A STUDY ON ICE CRYSTALS IN FROZEN MEAT

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SUMMARY

A study on ice crystals in frozen beef has been made in an effort to gain more information on the process of ice formation in meat during freezing and to determine a quantitative relationship between the rate of freezing and ice crystal formation. As a measure of the rate of freezing the rate of ice formation was calculated from the slope of measured time/temperature cooling curves and eutectic data for meat, and by a calculation method based on a solution of the heat transfer equations by finite difference calculus. This latter method was found to be rather unsatisfactory as a result of the large changes in specific heat in the temperature range 27-30°F.

It was found that the rate of freezing and the physiological condition of the meat prior to freezing had a marked effect on ice crystal size and location, relative to tissue structures. These phenomena have been explained in terms of the water permeability characteristics of the major structural components of the tissue, and the water binding ability of the proteins. There was considerable variation in ice crystal size for any given rate of freezing and physiological condition. The variation was dependent on the rate of freezing and a relationship between rate of ice formation and maximum ice crystal size was established. Ice was found intracellularly, extracellularly within fibre bundles and extracellularly between fibre bundles at high rates of ice formation and only extracellularly at low rates.

"O le aso ma le matainatila, o le aso ma le filigaafa."

(Each day brings new problems, and new measures must be found to solve them.)

Samoan proverb

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INTRODUCTION

In 1924 in a paper delivered to the Fourth International Congress of Refrigeration T. Moran (1924) stated, "Probably nothing is more needed by the refrigerating industry than an adequate theory of the freezing of tissues, because on it must be based any important advance in practical procedure other than such as one of a purely engineering nature."

Addressing an advanced study institute held at the University of Strathclyde in September 1966, H.A. Symons said, "Important though it is, technology occupies a relatively minor position in the structure of the frozen food industry."

It is of interest then to consider just what technological advances have been made, particularly in the freezing of meat, since the advent of commercial food freezing. The most significant advance is the introduction of quick freezing techniques such as blast and plate freezing. With fruit and vegetable products there is an obvious improvement in quality to be gained by using these methods but with meat the improvement is not so obvious. The reason for adopting these techniques for meat freezing has been the economic pressure caused by ever-increasing production.

A. THE EFFECTS OF FREEZING ON MEAT

Probably the first detailed study of the effects of freezing on meat was made by Richardson & Scherubel (1908). They found from histological studies that water separates as ice from the meat fibres during freezing and that on thawing much of this water is lost from

the meat as drip, particularly from freshly cut surfaces. Some of the nutritional value in the form of minerals and soluble protein was lost with the drip. Subsequent studies by Plank, Elerenbaum & Reuter (1916) and Fearon & Foster (1922) demonstrated the existence of a critical rate of cooling. At cooling rates faster than this there was little drip loss on thawing and the thawed meat had similar organoleptic characteristics to fresh meat. Histological studies (Koonz & Ramsbottom, 1939, Ramsbottom & Koonz, 1939) showed that in meat frozen at speeds greater than the critical rate, ice crystals were located within the muscle fibres, or cells, so that the fibres were not dehydrated during freezing. Unfortunately the critical cooling rate has been considered too high to be practical in the commercial freezing of large meat cuts.

1. Freezing Rate and Drip Formation

The existence of a critical freezing rate, as demonstrated by the absence of drip after freezing beef by immersion in liquid air, was confirmed by Cook et al (1926) in an extensive study of the factors influencing drip formation from frozen beef. They found that the amount of drip increased with decreasing freezing rate. Also the age and type of animal, the condition of the beef before freezing and the thawing temperature, influenced the amount of drip formed. From studies of changes in juices extracted from minced unfrozen beef with freezing, it was concluded that changes in the sarcolemma (cell wall) rather than the plasma were causing the drip (Vickery, 1926).

The observation that the amount of drip increases with decreasing freezing rate was subsequently confirmed by a number of workers.

(Moran, 1932 & 1933, Du Bois et al, 1940, Moiseva & Piskareva, 1959, Hankins & Hiner, 1940, Hiner et al, 1945, Ramsbottom & Koonz, 1939, Hiner & Hankins, 1941).

However, it has been suggested (Empey, 1933) that the rate of freezing has no significant effect on the amount of drip formed, but rather the amount of thaw drip was a function of the hydrogen ion concentration. It has been confirmed (Sair & Cook, 1936, Ramsbottom & Koonz, 1940) that pH could markedly influence the amount of drip on thawing. Ramsbottom & Koonz (1940) went further and showed that pH was not the only factor involved and that the condition of the meat prior to freezing was just as important, this was not a pH effect. They also demonstrated by histological studies that the lack of drip in pre-rigor meat was the result of intracellular ice formation rather than high pH. In post-rigor meat, for an equivalent rate of cooling, the ice formation was extracellular and tended to increase in size with ageing, an interesting observation as the amount of drip decreased with ageing. However, they did demonstrate that the amount of drip formed was dependent on the rate of freezing for each stage of ageing.

Extended studies on drip (Ramsbottom & Koonz, 1941) indicated that storage of the frozen meat greatly increased thaw drip and that the increase over a year was independent of storage temperature. The initial differences caused by different rates of freezing were still apparent after a year's storage.

2. Freezing Rate and Organoleptic Quality

Opinions on the influence of freezing on the organoleptic properties of meat tend to be rather more conflicting than those on

dip formation. Generally there is an increase in tenderness when meat is frozen and the amount of increase is related to the rate of freezing, being greater with rapid freezing. (Hankins & Hiner, 1940, Tressler et al, 1932, Du Bois et al, 1940, Dansk Koleinstitut, 1944, Nicholas et al, 1947, Hiner & Hankins, 1941, Hiner et al, 1945, Moiseva & Piskareva, 1959). This gain in tenderness, however, is lost after about six months storage at 0°F (Hiner & Hankins, 1941, Nicholas et al, 1947). Against this there is a considerable amount of evidence which can find no conclusive relationship between organoleptic properties and freezing (Paul & Child, 1937, Bray et al 1942, MaCoy et al, 1949, Moran, 1932 & 1933, Fin, 1933, Pennsylvania Agricultural Experiment Station, 1953, Valdecantos, 1963). A notable feature of the work done by Valdecantos is that he attempted to assess the difference in quality produced by the different rates of cooling within a single piece of meat. With the freezing conditions he used the differences in cooling rate were small and he was unable to detect any significant quality differences.

The colour of frozen meat is influenced by surface ice crystal size (Taylor, 1930 & 1931) being a darker colour with large ice crystals. The colour difference is lost on thawing so this is of little importance to the consumer who buys thawed meat. During storage the surface colour changes with the breakdown of oxymyoglobin to metmyoglobin, this change is not related to ice crystal size (Ramsbottom & Koonz, 1941).

The size of the surface ice crystals influences the type of freezer burn which develops (Kness & Weidemann, 1962 & 1967). The finer the crystals the whiter and less visually acceptable the burn becomes.

In general ice crystals do not grow significantly during the storage of frozen meat when large intracellular ice crystals or extracellular ice is the predominant form (Ramsbottom & Koonz, 1941). When finer ice crystals are present and storage is at high temperatures (15-20°F) some regrowth is apparent (Moran & Hale, 1932).

3. Freezing Rate and Ice Crystal Formation

Much of the conflicting opinion on the way in which freezing affects the quality of meat has arisen from a lack of appreciation of all the factors which govern the rate of cooling in meat which makes comparison of findings difficult.

Moran (1931) was one of the first people to appreciate that the rate of freezing was not uniform throughout a piece of meat being frozen. He found from studies of ice formation in frozen meat that the largest crystals were formed at the centre and the smallest at the surface. Du Bois et al (1940) and Tressler & Du Bois (1940) found that ice crystal size in air blast frozen beef and chicken was related to air temperature and air velocity. Hiner et al (1945) conducted tenderness, drip and histological examinations on beef frozen in still air at various temperatures. They found a decrease in crystal size with freezer air temperature. Ramsbottom et al (1949) demonstrated that crystal formation varied with position relative to the cooling surface and that the freezing time as determined from measured cooling curves also varied with position. They observed both extracellular and intracellular ice within the one piece of meat. Koonz and Ramsbottom (1938) made a detailed histological study of the types of ice formation in frozen poultry meat, particularly of

intracellular ice formation at high cooling rates. They observed that crystallisation was profoundly influenced by cooling rate but did not define the cooling rate in a way which could be quantitatively related to their observations.

More recent histological studies of frozen meat (Biro, 1962, Kaess, 1966, Chizhov & Kulmanova, 1966) suggest that the condition of the meat before freezing has a greater influence on the histological structure of the frozen meat than the rate of freezing. Kaess found that in pre-rigor frozen bovine muscle, ice crystals form predominantly intracellularly. In slow frozen post-rigor muscle, ice crystals appeared extracellularly, and in quick frozen post-rigor tissue both extracellularly and intracellularly. The number of ice crystals were found to increase and their sizes to decrease with increasing rate of freezing, independently of the physiological condition of the tissue.

Plank (1941) made an analytical study of the rate of ice front advance during freezing and suggested that this has some influence on ice crystal size. He determined the effects of freezing conditions and the shape and size of blocks of material being frozen on the rate of ice front advance and concluded that these factors could cause considerable differences in ice crystal sizes within a piece of frozen food. This he considered would be detrimental to the product as it would encourage recrystallisation by virtue of the fact that large ice crystals have a lower vapour pressure than small ice crystals. To avoid this he proposed freezing methods which would produce uniform freezing rates throughout the material. The implications of this

work as regards ice crystal size and quality have been largely overlooked by subsequent workers in their attempts to relate ice crystal size or rate of freezing to quality changes in frozen foods. In order to make his analytical solution, Plank made certain assumptions which limit its application to real systems. However, more recently numerical solutions based upon the use of finite difference approximations to heat conduction equations have been used successfully to calculate cooling rates during the freezing of meat (Earle & Earl, 1966, Cullwick, 1967). By combining the cooling rate so obtained with eutectic data for meat it is possible to predict the rate of ice formation in terms of the rate of change of the fraction of freezable moisture frozen. In this way it is possible to express the rate of freezing in fundamental terms.

B. THE OBJECTIVES OF THIS STUDY

The object of this study was to evaluate ice crystal formation in frozen meat in terms of the rate of change of the fraction of freezable moisture frozen, to observe what effect the physiological condition of the muscle prior to freezing has on ice crystallisation with regard to the rate of freezing, and to determine the degree of variation in ice crystal formation within a single block of frozen meat.

From a fuller understanding of the process of ice formation in frozen meat it is hoped that it will be possible to determine with more certainty what influence the rate of freezing has on the initial quality of frozen meat and upon subsequent quality changes on storage.