UNIT 2 CONVERSION OF MUSCLE TO MEAT

Structure

2.0 OBJECTIVES

After reading this unit, you will be able to:

- narrate the biochemical postmortem changes which occur during the process of conversion of muscle to meat,
- identify the changes in different physical characteristics of muscle in the post mortem period, and
- describe the important events of meat production.

2.1 INTRODUCTION

We, the general people think that the flesh of a living animal is converted into meat immediately after the slaughter of the animal. But the idea is wrong, because muscles take some time to be converted into meat. After the slaughter of a meat animal, circulatory system, nervous system and hormonal control etc. gradually stop to function and muscles of the dead animal traverse through a series of biochemical and physical changes over a period of time. These altogether lead to production of meat and the process is called as conversion of muscle to meat.

2.2 BIOCHEMICAL POST MORTEM CHANGES

After slaughter of the animal, a series of biochemical changes occur in the carcass. These changes are discussed below:

2.2.1 Exsanguinations

In conventional slaughter of animal, exsanguinations is the first step where blood is removed from the animal. It marks the beginning of a series of postmortem changes in the muscle. Sheep and goat bleed better in vertical position whereas cattle bleed better in horizontal position. As the blood pressure begins to drop following exsanguinations, the circulatory system starts to adjust its functions to maintain a blood supply to vital organs. Generally, 50 per cent of total blood volume is removed from the body of the animal and remaining 50 per cent is retained in the vital organs. This point is very much important from the view point of keeping quality and appearance of the meat as we know that blood is an excellent medium for the growth of spoilage organisms and the meat cuts with excess blood are unappealing to the consumers. So, we must take care of sufficient bleeding of the slaughtered animal.

2.2.2 Loss of Homeostasis

Homeostasis is the maintenance of a physiologically balanced internal environment. We must have a very good concept of homeostasis to understand the events that occur during conversion of muscle to meat because many of the post mortem biochemical changes are direct result of homeostasis. Have you ever thought why our body temperature is always constant whether it is a summer or winter? This is because of homeostasis as body tries to cope with the external environment. Similarly, you might have observed reduced fat intake during hot summer. It is because our body energy demand gets reduced and co-operate with situation we are being forced for reduced feed intake by internal system. Muscles and organs function efficiently within a narrow range of internal parameters *viz.*, p^H, temperature, oxygen concentration and energy supply. Homeostatic regulation gives the ability to survive under many different and sometimes adverse environmental conditions. Following exsanguinations, all homeostatic mechanisms are eventually lost. Within 4-6 minutes after exsanguinations, nervous control from central nervous system is lost and uncontrolled impulses result in twitching of muscles for a considerable time. Body temperature also starts to decline as there is loss of mechanism for maintaining it at original level.

2.2.3 Postmortem p^H Decline

Now we know that exsanguinations results in loss of blood supply to the muscles which lead to loss of oxygen supply also. As the stored oxygen supply becomes depleted, the aerobic pathway of metabolic process must stop functioning. Then there will be a shifting of metabolic process from aerobic pathway to anaerobic pathway for the production of energy in the form of ATP. The lactic acid is produced from anaerobic metabolism and gets accumulated in the muscle instead of going to liver for further metabolism because the circulatory system is no longer available for this transportation. Until all the stored muscle glycogen is depleted and the conditions are reached that slow or stop anaerobic glycolysis, lactic acid will continue to accumulate in the muscle. This will result in a lowering of p^H in the muscle. This change in p^H is one of the most significant changes during the process of conversion of muscle to meat. This lactic acid production continues until the muscle attains the ultimate p^H of about 5.4 to 5.5 i.e., the isoelectric point of the meat proteins. The

rate of p^H decline is highly variable and depends on several factors like, species of animal, type of muscle, variation between animals, environmental temperature, exercise of the animal, pre-slaughter feeding, stress etc. Normally, there is a gradual decrease in postmortem p^H from 7 in living muscle to 5.6-5.7 within 6-8 hours and then to an ultimate p^H of 5.4-5.5 within 24 hours. But there may be two extreme varieties of rate of p^H decline. Firstly, the p^H drops very slowly only to a few tenths of a unit during first hour postmortem in some animals, where ultimate p^H remains at a higher level of 6.5-6.8. Secondly, the p^H drops rapidly during first hour postmortem to nearly about 5.4-5.5 and reaches ultimate p^H very fast in some animals. These two conditions results in DFD (Dark, Firm and Dry) and PSE (Pale, Soft and Exudative) meat respectively, which will be discussed later in detail. The accumulation of lactic acid in muscle adversely affects the meat quality as it leads to the denaturation of muscle protein. The extent of protein denaturation is influenced by temperature and the level of p^H attained.

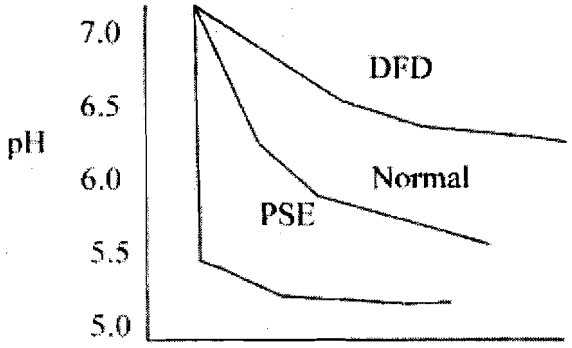


Fig. 2.1: Post mortem pH decline curve

2.2.4 Rigor Mortis

Literal translation of rigor mortis is "death stiffening". In conversion of muscle to meat, rigor mortis is the most important event. The muscles become inextensible or contracted and joints become stiffened after death and this condition is called as 'rigor mortis'. This stiffening results from the permanent cross bridges between actin and myosin filaments in the muscle. Again these cross bridges are result of accumulation of lactic acid in the muscle, decline in muscle p^H and coagulation of muscle protein.

Stages of rigor mortis:

The onset of rigor mortis is correlated with the disappearance of ATP (Adenosine triphosphate) from the muscle. Actomyosin complex forms during contraction of muscle in living condition also, but that is reversible change as the relaxation is possible in living animal. But in the absence of ATP, actin and myosin combine to form rigid chains of actomyosin in postmortem muscle which is irreversible in nature. Following three phases of postmortem actomyosin formation are observed in development of rigor mortis:

(i) **Delay phase:** When there is plenty of ATP in the muscle (complexed with Mg^{2+}), the muscle remains in the relaxed state and no cross bridge between the thick and thin myofilaments occurs. During the period immediately following exsanguinations, the muscle is quite extensible. If a force is applied to it, the muscle passively stretches and when the force is removed, the natural elasticity of the muscle returns to its original length. The period when the muscle is relatively extensible and elastic, is the 'delay phase' of rigor mortis.

(ii) **Fast phase:** The formation of actomyosin proceeds with great rapidity after delay phase and this is called fast phase of rigor mortis. This phase depends upon the quantum of ATP available. After the depletion of muscle glycogen, ATP level is maintained from rephosphorylation of adenosine diphosphate (ADP) by creatine phosphate (CP). In this way the CP stores start to be depleted and rephosphorylation of ADP becomes insufficient to maintain the muscle in a relaxed state. The muscles become less extensible due to formation of more and more actomyosin complex.

(iii) **Completion of rigor mortis:** When ATP formation from ADP is totally stopped due to depletion of all the CP, the muscles become relatively inextensible and this state is called completion of rigor mortis. In this phase irreversible actomyosin bridges are formed. These permanent bonds produce tension within the muscles which results in shortening and stiffening of the muscle during rigor mortis.

All the muscles do not enter into rigor simultaneously but most active muscle enters first. Thus the rigor mortis commences from palpebral muscles of eyelids, muscles of hearts, head, neck, shoulder, loin and hind limbs and passes off in the same direction.

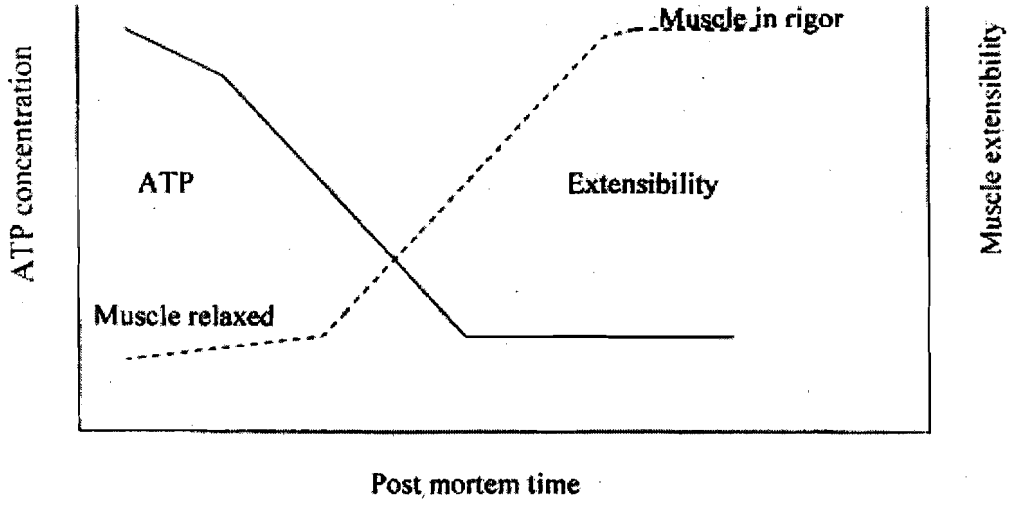


Fig. 2.2: The relation between ATP depletion and the onset of rigor mortis

(*Source* : Meat Science – An Introductory Text Book, 2000 by P.D. Warriss).

Patterns of rigor mortis: The rigor mortis onset can be classified as:

(a) **Acid rigor:** This is characterised by a long delay period and a short fast phase in immobilised animals. In struggling animal it is characterised by drastic curtailment of the delay period. Stiffening is accompanied by shortening at body temperature.

(b) **Alkaline rigor:** This is characterized by rapid onset of stiffening and marked shortening even at room temperature. This is also characterised by a high p^H of the muscles when they are in rigor.

(c) **Intermediate rigor:** This is characterised by the curtailment of the delay phase but not of the rapid phase in starved animals. There is some degree of shortening also.

2.2.5 Resolution of Rigor

After a period of completion of rigor mortis, rigors 'passes off' i.e., the muscles do not remain stiff indefinitely. The muscles again soften during this progressive 'resolution' of rigor. This 'resolution' of rigor occurs due to physical changes in muscle structure. Z-line structure of the muscle fibre becomes disintegrated. The degradation of muscle

structure can be estimated from the myofibrillar fragmentation index (mfi). After death of the animal, mfi increases with advancement of ageing time and the meat becomes more tender on cooking.

2.2.6 Conditioning of Meat

Conditioning of meat is also known as ripening or ageing of meat. It is the natural process of tenderization by holding a carcass at a particular temperature. Two types of changes are seen in conditioning — (i) weakening of the myofibrils and (ii) structural changes in intramuscular connective tissue. The main causative factor for conditioning is the myofibrillar change which is associated with breakdown of attachments of the thin (actin) filaments to Z-discs. Neither actomyosin complex dissociates nor the muscle becomes extensible during conditioning. There is a very small change in the connective tissue component like collagen where some cleavages of cross-links are seen. There are two main sorts of proteolytic enzymes – calpains and cathepsins which are responsible for tenderization. Cathepsins occur in the lysosomes and generally act at acidic p^H. They tenderized meat by degrading troponin-T, some collagen cross-links and mucopolysaccharides of the connective tissue ground substances. Calpains are located in the region of Z-lines and activated by calcium ions, higher p^H, and temperature and reduced calpastatin activity. Calpastatin is the inhibitor of calpains. Calpain is otherwise known as CASF i.e., calcium activated sarcoplasmic factor. Generally two forms of calpains are seen — m-calpain and μ-calpain. After completion of rigor mortis, sarcoplasmic reticulum and mitochondria do not take up calcium ions. Thus, the increased calcium ion concentration in the sarcoplasm activates calpains. Calpains degrade Z-line and promote breakdown of tropomyosin and titin. We will study more about the conditioning in Unit-7 of this course.

2.2.7 Loss of Structural Integrity

We have already studied that resolution of rigor mortis results in disintegration of Z-line structure and conditioning leads to breakdown of myofibrillar structure and denaturation of collagenous connective tissue. Thereby the membrane properties are altered and the microscopic muscle structure does not remain same after all these postmortem events as they were in the living muscle.

2.2.8 Loss of Protection from Bacterial Invasion

Due to altered membrane properties muscles become susceptible to invasion of microorganisms. We know that the lymphatic system and white blood cells of circulatory system prevent the spread of microorganisms. After exsanguinations of the animal, these two systems do not work and microorganisms can spread throughout the muscles very easily. Most of the postmortem changes favour the growth of the microorganisms except the lowered p^H of the muscle which inhibits the microbial proliferation.

2.3 POSTMORTEM CHANGES IN THE PHYSICAL CHARACTERISTICS OF THE MUSCLE

All the above said biochemical postmortem changes bring about the following changes in the physical characteristics of the muscle:

2.3.1 Colour

Have you ever noticed the colour of meat in the meat shop? Sometimes it may be

bright red or may be dark purplish red. The reasons behind this colour difference are the postmortem changes. Generally the colour of living muscle is bright red. After exsanguinations of the animal, the oxygen is used up and the muscles become dark purplish red in colour. So the exposed surface of freshly cut meat is dark red in appearance which is converted into bright red upon exposure to the atmosphere for a few minute. This colour change becomes possible by the oxygenation of myoglobin. The freshly cut meat sometimes may appear pale when the muscle is subjected to severe denaturation.

2.3.2 Firmness

The firmness of muscles changes with the progress of the postmortem period. The living muscles are relatively firm because they usually attached at both ends to the skeleton either directly or indirectly. With the progress of the rigor process, they tend to be more and more stiff and firm due to formation of permanent actomyosin complexes. Again after resolution of rigor, enzymatic degradation and protein denaturation give the muscles less firm consistency. But the extremely severe protein denaturation makes the muscle very soft.

2.3.3 Water Holding Capacity

We will study about water holding capacity in detail in next block. Here we will learn the relation between water holding capacity of meat and different phases of post mortem changes. During the conversion of muscle to meat, the changes in water holding capacity of meat depend upon the rate and extent of the p^H decline and the extent of protein denaturation. As the p^H approaches the isoelectric point (p^H at which positively and negatively charged groups are equal in number) of the muscle protein, the reactive groups available for water binding on the protein are reduced. Thus, the water holding capacity of the meat is minimum at isoelectric point. Both the limited and excessive extents of post mortem glycolysis affect the water holding capacity of meat. Limited glycolysis results in dry, firm and dark cutting meat (DFD) whereas, excessive glycolysis leads to pale, soft and exudative meat (PSE). The loss of ATP and the consequent formation of actomyosin as muscles go into rigor mortis cause loss of water holding capacity at any p^H.

So, from the above discussion it is clear that the meat quality parameters like tenderness, juiciness, emulsifying capacity, cooking loss, binding properties, flavour which are related with above mentioned parameters may be affected during conversion of muscle to meat.

2.4 IMPORTANT EVENTS OF MEAT PRODUCTION

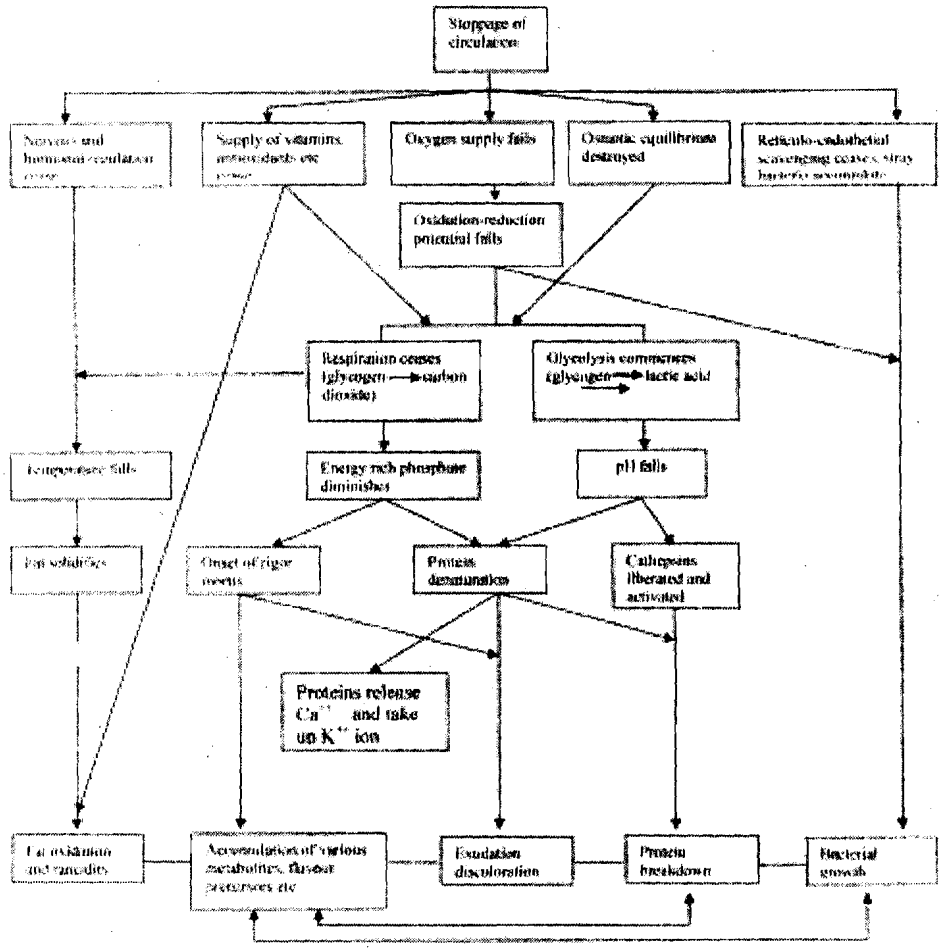
Upon the slaughter of a well rested domestic food animal, a series of events take place that lead to the production of meat.

Following an animal's slaughter:

- Its circulation ceases.
- The oxygen supply falls resulting in a reduction of the 'oxidation-reduction' potential; the supply of vitamins and antioxidants cease resulting in a slow development of rancidity.
- Nervous and hormonal regulations cease; thereby causing the temperature of the animal to fall and fat to solidity;
- Respiration ceases which stops ATP synthesis;

- Glycolysis begins resulting in the conversion of most of glycogen to lactic acid which reduces pH from about 7.4 to its ultimate level of about 5.6.
- The ability to resynthesize ATP is lost, lack of ATP causes actin and myosin to combine to form actomyosin which leads to a stiffening of muscles;
- pH depression initiates protein denaturation, liberates and activates cathepsins and calpains.
- The reticulo-endothelial system ceases to scavenge, thus allowing microorganisms to grow unchecked;
- Accumulation of various metabolites denatures muscle proteins.

These events require approximately 24 to 36 hours at the usual temperature of holding freshly slaughtered domestic food animals (2 to 5^0C).



Flow diagram of post mortem changes in muscle

(Source: Lawrie's Meat Science by R. A. Lawrie, 1998)

Fig. 2.3: Flow diagram of postmortem changes in muscle

(*Source*: Lawrie's Meat Science by R. A. Lawrie, 1998)

Check Your Progress

1) What do you mean by homeostasis?

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2) What is meant by loss of protection from bacterial invasion?

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3) Write short notes on —

(a) Exsanguinations

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(b) Rigor mortis

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(c) Ageing of meat.

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4) Fill in the blanks

(a) .....accumulation causes a lowering of pH in the muscle.

(b) Denaturation of the proteins causes a .....of protein solubility.

(c) In the absence of ATP, ...and .....combine to form rigid chains of actomyosin.

(d) In muscle cells, proteolytic enzymes called cathepsins are held in an inactive state in organelles called.....

(e) In postmortem muscles, as the .....is used up, the muscle becomes dark purplish red in colour.

(f) As the muscles go into....., they become firm and stiff.

(g) The changes in water binding that occur during the conversion of muscles to meat, depend upon the rate and extent of the .....drop.

2.5 LET US SUM UP

The whole chapter may be summarized under following points:

- After the slaughter of a food animal, the muscle stops its living function. Then a number of physical and chemical changes take place over a period of time and

the muscle becomes meat. This process is referred to as the conversion of muscle to meat.

- After exsanguinations, the aerobic pathway of metabolic process in muscles stops functioning. Energy metabolism is then shifted to the anaerobic pathway.
- The glycogen stored in the muscle is depleted to lactic acid and its accumulation causes a lowering of pH in the muscle.
- During the conversion of muscle to meat, the production of lactic acid from muscle glycogen effects the coagulation of muscle protein and produce muscular rigidity and is known as 'rigor mortis'. The stiffening observed in rigor mortis is due to the formation of permanent cross bridges in the muscle between the actin and myosin filaments.
- Muscles do not remain stiff indefinitely. The apparent 'resolution' of rigor mortis is probably due to a physical degradation of the muscle structure.
- The tenderization that occurs during the postmortem ageing of muscle may be partly due to the breakdown of some of the collagen connective tissues and partly due to change in myofibrillar structure.
- During conversion of muscles to meat, certain aspects of meat quality, parameters such as the tenderness, juiciness, flavour, colour, emulsifying capacity, binding properties, cooking losses, cooked meat colour etc. may be affected to varying degree.

2.6 KEY WORDS

Conditioning : It is the natural process of tenderization i.e., making the meat tender by holding the carcass at a particular temperature.

Delay phase : First phase of rigor mortis when the muscles are relatively extensible and elastic.

Exsanguinations : Removal of blood by conventional method of slaughter of an animal is called exsanguinations.

Fast phase : The period after delay phase when the muscles becomes less extensible due to formation of more and more actomyosin complex.

Glycolysis : Breakdown of glucose into pyruvic or lactic acid for the production of energy in the form of ATP.

Homeostasis : The maintenance of physiologically balanced internal environment in the animal body is termed as homeostasis.

Rigor mortis : During the conversion of muscle to meat, the muscle proteins produce rigidity to muscles which is known as rigor mortis.

Resolution of rigor : Rigor 'passes off' after the completion of rigor mortis and the muscles again soften. This is called resolution of rigor.

2.7 SOME USEFUL BOOKS

Biswas, S. (2005). *Meat and Egg Technology*. 1st edition. University Publication,

WBUAFS, Kolkata. West Bengal.

Forrest, J.C, Aberle, E.D., Hedrick, H.B., Judge, M.D and Markel, R.A. (1975). *Principle of Meat Science*, W.H. Freeman and Company.

Lawrie, R.A. (1998). *Lawrie's Meat Science*. 6th Edn. Woodhead Publishing Limited.

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Warriss, P.D. (2000). *Meat Science — An Introductory Text*. CABI Publishing, U.K.

2.8 ANSWERS TO CHECK YOUR PROGRESS

1) Homeostosis is the body phenomenon of maintenance of a physiologically balanced internal environment. Muscles and organs function efficiently within a narrow range of internal parameters *viz.*, p^H, temperature, oxygen concentration and energy supply. Homeostatic regulation gives the ability to survive under many different and sometimes adverse environmental conditions.

2) Loss of protection from bacterial invasion: In living condition body possess self- defence mechanism that abolished after slaughter. In living condition the invaded foreign organisms are either phagocytized, or killed by enzymatic mediation. But once the animal is dead none of the defence mechanism (lymphatic and white blood cells of circulatory system) is in operation i.e., a complete loss of protection from bacterial invasion takes place.

3) (a) **Exsanguinations:** It is the process of removal of blood during slaughter process. The usual practice is to severe jugular vein. The complete bleeding from an animal is not possible and about 50 per cent of blood remained in blood vessels and vital organs. Following exsanguinations, blood pressure starts to drop and circulatory system begins to adjust its function to maintain a blood supply to vital organs.

(b) **Rigor Mortis:** In simple words it is stiffening of muscle after death. After the death of animal, ATP depletes and after sometime energy to degrade actomyosin link is not available. The actomyosin cross link leads to stiffening of muscle. There are 3 stages of rigor mortis (1) Delay phase : when ATP is available to body (2) Fast phase: during this phase cross linking of actin-myosin begins (3) Completion of rigor : when the muscle is totally stiff because of actomyosin link.

(c) **Ageing of meat:** Ageing is the natural process of tenderization of meat by holding a carcass at a particular temperature. The meat is aged by — (i) weakening of the myofibrils and (ii) structural changes in intramuscular connective tissue. The main causative factor for ageing is the myofibrillar change which is associated with breakdown of attachments of the thin (actin) filaments to Z-discs. Proteolytic enzymes tenderize meat by degrading troponin-T, some collagen cross-links and mucopolysaccharides of the connective tissue ground substances.

4) (a) lactic acid (b) loss (c) actin, myosin (d) lysosomes (e) oxygen (f) rigor (g) pH.