem. In the present study meat packed in oxygen permeable film (HDPE) scored better than that of PAPE packaging. As storage period enhanced, the flavour score reduced due to various biochemical changes in the meat and these changes were rapid in chiller temperature compared to the freezer temperature as evidenced by the lower score obtained by them. Even after 45 days of storage the irradiated sample in both the packaging retained a fairly good score of above seven.

5.7.3. Juiciness

The control sample in HDPE package had a very good score of 8.74±0.04 on the day of preparation. The juiciness score was improved by the process of irradiation and were contradictory to the flavour score recorded in the present study. The results of the present study were in agreement with Murano *et al.* (1998) and Johnson *et al.* (2004). Among packages there was no significant ($P < 0.05$) difference. Luchsinger *et al.* (1996) did not observe any difference in juiciness score in pork, whereas Abu-Tarboush *et al.* (1997) reported little sensory difference due to irradiation in cooked chicken. In the present study irradiation had non-significantly ($P < 0.05$) improved the score of juiciness.

As storage period enhanced, storage had significant ($P < 0.05$) effect in reducing the juiciness score with higher score in frozen sample compared to chiller stored samples. Shijin (2008) reported lower values in meat products due to storage and the results of the present study were in agreement with the findings. The samples under frozen condition retained a fairly good score of 7.40±0.05 in HDPE IR F and 7.37±0.07 in PAPE IR F samples on 45th day of storage.

5.7.4. Tenderness

The control sample on the day of preparation had a score of 8.64±0.04. This was significantly ($P < 0.05$) improved due to irradiation in both types of packaging. An improved score due to irradiation was reported by Hashim *et al.* (1995), Murano *et al.* (1998), Arthur *et al.* (2005) and Shijin (2008) and the present study results were in agreement with them. Coleby *et al.* (1961) reported shrinkage of collagen as the cause of immediate softness and tenderness of meat foods. Histological examination showed collagen swelling of the samples. This might be the reason for the significantly ($P < 0.05$) higher tenderness score obtained for the sample.

A slow and steady decrease was noticed in tenderness on storage. Among packaging under chiller storage, HDPE packaging was better than PAPE packaging. Whereas, such a significant ($P < 0.05$) difference was not noticed for frozen samples. Even after 45 days of storage the sample had a very good score even though it was significantly ($P < 0.05$) reduced due to storage.

5.7.5. Overall acceptability

The overall acceptability score which is the product of the individual sensory qualities indicated a fairly good score of 8.51±0.04. This was significantly ($P < 0.05$) improved by the process of irradiation in both the types of packaging. Since many of the scores like colour, juiciness and tenderness improved significantly($P < 0.05$) due to irradiation, the overall acceptability of the product also improved. Johnson *et al.* (2004) and Kanatt *et al.* (2005) reported a similar trend in meat products.

As storage period enhanced, the overall acceptability was reduced and storage had a significant ($P < 0.05$) effect in reducing the overall acceptability score under both the types of storage. Jenifer (2006), Salke Dinkar Babanrao (2007) and Shijin (2008) reported a reduction in overall acceptability of various meat products due to storage. The PAPE packages in both irradiated and non-irradiated samples had a better score compared to HDPE packages in different storage periods and the difference was higher in frozen samples.

Since the sensory quality attributes like colour, juiciness, tenderness and overall acceptability were improved significantly ($P < 0.05$) due to irradiation and the PAPE packaging recorded better score through out the storage period, it could be concluded that packaging in PAPE followed by irradiation and chilling could be advocated for short term storage. Packaging in PAPE followed by irradiation and freezing of the samples would have a better storage life without affecting the quality parameters and the meat was wholesome without any nutritional changes. The process of irradiation destroys many of the spoilage bacteria and fungi including the pathogenic organisms and hence, the meat is safe and could be popularized.

Summary

6. SUMMARY

The livestock census conducted in India, particularly in Kerala showed a downward trend in the livestock population. This was mainly because of the lack of available land for the animal farming especially for large animals. In order to obtain food security with respect to meat and meat products, it is high time to popularize small animal farming where there would not be any human-animal conflict in terms of either land or food. Among various smaller livestock, rabbit is the one which doesn't require larger area for housing. Rabbits are animals meant for meat as well as for fur production. The quality and preservation studies of rabbit meat are scanty, hence the present study was undertaken to assess the quality as well as to evolve a suitable technique for preservation of the same under domestic refrigerator.

Seven batches of crossbred rabbits were procured from the local market and humanely slaughtered under hygienic conditions at the Department of Livestock Products Technology, College of Veterinary and Animal Sciences, Mannuthy. The samples were packed at a rate of 120 g in HDPE and in PAPE packages. Half of the packages from each treatment groups were subjected to irradiation at melting ice temperature at a dose rate of 2.5 kGy employing Gamma Chamber 5000, (BRIT-DAE, Mumbai). Sufficient number of the packages were stored under chiller condition (1 to 4°C) and freezer condition (-6 to -8°C) in a domestic refrigerator. The effect of irradiation on the keeping quality of rabbit meat under aerobic and vacuum packaging was assessed with respect to nutritional, physicochemical, microbiological and sensory qualities on different days of storage.

The dressing percentage of the rabbits was only 49.35 per cent. The irradiation processed meat had a shelf life of 15 to 18 days and 17 to 19 days in HDPE and PAPE packaging respectively at chiller temperature. The non-irradiated samples at chiller temperature were spoiled by 5 to 7 days (HDPE) and 7 to 9 days (PAPE). At freezer temperature the shelf life were 45 to 47 days and 47 to 49 days for irradiated samples in HDPE and PAPE packing respectively. Whereas, the non-irradiated samples spoiled between 25 and 27 days and 27 and 29 days respectively. The histological examination of the irradiated samples has showed swelling of the collagen fibres without affecting the muscle architecture compared to the non-irradiated samples.

The proximate composition, viz., moisture, fat, protein, total ash and carbohydrates of the samples were analyzed on the day of preparation. The highest percentage of moisture was recorded in the irradiated samples. The fat, protein and ash percentage did not exhibit any significant ($P < 0.05$) change either due to irradiation or packaging. The non-irradiated samples had a high energy level than that of irradiated samples. The pH of irradiated and non-irradiated samples varied significantly ($P < 0.05$) on the day of preparation, but the packaging had no significant ($P < 0.05$) effect. As storage period was enhanced there was a uniform decrease in the pH values towards acidic side.

The WHC of the rabbit meat was significantly ($P < 0.05$) reduced on the day of preparation by irradiation in both type of packaging. Storage had a significant ($P < 0.05$) effect in reducing the WHC in all the treatment groups under both storage conditions. About 40 per cent reduction in WHC was noticed in the irradiated samples by 45th day. On the day of preparation none of the treatments significantly ($P < 0.05$) influenced the drip loss. Storage had a significant ($P < 0.05$) effect on increasing the drip loss. Irradiation had a significant ($P < 0.05$) effect in enhancing the cooking loss whereas packaging had little effect in the physicochemical parameter of meat. As storage period enhanced there was a change in the cooking loss of meat between chilled and frozen meat. The values were significantly ($P < 0.05$) lower in frozen samples.

The oxidative rancidity changes of the sample were measured by TBARS values. There was a significant ($P < 0.05$) increase in the TBARS values due to irradiation but packaging had no significant ($P < 0.05$) role on the day of preparation. As the days of storage enhanced, the TBARS values were increased and showed a significant ($P < 0.05$) treatment effect. The values of TBARS in frozen samples were significantly ($P < 0.05$) lower than that of chiller stored samples. Irradiation had a significant ($P < 0.05$) effect in reducing the TV in both type of packaging. Storage had a significant ($P < 0.05$) effect in enhancing the TV.

Irradiation significantly ($P < 0.05$) reduced the APC of rabbit meat. The initial count of 4.43±0.04 $\log_{10}$ cfu/g was significantly ($P < 0.05$) reduced to 1.96±0.03 $\log_{10}$ cfu/g indicating nearly three log reduction in case of ordinary packaged rabbit meat by irradiation. Compared to frozen samples chiller samples had higher count especially in non-irradiated samples. The count of psychrotrophic organisms in rabbit meat initially was 3.91±0.02 $\log_{10}$ cfu/g. The irradiation of the samples both in HDPE and PAPE packaging significantly ($P < 0.05$) reduced the count on the day of preparation as well as on storage.

The sensory evaluation was carried out with the help of nine-point Hedonic scale for cooked rabbit meat for colour, flavour, juiciness, tenderness and overall acceptability. The colour score of non-irradiated meat was 8.63±0.04 which was improved to 8.90±0.03 due to irradiation of meat. Initially the rabbit meat showed a very good flavour score of 8.77±0.04 was slightly decreased to 8.69±0.03 due to irradiation. The juiciness and tenderness scores were increased due to irradiation when compared to non-irradiated meat. The overall acceptability was significantly ($P < 0.05$) improved by irradiation both in HDPE and PAPE packages. Throughout the study period irradiated sample had a better score compared to non-irradiated samples. The PAPE packaged samples had a better score than HDPE packaged samples both in irradiated and chiller and freezer stored samples indicating PAPE packaging was advantageous than HDPE packaging. The panelists did not detect any objectionable odour or taste due to irradiation of rabbit meat. Storage under chiller and freezer had significantly ($P < 0.05$) reduced all the sensory attributes, with less reduction in vacuum packaged samples compared to aerobically packaged samples.

Considering many of the advantages of rabbit meat and to help the poor farmers maintain smaller number of animals there should be a proper marketing system of the live animals and the final product - the meat. Preservation of meat by packaging in vacuum package followed by irradiation showed an extended shelf life. So it could be advocated that packaging the meat either in HDPE or PAPE, preferably in PAPE with irradiation would save energy for freezing for short term preservation. If extended storage life is required it should be frozen. The meat can be rendered safe by the process of irradiation which destroys many of the pathogenic and spoilage organisms without affecting the nutritional and sensory attributes.

References

REFERENCES

Abu-Tarboush, H.M., Al-Kahtani, H.A., Atia, M., Abou-Arab, A.A., Bajaber, A.S. and El-Mojaddidi, M.A. 1997. Sensory and microbial quality of chicken as affected by irradiation and post irradiation storage at 4°C. *J. Food Prot.* 60:761-770

*ACSH. 1998. *Irradiated food.* 3rd edition. American Council on Science and Health

Ahmad, H.A. and Marchello, J.A. 1989. Effect of gas atmosphere packaging on psychrotrophic growth and succession on steaks surfaces. *J. Food Sci.* 54: 274-276

Ahn, D.U., Jo, C., Du, M., Olson, D.G. and Nam, K.C. 2000. Quality characteristics of pork patties irradiated and stored in different packaging and storage conditions. *Meat Sci.* 56:203-209

Ahn, D.U. and Lee, E.J., 2005. Quality characteristics of irradiated turkey breast rolls formulated with plum extract. *Meat Sci.* 71:300-315

Ahn, D.U., Olson, D.G., Jo, C., Chen, X., Wu, C. and Lee, J.I. 1998. Effect of muscle type, packaging and irradiation on lipid oxidation, volatile production and color in raw pork patties. *Meat Sci.* 49:27-39

Alasnier, C., Meynier, A., Viau, M. and Gandemen, G. 2000. Hydrolytic and oxidative changes in the lipids of chicken breast and thigh muscles during refrigerated storage. *J. Food Sci.* 65:9-14

Al-Bachir, M. 2005. The radiation of spices, packaging materials and luncheon meat to improve the storage life of the end products. *Int. J. Food Sci. Technol.,* 40:197-200

Al-Bachir, M. and Zeinou, R. 2009. Effect of gamma irradiation on microbial load and quality characteristics of minced camel meat. *Meat Sci.* In press.

Animal Husbandry Department (AHD) Kerala. 2003. AHD Data base (online). Available. http://ahdkerala.gov.in.

AOAC, 1990. Meat and Meat Products. *Official Methods of Analysis of official analytical chemists*. 15th edition. Association of Official Analytical Chemists Inc., Arlington, Virginia, pp. 931-948

Apple, J. K., Davis, J. R., Rakes, L. K., Maxwell, C. V., Stivarius, M. R. and Pohlman, F. W. 2001. Effects of dietary magnesium and duration of refrigerated storage on the quality of vacuum-packaged, boneless pork loins. *Meat Sci.* 57:43-53

Arthur, T.M. and Wheeler, T.L., Shackelford, S.D., Bosilevac, J.M., Noaz, M. and Koohmaraie, M. 2005. Effect of low dose, low-penetration electron irradiation of chilled beef carcass surface cuts on *Escherchia coli* 0157: H7 and meat quality. *J. Food Prot.* 68:666-672

Aymerich, T., Picouet, P.A. and Monfort, J.M. 2008. Decontamination technologies for meat products. *Meat Sci.* 78:114–129

Badr, H.M. 2004. Use of irradiation to control food borne pathogens and extend the refrigerated market life of rabbit meat. *Meat Sci.* 67:541-548

Balamatsia, C.C., Rogga, K., Badeka, A., Kontominas, M.G. and Savvaidis, I.N. 2006. Effect of low dose radiation on microbiological, chemical and sensory characteristics of chicken meat stored aerobically at 4°C. *J. Food Prot.* 69:1126-1133

Basker, D., Klinger, I., Lapidol, M. and Eisenbery, E. 1986. Effect of chilled storage of radiation-pasteurized chicken carcasses on the eating quality of the resultant cooked meat. *J. Food Technol.* 21:437-441

Bendall, J.R. and Restall, D.J. 1983. The cooking of single myofibers, small myofibre bundlesand muscle strips of beef *M. psoas* and *M. sternomandibularis*. *Meat Sci.* 8:93-117

Boccard, R., Buchter, L., Casteels, E., Cosentino, E., Dransfield, E., Hood, D. E., Joseh, R. L., MacDougall, D. B., Rhodes, D., Schon, J., Tinbergen, B. J. and Tonraille, C. 1981. Procedures for maintaining meat quality characteristics in beef production experiments. Rpt. Working group in commission of the European communication (CEO) beef production research programme. *Livestock Prod. Sci.* 8:385

Buzby, J. C. and Morrison, R. M. 1999. Food irradiation- an update. *Food Review* 22:21-22

*Cain, R. F., Anglemier, A. F., Sather, L. A., Bautista, F. R. and Thompson, R. H. 1958. Acceptability of fresh and precooked radiated meats. *Food Res.* 23:603-610

Chouliara, I., Samelis, J., Kakouri, A., Badeka, A., Savvaidis, I.N., Riganakos, K. and Kontominas, M.G. 2006. Effect of irradiation of frozen meat / fat trimmings on microbiological and physicochemical qualities attributes of dry fermented sausages. *Meat Sci.* 74:303-311

Chungath, J. J. and Kuttinarayanan, P. 2008. Myostructural changes in radiation. In: *Abstracts, National Symposium on Advances in Veterinary Anatomy Teaching and Research with Reference to their Clinical Applications*; 5-7, November, 2008, College of Veterinary Sciences, Hisar. Abstract No. 53

Coleby, B., Ingreaw, M. and Shephered, H.I. 1961. Treatment of meats with ionizing radiation VI. Changes in quality during storage of sterilized raw beef and pork. *J. Sci. Food Agric.* 12:417-420

Cousin, M. A., Jay, J. M. and Vasavada P. C. 2001. Psychrotrophic Microrganisms. *Compendium of methods for the microbiology Examination of foods.* (eds. Downes, F. P and Ho, K.) 4th edition. APHA, Washington, D. C. pp. 159-166

Daoud, J.R., Kamal, A.M., Khalafalla, F.A. 2002. Studies on the effect of gamma irradiation on the chemical and microbial parameters of chilled minced beef meat. *Vet. Medical J.* 50:559-570

Dempster, J.F. 1985. Radiation preservation of meat and meat products: A review. *Meat Sci.* 12:61-89

Du, M., Ahn, D.U., Nam, K.C. and Sell, J.L. 2001. Volatile profiles and lipid oxidation of irradiated cooked chicken meat from laying hens fed diets containing conjugated linoleic acid. *Poultry Sci.* 80:235–241

Dushyanthan, K., Shanmugam, A.M. and Venkataramanujam, V. 2001. Influence of vacuum packaging on certain chemical qualities of mutton. *Indian J. Anim. Sci.* 71:573- 576

FAO, 2002. Food energy methods of analysis and conversion factors. Report of a technical workshop. FAO Food and Nutrition. Paper 77

Farkas, J. 1998. Irradiation a method for decontaminating food a review. *Int. J. Food Microbiol.* 44:189-204

Forrest, J.C., Aberle, E.D., Hedrick, H.B., Judge, M.D. and Merkal, R.A. 1975. *Priniciples of meat science.* W. H. Freeman and Company, SanFrancisco, 417p.

Gomes, H.A., Da Silva, E.N., Cardello, H.M.A.B. and Cipolli, K.M.V.A. B. 2003. Effect of gamma radiation on refrigerated mechanically deboned chicken meat quality. *Meat Sci.* 65:919- 926

*Grau, R. and Hamm, R. 1957. Quoted by Hamm, R. 1960. In: Biochemistry of meat hydration. *Adv. Fd. Res.* 10:356

Hashim, I.B., Resurreccion, A.V.A., and McWatteres, K.H. 1995. Descriptive sensory analysis of irradiated frozen or refrigerated chicken. *J. Food Sci.* 60:664-666

Heath, J.L., Owens, S.L. and Tesh, S. 1990. Effect of high-energy electron irradiation of chicken meat on thiobarbituric acid values, shear values, odour and cooked yield. *Poultry Sci.* 69:313-319

Hernandez, P., Pla, M., Oliver, M.A. and Blasco, A. 2000. Relationships between meat quality measurements in rabbits fed with three diets of different fat type and content. *Meat Sci.* 55:379-384

Huff-Lonergan, E. and Lonergan, S.M. 2005. Mechanisms of water holding capacity of meat: The role of postmortem biochemical and structural changes. *Meat Sci.* 17:194-204

Indian Council of Agricultural Research (ICAR). 2004. Why to eat rabbit meat? (online). Available. http://icar.org.in.

International Atomic Energy Agency (IAEA). 2003. IAEA Data base (online). Available. http://nucleaus.iaea.org.

Javanmard, M., Rokni, N., Bokaie, S. and Shahhosseini, G. 2006. Effects of gamma irradiation and frozen storage on microbial, chemical and sensory of chicken meat in Iran. *Food Control.* 17:469-473

Jenifer, P. 2006. Low dose gamma irradiation on the keeping quality of minced beef. M.V.Sc. thesis, Kerala Agricultural University, Thrissur, 81p.

Jo, C., Jin, S.K. and Ahn, D.U. 2000. Colour changes in irradiated cooked pork sausage with different fat sources and packaging during storage. *Meat Sci.* 55:107-113

Joo, S.T., Kauffman, R.G., Van Laack, R.L.J.M., Lee, S. and Kim, B.C. 1999. Variations in Rate of water loss as related to different types of post-rigor porcine musculature during storage. *J. Food Sci.* 64:865-868

Jones, J.M., Mead, G.C., Griffiths, N.M. and Adams, B.W. 1982. Influence of packaging on microbiological, chemical and sensory changes in chill-stored turkey portions. *Br. Poultry Sci.* 23:25-40

Johnson, A.M., Reynolds, A.E., Chen, J. and Resurreccion, A.V.A., 2004. Consumer Acceptance of electron beam irradiated turkey ready-to-eat poultry meat. *J. Food Processing Preservation.* 28:302-319

Kanatt, S.R., Chander, R. and Sharma, A.K. 2005. Effect of radiation processing on the quality of chilled products. *Meat Sci.* 69:269-275

Karakaya, M., Saricoban, C. and Yilmaz, M.T. 2006. The effect of mutton, goat, beef and rabbit meat species and state of rigor on some technological parameters. *J. Muscle Foods.* 17: 56-64

Karthikeyan, J., Kumar, S., Anjaneyulu, A.S.K. and Rao, K.H. 2000. Application of hurdle technology for the development of caprine keema, and its stability at ambient temperature. *Meat Sci.* 54:9-15

Katta, S.R., Rao, D.R., Sunki, G.R. and Chavan, C.B. 1991. Effect of gamma irradiation of whole chicken carcasses on bacterial loads and fatty acids. *J. Food Sci.* 56:371-372

Kristensen, L. and Purslow, P.P. 2001. The effect of ageing on the water holding capacity of pork: role of cytoskeletal proteins. *Meat Sci.* 58: 17-23

*Kropf, D.H. 1980. Effects of retail display conditions on meat colour. *Proc. Recip. Meat Conf.* 33:15-32

Kuttinarayanan, P. 2005. Consumer acceptance and shelf life studies on irradiated beef products. In: *Abstracts, Radioisotopes and Radiation Technology: Users'*

Perception and Experience; 10-11, November, 2005, National Association for Applications of Radioisotopes and Radiation in Industry, Mumbai. Abstract No. 5

Kuttinarayanan, P. 2007. Effect of low dose gamma radiation on certain qualities of buffalo beef and its consumer acceptance. *National Seminar on Radiation Processing of Agri-Foods-Domestic and Export Market Potential*; 1-2 November, 2007, Sri Venkateswara University, Tirupati. pp. 107-111

Kuttinarayanan, P., Menon, V.K. and Ramanathan, R. 2006a. Preservation of meat and meat products employing gamma radiation. In: Abstracts, National Seminar on Education, Research and Development of Animal Husbandry Sector in India; 17-18, February, 2006, College of Veterinary and Animal Sciences, Mannuthy. Abstract No. 25

Kuttinarayanan, P. and Nandakumar, P. 1989. Carcass yield and characteristics of broiler rabbit. *Kerala J. Vet. Sci.* 20:84-87

Kuttinarayanan, P., Ranjith, R. and Chander, R. 2005. Shelf life of irradiated (2.5 kGy) turkey breast at chiller storage. In: *Abstracts, Annual Conference on Radioisotopes and Radiation Technology: Users' Perception and Experience;* 10-11, November, 2005, National Association for Applications of Radioisotopes and Radiation in Industry (NAARRI), Mumbai. Abstract No. 49

Kuttinarayanan, P., Ranjith, R. and Kishor, K. 2006b. Keeping quality and organoleptic studies of beef fry preserved by employing gamma irradiation. In: *Abstracts, IMSACON-II second convection of Indian Meat Association and National symposium on Prospects and Challenges in Indian Meat Industry;* 27-29, July, 2006, Madras Veterinary College, Chennai. Abstract No. 171

Lacorix, M., Smoragiewicz, W., Jobin, M., Latreille, B. and Krzystyniak, K. 2000. Protein quality and microbiological changes in aerobically-or vacuum-packaged, irradiated fresh pork loins. *Meat Sci.* 56:31-39

Lambert, A.D., Smith, J.P. and Dodds, K.L. 1992. Physical, chemical and sensory changes in irradiated fresh pork packaged in modified atmosphere. *J. Food Sci.* 57:1294-1299

Lawrie, R.A. 1998. *Meat Science.* 6th edition. Woodhead Publishing Limited. Cambridge, England, 336 p.

Lee, B.H., Simard, R.E., Laleye, L.R. and Holley, R.A. 1983. Microflora sensory and exudate changes of vacuum-or nitrogen-packed veal chunks under different storage conditions. *J. Food Sci.* 48:1537-1563

Lee, M.S., Sebranek, J.G. and Parrish, J.F.C. 1996. Accelerated postmortem ageing of beef utilizing electron beam irradiation and modified atmosphere packaging. *J. Food Sci.* 61:133-141

Lee, S.Y. 2004. Irradiation as a method for decontaminating food. *Int. J. Food Saf.* 3:32-35

Lefebvre, N., Thiabault, C., Charbonneau, R. and Piette, J.P.G. 1994. Improvement of shelf life and wholesomeness of ground beef by irradiation-2. Chemical analysis and sensory evaluation. *Meat Sci.* 36:371- 380

Luchsinger, S.E., Kropf, D.H., Zepeda, C.M.G., Hunt, M.C., Marsden, J.L., Canas, E.J.R., Kastner, C.L., Kuecker, W.G. and Mata,T. 1996. Color and oxidative rancidity of gamma and electron beam irradiated boneless pork chops. *J. Food Sci.* 61:1000-1005

Luna, L.G. 1968. *Manual of Histological Staining Methods of the Armed Forces Institute of Pathology.* 3rd edition. Mc Graw-Hill Book Company, New York, 258 p.

Mcateer, N.J., Grant, I.R., Patterson, M.F., Stevenson, M.H. and Weatherup, S.T. 1995. Effect of irradiation and chilled storage on the microbiological and sensory quality of a ready meal. *Int. J. Food Sci. Technol.* 30:757-771

Melody, J.L., Lonergan, S.M., Rowe, L.J. and Huiatt, T.W. 2004. Early postmortem biochemical factors influence tenderness and water holding capacity of three porcine muscles. *J. Anim Sci.* 82: 1195-1205

Miller, K. D., Ellis, M., Bidner, B., McKeith, F. K. and Wilson, E. R. 2000. Porcine *longissimus* glycolytic potential level effects on growth performance, carcass, and meat quality characteristics. *J. Muscle Foods.* 11:169-181

Mortan, R.D. 2001. Aerobic plate count. *Compendium of methods for the microbiological examination of foods* (eds. Downes, F.P. and Ito, K.). 4th edition. APHA. Washington, D.C., pp.63-67

Murano, P.S., Murano, E.A. and Olson, D.G. 1998. Irradiated ground beef sensory and quality changes during storage under packaging conditions. *J. Food Sci.* 63:548-551

Nagai, N.Y. and Moy, J.H. 1985. Quality of gamma irradiated California Valencia oranges. *J. Food Sci.* 50:215-219

Nam, K.C. and Ahn, D.U. 2002a. Combination of aerobic and vacuum packaging to control lipid oxidation and off odor volatiles of irradiated raw turkey breast. *Meat Sci.* 63:389-395

Nam, K.C. and Ahn, D.U. 2002b. Effect of double-packaging and acid combination on the quality of irradiated raw turkey patties. *J. Food Sci.* 67:3252- 3257

Nam, K.C., Du, M., Jo, C. and Ahn, D.U. 2001. Cholesterol oxidation products in irradiated raw meat with different packaging and storage time. *Meat Sci.* 58:431-435

Narsimharao and Sreenivasmurty, V. 1986. A preliminary study on the effects of urea in the preservation of meat. *Meat Sci.* 17:51-265

Niemand, J.G., Van der Linde, H.J., and Holzapfel, W.H. 1981. Radurisation of prime beef cuts. *J. Food Prot.* 44:677-681

Niemand, J.G., Van der Linde, H.J., and Holzapfel, W.H. 1983. Shelf life extension of minced beef through combined treatment involving radurization. *J. Food Prot.* 46:791-796

Nortje, K., Buys, E.M. and Minnaar, A. 2005. Effect of gamma irradiation on the sensory quality of moist beef biltong. *Meat Sci.* 71:603-611

O'Halloran, G. R., Troy, D. J. and Buckley, D. J. 1997. The relationship between early post-mortem pH and the tenderization of beef muscles. *Meat Sci.* 45:239-251

Ohene-Adjei, S., Bertol, T., Hyun, Y., Ellis, M., Mckeith, F.K. and Brewer, M.S. 2004. Effect of vitamin E, low dose irradiation and display time on the quality of pork. *Meat Sci.* 68:19-26

Olson, D.G. 1998. Irradiation of food. *Food Technol.* 52:56-61

Pascual, M. and Pla, M. 2007. Changes in carcass composition and meat quality when selecting rabbits for growth rate. *Meat Sci.* 77:474-481

Paul, P., Venugopal, V. and Nair, P.M. 1990. Shelf-life enhancement of lamb under refrigeration by gamma irradiation. *J. Food Sci.* 55:865- 866

Pearson, D. 1968. Application of chemical method for assessment of beef quality. ii. Methods related to protein breakdown. *J. Sci. Food Agric.* 19:366

*Perron, R.B. and Wright, B.A.1950. Alteration of collagen structure by irradiation with electrons. *Nature* 166:863-864

Prevention of Food Adulteration Act. 1998. The Gazette of India. Extraordinary, part II, section 3- subsection (1) dated 06. 04. 1998

Pryzbylski, L.A., Finerty, M.W., Grodner, R.M. and Gerdes, D.L. 1989. Extension of shelf life of iced fresh channel catfish fillets using modified atmospheric packaging and low dose irradiation. *J. Food Sci*, 54:269-276

Rana Raj, V.R. 2006. The effect of low dose gamma radiation on the quality of intermediary moisture Pet food. M.V.Sc thesis, Kerala Agricultural University, Thrissur, Kerala, 95 p.

Roberts, W.T. and Weese, J.O. 1998. Shelf life of ground beef patties treated by gamma radiation. *J. Food Prot.* 61:1387-1389

Rodríguez-Calleja, J.M., García-López, M., Santos, J.A. and Andrés Otero, 2005. Development of the aerobic spoilage flora of chilled rabbit meat. *Meat Sci.* 70:389-394

Rodriguez, H.R., Lasta, J.A., Mallo, R.A. and Marchevsky, N. 1993. Low dose gamma irradiation and refrigeration to extend shelf life of aerobically packed fresh beef round. *J. Food Prot.* 56:505-509

Roserio, L.C., Santos, C. and Melo, R.S. 1994. Muscle pH 60, colour (L,a,b) and water holding capacity and influence of postmortem meat temperature. *Meat Sci.* 38: 353-359

Sakala, J.H., McGrown and Waring, P.P. 1987. Wholesomeness of irradiated foods. *J. Food Prot.*50:150-160

Salke Dinkar Babanrao, 2007. Preservation of beef cutlet employing gamma radiation under different packaging systems. M.V.Sc thesis, Kerala Agricultural University, Thrissur, Kerala, 91 p.

Sawant A. A. 1998. Improvement of microbiological quality and shelf life of processed meat products employing low dose gamma irradiation. M.V.Sc Thesis, Konkan krishi Vidhyapeeth, Dapoli, 70 p.

*Schweigert, B.S. 1959. The effects of radiation on protein. *Int. J. Appl. Isotopes.* 6:76

Seideman, S.C., Carpenter, J.L., Smith, G.C., Dill, C.W. and Vanderzant, C. 1979. Physical and sensory characteristics of beef packaged in modified gas atmospheres. *J. Food Prot.* 42:233-239

Seydim, A.C., Acton, J.C., Hall, M.A. and Dawson, P.L. 2006. Effects of packaging atmospheres on shelf life quality of ground ostrich meat. *Meat Sci.* 73:503-510

Shijin, A. 2008. Effect of hurdle technology, chitosan and gamma radiation on quality parameters of chicken fry. M.V.Sc thesis, Kerala Agricultural University, Thrissur, Kerala, 99 p.

Smith, G.C., Seideman, S.C., Savell, J.W., Dill, C.W. and Vanderzant, C. 1983. Vacuum packaging versus modified atmospheric packaging of lamb loins. *J. Food Prot.* 46:47-51

Smith, J.S. and Pillai, S. 2004. Irradiation and food safety. *Food Technol.* 58:48-55.

Snedecor, G.W. and Cochran, W.G. 1994. *Statistical Methods.* 8th edition. The Iowa State University, Ames, Iowa. 313 p.

Soultos, N., Tzikas, Z., Christaki, E., Papageorgiou, E. and Steris, V. 2009. The effect of dietary oregano essential oil on microbial growth of rabbit carcasses during refrigerated storage. *Meat Sci.* 81:474–478

Taylor, A. A., Down, N. F., and Shaw, B. G. 1990. A comparison of modified atmosphere and vacuum skin packing for the storage of red meats. *Int. J. Food Sci. Technol.* 25:98–109

Thayer, D. W. 1993. Extending shelf life of poultry and red meat by irradiation processing. *J. Food Prot.* 56:831-833

Thayer, D.W., Lachca, R.V., Huhtanen, C.N. and Weierbicki, E. 1986. Use of irradiation to ensure the safety of processed meats. *Food Technol.* 40:159-162

Urbain, W.M. 1989. Food microbiology: the past fifty years to prologue to tomorrow. *Food Technol.* 43:76-92

Van Laack, R.L.J.M., Kauffman, R.G., Pospiech, E., Greaser, M., Lee, S. and Solomon, M.B. 1996. A research note the effects of prerigor sodium bicarbonate perfusion on the quality of porcine *M. semimembranosus*. *J. Muscle Foods.* 9:185-191

Van Laack, R.L.J.M. and Smulders, F.J. 1992. On the assessment of water holding capacity of hot versus cold-boned pork. *Meat Sci.* 32:139-147

Vergara, H., Berruga, M. I. and Linares, M. B. 2005. Effect of gas composition on rabbit meat quality in modified atmosphere packaging. *J. Sci. Food Agric.* 85:1981–1986

Vivek, A.K. 2006. Effect of preslaughter stress and irradiation on physicochemical qualities of meat. M.V.Sc thesis, Kerala Agricultural University, Thrissur, Kerala, 99 p.

Wardlaw, F.S., Mc Caskill, L.H. and Acton, J.C. 1973. Effect of post mortem muscle changes on poultry meat loaf properties. *J. Food Sci.* 38:421-423

Wheeler, T.L., Shackelford, S.D. and Koohmaraie, M. 1999. Trained sensory panel and consumer evaluation of the effect of gamma irradiation on palatability of vacuum packaged frozen ground beef patties. *J. Anim. Sci.* 77:3219-3224

WHO. 1981. Report of Joint FAO/WHO Committee. WHO Tech. Rep. Ser. No.659

WHO. 1999. High dose irradiation: wholesomeness of food irradiated with doses above 10 kGy. Report of Joint FAO/ IAEA/ WHO study group. WHO Tech. Rep. Ser. No.890

Xiong, G. Y., Xu, X. L., Zhu, X. B., Zhou, G. H. and Shi, S. 2007. Effects of withholding food and/or water supply on the quality of meat from rex rabbits. *J. Muscle Foods.* 19:374-384

Yoon, K.S. 2003. Effect of gamma irradiation on the texture and microstructure of chicken breast meat. *Meat Sci.* 63:273-277

Zhao, Y., Sebranek, J.G., Dickson, J. and Lee, M. 1996. Bacteriological, physicochemical and sensory quality of fresh pork chops with low- dose irradiation and modified-atmosphere packaging. *J. Food Prot.* 59:493-501

Zhu, M.J., Lee, E.J., Mendonca, A. and Ahn, D.U. 2003. Effect of irradiation on the quality of turkey ham during storage. *Meat Sci.* 66:63- 68

Zhu, M.J., Mendonca, A., Lee, E.J. and Ahn, D.U. 2004a. Temperature abuse affects the quality of irradiated pork loins. *Meat Sci.* 67: 643-649

Zhu, M.J., Mendonca, A., Lee, E.J. and Ahn, D.U. 2004b. Influence of irradiation and storage on the quality of ready-to-eat turkey breast rolls. *Poultry Sci.* 83:1462-1466

Ziauddin, S.K., Mahendrakar, N.S., Rao, D.N. and Amla, B.L. 1993. Effect of freezing, thawing and frozen storage on physico-chemical and sensory characteristics of buffalo meat. *Meat Sci.* 35:331- 340

Zotte, A.D. 2002. Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. *Livestock Prod. Sci.* 75:11-32*

*Originals not consulted.

SHELF LIFE OF IRRADIATED RABBIT MEAT UNDER AEROBIC AND VACUUM PACKAGING

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ABSTRACT

Prevention of Food Adulteration Act (1954) as amended in 1998 has permitted irradiation at a dose rate of 2.5 to 4.5 kGy to control pathogenic microorganisms and to extend the shelf life of meat and meat products including poultry products. A study was conducted to evaluate the shelf life of irradiated rabbit meat under aerobic and vacuum packaging. The rabbit meat was prepared by slaughtering locally purchased rabbits under hygienic conditions and was packed in HDPE and PAPE packages at a rate of 120 g each. Half of the packets of aerobic and vacuum packaged samples were subjected to gamma radiation at 2.5 kGy at melting ice temperature and kept immediately at chiller temperature (1 to 4°C) and domestic refrigerator freezer (-6 to -8°C). Samples were analyzed for physical, physicochemical, microbiological, and organoleptic qualities on the day of preparation and on days 3, 5, 10, 15, 20, 25, 30, 40, 45, 50, 60, and 70 of storage or until spoilage, whichever was earlier. The samples were also analyzed for proximate composition on the day of preparation. The dressing percentage of the rabbits subjected to the study was 49.35 per cent.

The keeping quality of the rabbit meat was 15 to 18, 17 to 19, 5 to 7 and 7 to 9 days in HDPE IR, PAPE IR, HDPE NR and PAPE NR respectively at chiller temperature. In freezer temperature it was significantly ($P < 0.05$) increased to 45 to 47, 47 to 49, 25 to 27 and 27 to 29 days in HDPE IR, PAPE IR, HDPE NR and PAPE NR respectively. Irradiation or packaging did not significantly ($P < 0.05$) affect fat, protein and ash composition but higher moisture percentage was observed in irradiated samples. Swelling of the collagen fibres was noticed in irradiated samples on histological examination.

The physicochemical parameter, pH of irradiated and non-irradiated samples varied significantly ($P < 0.05$) on the day of preparation. On storage the pH values decreased uniformly. The WHC was significantly ($P < 0.05$) reduced in irradiated samples. The ability of the rabbit meat to retain its water decreased gradually on

storage and a reduction of about 40 per cent could be noticed from the initial level. Drip loss was not significantly ($P < 0.05$) different on the day of preparation. Irradiation had a significant ($P < 0.05$) effect in enhancing the cooking loss whereas packaging had little effect. Both drip loss and cooking loss was increased significantly ($P < 0.05$) due to storage under chiller and freezer temperature.

Irradiation had a significant ($P < 0.05$) role in increasing the TBARS value of rabbit meat. As the days of storage enhanced, the TBARS values were increased. Irradiation had a significant ($P < 0.05$) effect in reducing the TV in both type of packaging. As storage period enhanced, TV increased with significant ($P < 0.05$) changes among treatments.

Irradiation had a beneficial effect on microbiological qualities of rabbit meat. There was a significant ($P < 0.05$) reduction of nearly three log in APC of irradiated meat from that of control. The irradiation of the samples both in HDPE and PAPE packaging significantly ($P < 0.05$) reduced the PC of meat on the day of preparation where as storage had significant ($P < 0.05$) effect in enhancing the microbial load of meat. The colour score was non-significantly ($P < 0.05$) higher in irradiated samples. The juiciness, tenderness and overall acceptability scores were improved significantly ($P < 0.05$) due to irradiation, where as flavour score was reduced. The sensory attributes were significantly ($P < 0.05$) reduced due to storage in all the treatment groups.

The keeping quality of rabbit meat was significantly ($P < 0.05$) increased by irradiation both in chiller and freezer under different packaging. In addition irradiation could effectively control food borne illness by destroying the major pathogenic organism without affecting the sensory and nutritional quality of the product. Considering these advantages it can be recommended that packaging the meat in PAPE packages followed by low dose gamma irradiation and maintaining the cold-chain contribute to extended storage life of rabbit meat.