F U R T H E R   A P P L I C A T I O N S   F O R   T H E

H E A T   S H O C K   P U F F I N G   O F   F O O D   G E L S

A Thesis presented in partial fulfilment of the requirement for the degree of Master of Food Technology in Food Processing at Massey University, Palmerston North, New Zealand.

Buncha Ooraikul

1967.

A C K N O W L E D G E M E N T S

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S U M M A R Y

Factors governing the puffability of food gels were studied in detail. Some experiments were conducted and results discussed on the effects of soluble solids, changes of pH and pretreatment of food gels on their water holding capacity. The effects of the soluble solids, fat and fibrous texture on the thermoplasticity of food gels were also examined.

The application of a puffing technique was directed toward two main types of food, i.e. non-protein foods which include carrots and bananas and protein foods which include three types of cheese, fish and meat. Different techniques were necessary to manipulate each product to puff. Carrot slices may be puffed raw but the product characteristics may differ widely from those of blanched and leached slices. Some foods such as bananas with high sugar content and cheese with high fat content may not puff without the addition of sufficient amount of a puffing agent. Fish and meat as fibrous protein foods need similar physical and chemical modifications, before their products can puff, such as the destruction of their fibrous structure and the adjustment of their pH to alter their water holding capacity to a suitable level.

The food gels may be puffed by other heat-shock

techniques other than deep-fat frying. Radiant heat was applied successfully to puff food gels such as sodium caseinate gel, starch gel, and fish product. The products could be puffed to the comparable volumes achieved by deep-fat frying techniques, yet they were superior in some respects. They were free of fat pick-up problems. They could be rehydrated very quickly and the rehydration rate of the radiant heat puffed fish product, for example, was comparable to that of the dehydrated products of the highly sophisticated processes such as freeze-drying, and vacuum contact plate drying.

I N T R O D U C T I O N

In recent years a great deal of interest has been displayed concerning ways by which aid can be given, or development can be undertaken in food production and consumption in developing countries. It has been realised that there are two major problems these countries are facing in their food situation, viz. the inadequate supply of food, and the nutritional inferiority in the food they consume.

Aid from the developed countries have been given to these nations in essentially two ways, materially and technologically. Materially, millions of tons of basic foods, which may be merely a surplus in the developed countries, are given or sold at a give-away price to the needing countries. Technically, they are taught the modern scientific knowledge concerning the more efficient methods to produce more food in their own countries to meet the demand and also the technology of food processing to upgrade their food nutritionally, with the realisation of the importance of balanced diets and how to obtain it in the foods they consume.

The imbalance in diets or malnutrition widely prevalent among children belonging to low-income groups of the population in many developing countries (3) is the subject of great concern. The shortage of protein foods comes largely from the way their animal husbandry is operated (73) and the lack of relatively modern technology of food preservation and preparation results in seasonal shortage of food in general (40).

In Southeast Asia one of the most important sources of animal protein is fish (81). It is generally consumed in both fresh and preserved forms. Most of their preservation methods are simple. Fish is generally preserved by salting or processing it into products e.g. fish pastes, fish sauces, dried-salted fish, or a more refined product such as fish slices which puff in hot fat. The last product is prepared from starch gel which constitutes some 60 - 70% of the product, mixed with about 20 - 30% fish flesh and some other ingredients such as spices and flavourings.

Perreau (60) studied, in considerable detail, the phenomenon of puffing and concluded that this phenomenon relied not on the presence of starch but on the formation of gel. So all food gels possessing suitable properties such as moisture content and thermoplasticity should puff.

Realizing that these puff-products are the readily acceptable form of food and that the consumption of more protein should be encouraged in the developing countries, the puffing technique and its application was further examined. The techniques by which the gel structure could be induced in various types of food especially protein food were investigated. The protein-based gelling agents were studied in further details and it was hoped that these studies will provide some knowledge of how to produce the Asian traditional foods containing high protein content, or how to present high-protein foods to the needing people in their own traditional forms. The studies were also conducted on the puffing techniques other than deep-fat frying to provide a porous texture to the foods thus improving their rehydratability.

The Thesis is presented in three sections. The first section deals with the study of the factors governing the puffability of food gels. The second section concerns the application of puffing techniques to various types of food and in the third section, various heat-shock techniques for puffing are reviewed. The application of the radiant heat shock techniques and the rehydration of puffed products derived from this method are also described.

S E C T I O N I

CHARACTERISTICS OF GELS AND THEIR PUFFABILITY.

A. Gels:

Gel formation is a very important process in food chemistry on which properties of living cells, both animal and vegetable, depend. In food preparation the stiffening which occurs during meat and flour cookery, the rigidity of pectin and starch gels, the high viscosity of many plant juices, the changes that occur in egg cookery, and many other processing operations are a function of the gel.

Gels are differentiated from other systems in which small proportions of solid are dispersed in relatively large propertions of liquid by the property of mechanical rigidity, or the ability to support shearing stress at rest. The rigidity may be accompanied by viscous retardation, which delays the response to stress; it may be associated with slow deformation under constant stress, resulting in flow and permanent set; it may be reduced or destroyed under high stresses, resulting in thixotropic effects. Among these complicated mechanical phenomena, however, rigidity is the characteristic property common to all gels (25).

It has been established that most of the gels, especially those that will be discussed in this paper are formed through the formation of a three-dimensional network of the molecules by reacting at widely separated intervals on the chain or at relatively small distances.

The bonds which tie these molecules into the network can be either

i) primary bonds between functional groups,

ii) secondary bonds such as H-bonds, or,

iii) non-localized secondary attractive forces e.g. that might occur between alkyl groups.

It has been shown by a previous worker (60) that only those gels formed with secondary bonds or non-localized secondary bonds that can be puffed satisfactorily as those formed with primary bonds will be too strong to be expanded or disrupted by steam pressure from puffing mechanism. Fortunately, gel system in most foods, except those fruit and vegetables whose gel system relies mainly on pectic substances, is formed essentially with those two types of bonds.

The importance of gel in food preparation is illustrated to the fact, for example, that the intracellular proteins of meat are in the gel state; eggs, starch and flour proteins form gels in souffles, puddings, and batter and dough products (49).

B. Puffability of Food Gels:

(a) Puffing Mechanism:

The mechanism of the puffing is to create foam texture in food gels through the vaporization of a portion of moisture content in partly dried gels. The steam pressure so formed will expand the gel texture forming pores within the gel. This occurs only at certain level of moisture and puffing temperature when the gel can no longer contain evaporating moisture and expands to accommodate it (60). For example, for 10% starch gel the critical moisture content for puffing at $400^{o}F$ is 7.0%, and will give maximum puffing volume at 11.0%.

The formation of the foam texture in the puffed gel is, to a considerable extent, similar to the foam formation in "fluff" desserts, e.g. marshmallow, meringues etc. The texture so formed is, to a great extent, a function of rheological properties of the plastic substances making up the bubble walls. The differences between these two foam forming mechanisms depend on the fact that the foam texture products like marshmallow are formed either by introducing air into plastic sugar and relying on the cooling and setting to hold the air in suspension, or by incorporating into the mix certain proteins known as whipping agents e.g. albumin, gelatin, casein, fish albumin and soya albumin (51). The porous texture in heat puffed gels, on the other hand, is created through the expansion of the gel structure by moisture vapour within the gel itself. The energy to incorporate air in the marshmallow type product is supplied by beating, or pulling, or supplying air under pressure while the energy for heat shock puffing is supplied by a heating medium such as hot-fat or hot air or radiation. The firmness of a product like marshmallow will normally be obtained through the practice of hardening of the continuous phase as a result of either denaturation of the protein component or due to drying and/or cooling of the plastic mass involving thermal treatment, but the extent of the treatment is much less than that in puffing. In puffing, a very high temperature is required for a sufficient period of time to dry the puffed product to near completion, while in the former case (of marshmallow type products) the whole or part of the product is still soft and contains high moisture.

However, once the pores are formed the desirable characteristics of the texture will be quite similar, such as; for a good product we may require uniformity of the pore size, small average pore size and optimal thickness of the walls of the pores.

The formation of the pores in puffed products could also be explained by the equation given for the explanation of formation and growth of any foam, i.e:-

$$P_1 = \frac{2\gamma}{R}$$

where P_1 in this case is the pressure exerted by water vapour in the gel in a certain pore,

γ is the resistant force resulting from thermoplasticity of the gel.

R is the radius of the pore.

The pore can be formed only when P_1 built up is greater than $\frac{2\gamma}{R}$, and if P_1 is the vapour pressure in a pore (1) and P_2 is the vapour in a pore (2) adjacent to pore (1), and P_1 is greater than P_2, the two pores will merge into one bigger pore when the wall between them is thin and weak enough for P_1 to break through. So to obtain uniform firm porous texture small pores of similar thickness of the walls and having similar P must be formed throughout the gel. In some cases, which will be discussed later, this is not so, and the products of big, irregular pore size are obtained. A hollow "pillow case" - like product is a good illustration of how small pores may merge into only one big void.

(b) Factors Governing the Puffability of Food Gels:

Once the gel system is successfully induced in a food, the puffability of the food is then dependent upon two major factors as stipulated by Perreau (60), i.e:

(i) Moisture content, or, to be more accurate, water holding capacity of the food.

(ii) Thermoplasticity of the food gel.

These two factors are interrelated to each other as when internal pressures, deriving from the moisture in the food gel, exceed the plastic strength, the food puffs, but when the internal pressures are less than, or equal to, the plastic strength, no puffing occurs. The pressure is temperature dependent and, similarly the plastic strength, necessary to be in equilibrium with pressure, is also dependent on temperature, moisture content and internal pressure.

Due to their close interrelationship, factors affecting these two essential characteristics, which will be discussed in more detail, are also interrelated, and inevitably overlap one another.

Factors Affecting Water Holding Capacity of Food Gels and Their Puffability:

Water, regarded as the only solvent of importance in food gels, may be continuous or finely dispersed in the continuous solid phase of gel (54).

The amount of water present in food gels is not a fixed quantity. Food gels from different origins hold water of different quantities under specific conditions.

It was stipulated by Perreau (60) that the vapour pressure required for any gel to show signs of puffing at a particular temperature is the same, and under those conditions the resistance to puffing of such gels is also the same. However, different types of gel contain different levels of moisture to give that same effect. For instance, at 325°F the moisture content of 10% starch gel is 13.7% while that of 10% gelatin gel is 7.5% to show signs of puffing. Hence, each food gel must acquire a particular "water-holding capacity", and plasticity before the puffing state can be attained. This characteristic may be intrinsic to some foods, but in some foods some types of modificiation must be introduced to their physical and/or chemical properties.

Water-holding capacity is defined as "the ability of food to hold fast to its own or added water during application of any force (pressing, heating, grinding, etc.)" (36). It can be best expressed in terms of the amount of bound water related to food gels.

Water is held in gel system in two forms:-

a) that forming part of the molecule, designated as "bound" water or water of hydration in case of proteins.

b) that which contains the dissolved salts, proteins, sugar, etc., known as "free" water.

Bound water is very closely associated with the molecule with which it is combined, differs from ordinary water as (49):-

a) it no longer acts as a solvent for solutes e.g. sugar,

b) it has no appreciable vapour pressure,

c) it cannot be frozen,

d) it cannot be pressed from the tissue,

e) it is very dense.

Bound and free waters are closely connected that a portion of bound water may become free and vice versa.

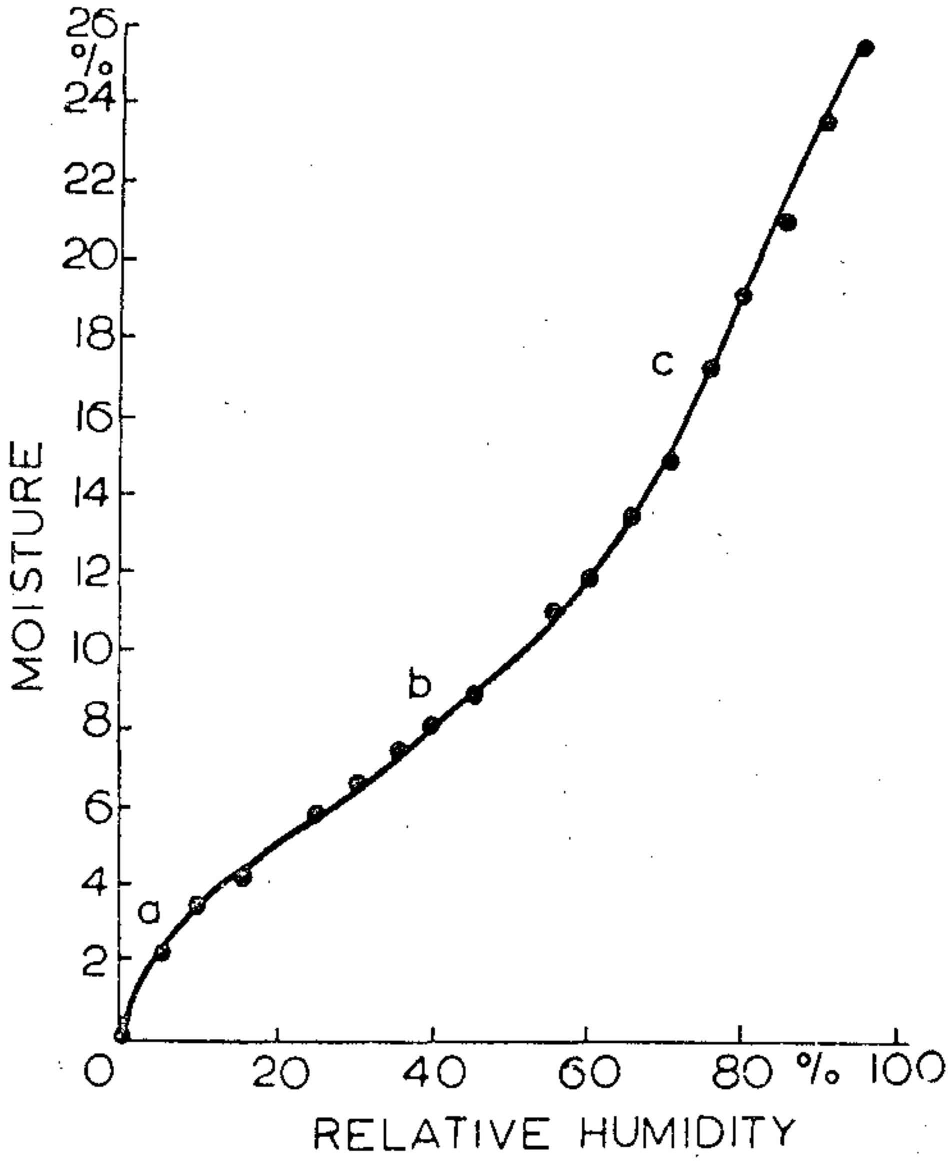


FIG.1 Adsorption isotherm of freeze-dried beef muscle (+5°C.) (Hamm, 1960).

It is understood from the B.E.T. equation of a theoretical monomolecular layer of adsorbed water that moisture in excess of the monolayer value represents free water (68).

Figure 1 shows a typical adsorption isotherm curve of dehydrated protein. It is pointed out that (32) the amount of water in (a) region is monomolecular adsorption according to the law of Langmuir. It is assumed that the water is bound to certain hydrophilic groups forming, between the peptide chain, a layer of water of one molecule thick.

The amount of water (b) probably represents a second layer formed over the same hydrophilic groups, so that in these areas each of the adjacent peptide chain has its own water layer. The process is called "multi-molecular adsorption" by Brunauer et al (8).

The water (c) is formed by the condensation of randomly oriented water molecules in the hydrated surfaces. The process is called "capillary condensation" (36).

It is experimentally shown by Perreau (60) that unless it is subjected to puffing at very high temperature, dry gel containing moisture below monolayer value will not puff. For example, 10% starch gel of moisture content less than 7% will not puff at temperatures up to 440°F. The monolayer value of this gel is calculated to be 6.75%.

Puffing does occur only at extremely high temperature of 550°F, and the puffing value obtained is not large.

Perreau, then, suggested that:-

(a) The hydrophilic nature of the gel may make it more difficult for moisture to be vaporised to give enough vapour pressure as obtainable with free water. Even though puffing temperature is sufficiently high to remove all moisture, but that in monolayer region will contribute only little, or none, to the puffing.

(b) The optimum thermoplasticity of a gel, which is strongly related to moisture content, can be obtained in the monolayer region only at substantially higher temperatures. The strongly bound water is unable to act as a "lubricant" between long molecular chain as free water above the monolayer.

In pure gel system, especially starch and protein gels, its water-holding capacity, hence its moisture adsorption isotherm characteristics are specific and straightforward; but when the gel system includes impurities e.g. sugar, fibrous materials, fat, etc., then these characteristics will be changed. In food products which gel system must be induced before puffing can occur, e.g. in fish or meat, the modification techniques are directed towards the change of at least two equally important characteristics of the food i.e. its water-holding capacity and its texture.

Three factors affecting the water-holding capacity of food gels were studied in some depth. They are:-

(i) the effect of soluble solids, especially sugar,

(ii) the effect of changing of pH through the addition of salts,

(iii) pre-treatment of the raw materials.

(i) The Effect of Soluble Solids:

Perreau (60) has tentatively shown that 10% sucrose in 10% starch gel almost completely inhibits puffing of the gel. In this experiment the effect of sugar on puffing was studied in greater detail. Since sodium caseinate was discovered to be one of the best protein-based gelling agents and as protein foods dominated the work in this paper, so it was thought best to use the sodium caseinate gel as a model in most of the basic studies.

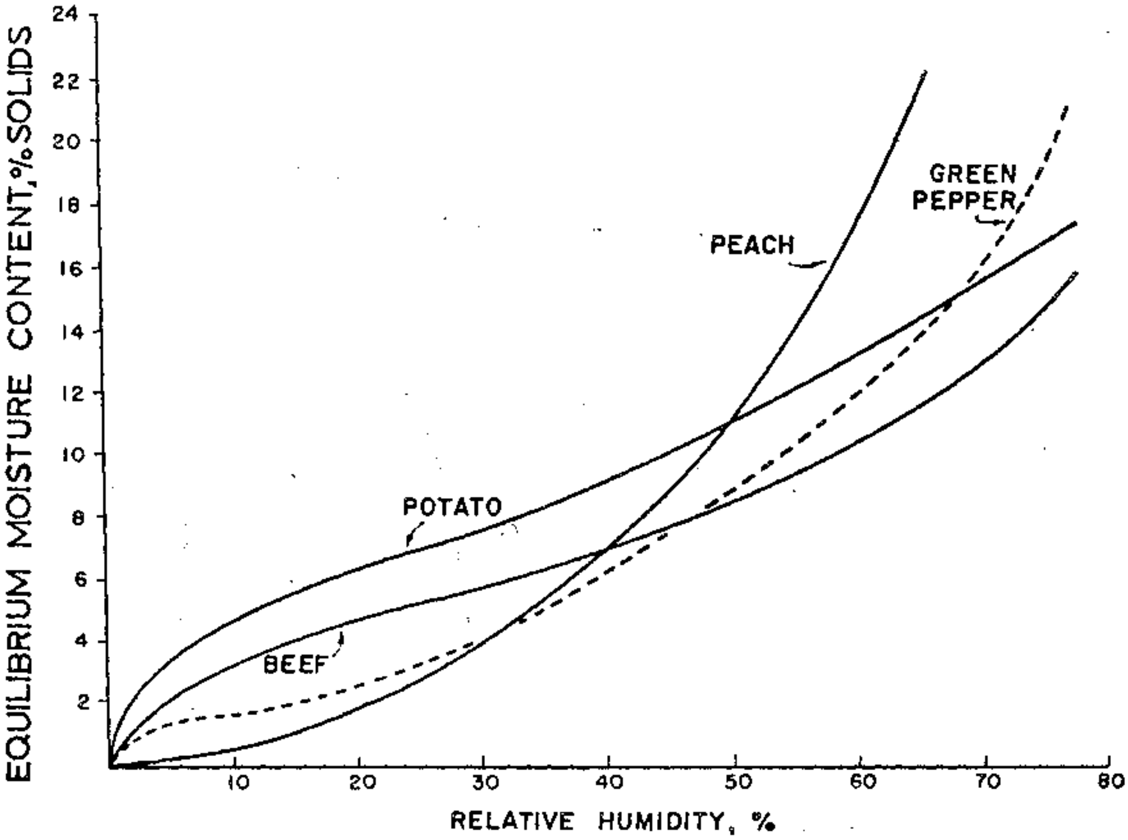


FIG.2 Typical moisture-sorption isotherm for dehydrated foods, 72°F (Salwin,1962).

It is well known that glycerine and sucrose increase the modulus of elasticity of gelatin (42). Sweetman and MacKellar (76) report that sugar increases transparency and tenderness in starch gels, and may turn a gel into a syrupy mass if present in sufficient amount, due to the competition of the sugar for water, whereby the proportion available for hydration of starch being diminished.

In pectin gels sugar is known to function as a dehydrating agent (54).

Salwin (68) in his study of the role of moisture in dehydrated food reports that green peppers which contain 30% sugar have a lower water-holding capacity than potato and beef which contain lower sugar content, and peaches which contain highest sugar content of 67% has very peculiar shape of adsorption isotherm curve which can be interpreted as having only traces of water-holding capacity as its moisture exerts a high vapour pressure, even at very low percentages. (See Fig. 2).

Hence, it is reasonable to advocate that in food gels containing high percentages of sugar, the sugar inhibits or hinders the gel to fully absorb the moisture. If the level of sugar in the gel is sufficiently high the moisture left in the actual gel structure may be just equal to, or well below monolayer level. Hence there is no water available to form vapour pressure to expand the gel, hence only little or no puffing occurs.

TABLE 1 Moisture Contents and Volumes of Sodium Caseinate Gels of Different Sugar Contents:

% Sucrose	% R.H.	% Moisture Wet Basis		Volume/Weight of dry gel in C.C./grm		
		Before Puffing	After Puffing	Before Puffing	After Puffing	
					As Is	Weight Before Puffed Basis
0	32.0	8.90	1.60	0.75	3.80	20.40
0	43.6	11.25	1.20	0.75	4.60	24.00
0	74.9	14.75	1.50	0.75	4.40	21.20
0	84.5	17.50	3.30	0.73	3.50	12.75
10	32.0	7.50	1.40	0.75	1.90	9.30
10	43.6	10.00	1.60	0.73	2.60	9.95
10	74.9	15.35	1.30	0.87	2.20	10.35
10	84.5	20.90	2.50	0.87	2.55	7.30
30	32.0	7.30	1.00	0.73	1.20	3.88
30	43.6	7.50	1.20	0.68	1.15	3.74
30	74.9	13.60	1.55	0.90	1.55	4.80
30	84.5	22.50	4.00	0.68	1.42	2.80
50	32.0	4.67	1.57	0.68	0.91	1.82
50	43.6	7.00	2.27	0.68	0.80	1.60
50	74.9	18.80	4.02	0.67	1.10	2.18
50	84.5	25.50	3.75	0.80	0.93	2.00

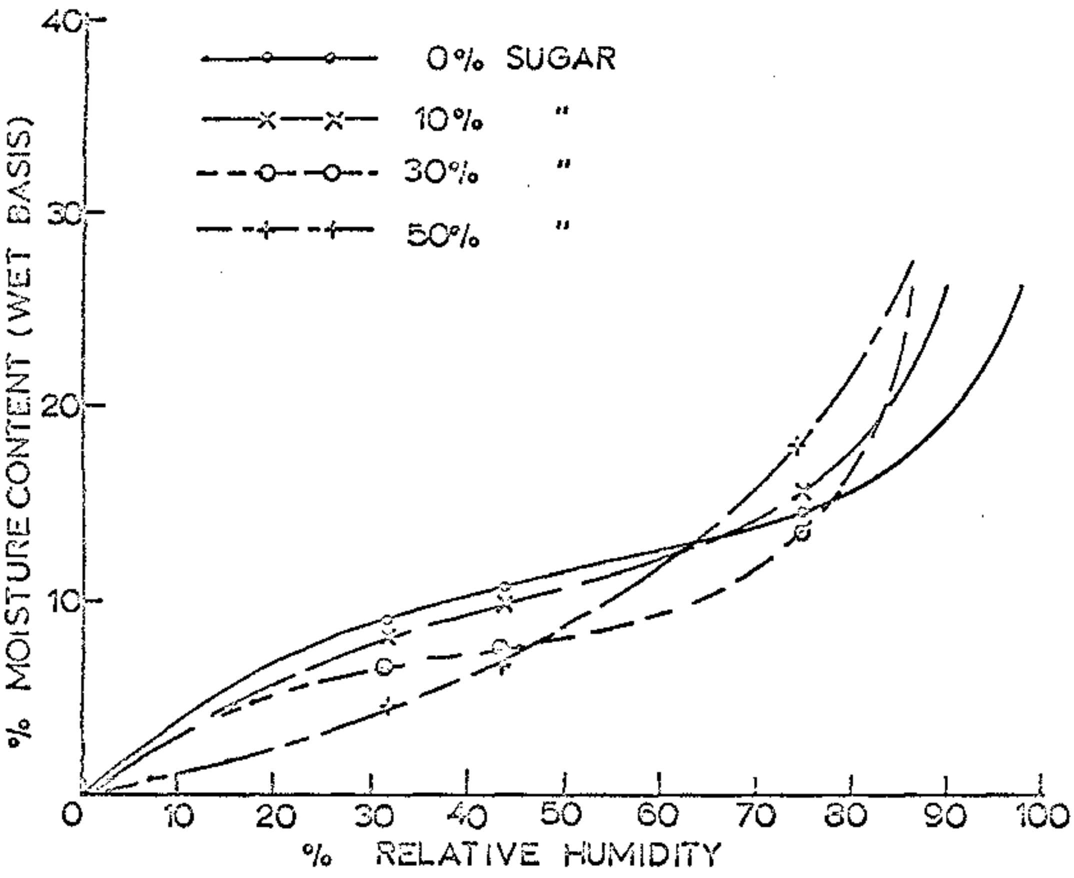


FIG. 3 The effect of sugar on adsorption isotherm of sodium caseinate gel.

This reasoning is well proved by our experiment on caseinate gel at different levels of sugar. Ten percent sodium caseinate gels plus 10%, 30% and 50% sugar (based on sodium caseinate dry weight) were equilibrated in humidity jars at different % relative humidity levels then puffed under similar conditions. The results are tabulated and plotted in Table 1 and Figure 3 respectively.

It is clearly shown in this data that sugar added to a pure sodium caseinate gel system acts similarly toward moisture to that in natural foodstuffs of heterogueous nature. The gel absorbs increasingly less moisture with increasing sugar content in low % R.H. regions, but the moisture - adsorption surpasses that of the pure gel at higher % R.H., e.g. from 64% upward in case of the gel of 50% sugar content. This can be hypothetically explained that:

(a) Firstly, it must be realised that pure sodium caseinate gel and pure sucrose (in amorphous state) behave differently in a particular humid atmosphere and thus they give different shapes of adsorption isotherm curves. (Fig. 5). That is, the gel gives a typical S - shape curve while sugar, on the other hand, does not absorb moisture to an appreciable level until the R.H. is well over 20% (50) and thus it gives a curve completely convex toward y - axis.

(b) Sugar, in the gel, acts as a diluent for sodium caseinate, hence, in the lower part of the curve, the sugar, while itself does not take up any moisture, will reduce the amount of water taken into the whole gel, e.g. a gel with 10% sugar will absorb approximately 10% water less than a pure gel (Table 1).

In higher part of the curves where sugar in the added gel absorbs more water than pure gel under the same atmosphere, the mechanism of the absorption is mainly through tertiary bondings and cappillary action and the moisture will be freely distributed between sodium caseinate molecules and sugar molecules. The sugar under these circumstances could be said to be more hygroscopic than the sodium caseinate, or that the tertiary bonds and the cappillary force exerted by the sugar may be stronger than that of sodium caseinate. Hence the gel with added sugar will absorb more water than pure gel but less than sucrose (and in proportion to amount of sugar added) (Fig. 5).

(c) The sugar not only acts as a diluent, but it also binds closely with sodium caseinate molecules, probably by primary and secondary bonding e.g. hydrogen bonds, polar groups of the side chain of protein e.g. carbonyl-, amino-, hydroxyl and sulphydryl groups (36). These bonding sites on the protein are believed to extend to water molecules to form monomolecular layer. Instead, they are either partly or completely blocked by sugar molecules, depending on the amount of sugar added. This phenomenon then explains the reduction of a monolayer on the curve of the gel in proportion to the increase of the added sugar. For a gel with 50% sugar, these sites are completely blocked thus there is no monolayer formed (Fig. 5).

In fact, we can regard sugar and sodium caseinate portion of the gel as two separate foods packed in the same container where the moisture can travel freely between them until they attain equilibrium state. If we do so then we can predict the final or equilibrium humidity in the package by using the following equation:- (68)

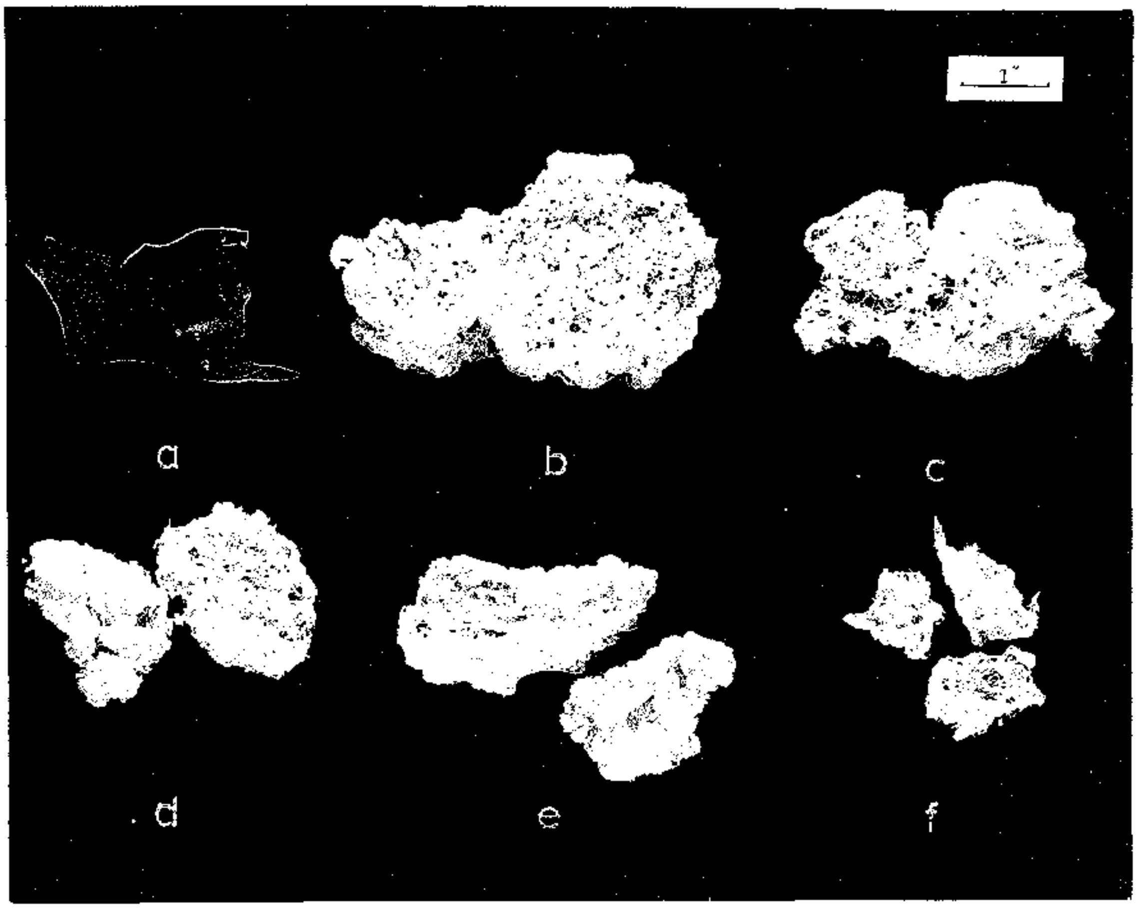


FIG. 4. Effect of solutes on the puffing characteristics of caseinate gels:

a. Unpuffed pure caseinate gel

b. Puffed " " "

c. " gel with 10% sucrose

d. " " " 20% "

e. " " " 30% "

f. " " " 50% "

TABLE 2. Equilibrium Moisture Content for Amorphous Sucrose at 25°C

% Relative Humidity[a]	Moisture Content, % by weight	
	Dry Basis[b]	Wet Basis
4.6	0.9	0.89
8.6	1.6	1.57
11.8	2.2	2.15
16.2	2.8	2.73
24.0	4.1	3.93
85.3[c]	47.7	32.30
87.8[d]	58.4	36.80
90.6[d]	73.1	42.25
93.3[d]	98.7	49.60
95.8[d]	146.5	59.50

a, b – Reproduced from Makower and Dye (50)

c – Saturated Sucrose Solution

d – Sucrose Solutions

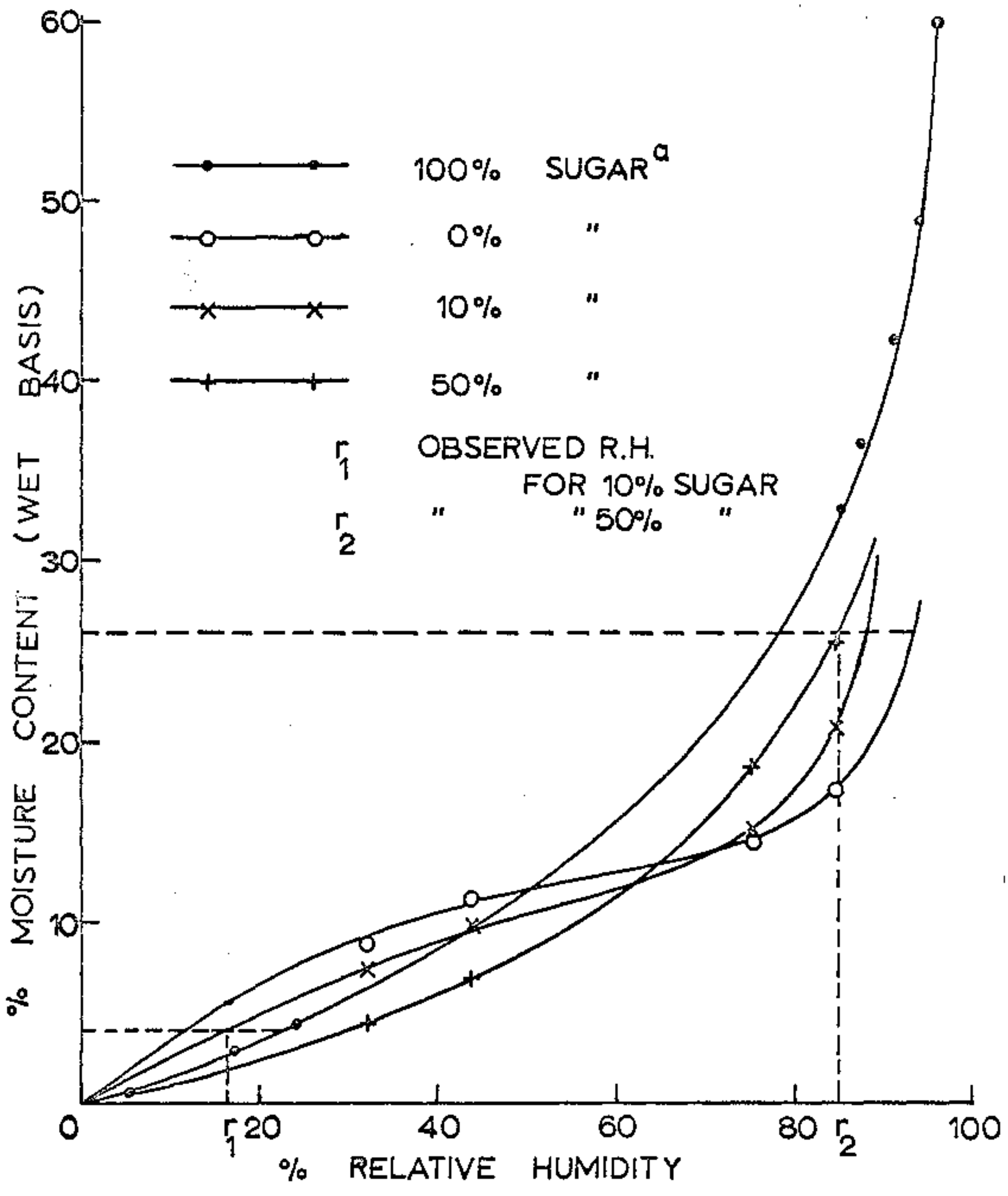


FIG.5 Solutes and moisture equilibria in sodium caseinate gel.

a: from Makower & Dye (1956).

$$R = \frac{R_A S_A W_A + R_B S_B W_B}{S_A W_A + S_B W_B}$$

Where R = the humidity at equilibrium

R_A, R_B = the initial humidity of the component A, B,

S_A, S_B = the slopes of the isotherms between the initial and final points.

W_A, W_B = dry weights of the component A and B.

This is true for the gel with 10% sugar in the lower portion of the curves and for the gel with 50% sugar in the upper part of the curves. The predicted and the observed figures are shown in Table 3.

The calculation may be undertaken by assuming pure amorphous sugar and pure sodium caseinate gels to contain the same levels of moisture (thus giving different R.H.'s). On mixing these together, and by assuming that we can keep them at their original moisture levels, one may predict the % R.H. that the final mixture will assume. The predicted results of the lower regions of R.H. correspond very well with the observed % R.H.'s given by the gel with 10%

sugar, and that of the upper regions with the gel with 50% sugar.

TABLE 3. Predicted and Observed % R.H. of the Gels with 10% Sucrose and with 50% Sucrose:

Gels	Dry Weight gm	% Moisture (wet basis)	% Relative Humidity	
			Predicted	Observed
with 10% Sucrose	96	4	16.6	17.5
	94	6	27.1	24.0
	92	8	36.0	34.0
	90	10	44.5	42.0
with 50% Sucrose	84	16	68.4	71.0
	78	22	81.1	81.0
	74	26	85.5	85.5
	70	30	89.4	89.0

We can say confidently up to this point that sugar, whether intrinsic or added, definitely affects the water-holding characteristics of food gels. In Fig. 4 the puffed volumes of the gels are decreasing with increasing amount of sugar added. The product characteristics also deteriorates with increasing sugar. The gels form localised large bubbles while being fried, then mostly collapse immediately after they are taken out of the hot fat. The size of bubbles formed increases with increasing sugar, hence they collapse

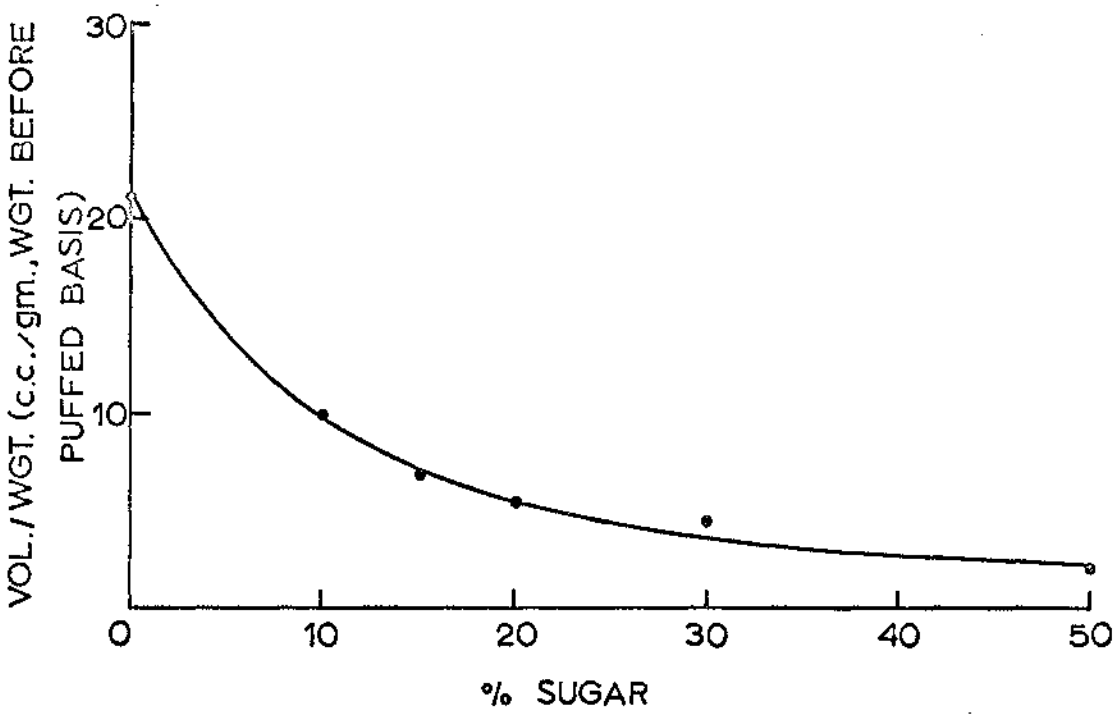


FIG.6 Effect of solutes on puffed volume.

(under 74.9% R.H.).

more readily. The puffed products become hard and glassy soon after being taken out of the hot fat, especially with the added sugar as high as 30 and 50%. Browing reaction also takes place more readily with higher sugar contents.

The plot of puffed volumes against the sugar contents shown in Fig. 6 are that of gels equilibrated under 74.9% R.H. From Fig. 4 and Fig. 6 it is clearly shown that the sugar as low as 10% can probably be tolerated. Anything higher than that will decrease puffed volume and aggravate the puffed product characteristics beyond practicality.

(ii) The Effect of Change in pH Consequent to Addition of Salts:

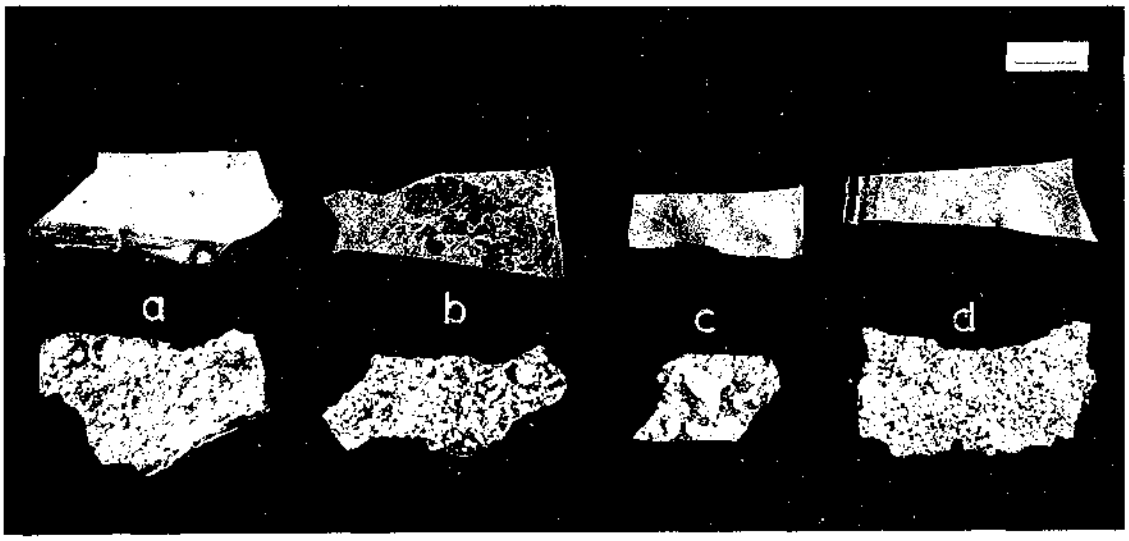
Salts added to food gels have profound effects on many of their characteristics. In some cases salts affect the system by altering its acidity or alkalinity, in other cases the system is directly affected by the salts themselves through the absorption of salt ions.

(a) On Starch Gels: Harris and Banasik (38) report that salt and other electrolytes markedly alter the viscosity of starch suspensions, some diminishing and others increasing viscosity (76). With addition of acid, starch gel tends to become syrupy due to acid hydrolysis or a "dextrinization" process, thus the viscosity is lowered and gel-forming tendency reduced (76). The alkalies, on the other hand, increase the viscosity (10).

The effect of salts on starch appears to follow the same rules as for gelatine and proteins, as regards swelling. The influence of the anion on swelling is marked, but different anions from different salts affect gels to different extents, and has been proved to follow a Hofmeister lyotropic series, being arranged in order Cl<Br<I<CNS<salicylate<OH. Different cations also have different effect on the swelling, e.g. the starch treated with sodium salt swells much more than that treated with calcium salt (65). In general, the swelling increases with increase in concentration of the salt used.

(b) On Pectin Gels: In pectin gels, hydrogen - ion concentration is very important in gel formation. The inconclusive work done in our laboratory on the effect of acidity on pectin gel as related to its water-holding capacity and puffability, suggests that the pectin gel, formed without sugar, swells less or possesses lower water-holding capacity between pH 4.0 and 6.5. The partly dried gel tends to have best water-holding capacity at pH above 7.0 and below 3.5. This seems to agree well with the work of other workers who advocate that the minimum pH for pectin gel formation is 3.46 (49). However, several other workers have reported inconsistent results on the behaviour of the pectin gel as related to its pH. Hinton (39) reported widely on the subject of the modification of jelly strength by the adjustments of pH induced through the addition of acids or alkalis. This effect, he stated, was due to the alteration of the balance between the pectin in the free acid condition, and that in salt - combination caused by the adjustments. He also reported that by using orange pectin solution whose pH was adjusted by the addition of HCl or NaOH, the jelly strength of the solution rose to optinium at pH about 2.0, then sharply dropped to minimum as pH rose to about 3.0. Pippen et al (63), on the other hand, reported that by using pectins and pectate commercially prepared from citrus peel or apple pomace, the relative viscosity of the solution was found to be only slightly dependent on pH, if the pectin was fully esterified, and became markedly pH dependent as the number of carboxyl groups increased. They found that the viscosity increased sharply with increase in pH in the range of pH 2.5 - 4.5 and levelled off below and above that range. This, they stated, might be attributable primarily to repulsion effects along the chain, with some elongation of the polymeric molecule.

It is evident that the research results reported in the literature on the effect of pH on gel conditions in pectin dispersions is confusing and indicates certain discrepancies undoubtedly related to the particular character of the pectinic substances used in particular experiments. Results for the present work therefore, cannot be claimed to contribute to a greater understanding of this subject but rather to illustrate specific results for a commercial pectin product and viewed from the view-point of potential puffing behaviour.



(a) pH 3.6 (b) pH 6.9 (c) pH 11.2 (d) pH 11.85

(upper row : unpuffed ; lower row : puffed)

FIG. 7 Effect of pH on the puffing characteristics of pectin gels:

The highest water-holding capacity does not mean, however, the best puffability in case of pectin gels. As it was found in our experiment that, in fact, the highest puffed volume of the pectin gels was obtained when the pH of the gel was adjusted with acetic acid to 3.6. The moisture content of the gel at this pH after equilibrated under the same atmosphere, was nearly at its minimum, i.e. about 16.1%. Whereas the gel of pH 7.0 which held moisture content at about 20% gave only medium puffed volume.

Fig. 7 shows the pectin gels, before puffing (upper row) and after puffing (lower row), of wide range of pH ranging from (a) pH 3.6, (b) pH 6.9, (c) pH 11.2, and (d) pH 11.85. Note that in all cases the texture of the puffed gels consisted of non-uniform - localised bubbles from biggest size at pH 3.6 (a) to smallest size at pH 11.85 (d). In fact, the gels do not expand sidewise to any noticeable extent. They only puff up into a single thin layer of bubbles. The puffed products tend to be rather hard and glassy.

The addition of some salts such as calcium chloride favours jelly formation. However, this is true only for certain salt concentrations, and over certain pH range. No jelly formed, for example, with added salts above pH 3.6 (49).

(c) <u>On Protein Gels</u>: The effect of salts and pH on protein gel system, though follows the pattern of that on starch gel, but is much more complicated, as protein systems from different sources possess different chemical and physical properties e.g. composition and iso-electric point. However, it is suggested that all properties such as swelling of gels, osmotic pressure, viscosity, are affected by electrolytes in a very similar way to that outlined for other gel types. Loeb (47), by working on this basis, reports that the osmatic pressure is a minimum at the isolectric point and reaches a maximum at a higher acidity, and when alkali is added to protein at the isoelectric point, a maximum osmatic pressure is again observed. According to Loeb, the influence of acids and salts on osmotic pressure is practically identical to those of the same electrolytes on swelling and viscosity (10).

Lowe (49) reports that, with acids, the swelling of colloidal gels increases until a maximum is reached at pH 3.0 to 2.5, when imbibition is decreased with greater acidity; and with alkalies the maximum swelling is about pH 10.5, though some systems like gluten gels may disintegrate at this alkalinity.

This effect of pH and salts on swelling and viscosity of gels is, of course, directly related to water-holding capacity of the gels, before and after drying, and hence the puffability of the gels. Work on heteregeneous protein gel systems, e.g., on cheese, meat and fish agree well with this phenomenon.

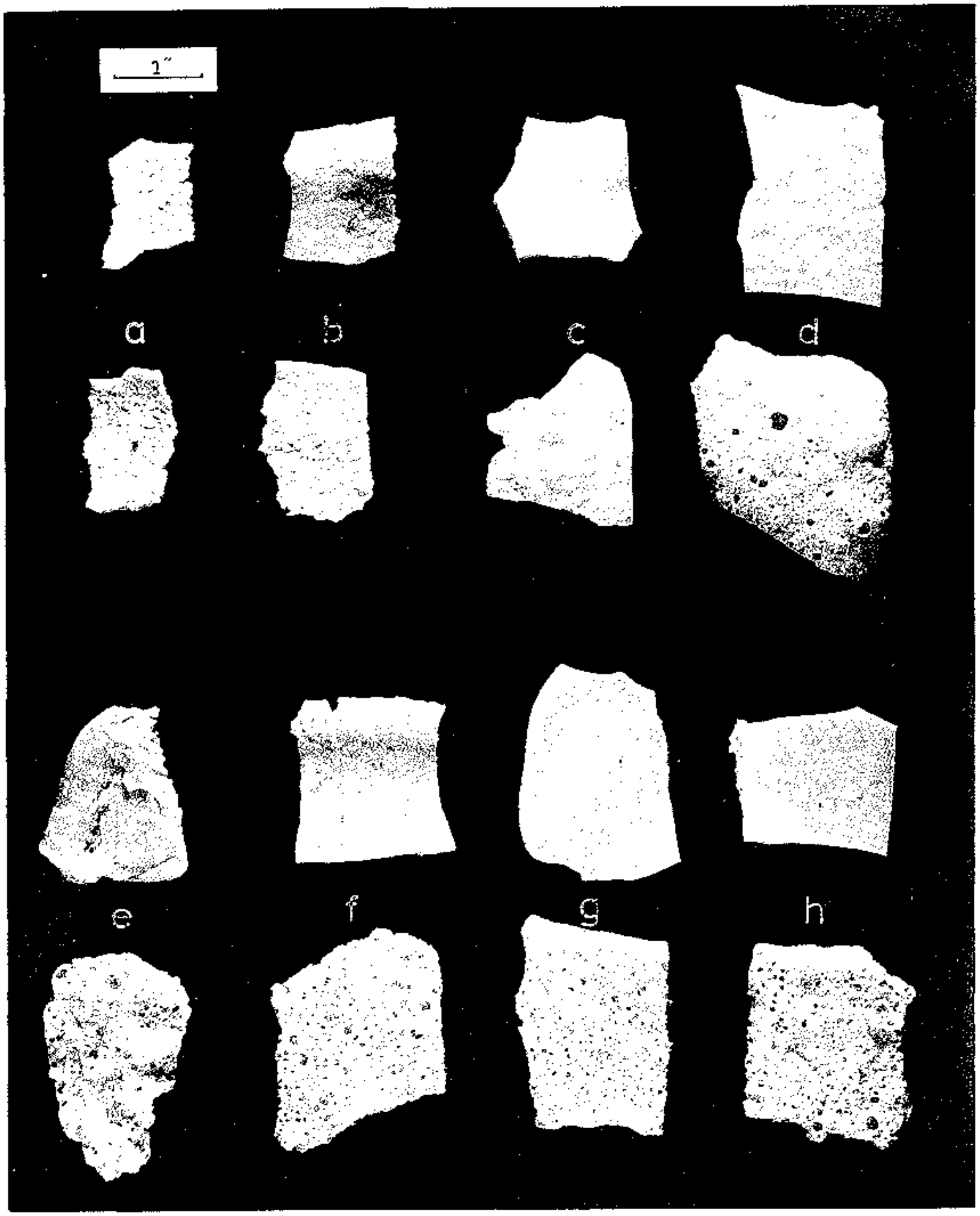


FIG. 8 Effect of pH on the puffing characteristics of cheese slices:

(upper row : unpuffed ; lower row : puffed)

Fox et al (26) report, from their work on gelation of milk solids by orthophosphate, that the rate of a gelation process is dependent on the concentration of phosphate, calcium, and caseinate complex; and also on pH, temperature, agitation, and the identity of the phosphate counterion. They show that maximum gelation rates can be obtained at neutrality, and the rates fall off more rapidly as the pH of the systems move toward lower values.

The work in our laboratory on the effect of pH on cheese texture and its puffability agrees with the above mentioned results. The texture of the cheese becomes increasingly crumbly, discontinuous as pH decreases below 5.0, becomes increasingly plastic, gelatinous and sticky as pH increases to 7.0, then deteriorates to a broken texture again at high pH but at a much slower pace. (See Fig. 8 upper row). These effects relate to the water-holding capacity of the dried cheese slices, as can be seen from Fig. 9A. The water-holding capacity is at its minimum at about pH 6.0 and increases on either side of this value to approximately the same level. Thus the effect of pH on water-holding capacity of cheese proteins is quite similar to that of proteins from other sources such as meat (which is discussed below) as exemplified by the work of Hamm (36). The shape of this curve is also quite similar to that of the effect of pH on gelation rate of milk solids (which is believed to have direct bearing on water-holding capacity of the subsequent curd) as shown by Fox et al (26).

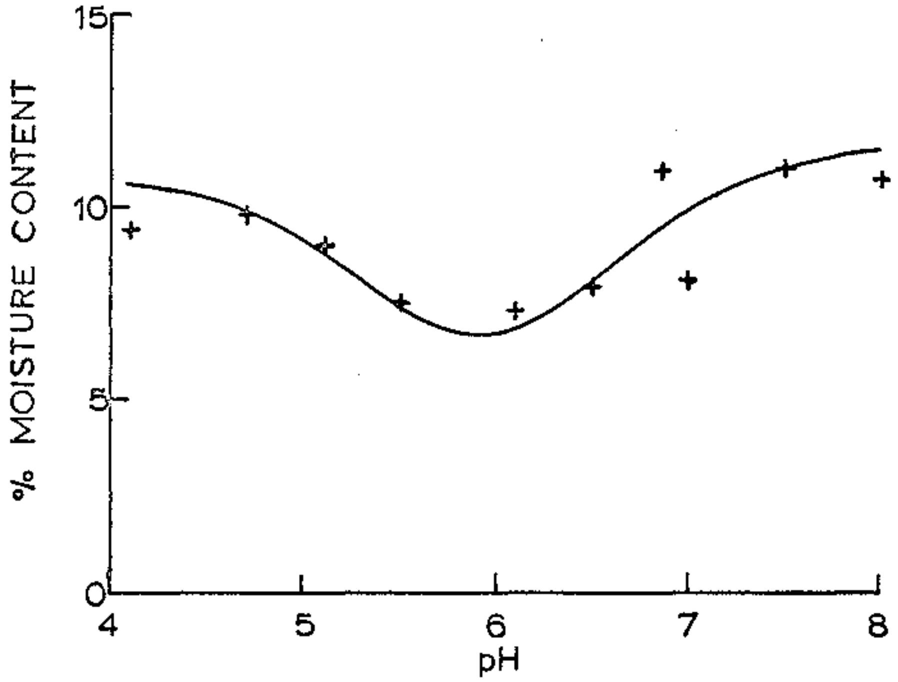


FIG. 9A Effect of pH on moisture retention of cheese. (under 43.6% R.H.).

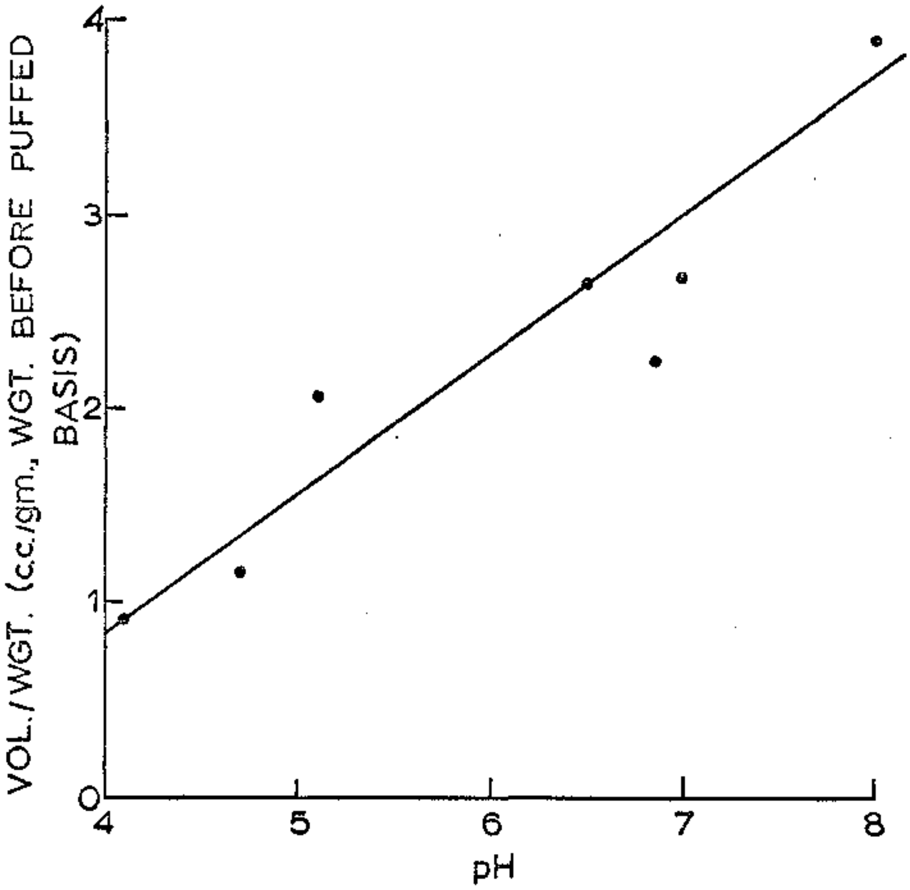


FIG. 9B Effect of pH on puffed volume of cheese. (under 43.6% R.H.).

The characteristics of the puffed cheese improve with increasing pH (see Fig. 8 bottom row). The uniformity of the expanded texture improves concurrently with puffed volume and this volume increases with increasing pH (see Fig. 9B). However, the puffed product tends to be soft and sticky as the pH rises higher than 6.5. As the pH increases the cheese becomes very soft and plastic, while still in the hot fat, but it also expands and becomes porous. The most desirable pH range, therefore, for a cheese puffed product is in the range of pH 5.0 to pH 6.0.

This pattern of the pH - moisture curve also occurs in the study of the effect of pH on other types of protein - gel systems e.g. that of fish and meat.

The effect of salts and/or pH on meat-gel in relation to its water-holding capacity is well documented. Protein content of meat varies from around 15% in pork to 20% in beef, veal and lamb. The sarcoplasm of the muscle cell is primarily protein, consisting of a group of proteins, collectively called "albuminoids" (86). These intracellular proteins are in gel state (49), and are soluble in certain concentrations of salt solutions such as NaCl, KCl, Na_2SO_4, $MgSO_4$ and Na_2HPO_4. The other main type of muscle proteins is the structural or extracellular proteins, which consist principally of collagen and elastin. They are insoluble in salt solutions (49).

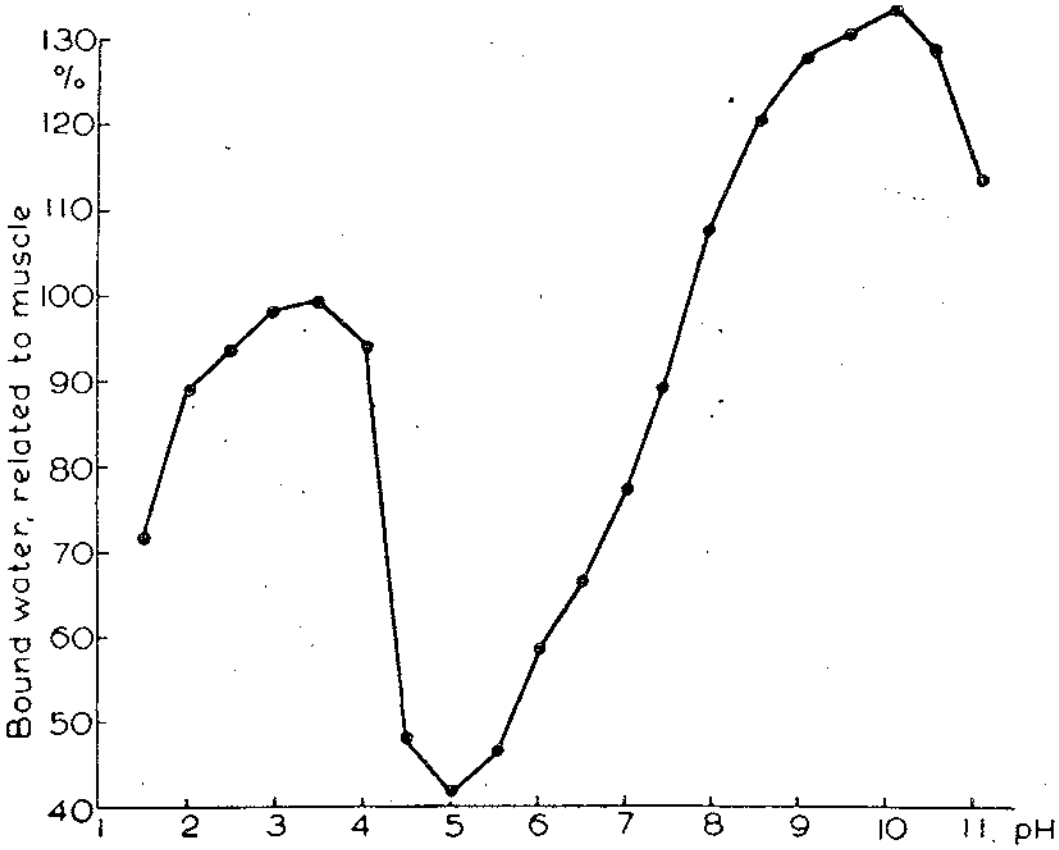


FIG.10 Influence of pH on the hydration of beef muscle homogenate (Hamm,1960).

Meat in its original condition will not puff. This is mainly because the muscle is not in continuous gel state as in starch gel or sodium caseinate gel. The non-continuous gel portion of the muscle is separated by the continuous phase of the muscle fibres. These fibres must be destroyed to allow the gel portion to form a continuous phase before the meat will show any signs of puffing.

However, this treatment is not by itself sufficient to allow meat to puff to any appreciable extent. It is found that to obtain a satisfactory puffed volume, the meat paste must be chemically modified so that the dried meat paste or meat "gel" will possess higher water-holding capacity.

Deatherage (17) reports that water-holding capacity of the meat is the minimum at the isoelectric point. The change of pH away from this point will increase the water-holding capacity.

Hamm (36) also reports that the minimum hydration of the meat is obtained around pH 5.0 which corresponds approximately to the isoelectric point of actomyosin, and the normal pH of the meat.

Grau et al (34) showed that the pH - swelling curve is quite similar to the pH - water-holding capacity curve (see Fig. 10). It is also known that protein gels have a minimum of swelling at their isoelectric point.

This effect of acid or base on swelling of muscle is due to a cleavage of the electrostatic cross linkages between the peptide chains of the protein, therefore more water can penetrate through.

Citrate and polyphosphates are used in practice to increase the water-holding capacity of frankfurter-type sausages and to reduce the release of water during canning of ham. Sodium chloride is found to increase the water-holding capacity and the swelling of the meat, by shifting the isoelectric point of the muscle to lower pH values by a binding of chloride ions. However, Hamm and Grau (36), after studying the influence of several sodium salts of weak acids on the water-holding capacity of muscle homogenate in the absence of NaCl, concluded that it is not the effect of pH alone that causes these changes for differences may be observed in the effects of several salts at the same pH value. They suggested that salts with polyvalent anions are the most effective. Such salts as polyphosphates, oxalate and citrate increase muscle hydration very strongly. They also suggested a series of salts of weak acids that increase hydration and rated sodium polyphosphate and sodium-triphosphate as some of the best (36) (37).

At low temperature in the range of 0 - 20°C, meat hydration is increased considerably by the simultaneous addition of NaCl and polyphosphates and a nearly optimum effect is obtained after storage of 16 hours at 0°C (77), (36), (70).

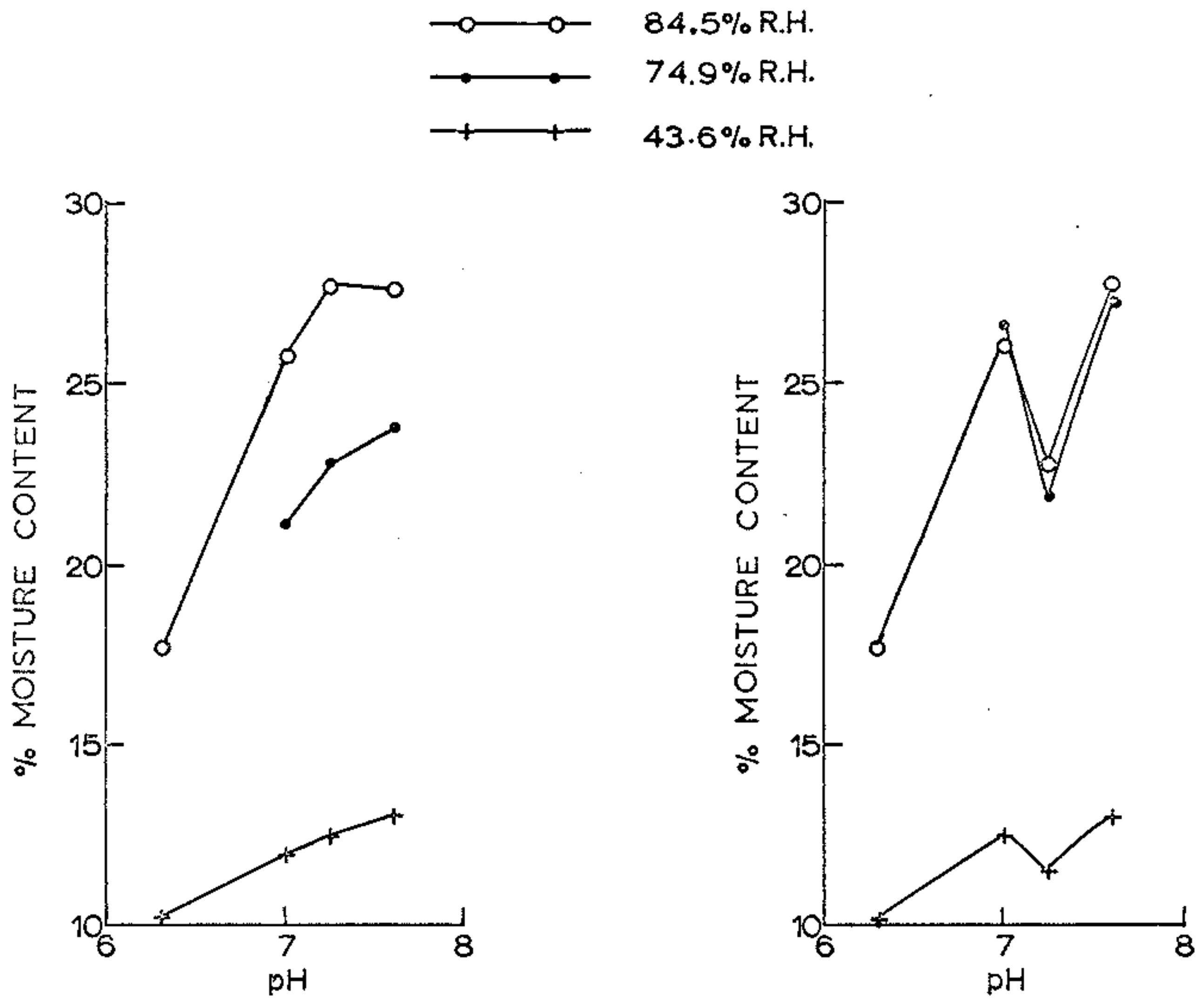


FIG.11A Effect of tri-sodium phosphate on moisture retention of fish product.

FIG.11B Effect of "Accoline" on moisture retention of fish product.

The work on meat and fish in our laboratory agrees very well with the above mentioned work on the account of the effect of polyphosphate salts and NaCl. Our present work has been concerned only with the effect of the salts on the high pH side of the curves. However, the effect of tri-sodium phosphate and "Accoline" (mixed polyphosphates) on meat follows the trend of the curve in Fig. 10 quite well. The difference of the curves of tri-sodium phosphate and Accoline for fish may account for the fact that the chemical and physical properties of fish muscle such as isoelectric points, protein composition, etc. are different from those of meat, and that different salts have different effects on water-holding capacity of fish muscle. (See Fig. 11A & 11B).

(iii) Pre-treatment of Raw Materials:

A rather brief but significant experience on the treatment of raw materials such as fish or meat prior to subsequent processes leads us to conclude that the treatments such as freezing and pulverising have a profound effect on water-holding capacity of the food gels.

(a) Freezing: It is well known that freezing of gels causes ice separation, the residual gel being relatively dehydrated and the micro-structure dependent on the rate of freezing. On thawing, the reabsorption of water may be difficult. (10).

Slow rate of freezing causes external formation of big ice crystals and water may be completely reabsorbed on thawing, while fast rate of freezing causes internal formation of small ice crystals. Conceivably "bound water" will not freeze even at very low temperatures.

In general, the more rapid the freezing of a pure continuous gel, the greater is the damage it suffers and the less its subsequent affinity for water. Rapid freezing, apparently removes part of the bound water, hence the system increases in volume (10).

For protein tissue gel systems e.g. in meat and fish, it is shown that there are certain critical temperatures where damage is more extensive, ranging about -15^{o} to $0^{o}C$. Damage in a protein tissue gel is also caused through ice crystal formation which ruptures the physical structures (e.g. cell membranes), and denatures the protein due to surface phenomena at the ice-solution interfaces. The ice formation also causes the removal of the bound water essential for normal structure (24).

Freezing of meat or fish is usually accompanied by toughness due to a loss of the true water-holding capacity of the muscle (12). The thawed meat becomes tougher and considerable amounts of liquid may be lost through drip or leakage. It is found that for smaller cuts of meat, such as individual steaks, the slow-frozen products will lose more fluid on being defrosted since the relatively large cut surface enables fluid to be lost before the muscle fibres can absorb the thawed liquid, which may be largely extra-cellular.

Drip has been observed to be related to the acidity, or pH, of the tissue, and is absent from slowly frozen tissue at pH 6.4 (33). Cole (11) confirms this, in his work on rehydratability of freeze-dried beef, that freeze-dried meat exhibits greater water binding capacities than fresh at pH greater than 6.5, but less at pH less than 6.5.

Tressler, et al (79) reports that if haddock fillets are treated before freezing with an alkaline solution containing buffer substances to increase the pH of the fish to nearly 7.0 and then frozen and stored little drip or leakage will occur when they are thawed. Taylor (78) recommended solutions of tri-sodium citrate, or tri-sodium phosphate and sodium carbonate, or sodium hydroxide, containing some sodium chloride to be used.

We have found from the experiments on fish and meat that frozen fish or meat subjected to similar subsequent processes will not puff, but if they are mascerated with addition of salts such as tri-sodium phosphate prior to freezing the subsequent product will puff though to a lesser extent than those derived from fresh raw materials.

(b) Pulverisation: Hamm (36) stated that loosening of protein structure by increasing the electrostatic repulsion of the peptide chains, by proteolytic processes or by rapid freezing, increases the water-holding capacity of meat. For this reason, he also showed that loosening muscle structure by grinding also increases meat hydration. The more intensive the grinding, the higher is the water-holding capacity of the ground tissue. Increase in time and speed of grinding also increases meat hydration.

Hamm also showed that water-holding capacity of meat also influences the results of various degrees of grinding. The higher the water-holding capacity of meat, and consequently the swelling of tissue, the more intensive is the effect of grinding with meat of hydration increased by presalting or adding NaCl, polyphosphate, citrate or ATP.

"Dry-cutting", i.e. grinding the salted meat without added water is more effective in disintegration of the muscle, and, consequently, the greater the ability of the muscle to bind added water.

Hamm also discussed the effect of the rise of temperature during grinding which he stated to have deteriorative effect on water-holding capacity of the ground meat.

The importance of pulverisation in puffability of meat or fish is clearly shown in our work. Meat or fish will not puff unless they are ground, with added salt, to a considerable extent, and the puffability, as expressed in puffed volume, increases with increasing extent of pulverisation.

As it has been mentioned, the combined effect of salting and pulverisation can overcome the detrimental effect of freezing of raw materials provided that salting and pulverisation are enforced prior to freezing.

Hamm also discussed the effect of added water and fat on water-holding capacity of the meat. He stated that addition of water is beneficial only to one day post-mortem meat, otherwise it will give detrimental effect if applied on more than one day old meat.

Fat increases water retention of meat paste up to certain limits of fat-protein ratio (2.8:1), and will decrease the water retention at higher contents of fat.

Though, these two factors have not been extensively investigated in our experiments, but they are expected to play very important roles in water-holding capacity of the meat or fish products.

From the fairly extensive studies in this present work of puffability in relation to the water-holding capacity of various systems it is evident that the phenomenon of puffing may be a valuable index to water-holding capacity in a given product and/or may be used to follow changes in water-holding capacity. For example in a given food known to be of gel form, the puffing volume achieved by heat shock methods, will denote the degree of water-holding capacity in the food. This could be developed as a test technique therefore and might be used to follow the effects of pH and added substances etc. on the water-holding capacity of a given food.

Factors Affecting Thermoplasticity:

Perreau (60) reported that thermoplasticity of a gel is another major factor determining the puffing characteristics of the dried gel.

Perreau determined the thermoplasticity of a gel by determining a temperature at which the gel of known moisture content on his "plastometer" collapses within 5 seconds after submerging it in hot fat at that temperature. He called this point a "critical softening point" (C.S.P.). This point of a certain gel, of course, varies with moisture content of the gel, and increases with increasing either of moisture content or temperature. When these points of a gel are plotted against its moisture contents, the steepness of the curve will indicate whether the gel will puff well or not. The flatter the curve the better the gel will puff, that is, the bigger the puffed volume to be obtained.

Puffing has been shown to occur only when the gel is sufficiently plastic and the internal pressure is significantly high and greater than the "resistance to puffing" of the gel. Hence, any factors affecting the thermoplasticity of the gel will profoundly affect its puffability.

Three factors have been shown in this present work to affect the thermoplasticity of a gel. They are:-

(i) Sugar

(ii) fat, and

(iii) fibrous texture of a raw material.

(i) Sugar:

As it has been stipulated previously under the effect of sugar on water-holding capacity of the gel, sugar is known to increase its plasticity or softening with temperature. A sugar-added gel becomes very tough and "rubbery" on drying, and its puffability is greatly inhibited with increasing amounts of sugar.

Perreau postulated that the C.S.P. curves of the sugar-added gels against their moisture content would rise steeply as moisture content decreases, thus allowing only minor expansion during puffing. Our experiment on sugar-added sodium caseinate gels confirms this postulate. As one can see on Fig. 6, the curve of puffed volumes versus sugar contents drops steeply to about 15% sugar content where it flattens off. The puffed products containing 10% sugar or more become increasingly tough, elastic, unattractive, lower in volumes, and brownish. Their higher elasticity results in a higher resistance to puffing or expanding of the gel structure. The wall of a bubble formed becomes tough and elastic and quite impermeable to diffusion of moisture vapour. Hence the increasing vapour pressure accumulated inside the bubble will push its wall further out, thus increasingly big, localised bubble is formed. The walls of some exceedingly big bubbles may be shattered, allowing the moisture vapour to escape while the broken walls, still soft and plastic, collapse back to the base. Some bubbles however will not break, even after long duration in hot fat and the product colour becomes exceedingly brown, presumably due to the toughness of the pore walls which can still hold the high pressures inside. Moisture vapour inside those bubbles may diffuse gradually through the wall, but some may still remain. Thus when the product is taken out of the fat, and its temperature falls, the vapour pressure decreases and the bubble wall which is still relatively soft, then collapses back, resulting in only small increase in volume. As in the case of cooled amorphous sugar, the product after being left cooled to room temperature will become very hard and glassy if the sugar content is high enough. The moisture content of this puffed product, normally, is still as high as 4 - 5% as it cannot readily escape through the "semi-impermeable bubble walls during puffing.

The overall effect of added sugar in the gel on puffing appears to be:

Increased elasticity associated with slower diffusion of moisture and reduced total evaporation resulting in:-

(1) Longer time for heat shock to achieve puffing.

(2) The product assumes a higher temperature

through the longer time required and through reduced evaporation and self-cooling. This will result in caramelization browning.

(3) The product tends to retain more moisture vapour in its structure at the completion of a puffing cycle, giving shrinkage on cooling and higher final moisture levels in the product.

(ii) Fat: Apart from having an adverse effect on water-holding capacity of food-gels, fat also affects their texture, hence thermoplasticity.

In the case of cakes and various bakery products fat is known to greatly influence texture. It is, for example, streaked through the main structure of a cake which is made up of gluten and starch, and serves as a lubricant so that when the cake is bitten, particles of gluten and starch slide on one another and the bubble walls crumble.

In pastry, a stiff dough is rolled out. The fat is flattened into sheets between the layers of flour and water and causes their separation. This produces flakiness. The fat is also squeezed in between gluten particules or strands so that a continuous tough matrix is not formed but rather one which is very brittle and short (57).

The characteristic textural qualities of some products such as chocolates are largely dependent on a plasticity of their fat component. Cocoa - butter with a narrow plastic range is responsible for a brittleness, and an agreeable plastic texture felt in the mouth (55). However, the operational puffing temperature is much higher than this range, so this property of the fat cannot be accounted for in the puffed products.

In pie crusts, high proportion of fat is used as a shortening agent to prevent the formation of a continuous gluten network through the dough mass, and result in baked products that are friable or flaky (55), (56).

The flakiness of these products is found to depend upon the flour being in layers with greater and lesser concentrations of fat in these layers. Water, presumably, is imbibed more readily by the portion of the flour not coated so thoroughly with the fat. The proportion of fat as well as its consistency affect the flakiness. This shortening power of fats and oils is attributed to their viscosity, surface tension of the oil, the melting point of the fat, and orientation of the molecule through the double bond of the fatty acid chains of the glycerides (49).

Certain free fatty acids present in milk, aged at reduced temperature, are found to inhibit or completely stop coagulation of the milk by rennin due to free fatty acids binding some of the calcium ions as insoluble salts (22).

Homoginisation hastens rennin coagulation of milk and cream but reduces the firmness of the curd (22).

Fat globules are finely dispersed in homoginised milk. When this milk is used in cheese manufacturing the curd obtained is soft, probably due to an increased absorption of casein on the greater area of the newly formed fat surfaces. The curd is fragile and easily shattered. The cheese develops cracks. This decrease in toughness of the curd is found to be due to the greatly increased dispersion of the fat which introduces points of weakness in the structure of the coagulum, and because of the increased amount of casein bound to the fat surface and in no condition to participate normally in the build-up of the casein fibres of the coagulum (22), (19).

Perreau (60) showed that starch gel with 10% fat puffed to a considerably less volume than pure starch gel.

In reviewing the texture effects due to the incorporation of fat in various food products it emerges that the level and degree of dispersion of fat as an ingredient simply introduces a discontinuity into the basic structure and in this way one can manipulate the texture characteristics of foods to give a wide range of properties.

With gels and puffing, as presently considered, discontinuity introduced into the gel will adversely affect puffability. The introduction of fat, for example, may be compared with the presence of fibre or tissue which in all cases reducing efficiency of puffing. For maximum puffing efficiency a uniform and continuous gel is desirable. Fat, of course, does present additional problems such as "oiling off" during drying etc.

All these facts are well substantiated by our work on cheese and meat. Ordinary types of cheese such as cheddar cheese with high percentage of fat will not puff unless:-

(1) the fat is rendered out of the gel texture before the cheese being spread and dried, or

(2) considerable quantity of a gelling agent such as sodium caseinate must be added into the cheese in the process.

Cheese with low fat content such as skim milk cheese and Mozzarella are found to puff very well with little modification.

Meat, before processing, must be trimmed so that there is as little fat left in the flesh as possible, or the dried meat paste will be oily and will not puff satisfactorily.

(iii) Fibrous Texture of Raw Materials:

Fibrous structures are the most important contributors to the texture of many foods. In fruits and vegetables fibres form one of the most important texture - influencing constituents. Their structures range from small, easily separated cells having thin walls and pectinous middle lamellae in immature examples to well-consolidated groups of thick walled cells forming long coarse and woody strings in the most mature specimen. The extent of lignification of cellulose fibres, the content of cellulose, stages of development or maturity, environment and variety all play some important parts in toughness or tenderness of fruits and vegetables (55).

In meat, muscles are composed of a large number of fibres gathered together in bundles lying approximately parallel to one another in a matrix of connective tissue. Fundamentally, the fibres are composed of elastic proteins and possess many gel-like characteristics. The content of connective tissue in the meat which varies considerably from about 0.5% to 30% or more plays a very important part in meat tenderness. Age, breed, sex, feeding practice, size, conditions before and after slaughtering and type of animal all play parts in tenderness of animal meat (55), (86), (75), (36).

The muscle fibres of fish are also striated, similar to skeletal muscle fibres of higher animals, and are generally supposed to have analogous ultimate structure. Hence most or all of the factors affecting meat tenderness are likely also to affect fish. The differences, of course, lie in the fact that fish has much less proportion and much tenderer connective tissue.

These structural fibres have to be destroyed somewhat completely before the food gels can be puffed satisfactorily as they will, otherwise, interfere or inhibit the expansion of the structure during puffing by resisting the vapour pressure built up inside the gels. In other words, these fibres, if remain intact, will increase the resistance of the gel thus give higher resistance to puffing resulting in no or very little puffing.

In practice, foods like bananas, fish or meat must be pulverised to completely destroy the structural fibres prior to subsequent processes. Fish, in particular, must be boneless and free of the skin or scales.

S E C T I O N   II

TECHNOLOGICAL STUDY ON PUFFING OF FOOD GELS

A. Non-Protein Foods:

Attempts have been made to puff foods of non-protein or low protein type such as fruit and vegetables in the hope that pectic substances and starch, which are abundantly present in many of them, will contribute to lesser or greater extent, to the puffability of these foods. Carrot was chosen to represent a vegetable group and banana, a fruit group.

I) Carrots: After unsuccessful trials, despite its starchy nature, to puff potato, carrot, as a fleshy vegetable low in starch was chosen for the experiment.

(a) Introduction:

Carrot tissue is known to be high in pectic substances distributed within the cellulose walls and in the middle lamellae predominantly in a form of calcium pectate (66), and these appear to be of much higher proportion in the stele or central cylinder than in the cortex (85).

Starch granules constitute about 0.1% by weight in young carrots (53) and gradually disappear at later stages of growth (85). Sugar (as invert sugar) forms about 4.4% of the wet weight in young carrots and 4.2% in old carrots (53) (85), and fibre about 1.6% (85).

One can gather from this information, then, that pectic substances probably play more important parts in forming gel texture in the carrot than starch, thus its puffing characteristics will be more towards that of pectin gels.

Ferreau (60) concluded from his work on carrots that carrot slices can be puffed satisfactorily after being subjected to boiling and leaching before drying, and that the gel matrix responsible for puffing is the pectin in cell walls with possibly some assistance from intracellular starch. The leaching is to reduce the level of soluble sugar in the carrots to puffable levels (60).

(b) Experimental:

Fresh carrot of various sizes and ages, sliced to approximately 1/16 inch thick were subjected to:-

1. drying to the moisture level of about 10%, and

2. blanching and leaching prior to drying to similar level of moisture content.

The dried slices from both treatments were subsequently puffed in a hot fat. The moisture contents of the slices before and after puffing and their puffed volumes were recorded.

Procedure:

Carrots were sliced crosswise on a domestic vegetable slicer to a thickness of 1/16 inch. The average total soluble solids of the raw slices as measured by a refractometer was 8.7%.

Half of the slices were spread singly on metal trays and dried in a hot air chamber at approximately 120°F for 36 hours. The slices were turned over once or twice during the course of drying to obtain uniform drying.

The second half of the slices were blanched in boiling water for 5 minutes prior to washing under running tap water for 4 hours. The average total soluble solids of the washed (leached) slices were determined by the refractometer to be 1.5%. The treated slices were then dried in similar manners as for the first batch.

The moisture contents of the dried slices were determined. The slices from both treatments were then puffed in a hot fat at 370°F for approximately 10 seconds. The displacement volumes and moisture contents of the puffed slices were determined. Procedures for puffing the product, determination of moisture contents, and volumes of puffing are detailed in the Appendix.

<u>Result:</u>

Most of the soluble solids in carrots are leached out by blanching and washing the slices. The total soluble solids decrease from 8.7% to 1.5% resulting in significant difference in characteristics of the dried raw slices and dried blanched and leached slices, i.e. the latter are much thinner and smaller as can be seen in Fig. 12 (c) as compared with the former, (a). The weight drops from an original fresh weight of 165.0 gms to 19.0 gms for the former and 7.8 gm for the latter. The moisture contents and volumes before and after puffing of both cases are tabulated in Table 4 below:-

Table 4 The Moisture Contents and Puffed Volumes of Carrot Slices:

Treatment	% Moisture		Vol/wgt., cc/gm			
				After Puffing		
	Before Puffing	After Puffing	Before Puffing	As Is	Wgt. Before Puffed Basis	Original Wet Wgt. Basis
Fresh Raw Slices	*89.0	-	0.978	-	-	-
Dried Raw Slices	10.2	3.5	0.684	2.19	2.47	0.284
Dried Blanched Leached Slices	9.0	3.0	0.680	3.33	3.84	0.182

(* From "The Structure and Composition of Foods" Vol. II; Vegetables, Legume, Fruits; p. 96; by A.L. Winton and K.B. Winton).

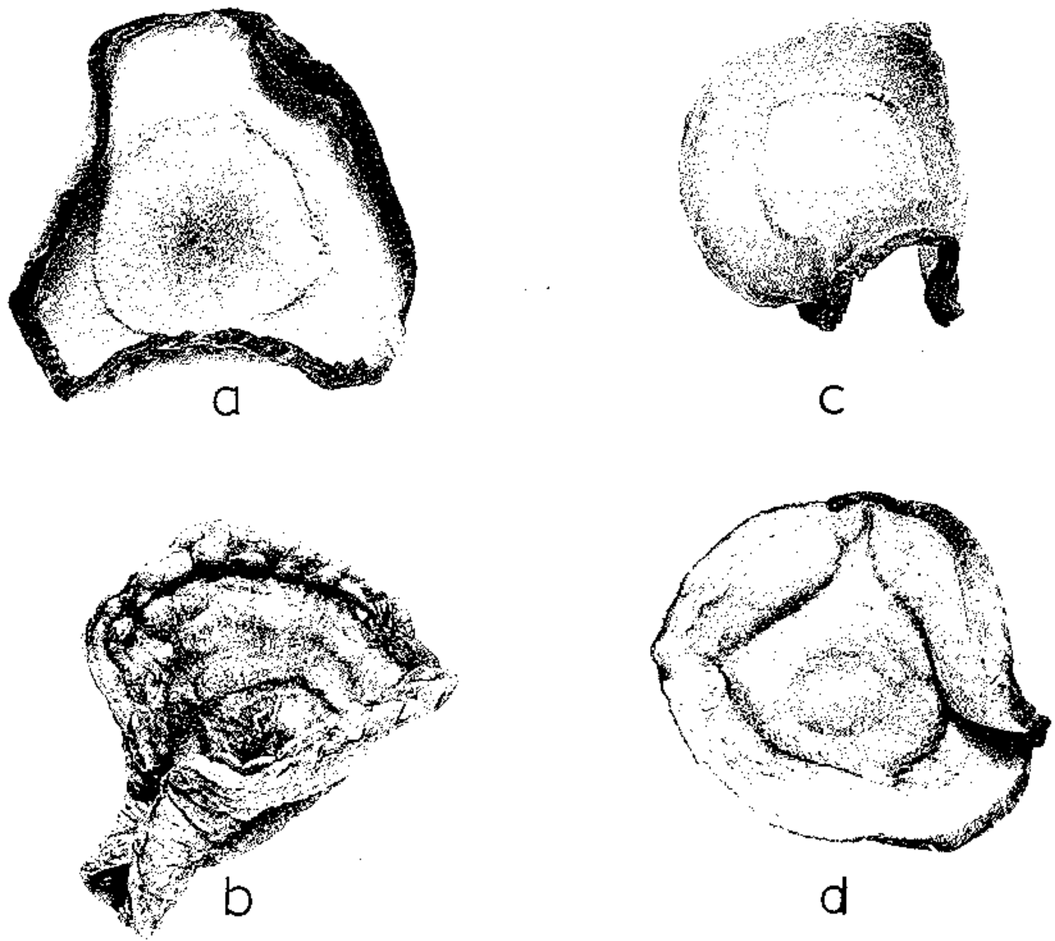


FIG. 12 Carrot Products:

(a) Raw carrot slice, unpuffed

(b) " " " , puffed

(c) Blanched and leached carrot slice, unpuffed

(d) " " " " " , puffed

(c) Discussion:

i) The effect of age and size of the carrots: The carrots used in the experiment are of various sizes and ages. The younger roots tend to have smaller steles, less fibre and slightly higher sugar content. The size of the stele also varies with the size of the root. Even in the same root, slices from different parts of the root tend to vary in size, tenderness and sugar content. For example, the slices from the upper end (i.e. that attached to the leaves), tend to be bigger, tougher, more mature and generally much bigger in stele size. All these discrepancies contribute to different characteristics of the puffed products.

For raw slices, the younger and smaller slices, puff well and expand to full volume while still in the hot fat, but shrink immediately when taken out, to a much greater extent than the older and bigger ones. This is probably due to slightly higher sugar contents, giving rise to higher thermoplasticity, and more tender fibres that are not strong enough to support the expanded texture when cooled down. The reverse is true, however, in case of blanched and leached slices where those from smaller and younger roots tend to puff better and more uniformly. In this case it is probably due to less variation of the texture between the stele and the cortex and the fibres are more tender so that they exert less resistance to the expansion of the texture.

The ring separating the stele and the cortex in both raw and blanched and leached slices is so tough and fibrous that it completely inhibits the expansion of the texture around that region as can be seen in Fig. 12. In Fig. 12 (b) the ring tissues simply stay intact causing a flat, unexpanded region around it. In Fig. 12 (d) the tissues also stay intact thus cause indentation of the puffed structure around the stele.

ii) Puffing characteristics of raw carrot as compared with blanched and leached carrot:

(1) Puffed Volume: From Table 4 one can see that vol./wgt. of the blanched and leached carrot is considerably greater than that of the raw product either as is, or a weight before puffed basis. This data may not, however, represent the complete picture with regard to maximum puffing volume on heat shock treatment because in fact:

(a) Raw carrots tend to shrink and although their ultimate cooled volume may be less than the leached and blanched equivalent, their puffed volume while still hot may be greater. The extent of the shrinkage can be slightly reduced by prolonging the time of immersion of the product in hot fat if the colour of the product can be sacrificed. (Colour generally turns dark brown due to caramelization of the sugar in carrots).

(b) Beginning with the same fresh weights the final product weight of blanched and leached carrots is much lower than that of the raw ones. As they are recorded, from the fresh weight of 165.0 gm the final product weight of the blanched and leached carrots is 8.5 gm to give a volume of 30.0 c.c. as compared to 21.4 gm and 47.0 c.c. for the raw ones.

(c) From (b) if one compares vol./wgt. based on the original fresh weight (of carrot slices) of both products one arrives at figures of 0.182 c.c./gm for the blanched and leached carrots to 0.284 c.c./gm for the raw ones (See Table 4). Hence in the leaching or blanching of product before puffing a significant loss in recovery is encountered.

(2) Uniformity of texture of puffed products: Microscopic examination confirms the fact that the blanched and leached carrots puff much more uniformly than their raw counterpart. Under the microscope the surface of the former is very smooth and uniform as also its cross section which shows very uniform minute pores as compared to that of the latter

with non-uniformed localised big air pockets. The former is also much crisper as compared to the softer and chewier characteristic of the raw-puffed product. The inferiority of the raw carrot product is obviously due to the higher level of sugar, the effects of which has been previously discussed.

(3) Product colour: A typical caramel-brown colour of the raw carrot puffed product is due to caramelization of the sugar and also possibly due, to less extent, to the non-enzymic browning reaction between the reducing sugars and proteins which constitute about 8.8% (dry basis) in the carrot (85). This colour on rehydration, will change, to an appreciable extent, towards the original colour of fresh carrot slices. The blanched and leached carrot product gives bright light yellow colour which will fade to much paler shade on storage due to the oxidation of carotene to beta-ionone with the development of a violet odour (68). On rehydration this product does not regain the original fresh colour but will give an unattractive pale-yellow colour.

(4) Taste: The raw carrot product give moderately sweet taste with quite pleasant odour while the blanched and leached product is tasteless with strawy flavour due to the loss of most of the sugars and other soluble materials which constitute good carroty taste and flavour.

(d) Conclusion: It is conceivable at this point, then, that the carrot slices, either raw or treated, can be puffed to an appreciable extent. The raw carrot product can be produced simply and cheaply as either a snack type product or a product for rehydration. The blanched and leached product, on the other hand, will prove to be a superior product all round if the lost soluble solids can be recovered and added back to the final product and the fading of the colour during storage can be prohibited. Both products which can, doubtless, be easily ground may provide a very interesting prospect to a soup manufacturer who needs ground-dried carrots as one of his ingredients.

II) <u>Bananas</u>: Banana was chosen to represent fruits in our work because:

(i) it possesses a compact, gel-like texture,

(ii) it has soft texture and low content of fibre which can be easily destroyed if required,

(iii) it is a starchy fruit when green which will mostly convert to sugar when ripe so that it can be used to illustrate the effect of sugar on puffability of fruits and methods of modification by the use of gelling agent such as sodium caseinate, and

(iv) it is a readily available tropical fruit.

(a) <u>Introduction</u>:

Banana is extensively grown in tropical and sub-tropical countries of the world. It is described as the poor man's fruit in the United States. Many types of banana products are well known, especially in tropical countries, such as dried fully ripe bananas ("banana figs"), a breakfast food ("banana chips") and banana-meal which is made from the green fruit while still starchy (85).

The banana flesh is white when green and starchy but turns creamy when ripe. The bulk of the fruit, starting from the middle mesocarp where the rind separates, is made up of large rounded starch cells, fibro-vascular bundles, and oleoresin cells then another layer of radially arranged chains of starch cells in loose contact and fibrovascular bundles and oleoresin cells, and ends up with endocarp of radially much elongated polygonal, thin-walled cells (85).

The starch which constitutes the great bulk of the carbohydrates at the time the fruit reaches its full size is rapidly converted into sugar during ripening. It is reported that banana ripened at 68°F after 14 days at 53°F reduces its starch content from 7.52% to 1.62% of fresh pulp between the nineteenth and the twenty-fourth day from harvest, while its total sugars increases from 6.59% to 11,25% and sucrose from 1.89% to 2.36% (57).

Like other types of fruit, pectic substances form one of the most important constituents in the middle lamellae of the banana tissue. A marked change in the pectic substances also occur during ripening. On storage the amount of soluble pectic substances increases, while the total pectic substances decrease. The pectin increases from 0.27% to 0.40% of fresh pulp during 8 days in ripening room, while protopectin decreases from 0.53% to 0.22% during 11 days (57).

Fibre, mainly in the form of fibro-vascular bundles forms about 0.62% to 0.37% of the banana flesh depending on the variety. In fact, the amount and toughness of the fibre also decrease considerably during ripening (85).

It is obvious at this point, therefore, that the gelatinous texture of the ripe banana is contributed mainly by the soluble materials such as sugar and pectin. It can also be expected that the puffability of banana flesh is definitely dependent on its stage of maturity. High level of starch in green bananas will, no doubt, aid in forming gel texture, hence puffing; while high soluble solids in ripe bananas will be a great inhibitive factor to the puffing. It can rightly be assumed also that fibre will play no important part in the puffability of the banana.

(b) Experimental:

It is very unfortunate that green bananas cannot be readily obtained in New Zealand, so the ones that were used in our experiment were those from Fiji which were readily available. The variety and stage of ripening of the banana were not known.

Procedure: The following attempts to puff bananas were conducted:-

(i) Bananas were sliced both cross-sectionally and longitudinally to about 1/16 inch thick, dried at 110°F for 36 hours, then puffed in hot fat at 370°F.

(ii) Bananas were firstly blanched in boiling water for 5 minutes, then proceeded with as (i).

(iii) Bananas were blanched and pasted, then spread thinly on metal trays to dry at 110°F for 36 hours, then puffed as (i).

(iv) Bananas were blanched and pasted before a certain amount of a sodium caseinate powder and water were incorporated, then proceeded with as (iii).

Of all these four attempts, only the fourth one could be puffed very successfully. The failure to show any signs of puffing of the first three can be only attributed to too high the level of the soluble solids (17% of the flesh as determined by a refractometer).

The details of the procedure employed in the (iv) are as follows:

The whole bananas (within the peel) were blanched, so that the loss of any constituents would be at a minimum. The blanching was carried out at 212°F for 5 minutes before they were peeled. The banana flesh was then pulped in the "Kenwood Mixer" until it became smooth - watery paste.

It was discovered from a series of trials that the addition of 40 parts of the sodium caseinate and 140 parts of water (preferably hot) to 100 parts of the banana paste gave a good jelly paste and good puffability,

The sodium caseinate powder was first dissolved in hot water and this solution, which was in an excellent gel state, was added into the banana paste in the mixer and the total mass was then blended for a period of time until a smooth, gel-like paste was obtained.

The mixture was further homogenised with the "Silverson Mixer" to obtain a very smooth homogeneous paste.

The paste was then poured on to plastic trays to about 1/16 inch thick before drying at 110°F for 36 hours.

The dried paste was cut into small square pieces and divided up into three portions to be equilibrated in the atmospheres of 43.6%, 74.9% and 84.5% relative humidity for 6 days (See Appendix for method), before being puffed in hot fat.

As in the case of the carrots, the moisture contents and volumes of the product before and after puffing were determined.

Result: The importance of moisture level for puffability in this particular product was recognised when the samples

Table 5. Moisture Contents and Puffed Volumes of Banana Product:

% Moisture		Vol./wgt., c.c./gm				
Before Puffing	After Puffing	Before Puffing	After Puffing			
			As is		Wgt. Before Puffed Basis	
			Ordinary (Thin gel)	Pillowcase (Thick gel)	Ordinary (Thin gel)	Pillowcase (Thick gel)
9.5	3.3	1.1	2.0	2.3	2.3	2.65
15.4	4.75	1.0	1.8	3.8	2.1	4.40
18.0	8.25	0.9	1.6	5.4	1.9	6.50

were taken out to be puffed at different stages of drying. Thickness of the dry paste also plays a very significant part in the puffing characteristics of this product. The thin dry paste gave maximum puffed volume at a moisture level of about 10%. The volume decreased with increasing moisture. For the thick dry paste (about 1/10 inch), however, the effect of the moisture content is reversed as they tended to form a hollow "pillowcase" - like product on puffing. The higher the moisture the bigger "pillowcase" structure the product formed, hence the bigger the puffed - volume. The results are tabulated in Table 5.

(c) Discussion:

(i) Sodium caseinate as gelling agent:

As one can expect, sugar level in banana pulp is so high that it destroys all the possibilities of bananas to puff as is. Furthermore, the level of starch and pectic substance in ripe bananas is too low to contribute to the formation of the gel texture of the banana paste to any appreciable extent. Since sodium caseinate has been proved to be one of the best protein-based gelling agents and an addition of proteinous materials into any foods is the most popular trend, so it is best chosen to be the additive in this case.

Attempts to achieve incorporation of sodium caseinate in a powder form into the banana paste were unsuccessful through the difficulties of attaining efficient mixture to a smooth homogeneous paste. Dissolving the powder in an adequate amount of hot water prior to incorporating into the paste is much easier, and results in a smooth jelly-like paste. The advantages of this technique are enough to offset the disadvantages of the additional amount of water to be removed in the drying stage.

(ii) Homoginisation of the paste:

The homogenisation of the paste with the "Silverson mixer" is necessary to ensure complete mixing of all components and for the breaking up of any possible lumps of bananas or sodium caseinate. Care must be taken, however, to ensure that no air is incorporated into the paste as sodium caseinate is also an excellent foaming agent. Any minute air pockets in the dry paste appear to upset the expansion of the paste during puffing by permitting accommodation of some vapour pressure built up inside the gel texture which would otherwise expand the product structure.

(iii) Spreading and drying of the paste:

It is difficult to spread paste in a uniform thickness on drying trays particularly since most standard or commercial trays suitable for such laboratory scale work are not completely flat. Moreover it is also obviously important that the trays be held in a completely level position during drying.

In the conditions of the described experimental work the occurrence of the above difficulties at a certain stage leading to variability in gel thickness, actually led to the accidental discovery of an important product-form alternative (i.e. the formation of hollow "pillowcase" type products from gels of thicker than normal types).

(iv) Moisture equilibration of the dry paste:

Through some experience it was found that a 6 day period for equilibrating the paste in atmospheres of different levels of relative humidity is sufficient. This is also confirmed by Kerreau (60) from his work on equilibration of starch gels in the atmosphere of R.H. ranging from 52.0% to 92.2%. The level of moisture in the paste has proved to be of extreme importance in determining the characteristics of the puffed product.

(v) Variations in characteristics of puffed product:

Moisture and thickness of the dry paste are two major determining factors of the characteristics of the puffed product. The paste of not over 1/16 inch thick will expand normally i.e. mainly horizontally. The optimum moisture content to give maximum puffed volume appears to be about 10%. The volume decreases with increasing moisture content probably due to the increase in the thermoplasticity. With higher moisture, bigger air voids tend to be formed, and case hardening tend to occur due to longer time taken to puff, thus the moisture vapour cannot escape readily.

This is, in fact, confirmed by the increase in the moisture content remaining after puffing with the increasing moisture content before puffing (See Table 5).

The thick paste (i.e. thicker than 1/16 inch) tends to form a case hardened surface on drying due to a slow drying rate which allows the escape of soluble solids with moisture to the surface of the paste. This may be observed in the cross section profile of the dissected paste after moisture equilibration when it appeared that the middle layers of the paste were moister and softer than the dry and hard surfaces. On puffing a great vapour pressure built up inside the hardened surfaces tending to form one big void while pushing the surface apart. The surfaces themselves expand to some extent by formation of minute pores. The whole piece then bubbles up in to a large "pillowcase" structure. The higher the moisture the higher the pressure built up, the bigger the case formed, and consequently the longer time it takes to obtain full puffed volume. The longer times leads to excessive browning of the product in some cases, due to the caramelization of the sugar and the non-enzymic browning reaction between the reducing sugars in the banana and protein molecules from sodium caseinate. The compromise to reduce the extent of browning results in higher moisture retained in the product after puffing. Hence it is of no surprise when it appears that the pillowcase-like product tends to be softer and chewier in comparison to the ordinary product which is crisp and tasty.

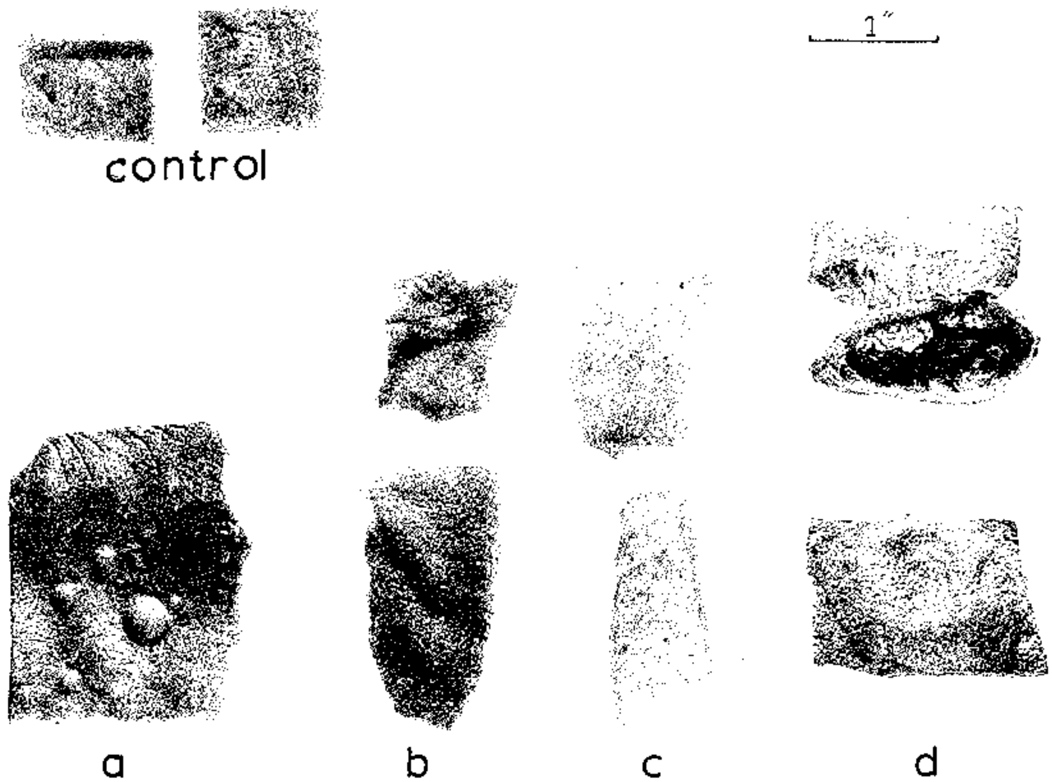


FIG. 13 Effect of moisture and thickness on the puffing characteristics of a banana product:

Top left : unpuffed

a) 9.5% moisture

b) 15.4% "

c) 18.0% "

d) 18.0% " , "pillowcase".

The puffed banana paste of both types are shown on Fig. 13.

(d) Conclusion:

It is shown to this point, therefore, that foodstuffs of almost any type can be puffed successfully, irrespective of the intrinsic inhibitive factors in the material, provided that a sufficient amount of gelling agent such as sodium caseinate is added to induce a continuous gel texture. The manipulation of the thickness and moisture of the dry paste is essential to obtain satisfactory puffed products.

Puffed banana products are potentially possible as a snack-type food. However, more work is needed to study the causes and inhibitive or preventive measures of the browning reaction, and also ways by which the banana flavour can be retained or increased in the products.

The study of the effect of stage of maturity on puffability of bananas is also necessary.

B. Protein Foods:

It was another aim of the current studies to increase nutritive value of the traditional Asian puff-foods. To present proteins in an already acceptable form of food such as puffed products to the people where protein malnutrition is widely prevalent is a praiseworthy course. The studies in this section are devoted to the finding of ways by which the readily available protein food such as dairy products e.g. cheese, and other animal protein e.g. fish and meat can be turned into gel texture and subsequently puffed so that the products can be consumed as such or can be easily rehydrated, aided by the porous texture, for other uses.

Cheeses already possess gel textures associated with the casein curd and were expected to puff readily with little modification. On the other hand, fish and meat are of heterogeneous nature with high proportions of fibres and other components such as fat and soluble solids. Hence some kinds of treatment must be employed to alter their physical and chemical properties so that the continuous gel texture is induced and the intrinsic inhibitive components are destroyed or modified to allow puffing.

I) Cheeses: Cheese is a highly nutritious and palatable food. It contains in concentrated form almost all the proteins and most of the fat, as well as essential minerals, vitamins and other nutrients of milk (69). The cheese curd contains calcium caseinate, which has become paracaseinate if rennin coagulation has been employed, or in part free casein if the coagulation was the result of increased acidity. Most of the fat and portions of mineral and vitamins remains entangled in the casein or paracaseinate gel (76).

There are probably about eighteen distinctive varieties of cheese differing primarily in the fat content of the milk, the source of the milk, the method of coagulation, the moisture content of the cheese, and changes after curd separation (76).

It has been advocated earlier that fat content and moisture content profoundly affect the puffability of food gels. Cheeses of different levels of fat content, moisture contents and hence the smoothness and continuity of the gel texture will vary in properties necessary for puffing, and may need different ways and extents of modification before they can be puffed successfully.

Parmesan cheese, representing hard texture and high fat content; Mozzarella, representing soft, plastic - curd cheese of medium fat content; and skim milk cheese, hard with low fat content, were studied to some depth.

(1) Parmesan Cheese:

(a) Introduction: Parmesan is a name of a group of very hard cheeses which have been made and known in Italy for centuries as Grana. The difference among the cheeses within this group are in size and shape and in the method of manufacture. It is made up of a skimmed cow's milk with a starter containing heat-resistant lactobacilli and *Streptococcus thermophilus* and is cured for at least 14 months until a very strong characteristic flavour is fully developed. Fully cured Parmesan is very hard but can be grated easily. It consists of 30% moisture and 28% fat and the rest is mainly protein (69). It becomes extremely hard and crumbly with a considerable degree of oiling-off when dried to about 10% to 15% moisture. This broken gel texture along with very high fat portion is enough to mar all the possibilities of puffing the cheese as such. The following experiment was set out to study ways by which these obstacles could be overcome.

(b) Experimental: The sodium caseinate was once more employed as a gelling agent to promote a continuous gel texture in the cheese and dilute the adverse effect of the fat. Various proportions of cheese to sodium caseinate were studied to find the optimum ratio that gave the best puff-product.

Procedure: Parmesan cheese was grated with a cheese grater to sufficiently fine particles to provide ease in mixing with sodium caseinate powder.

The following proportions of grated cheese to sodium caseinate powder were used:-

i) 1 part of cheese to 1 part sodium caseinate,

ii) 1.5 parts of cheese to 1 part sodium caseinate, and

iii) 2 parts of cheese to 1 part sodium caseinate.

The grated cheese was thoroughly mixed with the sodium caseinate powder prior to the addition of hot water in twice the amount, by weight, of the mixture. The whole mixture was mixed well before being homoginised with the "Silverson Mixer" to a smooth jelly paste. Great care was taken that no air was incorporated into the paste.

The paste was then spread onto the plastic trays to provide a thin film so that the dry paste was about 1/16 inch thick. Drying was undertaken in a hot air chamber at 110^{o}F for 36 hours.

The dry paste was then cut into small square pieces prior to puffing in the hot fat at 370^{o}F for 10 seconds. The moisture contents and the volumes in every case were determined before and after puffing.

Result: The volume per weight of the dry paste was similar in all cases. The puffed volume of the product decreased with the increasing proportion of the cheese in the mixture. Results in detail are tabulated in Table 6.

Table 6. The Ratio of Cheese to Sodium Caseinate, the Moisture Contents and Puffed Volume of Parmesan Cheese Products:

Cheese:Sodium Caseinate	% Moisture		Vol./wgt., c.c./gm		
	Before Puffing	After Puffing	Before Puffing	After Puffing	
				As is	wgt. Before Puffed Basis
1 : 1	5.5	2.5	0.8	3.6	5.4
1.5 : 1	5.6	1.9	0.8	2.2	3.3
2 : 1	5.8	2.2	0.8	1.8	2.7

(c) Discussion:

i) The effect of sodium caseinate: Sodium caseinate acts as a binding agent that binds the crumbly casein structure of the cheese into a continuous gel on the one hand, and dilutes the fat content of the cheese down to a tolerable level on the other hand. The sodium caseinate powder has its advantages as well as disadvantages over other types of gelling agents such as starch. It can be dissolved to give a paste in cool water, and it is an excellent protein additive, but its solubility in the water is very low and tends to form hard lumps which are very hard to break and completely dissolve. Its solubility can be increased several fold, however, by heating up to about 180°F while stirring the paste.

The thorough mixing of the sodium caseinate powder with the finely grated cheese also helps increase the solubility of the powder in the added water to form a continuous gel texture. Hot water is used to ensure the complete dispersion of both cheese and the sodium caseinate powder so that homogenisation with the "Silverson Mixer" can be accomplished with ease. The main set back of adding 100% water into the mixture, however, is that the amount of water to be dried is accordingly increased.

The amount of water used can, nevertheless, be reduced considerably if the thick mixture can be heated evenly to about 180°F while being homogenised but since the spreading of the paste on to trays was done manually, the thinner the paste, i.e. with maximum added water, the easier and the more uniform thickness could be obtained.

Also, with higher proportion of cheese in the mixture the easier it can be smoothly pasted.

ii) <u>On drying</u>: The paste tends to oil-off on drying leaving an appreciable amount of oil on both surfaces. The extent of oiling off is higher, of course, with a higher proportion of cheese in the paste. This reduction in oil content on drying probably helps considerably in increasing puffed volume of the products. The oil, which normally will completely inhibit puffing, as it can be recalled that 10% fat content is sufficiently to almost completely inhibit puffing (60), but with the aid of oiling-off, the oil content is reduced to a puffable level.

iii) Effect of moisture level: The effect of moisture on puffing characteristics was not studied extensively in this case. During the course of study, however, it was found that the puffed product characteristics were deteriorating with increasing moisture contents of the dry paste prior to puffing above 10%. The texture became less uniformly porous, and localised big air voids were formed with subsequent higher fat pick-up of the puffed product resulting in the product tendency to be softer and less attractive to eat. Furthermore it was found that the dry paste immediately after being subjected to drying in a chamber at 110°F for 36 hours, gave the best puffed product. So it was decided that the study of the effect of various moisture contents on puffing characteristics was not necessary in this case. The moisture of the pastes studied was kept well below a critical 10% level.

iv) Puffed product characteristics: The texture of the product, in most cases, was uniformly porous and crisp. The properties, however, deteriorate with increasing proportion of the cheese in the paste as can be seen in

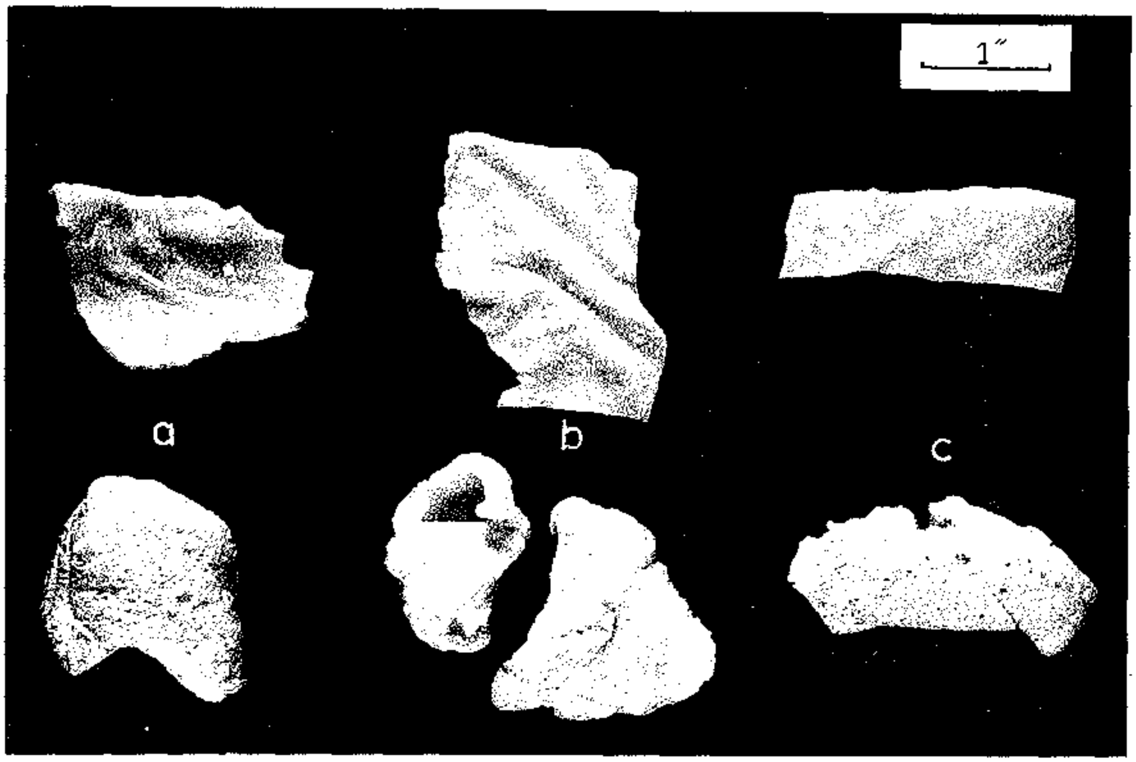


FIG. 14 <u>Effect of levels of gelling agent on the puffing characteristics of parmesan cheese</u>:

a) 1 : 1 cheese : sodium caseinate

b) 1.5 : 1 " : " "

c) 2 : 1 " : " "

(upper row : unpuffed ; lower row : puffed)

Fig. 14. The dry paste (upper row in the picture) and the puffed paste (lower row) are, of course, not of corresponding size. The picture merely shows the deterioration in the overall texture from (a) to (b) and (c). The 1 : 1 product (a) is extremely uniform in porosity and crispness while (b) shows localized bubbles that either collapse or shrink back after puffing, and the whole structure tends to curl up or shrivel after full expansion of the texture. The mealiness feeling in the mouth on chewing the products also increases with increasing proportion of the cheese in the paste.

The thickness of the dry paste also contributes, to some extent, to the product characteristics. The thin dry paste (not over 1/16 inch) puffs better and gives more uniform texture while the thicker forms tend to produce air pockets and may remain much softer after puffing with higher fat pick-up.

The flavour strength of the product increases, of course, with increasing proportion of cheese used. On a tentative taste panel trial, however, it was significantly agreed that a 1.5 : 1 ratio was the most favoured mixture as far as the flavour and crispness were concerned though some of the tasters prefered slightly milder flavour.

(d) Conclusion: It is demonstrated once again that foodstuffs of any type, even though they contain components inhibitive to puffing, can, with the aid of good gelling agents like sodium caseinate, be made to puff satisfactorily. This, indeed, opens the door to a very wide range of puff-products. Starch can be used as a very cheap but low nutritive value gelling agent, while sodium caseinate represents a more expensive but a nutritive gelling agent.

The cheeses of strong and attractive flavour like Parmesan possess a great potential as a snack-type puff-product Products of this type could be useful in bringing protein foods in an attractive and acceptable form to certain societies in e.g. Asia. Moreover certain populations unaccustomed to cheese as a product but in need of additional protein would more readily accept the puffed form of product. Puffed products of this type would also have potential markets as "snack type" foods in Western markets.

(2) Mozzarella and Skim-Milk Cheeses:

(a) Introduction: Studies on Parmesan cheese provided an idea that cheese with a continuous gel-texture and a reasonably low fat content would puff satisfactorily in its original or part dried form. Any cheese that could fulfil this specification might be simply sliced, dried and puffed without any addition of a gelling agent like sodium caseinate.

It was suggested, then, that Mozzarella and Skim-milk cheeses, which were readily available at the D.R.I. Pilot Cheese Plant, whose textures were continuously plastic, (especially in the very early stage of curing) could perhaps fulfil the specifications. One of these (Mozzarella) is of a moderately high fat content while the other (Skim-Milk Cheese) has a very low fat content.

Mozzarella is a soft, plastic-curd cheese of a type that was originally made in Southern Italy from either buffalo's or cow's milk using rennet as a coagulant. It is usually eaten while fresh. It contains 40 - 45% moisture, 25 - 27% fat, 24 - 26% protein, and 3.5 - 4.5% ash (69).

Skim-milk cheese, on the other hand, which is also known as "Radener" or "Skim-milk Rundkase" is a hard cheese with an elastic body, originally made in Mecklenburg, northern Germany, from cow's skim milk using bacteria as starters. It contains about 3.6% to 6.1% fat (69).

Studies of these two types of cheese have furthermore shown in the work undertaken that the continuous gel texture plays an essential role in the puffability of a food gel such as cheese, and this unique property of the cheese can, to a certain extent, compensate the inhibitive effect of fat content and permit cheese to puff satisfactorily.

(b) Experimental: As there are no other modifications apart from converting the cheeses into thin sheet forms, the processing method is, therefore, quite straightforward.

Procedure: Two methods of getting the cheeses into a thin sheet were employed:

i) the cheeses were manually sliced with a cutting knife into thin pieces about 1/16 inch thick prior to drying on the plastic trays in a hot air chamber at 110^{o}F for 36 hours.

ii) the cheeses were first sliced into thick pieces then spread singly on the small metal trays and cooked in a pressure cooker at 15 p.s.i. for 10 minutes. The idea was to melt the cheese down so that a better continuous gel texture could be obtained and to allow melted cheese to flow to cover the whole area of the tray bottom, and thus produce a uniformly thin film. The thin films were then dried as (i).

The dried cheese slices from (i) and (ii) were divided into 3 portions each to be equilibrated in the atmosphere of:-

(1) 32.0% R.H.
(2) 43.6% R.H., and
(3) 74.9% R.H.

for 6 days to get the cheese slices to assume different moisture levels.

Slices of fresh cheese were also left in the ambient atmosphere, whose temperatures varied from 55° to 65°F and R.H. varied from about 50 to 80%, for a period of 9 days to study the feasibility of ambient air drying. The moisture contents of the slices were determined after 4, 7, and 9 days.

The moisture contents and the volumes of the slices were determined before and after they were puffed at 370°F for 30 seconds in the hot fat.

Result: The moisture contents of the fresh cheeses used are:-

Mozzarella	36.2%
Skim-Milk Cheese	52.5%

After fresh slices were left in the room atmosphere for specified periods of time, their moisture changes were as shown in Fig. 15.

The results of the moisture contents and volumes of the cheese slices from (i) and (ii) are shown in Table 7.

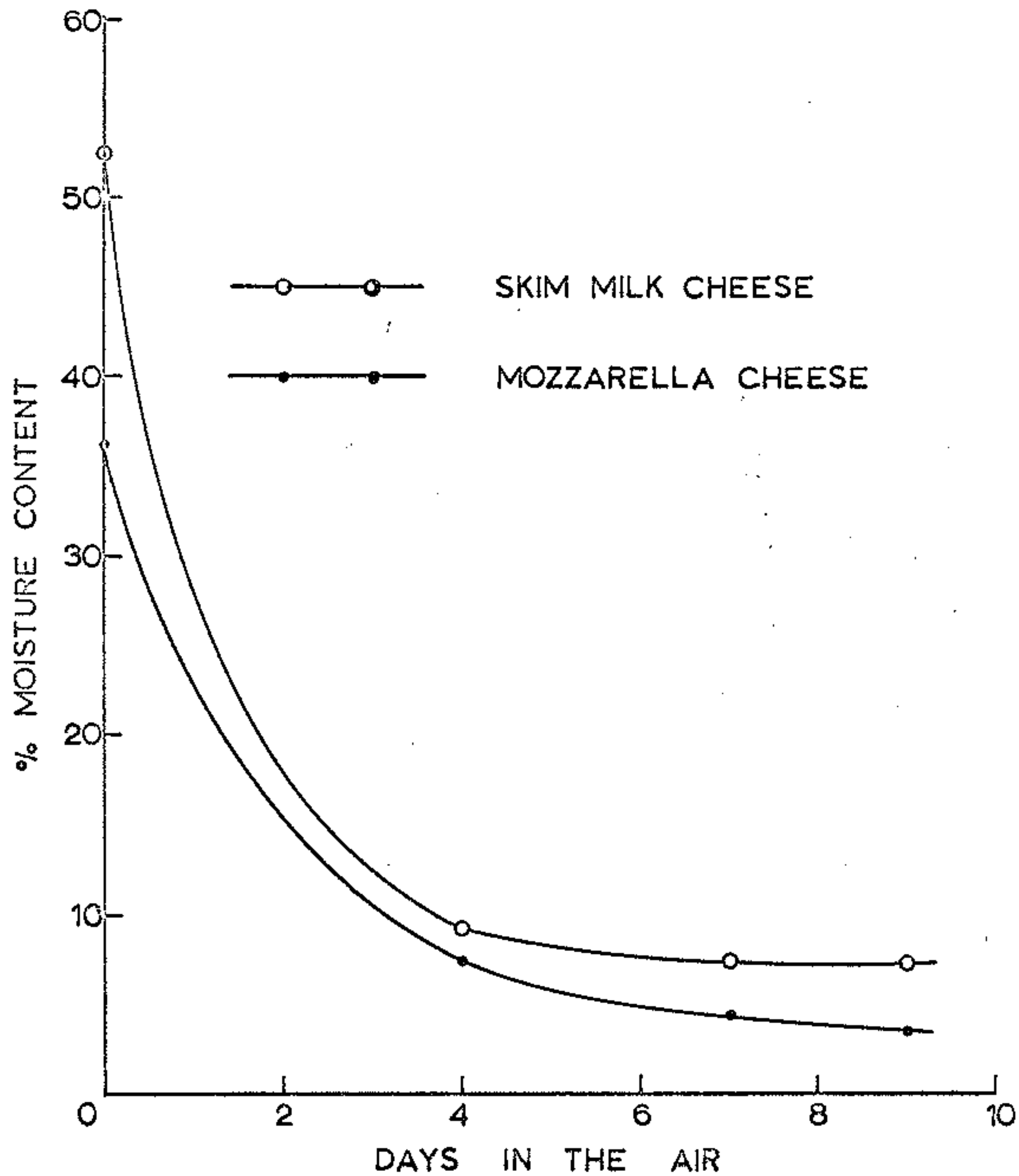


FIG.15 Graphical representation of air-drying of cheese slices.

(ave. R.H. = 70%, ave. temp. = 60°F).

Table 7. The Moisture Contents and Volumes of Mozzarella and Skim-Milk Cheese Products:

Type of cheese	% R.H.	% Moisture		Vol./wgt., c.c./gm		
		Before Puffing	After Puffing	Before Puffing	After Puffing	
					As is	wgt. Before Puffed Basis
Mozzarella Slices	32.0	6.56	2.20	0.80	3.5	3.76
	43.6	7.42	3.47	0.80	2.5	3.37
	74.9	14.10	2.46	0.80	2.1	3.15
Mozzarella Steam-Cooked	32.0	6.68	3.75	0.80	2.1	2.21
	43.6	8.05	3.51	0.80	2.7	3.08
	74.9	12.60	7.49	0.80	2.1	2.47
Skim-Milk Cheese Slices	32.0	7.98	2.30	0.82	2.5	3.68
	43.6	9.49	2.28	0.82	2.2	3.36
	74.9	18.87	11.10	0.80	1.9	2.47
Skim-Milk Cheese Steam-Cooked	32.0	8.43	5.58	0.80	2.9	3.68
	43.6	9.63	5.01	0.76	2.7	3.62
	74.9	17.50	10.02	0.80	1.8	2.16

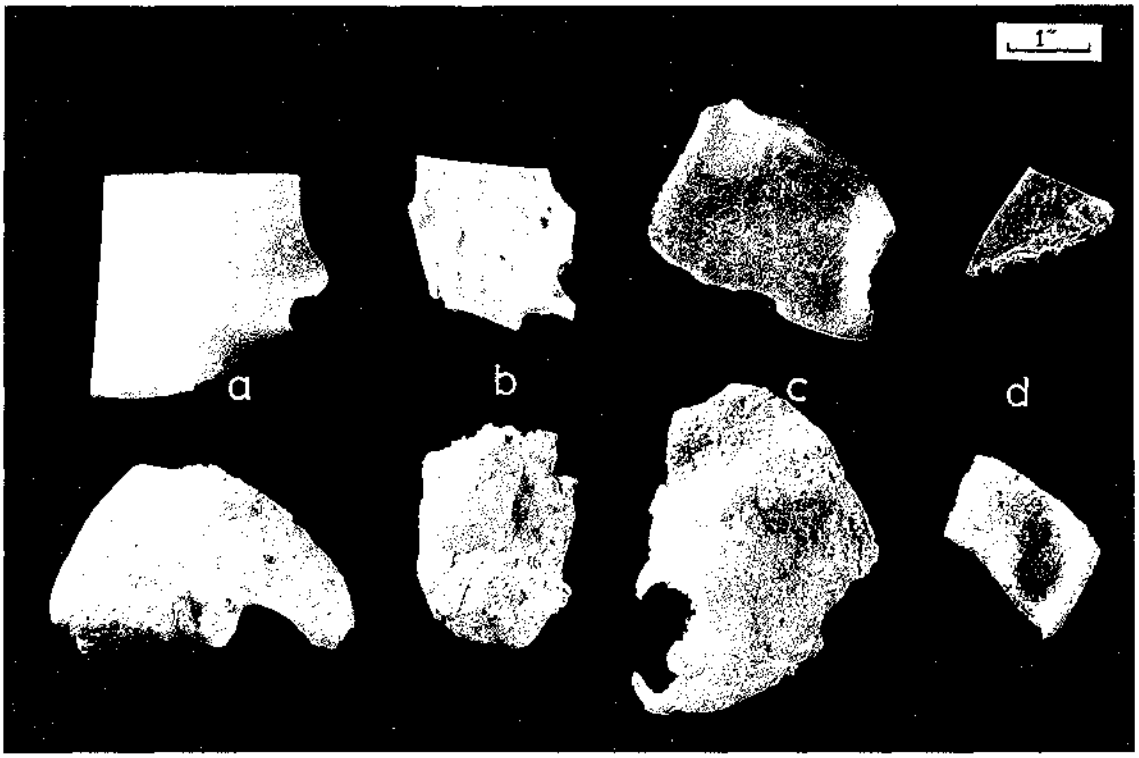


FIG. 16 <u>Mozzarella and Skim-milk cheese products:</u>

(a) Mozzarella, sliced

(b) " , melted

(c) Skim-milk cheese, sliced

(d) " " " , melted

(upper row : unpuffed ; lower row : puffed)

(c) Discussion:

(i) Untreated slices in comparison with steam-cooked slices:

There is no apparent advantage of the steam-cooking process as far as the puffed volume and the texture of the puffed product are concerned. In fact, there are some definite disadvantages of the steam-cooked slices, as one can see from Fig. 16.

(1) The steam-cooking process is far more complicated and expensive; and adds no virtue to the product.

(2) As is shown in Fig. 16, one can see the difference in a uniformity of the slices, especially those of Mozzarella cheese ((a) and (b)). Comparing the ordinary slice (a) with the steam-cooked slice (b) one can see that the latter tends to be thicker and much less uniform on the surfaces. This is due to the difficulty in spreading the melted cheese after being taken out of the pressure cooker. This invariably results in big air pockets and non-uniformity of the puffed product, which tend to give soft and mealy sensations in the mouth.

(ii) Comparison of the Mozzarella and the Skim-Milk Cheese:

The skim-milk cheese product is much more uniform in its texture. The porosity is made up of tiny pores that are distributed evenly throughout the whole structure (Fig. 16 (c) and (d)). Unlike the skim-milk cheese, the Mozzarella product, though puffing as well or in some cases to bigger volumes, tends to be harder, forming distinctive case hardening on the surfaces (Fig. 16 (a) and (b)). The tiny air pores are not uniformly distributed, and in some parts the structure remains solid without any sign of expansion. The reason that the Mozzarella product gives slightly bigger puffed volume in some cases is probably based on the fact that the product tends to form some localised big voids which will no doubt displace more water to give apparently bigger volume on volume displacement determination. The inferiority of the puffing characteristics of the Mozzarella product may be attributed to the higher proportion of fat content it possesses which results in the discontinuity of the gel texture in some parts due to the weakening effect of the fat that seeped into the structure during the gel formation of the cheese processing. When part of this fat is rendered out on drying it obviously leaves the shortened gel structure behind. The discontinuity of the gel structure on puffing, therefore, gives the non-uniform product texture. The moisture can also escape more readily through this type of texture on puffing than that in skim-milk cheese product, resulting in a harder product.

(iii) The effect of different levels of moisture contents in the slices prior to puffing:

It clearly appears from Table 7 that the optimum moisture contents that give maximum puffed volumes, and hence best texture are those obtained by equilibrating the slices in the atmosphere of 32.0% R.H., i.e. about 7.0% for the Mozzarella both untreated and steam-cooked slices, and about 8.0 - 9.0% for the skim-milk cheese, for both untreated and steam-cooked slices. In all cases for both types of cheese, it appears that the moisture pattern follows the same trend and the moisture contents after the equilibration are almost similar for both cooked and uncooked slices for each R.H. condition. Thus it is obvious that the cooking treatment of the cheeses does not have any significant on their moisture sorption isotherms. There are some discrepancies, however, in moisture retention of the products after puffing. The pre-cooked products tend to retain more moisture. The trend is true for both types of cheese, though the pre-cooked skim-milk cheese products tend to retain much higher moisture.

These findings strongly support the early hypothesis that the product must attain a multimolecular layer of moisture before it will show any signs of puffing, and it is mostly or only this moisture in the multimolecular layers that contribute to the expansion of the texture.

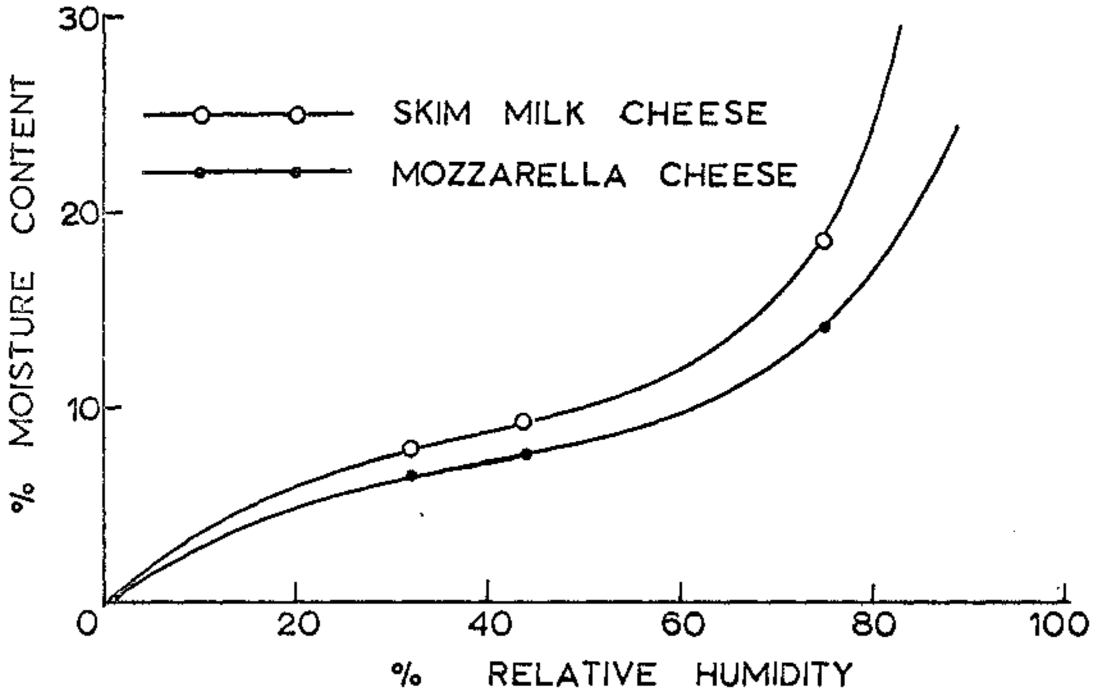


FIG. 17 Adsorption isotherm of cheese slices.

This reasoning can be more easily understood when the isotherm curves of both cheeses are plotted as shown in Fig. 17. The optimum moisture levels i.e. 7.0% for the Mozzarella and 8.0 - 9.0% for the skim-milk cheese lie in the regions of multimolecular layers. The monomolecular levels are about 2% for the former and about 3% for the latter. These moistures are just short of those retained after puffing in each case. So, it is clear, in this case at least, that the moisture in monomolecular region does not take part in expanding the puffed texture, and that it takes little additional moisture to be evolved to give good texture and high puffed volumes, provided that other requirements for puffing are favourable.

(iv) <u>The potential of air-drying techniques</u>:

Ambient atmospheres under local conditions during Summer mohths may be suitable to air-dry cheese slices; but the time involved; i.e. at least 4 days to dry the slices down to the optimal moisture levels may upset the commercial application. It is believed, however, that in the tropical countries where daily temperatures can rise to as high as 90^{o}F or more, the time required may be reduced to half or even less. If this is so then the processing technique of this type of cheese product can be greatly simplified, and indeed will be a very cheap one.

(d) <u>Conclusion</u>: Work on these two types of cheese has proved beyond doubt that any foods with gelatinous texture with reasonably low level of the inhibitive agents such as fat or sugar can, with very little modification, be puffed successfully.

As emphasized under conclusions p 92 (for parmesan cheese) there is undoubtedly some market potential for the puffed or puffable products in both Asian or Western markets.

II) Fish:

(a) Introduction:

Fish flesh has been used for centuries as one of the basic ingredients in a traditional puff - "Fish Slices" product in Asia. Tapioca starch, comprising some 70% of the product, is employed as a gelling agent. The coarsely ground fish flesh, the starch, salt and some spices are mixed together with small amount of water, then wrapped up into a sausage form with a banana leaf. The "sausage" is, then, steam-cooked to gelatinise the starch. The fish and spices will be distributed evenly in the continuous gel phase. The "sausage" is then sliced thinly crosswise, and the "Fish slices" then, be air-dried ready for puffing. The puffed product, with the aids of the spices, is very tasty with an agreeable fishy flavour.

Van Veen (81) reported that a product in Indonesia called "Krupuk" is manufactured with a similar method as described with perhaps slightly different proportions and kinds of the ingredients. The product has a very high keeping value and is highly valued by the local population and Europeans alike.

This "art" is still kept secret among a very small number of the "manufacturers" in most Asian countries. "Fish slices" are still enjoying a very high price in the limited local markets despite the fact that they can be manufactured with relatively simple method inexpensively and contains little nutritive value due to a very high starch content.

Experiments were directed towards the aim of finding techniques that, without the addition of any gelling agents, could permit fish flesh to puff. Also to simultaneously upgrade a traditional product nutritionally.

As it has been previously discussed in Section (I) under the factors affecting the puffability of food gels, fish flesh is in semi-gel state. There are two main properties of the flesh that need some modifications before a satisfactory puffing can be promoted. The two properties are:

i) The water-holding capacity of the flesh, and

ii) The texture of the flesh.

Hence certain types of salts such as phosphate salts were used to increase the first property, and the mechanical destruction of the fibres in the texture - to alter the second property. In this section the whole experiment on fish will be described in greater detail.

(b) Experimental:

Materials: i) The fish was bought as both fillet and whole fish from a wholesaler. Two types of fish were used with equal preference.

Gurnard (*Trigla spp.*) (6), and
Trevally (*Caranx lutescens*).

They were bought in a chilled state, and processed straightaway or kept in a chill-room until use.

ii) Two types of phosphate salt were used:-

Tri-sodium phosphate - technical grade,
"Universal Accoline" which is the mixture
of 3 Commercial grade salts:

Ortho meta phosphate
Tetra sodium pyrophosphate
Disodium pyrophosphate.

iii) A commercial grade table salt (sodium chloride).
iv) A commercial grade monosodium glutamate.
v) Commercial sodium caseinate powder.

Procedure: The fish was skinned and boned (in the case of whole fish). The skinless and boneless fillets were then chopped up into small pieces. 30% cold water was added into the chopped flesh, and the whole mix was then mascerated in a "Kenwood" mixer at a medium speed until the whole fish texture was broken down into a very smooth paste.

10% tri-sodium phosphate solution and 10% "Accoline" solution were prepared by dissolving 10 parts of the salts in 100 parts of boiling water.

The pH of the fish paste was determined with a pH meter. The pH of the paste was then increased over a range up to pH 7.6 by adding the salt solution to the paste and mixing thoroughly.

The adjusted paste was then spread thinly on the plastic trays and dried in a hot air chamber at 110°F for 36 hours. The paste was spread thinly and uniformly so that the dried paste was not over 1/16 inch thick.

The dry paste was then cut into small pieces and equilibrated in the atmospheres of

i) 43.6% R.H.

ii) 74.9% R.H., and

iii) 84.5% R.H.

for 6 days.

The moisture contents and the volumes of the product before and after puffing at 370°F for 30 seconds were determined.

The best condition i.e. the optimum pH and optimum moisture that gave the best puffed volume and product characteristics were then decided.

In the subsequent experiments 1.8% table salt and 0.2% monosodium glutamate (flesh weight basis) were added into the chopped flesh then proceeded with thereafter as above, except that the pH was adjusted to the decided optimum level and the dry paste was equilibrated in the atmosphere that gave the optimum moisture content.

The incorporation of 10% sodium caseinate powder (based on flesh weight) as a gelling agent was also tried without adjusting the pH or the addition of the table salt and monosodium glutamate. The sodium caseinate powder was first dissolved in 70% warm water prior to mixing with the paste in the mixer. This brought the total amount of water added to 100% flesh weight basis.

A trial of equilibrating the dry paste in the ambieht atmosphere was also conducted by leaving the dry paste straight from the dryer in the room atmosphere for a certain period of time. Its moisture contents and volumes before and after puffing were, as before, determined.

<u>Result</u>: The dry paste was light brown in colour and was quite transparent and brittle. The details of the results are tabulated in Table 8.

Table 8. The Moisture Contents and the Volumes of the Fish Product at Different Levels of pH.

Type Product	% R.H.	% Moisture		Vol./wgt., c.c./gm		
		Before Puffing	After Puffing	Before Puffing	After Puffing	
					As is	wgt. Before Puffed Basis
Control (Untreated)	43.6	10.25	1.88	0.93	1.07	1.24
pH 6.3	84.5	17.70	2.13	1.00	2.00	1.98
+ Na_3PO_4, pH 7.00	43.6	12.00	3.21	0.90	2.67	3.11
pH 7.25	43.6	12.50	2.19	0.90	2.17	2.60
pH 7.60	43.6	13.05	2.09	0.90	3.00	3.60
pH 7.00	74.9	21.20	2.36	0.90	3.00	3.68
pH 7.25	74.9	22.94	3.00	0.90	3.06	3.64
pH 7.60	74.9	23.78	3.76	0.90	2.50	2.74
pH 7.00	84.5	25.79	8.53	1.00	3.20	3.62
pH 7.25	84.5	27.83	2.84	1.00	3.00	3.34
pH 7.60	84.5	27.74	4.20	1.00	2.83	3.00
+ "Accoline" pH 6.97	43.6	12.52	2.43	1.00	2.40	3.08
pH 7.25	43.6	11.51	2.69	1.00	2.75	3.07
pH 7.50	43.6	13.09	1.86	1.00	1.50	1.50
pH 6.97	74.9	26.68	4.23	1.00	1.83	1.99
pH 7.25	74.9	21.93	2.68	1.00	3.47	4.28
pH 7.50	74.9	27.40	3.11	1.00	1.50	1.28
pH 6.97	84.5	26.06	4.01	1.00	1.80	1.96
pH 7.25	84.5	22.88	2.03	1.00	3.90	4.40
pH 7.50	84.5	27.87	1.81	1.00	1.00	1.34
+ 10% Sodium	32.0	8.50	1.48	1.25	1.25	1.56
Caseinate	43.6	9.45	1.29	1.00	1.00	1.24
	74.9	15.00	1.17	1.00	2.60	3.47
	84.5	15.55	3.00	1.00	1.90	2.39

It was decided from these results, then, that for those that were adjusted with tri-sodium phosphate solution the optimal pH that gave the best puffing lay between 7.0 and 7.25, and those with the "Accoline" was, almost invariably 7.25. The best atmosphere to equilibrate these products was found to be that of 74.9% R.H. which gave medium moisture contents in most cases. So these conditions were applied in a further experiment with the addition of the table salt and the monosodium glutamate which will be collectively called "salts". The results are tabulated in Table 9.

Table 9. The Moisture Contents and Volumes of the Fish Product with Further Addition of "Salts".

Type Product	% Moisture		Vol./wgt., c.c./gm		
	Before Puffing	After Puffing	Before Puffing	After Puffing	
				As is	wgt. Before Puffing Basis
+ Na_3PO_4 (pH 7.25) + "Salts"	19.53	4.92	0.83	3.5	4.08
+ "Accoline" (pH 7.35) + "Salts"	19.93	6.09	0.83	2.9	3.20

The room atmosphere during the experiment was determined and found that the % R.H. was varying from about 55% to about

Table 10. The Results of Moisture Equilibration of The Products in the Room Atmosphere:

Type Product	Days in Room Atm.	% Moisture		Vol./wgt., c.c./gm		
		Before Puffing	After Puffing	Before Puffing	After Puffing	
					As Is	wgt. Before Puffed Basis
+ Na_3PO_4 (pH 7.25) +"salts"	1	14.89	4.53	0.95	2.27	3.05
	48	15.33	6.37	1.00	2.00	2.24
+ Accoline (pH 7.35) + "salts"	1	16.99	3.47	0.95	2.20	3.08
	48	16.45	4.87	1.00	2.50	2.98

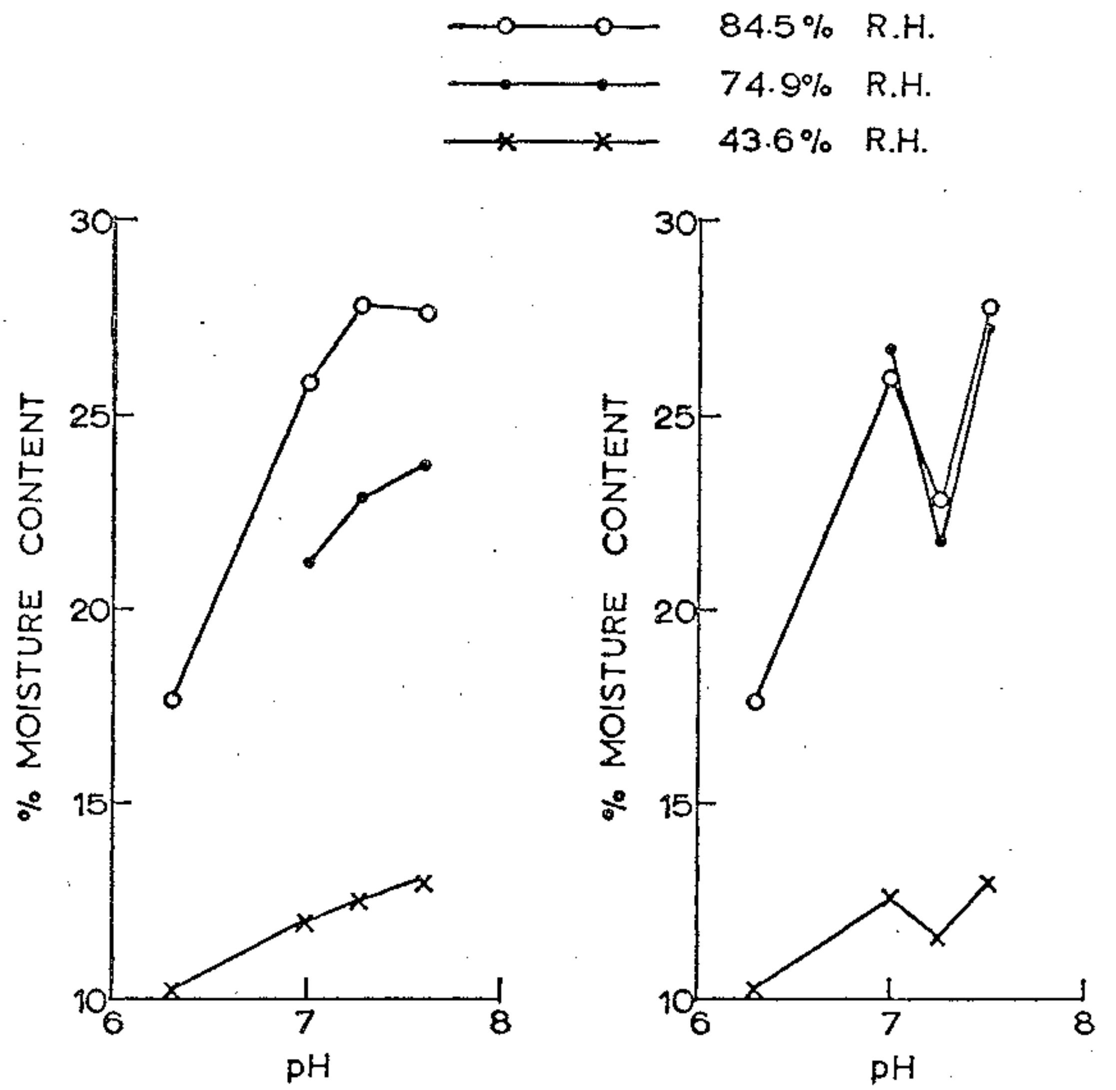


FIG.18A Effect of tri-sodium phosphate on moisture retention of fish product.

FIG.18B Effect of "Accoline" on moisture retention of fish product.

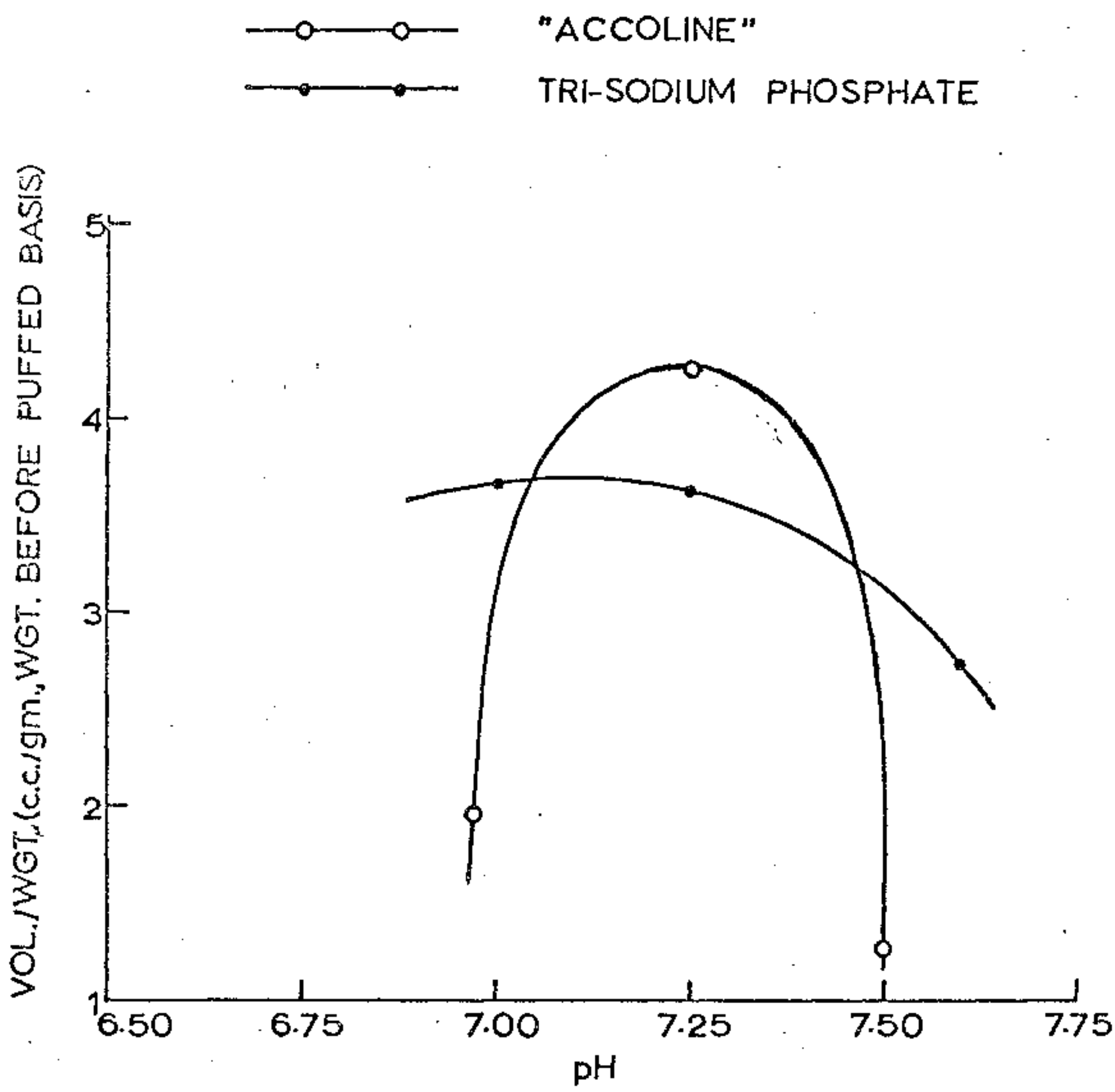


FIG.18C Effect of pH on puffed volume of fish product.

(under 74.9% R.H.).

80% which was the optimum range to equilibrate the products. So the room atmosphere equilibration of the products was tried and the results are tabulated in Table 10.

(c) Discussion:

(i) The effect of phosphate salts on the puffability of fish paste: The general effect of salts on the water holding capacity of fish and meat has been discussed in some detail in the first section (p41.). However, this experiment, more detailed behaviour and with respect to puffability was studied. The plots of moisture content vs. pH of the fish paste are presented here once more as a matter of convenience (Fig. 18A, 18B - See also Fig. 11A and 11B). The volume/weight vs. pH is also plotted on Fig. 18C.

The increase in water holding capacity of fish paste with the addition of the phosphate salts has a direct bearing on the puffability of the dry paste. It appears, however, that there is an optimum moisture level for each salt used to give the best puffing. For tri-sodium phosphate it appears that suitable moisture contents associated with a pH of the paste between 7.0 and 7.25 give the best puffed volumes (See Fig. 18C). These optimum moisture contents are those before the curves reach their maxima in Fig. 18A.

For "Accaline" (Fig. 18B), there is a peculiar drop of moisture on every curve corresponding to pH 7.25. These moisture contents give the maximum puffed volume as shown in Fig. 18C. This peculiar effect of the salt on the drop of the moisture at this particular pH is probably due to the effect of either anions or cations or both rather than change in pH alone. Since "Accoline" consists of three different phosphate salts, it is possible that these salts each give different ion strength and the combination of them provides a different balance of ions to that obtained with tri-sodium phosphate alone.

Hamm (36) in his work on the effect of several different salts on the hydration of meat, states that the effect of pH alone cannot explain the different effects of the different anions. He advocates that salts with polyvalent anions e.g. polyphosphates are the most effective in increasing the muscle hydration. This idea, he states, agrees with that of Loeb and the rule of Schultze-Hardy.

Hamm and Grau (36) state the following series for the hydrating effect of the phosphate salts on muscle homogenate within the meaning of increasing hydration (at the concentration of 3 molar and pH 6.4) : Na-monophosphate $\ll$ Na-cyclo-triphosphate $\ll$ Na-diphosphate $<$ Na-polyphosphate $<$ "Na-tetraphosphate" (polyphosphate), Na-triphosphate.

The optimum moisture levels derived from both tri-sodium phosphate and "accoline" that give maximum puffed volumes in every case, however, are very similar indeed. Hence it can be concluded that the fish paste must attain

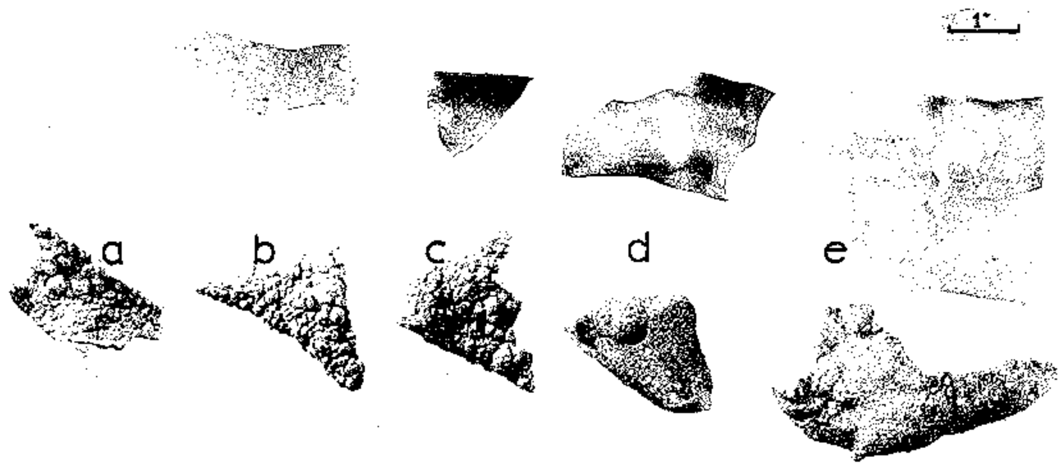


FIG. 19 Effect of pH on the puffing characteristics of fish products:

a) with tri-sodium phosphate, pH 7.0, under 74.9% R.H.

b) " " " " , pH 7.25, " "

c) " " " " , pH 7.6, " "

d) " " " " and "salts", pH 7.25, 70% R.H.

e) " "Accoline" and "salts" ph 7.35, 70% R.H.

(upper row : unpuffed ; lower row : puffed)

a certain level of water-holding capacity before puffing can be promoted. This can be achieved by adding a certain amount of phosphate salts to bring the pH of the paste up to a specific level. The addition of the salt more or less than this amount will have an adverse effect on the puffability of the dry paste.

From Fig. 19 one can see the deterioration of the texture of the product with the increasing pH. The bigger, localised bubbles tend to be formed as the pH increases. This is probably due to the increase in the moisture contents in the dry paste (Table 8). However, this is improved by the use of the combined salts, i.e. the further inclusion of the NaCl and monosodium glutamate to the phosphate salts, (Fig. 19 (d) and (e)), the combined effect of which is described below.

(ii) <u>The combined effect of the phosphate salts and the "Salts"</u>: According to Hamm (36), the effect of NaCl on water-holding capacity of meat is due mainly to Cl^- ion. This is confirmed by the fact that the iso-electric point of the muscle is shifted to lower pH values by the addition of NaCl, and that the addition of some other sodium salts to the meat does not increase the hydration of muscle in the basic range of the iso-electric point. In fact, these salts tend to slightly dehydrate the muscle due to the binding of Na^+ ions (17), (70).

Hamm further demonstrates that the hydration of muscle increases with increasing concentration of NaCl. Hydration reaches a maximum, then decreases below the original water-holding capacity. The concentration of the NaCl that gives this maximum is about 5% NaCl for meat without added water, and 8% NaCl for meat with 60% added water.

He also states that NaCl and polyphosphate added jointly into the meat increase the heat tolerance of the meat protein. Thus even after heat denaturation the increased water-holding capacity is still maintained to a considerable extent. He advocates that the ability of polyphosphates to eliminate the alkaline earth metals bound to the structural muscle porteins is probably the decisive factor in the combined effect of phosphates with sodium chloride.

From our experiment, the joint addition of NaCl with both types of the phosphate salts used was found to slightly reduce the moisture retained in the dry paste after equilibration under 74.9% R.H. for 6 days (Table 8 and Table 9). This reduction in the moisture retention, however, does not have any detrimental effect on the puffability of the dry fish paste. On the contrary, the complementary effect of the NaCl greatly improves the smoothness of the dry paste and uniformity of the texture of the puffed product. As one can see by comparing the results in Tables 8 and 9. The puffed product with the addition of the tri-sodium phosphate and the "salts" slightly increases in volume. However, the same effect does not occur in the case where the "Accoline" was used. Nevertheless, the joint effect of the "Salts" and the "Accoline" on the smoothness and the uniformity of the puffed texture is still as great as that with the tri-sodium phosphate. (See Fig. 19 (d) and (e)).

Monosodium glutamate was used only in trace amount (0.2%) so it was expected to contribute no significant effect on the puffability of the product. It was included only to accentuate the flavour of the product.

iii) <u>The effect of grinding on the puffability of the fish product</u>: The effect of grinding on water-holding capacity of meat has been discussed in some detail in Section I (p49). It should be emphasized here, however, that the extent of grinding of the fish flesh has a great bearing on the smoothness and the extent of gelation of the paste. These, in turn, affect the uniformity and continuity of the texture of the dry paste, and the puffability of the product as a whole. The longer the duration of grinding the more complete is the destruction of the muscle fibres.

The long duration of grinding in a "Kenwood Mixer" has some disadvantage that it tends to increase the temperature of the paste locally around the cutting blade.

Good care must be taken also to ensure the thorough circulation of the paste around the mixing bowl so that the paste is uniformly pulverised. The increase in the temperature can be as high as 150°F. This, according to Hamm (36), has a detrimental effect on the water-holding capacity of the paste. Hence in the experiment cold water was added to the chopped flesh before the pulverisation to offset this effect. Also the mixer was frequently stopped and the paste was stirred with a spoon intermittently to allow it to cool down. Great care was also taken to ensure that the paste was uniformly circulated and the "salts" distributed evenly.

It was found that for 300 gm. of the flesh, including added water, pulverising with the kitchen size "Kenwood Mixer" at speed 4 for 20 minutes is sufficient to give a smooth paste, sufficient gelation, and hence good puffing.

(iv) The effect of drying: The essential changes that occur during drying of the paste are the further gelation of the paste and the reduction in moisture content. Further gelation is caused by: (a) the alkalinic condition of the paste which causes the swelling of the fish collagenous proteins. In other words the phosphate salts and NaCl cause the hydrolysis of the collagen to gelatin which in turn forms the gel network of the paste (42), (49); and (b) the heat of 110°F (43.4°C) exploits one of the outstanding characteristics of gelatin i.e. its ability to form a sol around 35°C or higher temperatures and, with sufficient concentration, form a gel at lower temperature (49), (42).

The prolonged duration of heating during drying (36 hours) reduces the moisture down to the puffable level. The moisture retained in the dry paste after the drying period will, of course, vary with the water-holding capacity of the paste which has been increased by the addition of the salts.

It is conceivable at this stage then that the salts play an essential part in the earlier stage of the process. They increase the water-holding capacity of the paste to the optimum level. They also help form gel networks. Drying plays an essential part in the later stage to help form gel networks and reduce the moisture down to a desirable level.

It was found that the better results could be obtained if the partly-dried paste was carefully turned over at least once. This may be due to the fact that by doing so the paste is dried uniformly with less solid migration, if any, to any one surface.

The final moisture content of the dry paste is very important as has been previously discussed. It was found that after drying at 110°F for 36 hours if the dry paste was left in the atmosphere (about 55°F and 70% R.H.) overnight, the moisture content of the paste will be, more or less, around the optimum level. This coincidence is of great advantage as it may be quite impractical commercially to equilibrate the large bulk of dry paste under a specific atmosphere for 5 to 6 days prior to puffing, or packaging for shipment. However, prolonged exposure to the ambient atmosphere may result in slight reduction in the puffed volume (Table 10).

(v) <u>The effect of added sodium caseinate</u>: The results from Table 8 clearly show that, provided with the right moisture condition, the pulverised fish flesh with the addition of 10% sodium caseinate as a gelling agent can be puffed very satisfactorily.

These results show, however, that the gel structure induced by added phosphate salts is as good, or even better, than that formed by sodium caseinate as far as the puffability of the fish product is concerned. It may be even disadvantageous to use the sodium caseinate powder as more water is needed to dissolve the powder than it is needed for pulverising the fish flesh alone. This means more water to be dehydrated.

Nevertheless, the gelling agent has its advantages that it gives the smoothness to the puffed-texture and to the taste sensation in the mouth. It reduces the amount of fish used for the same amount of product while retaining or even improving its nutritive value. Furthermore, the extent of pulverisation of the flesh need not be as complete as when the salts alone are used.

(vi) The effect of freezing of the paste prior to drying:

An observation was made on the effect of freezing on the puffability of the fish paste by subjecting the paste of optimum pH adjustment to the freezer for 5 hours. The paste was first rolled into a cylindrical shape of about 1 inch in diameter prior to being frozen. The frozen rolled was sliced to thin pieces of about 1/16 inch thick, then dried in the usual manner.

The dried slices were puffed in the hot fat. The moisture and puffed volume of the slices were not recorded but it was noticed that though the slices puffed well and the product texture was uniform, the expansion of the texture was not as great as those of unfrozen product. This reduction in puffed volume can be attributable to the effect of freezing on gel texture which has been discussed in some detail in Section I (p46). The moisture in the paste crystallised out and was not completely reabsorbed when thawed. Thus the continuity of the gel texture was somewhat broken resulting in reduced puffability of the dry paste.

One advantage in freezing, nevertheless, is that the hard roll can be sliced into thin slices easily while frozen. Hence the difficulties in spreading the paste thinly and uniformly on the trays otherwise can be avoided.

(d) Conclusion:

The phosphate salts have, at least, twofold effects on fish paste. They help induce the formation of gel networks of the paste by hydrolysing the fish collagen to gelatin, through which, may be, the water-holding capacity of the paste is increased. Different phosphate salt has slightly different effect on the water-holding capacity of the paste. However, both tri-sodium phosphate and the commercial "Accoline" were found highly satisfactory.

From the puffed product point of view, however, the "Accoline" tends to cause a "burnt-flavour" if the amount applied is too high. Also the salt tends to migrate, during drying, to the surfaces of the dry paste forming white powdery spots on the surfaces. Furthermore, for the same amount of salt the tri-sodium phosphate is more effective in shifting the pH of the paste upward.

To improve the texture of the product small amount of a gelling agent like sodium caseinate powder can be used effectively. NaCl and monosodium glutanate can be used to great advantage to improve the flavour as well as the texture of the product.

As a snack product, the puff-fish product undoubtedly has a great potential in food markets. It can be regarded as a nutritionally upgraded Asian product, or as a novelty, a new refinement of a reasonably cheap protein source.

(III) Meat:

(a) Introduction:

After the successful experiment on fish it was decided that meat which is another type of animal protein, slightly different from fish in its chemical and physical properties, should also be investigated.

Meat has not been exploited by the Asian as a puffed product possibly because it is less available and more expensive than fish. It also may be because meat from the Asian stock is generally very tough due to the inferior breed of the stock. The age at which the animal is slaughtered is usually high and cattle will often be sent to the slaughter-house when it has passed its useful age on the paddy field. Thus it is presumably much harder, by their conventional method, to manipulate the meat to puff as well as fish.

In more developed societies, however, meat can be obtained in many different grades. The meat is graded according to many factors such as the age of the animal, colour of the meat, texture, character and size of rib bones, and carcass weight for example (49). The tenderer meat will, of course, be easier to be processed and puffed.

The texture and composition of meat have been discussed in some detail in Section I (p 41.). There are three main factors that we are most concerned in manipulating meat to puff. They are the fibrous nature of the muscle, the amount of connective tissue, and the amount of fat and adipose tissue. Muscles differ in tenderness, shape, weight, fat content, collagen content, elastin content, and colour. The variation in the texture or grain of muscles is caused principally by the size and amount of connective tissue. The microscopic appearance of fibres in some muscles also differs from that of fibres in other muscles (49).

The proximate composition of the edible meat is 67.0% water, 19.3% protein, 13.0% fat and 0.95%ash (76). Collagen proteins constitute about 35.5% of total protein (49).

In preparation of meat before processing most of the adipose and connective tissues are trimmed off as it is known that they are inhibitive to puffing.

The subsequent processing technique of the meat is quite similar to that of fish.

(b) Experimental:

Material: i) The meat used was beef steak bought fresh from the butchery.

ii) All other materials used are similar to those for fish processing.

<u>Procedure</u>: Most of the adipose and connective tissues were first trimmed out of the meat. The trimmed muscle was chopped into small pieces. The chopped meat was then pulverised in the "Kenwood Mixer" with 30% added cold water and 2% "salts" (1.8% table salt and 0.2% monosodium glutamate). The pH of the very finely pulverised paste was adjusted by the phosphate salt solutions as was fish paste.

The sodium caseinate powder was also used as a gelling agent by dissolving it in an extra 70% water prior to the incorporation. The experiment with the sodium caseinate was divided into two parts:-

i) to determine the best level of the powder used, and

ii) to see if the pH adjustment with a phosphate salt will contribute any extra advantages to the product.

One portion of the sodium caseinate solution was added to the paste without pH adjustment, and the other portion to the paste after pH adjustment; after which both of them were homogenised in the mixer.

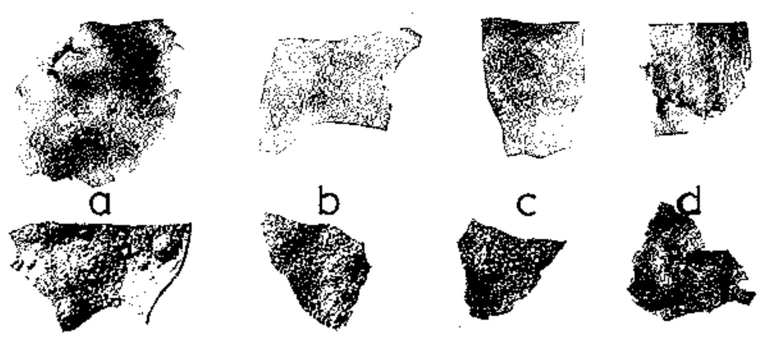
The pastes were spread and dried in the usual manner as were fish pastes. The dry pastes were equilibrated in the atmospheres of 43.6% and 74.9% R.H. for 6 days prior to puffing in the hot fat at 370°F for 40 seconds. The moisture contents and the volumes before and after puffing were recorded.

Result: Generally speaking the results from this experiment follow the same trend as those of fish in most respects, and results were therefore not repeated in detail. Typical data is tabulated in Table 11.

It was found that the optimum moisture contents required for best puffing of the meat product in all cases are slightly lower than those of fish product. Of all conditions used in the experiment, those products equilibrated in the atmosphere of 43.6% R.H. gave the best puff characteristics as compared to 74.9% R.H. for fish products. It was also found that meat needs a higher amount of phosphate salts i.e. higher pH level than does fish for good puffing.

The results tabulated below are the selected optima for each case considering the puffed volume and overall characteristics of the product. They all were equilibrated under the same atmosphere of 43.6% R.H. for 6 days before puffing.

Photographs of some unpuffed and puffed products are also shown in Fig. 20A, 20B, and 20C.



a) With tri-sodium phosphate, pH 7.4, 74.9% R.H.

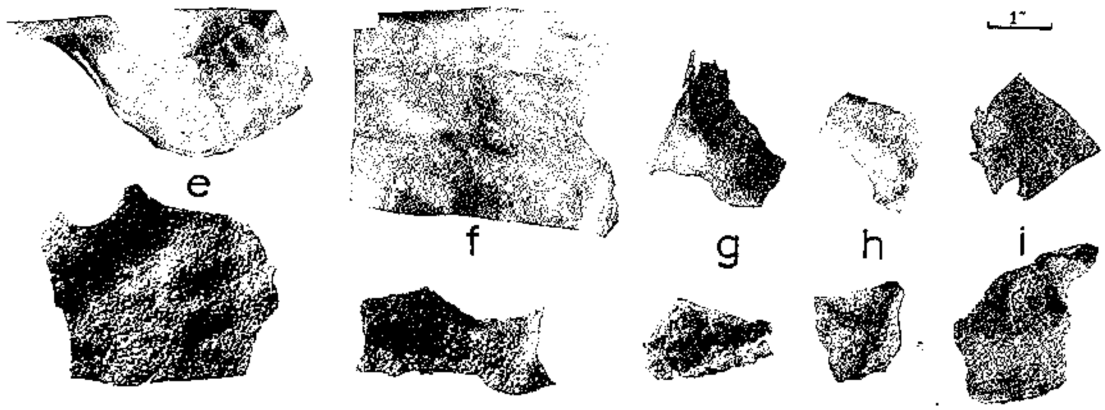
b) " " " " , and "salts", pH 7.45, 74.97% R.H.

c) " " " " , " " , pH 7.8, "

d) " " " " , " " , pH 8.15, "

(upper row : unpuffed; lower row : puffed)

FIG. 20A <u>Effect of pH on the puffing characteristics of meat products</u>:



e) With "Accoline", pH 7.18, 74.9% R.H.

f) " " , pH 7.55, "

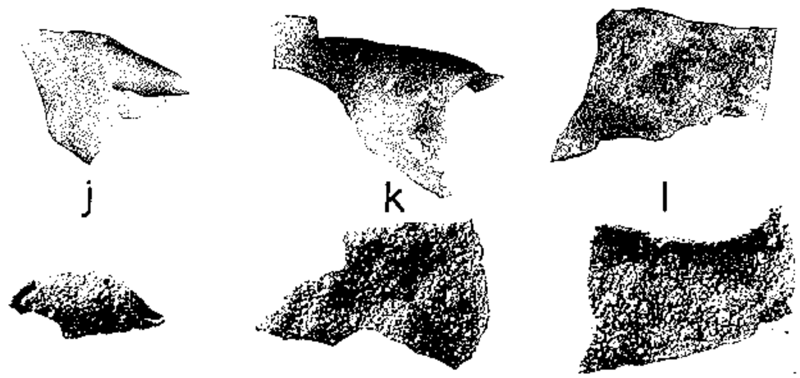
g) " " , and "salts", pH 7.45, 74.9% R.H.

h) " " , " " , pH 7.7, "

i) " " (Excess)" " "

(upper row : unpuffed ; lower row : puffed)

FIG. 20B <u>Effect of pH on the puffing characteristics of meat products:</u>



j) With 5% Sodium Caseinate and "salts", 43.6% R.H.

k) " 10% " " " " , "

l) " 5% " " " " and tri-sodium phosphate, pH 7.7, 43.6% R.H.

(upper row : unpuffed ; lower row : puffed)

FIG. 20C <u>Effect of gelling agent and salt on the puffing characteristics of meat product:</u>

Table 11. The Moisture Contents and Volumes of Meat Product:

Meat	% Moisture		Vol./wgt., c.c./gm		
	Before Puffing	After Puffing	Before Puffing	After Puffing	
				As Is	wgt. Before Puffed Basis
Control (Untreated) pH 5.5	12.59	2.30	1.0	1.0	0.89
+ Na_3PO_4, "Salts" pH 7.4	16.65	1.85	1.0	1.5	1.75
+ "Accoline", "Salts" pH 7.45	17.82	2.85	1.0	1.4	1.70
+ 5% Caseinate pH 6.8	10.75	1.55	1.0	1.8	2.05
+ 10% Caseinate + "Salts" pH 6.8	10.79	1.44	1.0	2.3	2.60
+ 5% Caseinate; Na_3PO_4 pH 7.7	12.05	1.90	1.0	1.7	2.04

(c) Discussion:

Two major factors responsible for lower puffed volumes of the meat products, as compared with those of the fish products, are:

i) Fat content of the meat: Although most of the adipose tissue was trimmed out prior to pulverisation, this does not mean, of course, that the amount of fat left in the muscle is negligible. In fact, a high proportion of meat fat is also deposited intramuscularly and known as marbling. Such fat is known to increase the tenderness and juiciness of the meat (41) and the amount of it in a particular muscle of an animal may vary in different locations of the same muscle. The fat content of the beef muscle was found to vary from as high as 20% to as low as 10% (49), (57). This fat was dispersed throughout the paste on pulverising.

When the paste was dried, an appreciable amount of "oiling-off" occurred. Both surfaces of the dry paste became quite oily, the continuity of the gel structure of the dry paste was quite obviously inferior to that of dry fish paste. However, it was found that the "oiling-off" was reduced to some extent with the increasing amount of the phosphate salts added. This increase in pH values contributed to the slight improvement of the texture and volume of the puffed product, as one can see on Fig. 20A and 20B. The products of higher pH tend to be more uniform in their texture which consisted of minute air bubbles more evenly distributed, as compared with the ones with lower pH. This is due to the fact that the phosphate salts are very good fat emulsifying agents (83), (71). Hence phosphate salts, in this case, perform two functions. Firstly, they disperse the fat globules evenly throughout the paste, thus reducing "oiling-off". Secondly, they increase the water-holding capacity of the paste, and hence improving its gel texture. However, over-use of the salts can adversely affect the product as will be discussed later.

(ii) Fibrous nature of the beef muscle: It is obvious that meat muscle fibres are generally much tougher than those of fish. This is clearly apparent in the greater difficulty experienced in the pulverisation of the meat. A much longer time was needed to convert the muscle to a smooth paste. Even so much of the fibre was still present in the dry paste. This resulted in a tough fibrous paste, not as friable as the fish paste. In some cases where the moisture was high and the oiling-off was greater, much force was needed to tear the dry paste apart.

The fibrousness of the dry paste obviously increases the puffing resistance of the paste considerably. (See Section I. p. 49.). The high resistance to the expansion of the texture resulted in much reduced puffed volume of the product. The increase in pulverising time and the reduction of the thickness of the dry paste by spreading the paste on the trays more thinly may offset the effect of the fibrousness to some extent.

To attain optimum moisture levels for good puffing, which is slightly lower than that of fish products, the dry meat paste was equilibrated in the atmosphere of 43.6% R.H. This indicates that in general the meat paste possesses a greater capacity to hold water than fish paste at the same pH level (compare results in Table 8 and Table

11). This could be partly due to an optimum fat content in meat (36). It also indicates that the meat product requires less moisture for puffing. Thus the greater amount of the phosphate salt required by meat product is not to increase its water-holding capacity, but mainly to assist in swelling the tough muscle fibres, and in forming gel structure. The phosphate salt is also needed to disperse the fat globules in the paste.

There is no significant difference between the tri-sodium phosphate or the "Accoline" as far as the puffed volume is concerned. However, the "Accoline" tends to give smoother product texture at the same pH level (See Fig. 20A and 20B). As it had been experienced with the fish product, more "Accoline" was required to give the same pH level than tri-sodium phosphate. This created a few problems.

i) At pH 7.6 and over the "Accoline" - added product seemed to give a burnt or hot sensation in the mouth.

ii) Both tri-sodium phosphate and "Accoline" tended to accentuate the saltiness of the products at pH 7.5 and above.

iii) At pH 7.6 and over the dry "Accoline" - added paste, after a few weeks storage underwent recrystallization of the salt on the surfaces.

The white, mould-like colonies were formed on both surfaces, especially on the thicker pieces. Under the microscope, the rhombic-shape phosphate crystals were identified. A similar experience has also been noted in and on the surface of cured meats prepared with polyphosphates (83). The crystals formed in the case of cured meat have been identified as di-sodium phosphate resulting from the hydrolysis of the polyphosphate. The same is thought to happen in the puffed meat product, and the control can be achieved only by the use of reduced levels of the phosphate.

The use of sodium caseinate powder as a gelling agent proves to be slightly more effective than pH adjustment to obtain high puffed volume and good product texture (See Table 11 and Fig. 20C). The product is smoother and crisper on eating. It markedly reduces the grittiness of the fibrous texture of the puffed product otherwise strongly experienced on eating the pH-adjusted products.

No significant advantage is noted in coupling the use of the sodium caseinate with pH adjustment with the phosphate salt. The product containing an added 5% sodium caseinate with the addition of the tri-sodium phosphate to pH 7.7 puffed to very similar volumes as did the same product without pH adjustment (Table 11 and Fig. 20C). A difference is reflected however in slight variations in the flavour and taste of the products, and the former proved to be saltier with less acceptable flavour.

The optimum level of the sodium caseinate used was found to be 10% fresh meat weight basis. This gave a significantly higher puffed volume and smoother texture (Fig. 20C (k)).

(d) Conclusion:

Tough muscle fibres and high fat content are two major problems in meat affecting its puffability. The pulverisation of meat to destroy the fibres and the manipulation of its pH by the use of the phosphate salts and NaCl have proved once again to be the important tool to promote the puffability to this type of food.

It takes more time and energy to destroy the meat muscle fibres, than does fish, to the puffable condition. A greater amount of phosphate salt is also needed, but for slightly different purposes. The functions of the salt in this case are primarily to promote the gel structure by softening the muscle fibres and dissolve the meat proteins, but its function is also to disperse the meat fat globules.

The use of a gelling agent like sodium caseinate is more effective in this case than it was in fish. It gives superior products to those derived from the use of the phosphate salts, and may, therefore, be a more advisable technique.

As for fish, the meat product offers a great potential for food marketing particularly perhaps in the utilization of tougher or lower grades of raw material. A meat product equivalent to the already accepted and popular types of fish puffs marketed in Asia could be of potential export value.

S E C T I O N   III

PUFFING TECHNIQUES OTHER THAN DEEP FAT FRYING ESPECIALLY FOR QUICK REHYDRATION OF THE PRODUCTS

A. Review on Different Heat Shock Techniques:

1. Introduction:

There are three conventional heat-shock techniques that have been widely used for puffing in many Asian countries. The more common technique of these is the deep-fat frying technique, which was also used in most of the experiments for this thesis. Perreau (60) has already described the technique in sufficient detail.

The other less commonly used technique is an "open flame heat shock puffing". It is used for a number of particular Asian puff-products that do not require fatty flavour e.g. the sweet glutinous rise wafer in Southern Thailand. The technique is extremely simple. The good flame is obtained from a sufficient amount of fire wood which is lighted in either open air or in a relatively primitive brick furnace. A bellows may be used occasionally to help increase the flame temperature. The product, supported on a wire net with a long handle, is then pushed into or over the flame and frequently turned over until the product is fully puffed which requires only a very short time. The extent of puffing and the texture are estimated to be as good as can be obtained from the deep fat puffing but with no problem of fat pick-up and the flavour of the product is very desirable.

The third technique is also widely used but for a wider range of products. It is a hot "sand bed" or "salt bed". A fine grain salt or sand, forming a sufficiently thick bed on a steel-round bottom pan, is heated over a furnace to a sufficiently high temperature. The product is then put onto the bed and is actually mixed and covered with the "bed" by stirring and turning the bed and the product over frequently until the product is cooked or fully puffed. This also requires only a short time. The technique is applied to products such as roast peanuts in the shell and puffed rice for example. However, there is a problem of very fine grains of sand or salt picked up by the product.

The second technique may be compared to a radiant heat shock technique. The third has been developed, with more refined knowledge of science, into a modern heat shock technique called "fluidized bed heating".

The experiments in this section were aimed toward investigating the possibility of puffing by other heat shock techniques that do not involve fat. The product may, then, rehydrate more readily, possess fat-free flavour, and avoid the risk of fat oxidation on storing. These techniques are, in fact, similar to modifications of dehydration techniques which in recent years have been developed and put into commercial use. Many driers may be adaptable to high temperature conditions for product exposure including tunnel drier, belt trough drier, and fluidized bed drier, to name a few; and in more recent years several units have been especially designed for high temperature - short time processes such as gun puffing technique, radiant heat drier, and microwave drier. These techniques can be successfully used for puffing purposes if they can be modified to fulfil the requirements of the puffing technique. That is to be able to quickly transfer heat at sufficiently high temperatures to the food gel and to create sufficient moisture vapour pressures. The heat in the process will also soften the gel to an optimum thermoplasticity so that the pressure can expand the texture and the total evaporation results in a puffed product of porous texture. Some of these techniques have been employed successfully and are discussed in more detail.

2. Discussion on Various Heat Shock Techniques:

(a) Heat Shock with Heated Air: Heated Air has been used in many types of drier as a heating medium. In a kiln drier, the product is dried with hot air rising from a furnace located on the ground floor of a small, square two-storey building through the slotted floor of the second storey. The product, usually fruit, is dried as a batch. The traditional kiln relies on natural draft to provide sufficient circulation of air up through the moist material, but the exhaust fan is used in more modern units (80).

In a tunnel drier, operated on a batch basis, trucks or trays are directed through a compartment or compartments operated in series. The heating systems used are of two basic types; direct combustion heating and indirect heating. In the first system the gaseous products of combustion are mixed and circulated with the drying air and hence come in direct contact with the product in the drier. In the second system the products of the combustion are not circulated with the drying air. Heating surfaces such as steam-air heating coils are used to transfer the heat from the primary source to the drying air. The first system is, of course, more efficient as there are no transmission losses. A gaseous fuel is usually preferred to fuel oil, in this system, for many reasons including, particularly, the less likelihood of the effect of the products of combustion on product quality (80), (46), (61).

The tunnel drier has been modified into, perhaps, more efficient drier with the addition of a belt-conveyor or screen-conveyor to make it truely continuous (61). The cross-flow of the drying air is frequently employed. Such as in a belt-trough drier (80) which consists essentially of an endless, closely woven, metal mesh conveyor belt supported between two horizontal rolls with a great deal of slack so that it hangs freely. The hot, dry air comes up through the grate at the bottom of the trough. Also a through-flow continuous conveyor drier which represents the completely mechanized development of equipment for drying food material in hot circulating air (80).

However, all these driers are operated at relatively low temperature over relatively long drying cycle for the benefit of best product quality. The temperature of the inlet air in most cases rarely rises above 300°F; 275°F in case of the belt-trough drier and 200° to 260°F in case of the continuous conveyor drier (80) for example. For heat shock puffing, however, the combination of a high temperature - short time is the primary requirement. The system works on the rapid build up of the internal steam pressure to expand the sufficiently softened gel structure into a porous texture with the quick subsequent evaporation of the moisture vapour. To achieve this further modifications of the above mentioned driers would be necessary. The aims are to provide a sufficiently high drying air temperature, and a suitable conveying speed of the product through the drier.

Attempts have been made to puff a food gel in a packaging shrinkage tunnel. This tunnel was designed to shrink a film packaging material such as polythene film with heated air so that the material inside the film is tightly wrapped. It consists of an endless screen conveyor moving through a small square tunnel at a fixed speed. The air is blown through a set of heating coils into the tunnel through the roof of the tunnel. There is a metal flap at each opening of the tunnel to retain the air for circulating internally and help maintain increased temperatures. The temperature of the heating air can be increased up to the maximum of 500°F.

During the trials it was found, however, that the conveyor speed was too fast. So it was decided not to pass the food gel through the tunnel by the conveyor but simply to support the material on a wire net, with a long handle in a central location in the tunnel. The temperature of the tunnel was set at its maximum.

Good signs of puffing were obtained from the trials on the sodium caseinate gels and dry fish paste. The heat transfer was uniform as the texture of the gels was affected uniformly. The heating air temperature, however, was found to be too low. It took as long as 5 minutes in some cases to show any sign of puffing, and the texture expansion was very slight.

Unfortunately, the air temperature could not be increased any higher with this equipment, but it was apparent, nevertheless, that similar equipment specifically designed for the purpose where the air temperatures could be increased to say 700°F and in which the conveyor speeds could be varied accordingly would be promising for puffing techniques. The puffing could be done continuously in such equipment. The product obtained would be satisfactory in quality as it would puff to a comparable volume with little risk of scorching or localized browning or burning because the heat transfer by forced convection was uniform throughout the pieces of the gels. No fat pick-up, of course, is involved and with uniform expansion of texture, products would be satisfactory for rehydration purposes, for grinding to powder, or even for being consumed as such.

(b) Fluidized Bed Heat Shock: The fluidized bed drier was developed primarily as a finishing drier to reduce final moisture contents of fruit or vegetable powders produced by primary driers (80). The process ensures the intimate contact between powdered or granular solid and a gas. It eliminates a localized zone of very high temperature which may be formed in a static bed in other types of driers. It is reported that the temperature throughout the mass in a fluidized bed rarely varies by more than 5° or $10^{\circ}F$ (52) and hence the product can be dried quickly and more uniformly and possibly more economically (61).

Sachsel (67) reported that this type of drier could be modified for a cooking process. The fluidized bed cooker could be said to be a modification of a static hot sand or salt bed used in Asian countries as mentioned earlier. A fluidized bed drier is operated by passing hot air or gas through the perforated bottom of a container of fine solid particles at a flow rate that expands the bed significantly and causes the solids to act much like a boiling liquid. The fluidized solids take the shape of their container, seek their own level, exert hydrostatic head, and have a much lower apparent density than the particles themselves. The vigorous mixing of solids and fluidizing gas leads to remarkably even temperature conditions in the bed. Heat transfer from an external source to an object suspended in a fluidized bed is extremely rapid. The bed materials suggested include common salt, tricalcium phosphate, sugar, limestone - salt mixtures, beans, monosodium glutamate and lentils (67).

The technique has been used very successfully for cooking green cashew nuts, raw potato slices, onion rings and breaded shrimp. The noted advantages of the method are quick cooking time, uniform temperature, and precise control over the time and temperature.

Ferreau (60) applied this technique as an alternative puffing technique to overcome the problem of fat pick-up associated with fat frying and to get some measure of control on the extent of puffing. He experimented on puffing of starch gel using fluidized salt bed temperature of 380°F and reported that at the same temperature puffed volumes obtained by heating in fluidized salt were about half those obtained by fat frying techniques.

In our experiment, the salt bed temperature of about 400°F was applied to puff sodium caseinate gels, cheese products and carrot slices. Although no experimental results were recorded, it was noted that all the products puffed well. The colour and flavour of the products improved significantly. There were, however, risks of non-uniform puffed texture and some localized brown spots due, probably, to localized "hot spots" in the bed. The puffed volumes were also slightly reduced in comparison with those obtained from fat frying. The adherence of the salt to the surfaces of the products was also a problem.

However, with careful design of specific equipment, it is believed that many of these problems could be overcome. For snack-type products like cheese, slight adherence of the salt on the product surfaces could be of advantage in improving the flavour and taste of the product. For products to be rehydrated e.g. carrot slices, the freedom from fat pick-up, the improvement in colour, and even the slight adherence of salt could also be of benefit to the end product.

(c) Microwave Heat Shock: Microwave cooking is of comparatively recent origin and has still found rather limited application. Many recent works have been done on the development of the energy generators and the application of the microwave heating technique. More powerful and versatile microwave generators have been invented, as well as new applications of the microwave have been found.

Microwaves, by definition, are electromagnetic waves differing from the more familiar light waves and radio waves only in frequency and wavelength (44). The waves, like light, travel in a straight line passing through some substances which are transparent to them, and reflected by others (29). The molecules of the material through which the microwave passes act as if they were magnets which try to orientate themselves in the electrical field, and consequently the molecules oscillate around their axes producing intermolecular friction which results in volume heating of the substance. Some materials exhibit more intermolecular motion than the others. The degree of this motion varies irregularly with frequency, temperature, and the nature of the material. The greater the degree of the motion the greater the absorption of the microwave energy and the greater the production of heat (15), (31).

Microwave energy penetrates to a considerable depth into a substance which is being heated. The depth depends on the transparency of the material, the microwave frequency, dielectric constant, and temperature. To get uniform heating, low frequencies of 900 to 3000 megacycles/second are preferable. Among these frequencies, that of 2450 Mc/s has been allocated particularly for heating purposes (4).

Gall and La Plante (28) reported that the microwave band with a wavelength of about 10 cm (2450 Mc/sec) was selected for industrial use because:

i) The frequency is high enough to permit power densities for industrial use without objectionable electric field strengths.

ii) There is still a reasonable penetration depth in most materials.

iii) It has proved possible to construct generator tubes of a suitable power and a reasonable price, life and efficiency. For example, the magnetrons designed for continuous power output of 2 kw and 5 kw at 2450 Mc/sec. give an efficiency of 50 to 60% with the operating cost at about 3.5 cents per RF kilowatt - hour of operation for the 2 kw tube.

Bengtsson (2) and Decareau (18) report that the frequency of 2450 Mc/s give higher power density which results in shorter time to defrost meat of 4 cm. thick or less, but it has lower power penetration. The reverse is true for the frequency of 900 Mc/s.

More powerful generators have been developed, however, to overcome these limitations. The generating capacity has been pushed to 100 kw, for example. In 1965 the Raytheon Co. of America developed an electronic device which generates 425 kw of continuous microwave power at 3,000 Mc/s. Another American company has recently produced a resonant cavity in which thick blocks of frozen food can be thawed using 100 Mc/s frequency (29).

Many applications have been found for the microwave heating technique in food industry. The advantages of this technique, in comparison to the conventional heating techniques, rely upon its speed to heat the material which is extremely fast as it heats the food internally and independent of thermal properties such as conduction, convection, or radiation etc. Uniformity of heating, self-regulating, with respect to moisture, high efficiency, instantaneous reaction and low cost are other appealing properties of the microwave methods (21).

Many papers have been published recently dealing with new applications of microwave heating in food industry.

Bengtsson (2) and Decareau (18) reported the possibility of application of microwaves in defrosting of frozen products. Jeppson (44) stated that faster thawing could be achieved in a tunnel fitted with a conveyor and using a high power magnetron source with emission of microwaves at 915 Mc/s. A thawing cycle could be reduced from hours to minutes, and with homogeneous materials the thawing was extremely uniform.

Copson (15), and Decareau (18) suggested the use of microwave in the drying cycle of freeze-drying process to get more uniform and complete drying and a better product.

In their recent publications Sherwood (72) and Gall (27) dealt with the use of microwave heating in catering. They advocated the hygienic and nutritional superiority of the food cooked or reheated with microwave, and especially the amount of time saved in cooking.

Blanching, pasteurisation, and sterilization of foods can also be accomplished with many advantages with microwaves (31), (59), (44).

Garrick (29) reported that potato chips fried with microwaves had less fat content, longer shelf-life, and no off-flavour.

A more dramatic use of microwave heating is in baking. Ward (82) reported that if electronic ovens are used in the colouring and drying stages of the baking of biscuits, a superior quality article could be produced. The output could be increased by 40 - 50%. The product would be drier, more porous, of longer shelf-life, and of better eating quality.

Geddes (30) reports that partially dried apple sections and diced potatoes can be successfully puffed under microwave energy to produce a high quality morsel of superior colour and shape. The apple sectors and diced potatoes are first dried in a conventional drier to about 20 to 30% moisture. The partially dried pieces are then placed in the microwave oven for 5 to 10 minutes where the penetrating heating action of the microwaves causes them to become thermoplastic, and the accompanying rapid generation of water vapour within the pieces causes them to puff. Cooling in a vacuum chamber at 20 to 100 mm Hg absolute pressure is needed to maintain the puffed texture of the apple sectors which otherwise will tend to collapse. The products increase roughly 300% in volume and rehydrate very well.

Note that the collapse of the puffed texture has also been experienced in our work on puffing of raw carrot slices and sodium caseinate gels with high sugar contents. It can be expected, then, that the method of cooling of products in a vacuum chamber immediately after puffing can be applied to those products likewise.

Attempts have been made to puff the sodium caseinate gels and meat and fish products by microwave heating. Unfortunately, the only microwave unit that was available for our work was an extremely small unit used for physiotherapy purposes in the local hospital. The energy it generated was too low to create sufficient heat for puffing. However, some initial signs of puffing were detected with sodium caseinate gels after subjected to the treatment for about 5 minutes.

Despite the lack of experimental knowledge in this field, the author strongly believes that microwave heat shock, with its internal and selective heating properties, can prove to be one of the most valuable tools for puffing of food gels for either direct consumption or rehydration purposes.

(d) <u>Gun-Puffing Technique</u>: A puffing gun has been employed successfully to dry 3/8 in. diced potatoes, carrots, beets, apples, and whole blue-berries.

It is reported (23) that the technique offers at least two important advantages:

i) It gives the product a porous structure.

ii) It permits rehydration in 4 - 5 min., in contrast with 20 - 30 min. for most conventionally dried produce.

Wilson (84) also reported that gun-puffed celery pieces improved in texture and rehydration rate.

The puffing gun is a pressure vessel with a quick-opening lid, and the charge is about one-third the volume of the gun. The product must be first dried in a conventional drier to an optimum moisture content for gun-puffing, which varies among products, e.g. 25% for apples up to 40% for potatoes. The product is then transferred to the gun. The product is heated in the gun with steam pressures of up to 75 psi. At the optimum pressure the pieces are discharged and the flashing off of water vapour creates the desired porous structure giving faster final drying than in orthodox equipment and more rapid rehydration characteristics in the product (23).

It is very interesting to note here that the mechanism by which the product is puffed in the gun is strikingly similar to the heat shock puffing of food gels in our experiments. The only major difference is that the puffing of the food gels is done in atmospheric pressure; and the expansion of the texture relies on the degree of the vapour pressure developed internally and the thermoplasticity of the gels while heated. Presumably, thermoplasticity of the product is less important in gun-puffing than in the conventional puffing technique.

In gun puffing, there are two critical factors namely the moisture content of the piece as it enters the gun, and the pressure to which it is subjected prior to puffing. The optimum pressure, as does the moisture, varies with various products. It ranges from 25 - 30 psig. for apples to 60 - 65 psig. for potatoes. Wilson (84) states that high moisture content and low pressure is most suitable for gun-puffing celery pieces.

The reconstituted puffed dice has proved to be superior organoleptically. Shorter drying time guards the flavour, and the product's porous texture permits very fast rehydration and good return to original shape.

The final drying cost may be higher than that of the conventional driers, but the superiority of the product may be sufficient to offset this disadvantage.

No experimental work has been done in our laboratory pertaining to gun-puffing due to lack of facilities. It is anticipated, however, that food gels can also be puffed successfully in the puffing - gun as the puffing mechanism of both techniques are basically similar. The gun-puffing technique may cater for wider range of products for rehydration purpose, as there is less limitation concerning process requirements. However, for snack type product the conventional puffing technique may still be most suitable and economical.

(e) Radiant Heat Stock Technique: Radiant heating is absorption and conversion of radiant energy to heat energy. The radiant energy is absorbed on the surface and heat is conducted inward. In an outdoor barbecue, for example, the heat is transferred to the meat or other food by radiation from the glowing fuel. Some of this heat is transferred by conduction through the heated holding vessel (45).

Some commercial radiant heaters are, for example, infrared lamps, heated silica glass tubes, heated boro-silicate glass panels, and muffle furnaces whose emission temperatures range from 820° to 4073°F or higher.

Infrared heat sources have been used for drying paint, ink, paper, powders, food products, and grain. Infrared is, like microwaves, a band of electromagnetic waves whose lengths range from 0.7 micron to 100 microns (35). Infrared energy is associated with heat in that it is radiated by hot bodies. The absorption of infrared radiation results in heating the absorbing material. Radiation of infrared energy arises from vibration and rotation phenomena associated with molecules at surfaces of radiating body. The total quantity of energy radiated is proportional to fourth power of the absolute temperature. The radiation and absorption is dependent upon characteristics of the surface called "emissivity of the surface" (58).

Nelson (58) and Proctor and Goldbrith (64) reports that in many drying applications, where direct surface absorption of heat is desired, the infrared energy is successfully employed. It gives faster drying than most conventional drying methods. It also gives a significant increase in heat yield in drying.

Person and Sorenson (62) state that in the drying of alfalfa the higher the radiation intensity, and the longer the exposure period the greater is the rate of moisture removal. They also advocate an extremely short time of exposure for the high intensity levels to avoid scorching of the product.

Hall (35) suggests that infrared heating is suitable for a thin layer of the product as it provides rapid means for heating and drying. It should be anticipated then that infrared heating might provide one of the best heat shock puffing technique for thin food gels.

The production of infrared electromagnetic radiation is done commercially with electric filaments or flames from fuel (35). Electrical filaments are used for wide range of temperatures. By decreasing or increasing voltage, the radiation energy can be decreased or increased as required.

Some attempts have been made to puff food gels with an infrared lamp in our laboratory. Unfortunately, the lamps available are too small and the energy they emit is not sufficient to puff the gels to any satisfactory extent. Some signs of puffing were detected, however, after subjecting the gel to the heating for about 10 minutes. With more suitable equipment, perhaps, the technique could be more successfully exploited.

In a muffle furnace, the furnace is so built that its charge of product is separated from the burners and combustion gases by a refractory arch. Heat is transferred by hot - gas radiation and convection to the arch, and by radiation from the arch to the charge (61). In a laboratory size furnace, radiation temperatures of up to about 1000°C can be attained.

Electric heating may be employed to many advantages instead of gas burners in a muffle furnace. It provides high temperatures, safety and convenience, cleanliness in the absence of combustion by-products, and rapid response and uniformity of temperature which can be precisely controlled. By using the resistance heating which is the direct application of a voltage to a resistor, the efficiency of conversion of electrical energy into heat may be as high as 100% (61).

Joselyn and Heid (45) state that low initial cost, fast heat-up, efficient conversion of electric energy to heat energy and easy installation characterize radiant heaters. They also suggest the possible applications of heating and drying of thin products on conveyor belts.

The electric muffle furnace was employed very successfully to puff food gels in our laboratory. The details of this work will be reported and discussed in the next section.

B) Radiant Heat-Shock Puffing Technique and the Rehydration Rates of its Products:

1. Radiant Heat-Shock Puffing Technique:

(a) Introduction: Open flame puffing has been practised in Asian countries for centuries. It is, of course, a rather primitive but effective way of employing radiant heat. On the persuit of non-fat puffing techniques, with the inspiration of this knowledge and some preliminary work on the subject performed by Perreau (60), a laboratory size electric muffle furnace was employed to study the technique in more detail.

The aims of the study, were to determine the best conditions, i.e. temperature of the furnace and the time of puffing, and to compare the puffing characteristics of the products of this technique to that of deep-fat frying technique.

(b) Experimental:

Procedure: A 10% sodium caseinate gel was prepared by dissolving 10 parts sodium caseinate powder in 100 parts of hot water. The homogeneous solution was poured to a thin layer on plastic trays and dried in a drying chamber at 110°F for 36 hours. The final moisture of the dry sodium caseinate gel was determined by oven method (See Appendix).

A few small pieces of the dry gel were deep-fat fried at $360^{o}F$ for 10 seconds. The volumes of the gel before and after puffing were determined. The moisture content of the puffed product was also determined.

A "Gallenkamp" electric muffle furnace whose temperature range is 0^{o} to $1000^{o}C$ was used as a radiant heater. The temperatures registered on a built-in dial type thermometer were checked against a standard glass thermometer at various temperature levels and appeared to agree well within $\pm$ $5^{o}C$ of each other. The furnace temperatures recorded in the experiment were those read off from the dial.

The sodium caseinate gel was puffed at various furnace temperatures ranging from $260^{o}C$ ($500^{o}F$) to $650^{o}C$ ($1202^{o}F$). The gel was supported on a wire net with a long steel handle. The door of the furnace was quickly opened while the wire net with the gel was pushed into a heating chamber, and was partly closed immediately leaving some space for observation of the puffing action taking place inside. The time from the gel was pushed in till it was fully puffed, i.e. prior to turning slightly brown, was recorded by a stop clock.

The volumes and the moisture contents of the puffed gels were determined.

Result: Some problems were experienced in puffing the gels at relatively high temperatures, and in determination of

FIG. 21 <u>Radiant heat puffing of sodium caseinate gels:</u>

(a) Unpuffed (b) 215°C

(c) 350°C (d) 450°C

(e) 550°C (f) 650°C

(g) Deep-fat fried gel.

Table 12. Temperatures, Time, Moisture Contents and Volumes of Radiant Heat Puffed Sodium Caseinate Gels In Comparison to the Deep-Fat Fried Product:

Type of Heat Shock	Heat Treatment		% Moisture		Vol./wgt., c.c./gm		
	Temp.	Time Sec.	Before Puffing	After Puffing	Before Puffing	After Puffing	
						As Is	wgt. Before Puffed Basis
Deep-fat frying	182.2°C (360°F)	10	8.24	1.00	0.9	2.50	13.55
Muffle furnace	260°C	60	8.24	4.10	0.9	9.33	8.71
" "	350°C	20-50	8.24	2.79	0.9	12.50	11.50
" "	450°C	5-10	8.24	5.63	0.9	16.50	15.55
" "	550°C	3-5	8.24	5.82	0.9	17.00	16.10
" "	650°C	2-3	8.24	6.73	0.9	16.00	15.19

their puffed volumes. The gels of uneven thickness tended to puff unevenly, and some rather thin parts might be fully puffed and turning brown while the thick parts were still puffing. Good, uniform gel pieces were carefully chosen to overcome this problem. In volume determination, the puffed gels tended to rehydrate very quickly, so the average values were taken while the quick determination was performed to ensure the best results possible. The results are tabulated in Table 12.

The photographs of gels, unpuffed and puffed with both techniques at various temperature are also illustrated in Fig. 21.

(c) <u>Discussion</u>: Many differences in puffing characteristics between deep-fat fried and radiant heat puffed products have been observed and discussed.

i) <u>The effect of temperature and time</u>: It is clearly shown in Table 12. that to puff a gel to a comparable volume, temperature exerted by a radiant heater must be approximately 3 times higher than that needed in deep-fat frying. This is, of course, due to much lower heat transfer coefficients attained by means of radiation as compared with that of conduction-convection in hot fat, and hot air in a fluidized bed. The heat transfer coefficient for radiation heating in the muffle furnace at 600°C has been calculated, using the equation given in reference (61) and found to be about 5 - 15 B.T.U./hr. ft^2. °F, as compared with 200 B.T.U./hr. ft^2°F in hot oil at 400°F, and 20 - 100 B.T.U./hr. ft^2°F in a fluidized salt bed (60).

At the temperature of 450°C and higher it takes, in general, decreasingly less time to puff the gel to the full puffed volume than it does in the deep-fat fryer. At very high temperatures, e.g. 650°C, an extremely short time is needed to fully puff the gel. Consequently extreme care must be taken to take the puffed gel out of the furnace before it is completely charred or catches fire.

There seems to be an optimum temperature to give the best puffed product, as far as the volume and texture are concerned. The temperatures below or above this the puffed volume will be lower and the uniformity of the texture will be sacrificed (See Fig. 21 (e) and compare it with (f), (b), (c) and (d)). (The effect of the temperatures on the puffed volumes is graphically shown in Fig. 22). At lower temperatures the puffed texture consisted of bigger vesicles. The size of vesicles increases with decreasing temperatures, due to slower rates of heat transfer, and hence slower rates of evaporation of the vapour. The vapour pressure is so slowly built up that it allows sufficient time for small vesicles to merge with the bigger ones. It also allows the vapour pressure in any vesicle to expand the wall further before it is thin enough to let the vapour escape.

At higher temperatures, however, the vapour pressure is built up very quickly and, in fact, it shatters many vesicles. The heat may soften the structure further before the product is taken out of the furnace, and some parts of the puffed texture collapse to give reduced final puffed volumes.

ii) Moisture: The effect of moisture contents of gels prior to puffing in the furnace follows the same trend as that in hot fat. The gels of higher moisture contents were puffed in the furnace, and the results invariably showed that the bigger air bubbles were formed with the higher moisture contents at all temperature levels. In fact, at very low temperatures and high moisture contents the hollow "pillow-case" type of puffed texture tended to be formed. Hence moisture contents of 10% and lower are most suitable for sodium caseinate gels with a radiant heat puffing technique.

It is interesting to note that the moisture retained in the puffed product tends to increase with increasing puffing temperatures (See Table 12). This emphasizes the fact (as has been commented on earlier) that the particular portion of total moisture that really contributes to the expansion of the structure is in a multimolecular region and not the tightly bound water in the monomolecular region. In fact, it takes only a small amount of the "free" moisture to puff the whole structure, e.g. 2.42% at 550°C and only 1.51% at 650°C. At higher temperatures the time taken to fully puff the gel is so short that the heat energy accumulated is insufficient to evaporate the more tightly bound water. The higher moisture retained may contribute to a slightly softer product texture and the collapse of some bubbles at 650°C.

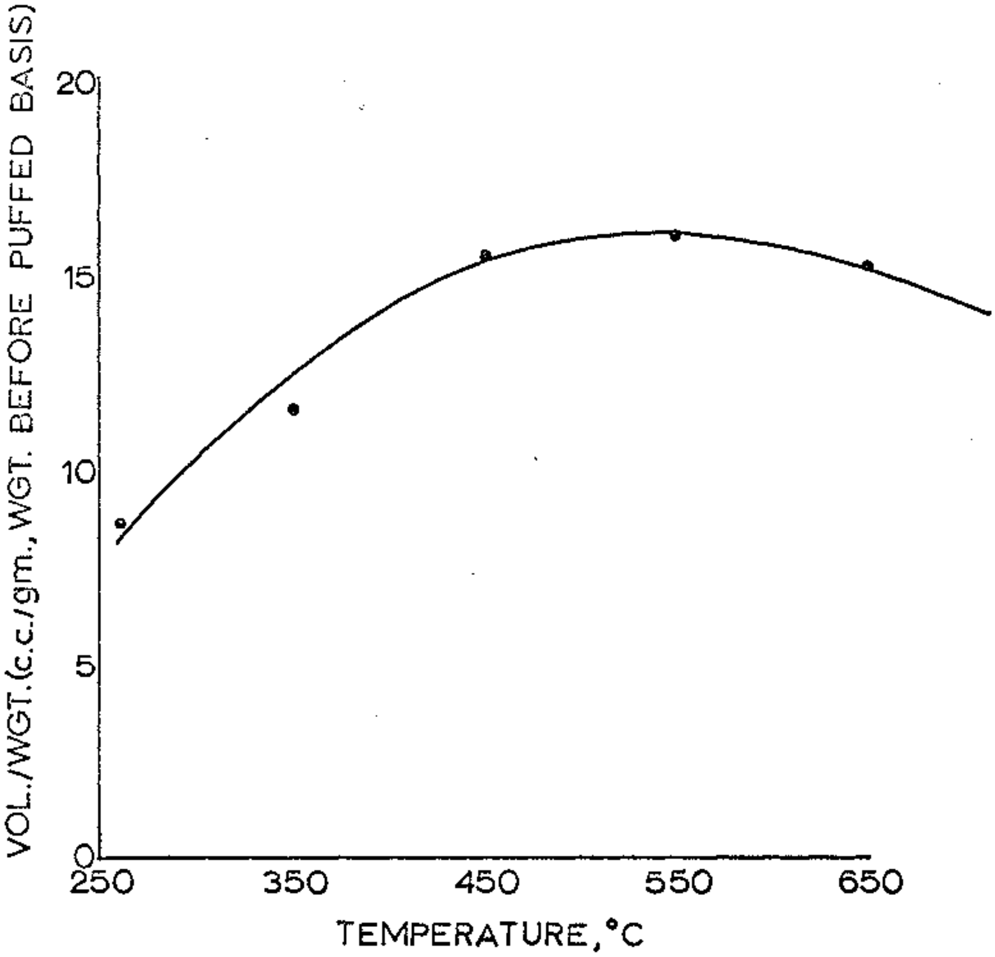


FIG. 22 Effect of muffle furnace temperature on puffed volume of caseinate gel.

iii) Volume and texture: The puffed volumes increase with increasing temperatures up to a maximum then decrease as has been shown graphically in Fig. 22. Note that under optimum conditions the radiant-heat puffed volume exceeds the fat-fried volume. This may be due to the fact that the former consists of bigger bubbles with thicker walls which mostly are still intact, while the latter consists of smaller and evenly distributed bubbles with thinner walls. Many of the thin walled bubbles are broken or have collapsed (See Fig. 21 (e) and (g)), permitting absorption of liquid fat.

The textures of the puffed gels are clearly shown in Fig. 21 to vary with puffing temperatures. The vesicles are becoming smaller and more numerous as the temperature increases. At a temperature of 650°C (Fig. 21 (f)), the texture very closely resembles that of the fat-fried product, i,e. the vesicles are uniform and minute and more evenly distributed. With the right combination of temperature and time to which the gel is subjected, therefore, a puffed product of comparable texture and volume can be produced, with perhaps, certain additional superiorities using radiant heat from a source such as a muffle furnace.

iv) Rehydration characteristics: The radiant heat puffed sodium caseinate gel rehydrates extremely fast even in cold water. In fact, the product becomes completely dissolved after a few minutes contact with a sufficient amount of water, resulting in gluey solution. The gluiness of the solution, however, is inferior to the solution of the sodium caseinate powder in water. This is, of course, due to some protein denaturation which undoubtedly takes place during puffing at high temperature. The result is the change or loss in some original properties of the proteins.

The gels puffed at higher temperatures rehydrate and dissolve faster than those puffed at lower temperatures. The reactions take place so fast that the rates of the rehydration cannot, with standard tests, be recorded to any reasonable accuracy.

However, the experiments on the rehydration rates of other radiant heat puffed products which do not dissolve in water have been carried out, and results are reported in the next section.

v) Improvement of the technique: Much can be done to improve the radiant heating technique by a muffle furnace to suit the puffing purposes.

Hall (35) suggests the circulation of air in the heating chamber to reduce and control the surface temperature of the product. This will provide means of eliminating or lessening the localized scorching of the product due to uneven heating by radiation. The flow of air at a suitable velocity will provide the combined means of heat transfer by radiation and convection which will be more efficient and uniform.

Joslyn and Heid (45) suggest the heating and drying of thin products on conveyor belts. The belt, set at an appropriate speed, will ensure the duration of time for which the product is subjected to the heating at the particular temperature so that the puffing is complete and perfect.

So the radiation/convection heating chamber, whose temperature can be raised up to about 700°C, with an endless conveyor belt whose speed can be varied will be a very suitable form of instrument for radiant-heat puffing.

(d) Conclusion: Radiant-heat puffing technique has proved to be a very efficient means of puffing food gels. Its products are of comparable quality with fat-fried product as far as their volumes and texture are concerned. The products may be of superior quality in some respects such as the speed with which they rehydrate, and the likely improved keeping quality through the absence of fat pick-up.

The proper combination of temperature and time under which the product is puffed is the most important factor to obtain the best puffed products and this may vary for different types of food gels.

Improvements in techniques for obtaining maximum heat transfer efficiencies and the means of conveying the puffing product through a heating chamber at a suitable speed is of prime importance to obtain maximum quality of product. The combination of radiation and convection heat transfer by circulating air in a radiating chamber coupled with the use of a conveyor belt is recommended.

2. Studies on Rehydration Rates of Radiant-Heat Puffed Products:

(a) Introduction: Dehydration of food products has been a subject of intensive research for a number of years. Foods are dried to preserve a perishable raw material against deterioration or spoilage under the intended storage conditions and for eventual usage; and/or to reduce the cost or difficulty of packaging, handling, storing and transporting of the material. Conversion of a moist food to a dry solid condition reduces its weight and in many instances also its volume (80).

Arising, principally, from the need during World Wars to supply armies with foods that keep well, took little space, and were easy to serve, many dehydration techniques were developed. Among these were spray-drier, roller drier, vacuum-puff drier, and freeze drier, to name a few (80). Continuing research is devoted to find new and efficient techniques to produce better dried products. Main aims in development of improved dehydration methods are to ensure the retention of fresh qualities in the dried product and faster and more complete reconstitution of the dried product.

In puffed products the first aim may not be fully met since the physical and some chemical properties of the food may have to be altered in preparation of a gel. For instance the texture of meat and fish is destroyed in the paste and the gelation of the paste is induced by pH adjustment. Also during puffing proteins may be denatured and indeed the product is equivalent to a fully cooked one. However, an improvement in reconstitution characteristics is the more important aim expected to be achieved by puffing technique.

Problems in rehydrations of dried foods may include the irreversible changes that take place during the dehydration process which often prevent the reabsorption of the water. The irreversible changes of the colloidal constituents of both animal and vegetable tissues are shown to take place if the material is held at high temperature for a period of time. The elasticity of cell walls and swelling power of starch gel, both important for good rehydration, are also reduced by heat treatment (80). Protein denaturation during drying of meat causes the loss of water-holding capacity by muscle proteins. This leads to an incomplete reabsorption of water of the dried meat on rehydration resulting in tougher and drier texture (7).

Many processes have been experimented with fish and meat to produce dried products that will rehydrate well. However, no dehydrated product has yet been produced whose texture is completely indistinguishable from that of the fresh product (13).

Cutting et al (16) reported that air dried, minced, cooked white fish and minced, cooked, smoked white fish picked up about 2.5 times their weight of water on steeping in cold water for 10 to 15 minutes. Cooked fish pressed before drying absorbed only about 1.5 times its weight of water and was far too tough to be palatable. Roller-dried cod absorbed nearly 5 times its own weight of water and became too moist to be made into satisfactory dishes.

Freeze-drying techniques are, perhaps, the most satisfactory methods so far. Products obtained are generally recognized as closely approaching the ideal type of dehydrated product (13). Even so certain products, such as freeze-dried fish fillets after reconstitution, are still noticeably tougher and drier in texture. This is believed to be largely due to the denaturation of the main structural protein complex of muscle, actomysin, on drying (14).

Ballantyne et al (1) experimented with the dehydration of cooked meat products and concluded that hot-air dried cooked ground beef was an acceptable item and rehydrated quickly. They also reported that freeze-drying appeared to be of little or no advantage for this type of product. The process was more suitable for either raw or cooked meat pieces such as chops or steaks.

The superiority of freeze-dried products lies in the formation of an open porous structure free from impermeable barriers. Smithies (74) states that on rehydration of freeze-dried meat slices it appears, at the microscopic level, that water penetrates the dried structure by capillary action aided by the ability of the muscle protein to be wetted. Occulusion of gas in the dried structure does not appear to restrict the rapid rehydration of the product prepared under good conditions. He suggests that a freeze-dried raw meat slice should rehydrate in less than 5 minutes and taste panels should be unable to detect gross differences from a frozen control sample.

Considering these facts it is perceivable then that the puffed products whose texture is extremely porous and are basically of gelationous structure should rehydrate very well. The fat-fried products, however, may have their disadvantages in that they are generally coated thinly with fat picked up during puffing, and hence their rehydration may be barred by the hydrophobic nature of the fat. The radiant-heat puffed products, on the other hand, do not have this disadvantage, and so should be able to rehydrate very well. That this is so has been quantatively confirmed by our experiments on the rehydration characteristics of the radiant heat puffed starch gel and fish product.

(b) Experimental:

Procedure:

i) Starch gel: A 10% starch gel was prepared by heating a suspension of 10 parts wheaten cornflour in 100 parts of water until it gelatinized and became a thick paste. The paste was spread thinly on plastic trays and dried at 110°F for 36 hours. The dried gel was left in the atmosphere overnight for moisture equilibration.

The gel was then:

puffed in the deep-fat frier at 375°F for 20 seconds,
puffed in the muffle furnace at 600°C for 5 seconds, and,
puffed in the muffle furnace at 600°C for 10 seconds.

The moisture contents and volumes before and after puffing were recorded.

The rehydration rates of the products puffed in the muffle furnace and of the control (unpuffed gel) were determined (See Appendix for the procedure of rehydration rate determination).

ii) Fish product: Gurnard fish flesh was used. The processing method has been described in Section II page108.Tri-sodium phosphate solution was used to adjust the pH of the paste to 7.3, and the dried paste was left in the air overnight for moisture equilibration before puffing in the muffle furnace at 400°C for 10,15, and 17 seconds.

The moisture contents, volumes before and after puffing, and the rehydration rates were determined as were

Table 12. The Moisture Contents and Volume of the Starch Gels and Fish Products:

Type of Product and Heat Shock	Heat Treatment		% Moisture		Vol./wgt. c.c./gm		
	Temp.	Time, Seconds	Before Puffing	After Puffing	Before Puffing	After Puffing	
						As Is	Wgt. Before Puffed Basis
Starch gel:							
Fat Frier	190.55°C (375°F)	20	11.59	2.98	0.67	3.12	5.15
Muffle Furnace	600°C	5	11.59	10.52	0.67	1.33	1.30
Muffle Furnace	600°C	10*	11.59	4.91	0.67	5.50	5.00
Fish Product:							
Muffle Furnace	400°C	10	14.75	12.40	1.00	1.36	1.31
Muffle Furnace	400°C	15	14.75	10.13	1.00	3.50	3.25
Muffle Furnace	400°C	17*	14.75	5.23	1.00	5.66	5.03

* Fully Puffed.

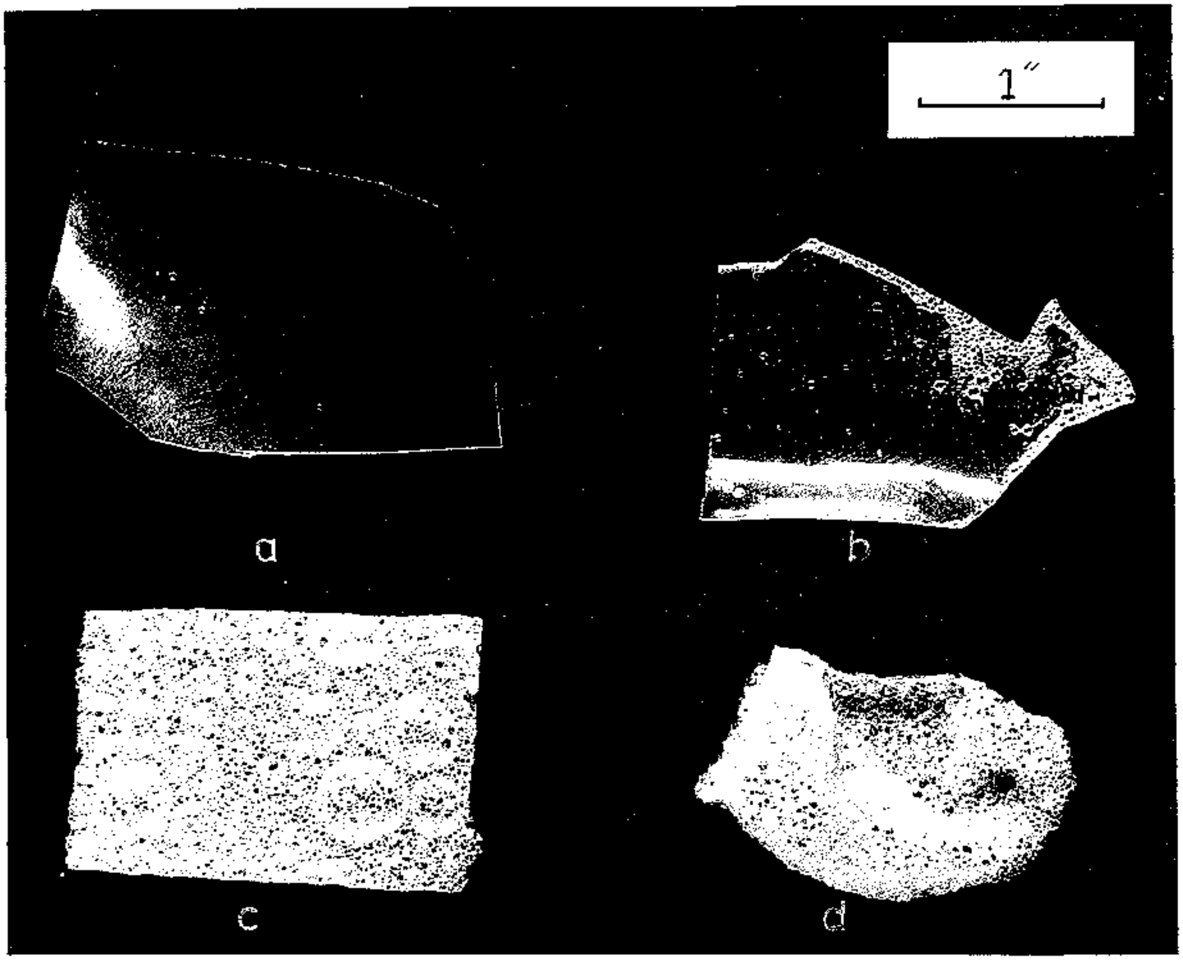


FIG. 23A Radiant Heat Puffing of Starch Gels:

(a) Unpuffed

(b) $600^{\circ}C/5$ sec.

(c) $600^{\circ}C/10$ sec.

(d) Deep-fat fried gel.

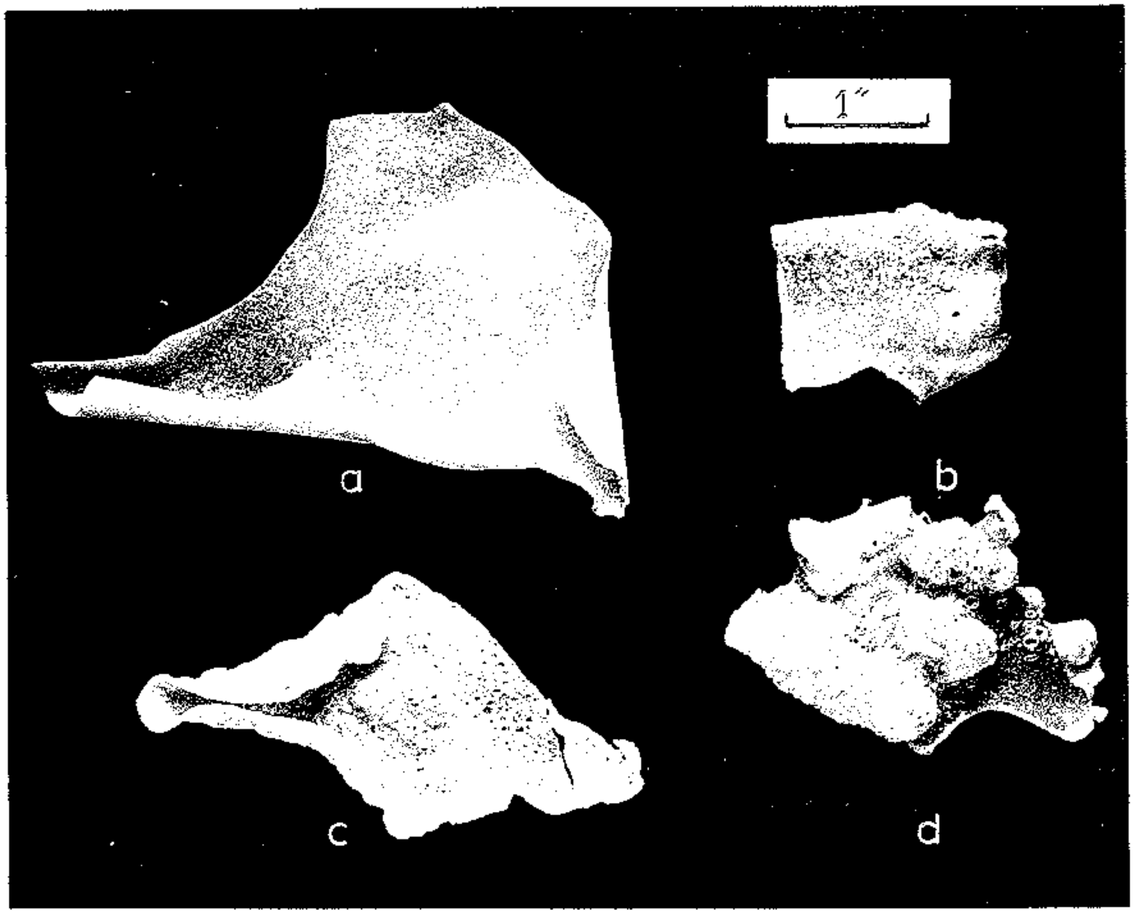


FIG. 23B Radiant Heat Puffing of Fish Product:

(a) Unpuffed

(b) 400°C/10 sec.

(c) 400°C/15 sec.

(d) 400°C/17 sec. (fully puffed).

those of starch gel.

Result: The results of the moisture contents and the volumes of the products are tabulated in Table 12. The corresponding unpuffed and puffed products are shown in Fig. 23A and 23B. The rehydration rates of each product are illustrated graphically in Fig. 24A, 24B, 24C and 24D.

(c) Discussion:

i) General: Different furnace temperatures were employed to puff starch gel and fish product. This is because after a few trials at different temperatures for each product it was found that temperatures of 600°C for starch gel, and 400°C for fish products were optimum conditions and it was found that the time of exposure could be used to manipulate the degree of puffing. Further, when the products were fully puffed at the chosen temperatures their puffed texture resembled closely those of fat-fried products, which was considered desirable.

A uniform puffed texture could not be obtained in a few cases such as starch gel puffed at 600°C for 5 seconds (Fig. 23A (b)), and the fish product puffed at 400°C for 17 seconds (Fig. 23B (d)). This was possibly due to many factors. For instance, the thickness of the dried food gels before puffing although controlled may not have been precisely uniform, and the heating may therefore not have been uniform throughout pieces of gels. The heating cavity of the furnace was about 6 ins. x 8 ins. x 15 ins.

with a sharp corner between the walls. Hence it could be expected that the temperature radiated from the walls on to the gel pieces, which lay flat on the supporting net parallel to the floor at about the middle of the cavity were not uniform. The pieces or the parts of the gels that lay nearer to the walls could be expected to be heated faster and to higher temperature than the middle pieces or parts of the gels.

It is clearly shown in Table 12. that there is no significant difference between the radiant-heat puffed volume (600°C/10 seconds) and fat-fried volume of the starch gel. The only obvious difference is in the texture. The texture of fat-fried gel consisted of uniformly distributed small bubbles. The texture of radiant-heat puffed product, on the other hand, consisted of bubbles of comparable size, is not evenly distributed. The bubbles seem to group themselves up and push the product surface out to form number of porous, semi-circular structures (Fig. 23A (c)). The product also tends to be harder and more brittle than the fat-fried one.

For fish product the radiant-heat puffed volume at 400°C/17 seconds is quite significantly higher than the best fat-fried volume obtained in Section II page 111. The best radiant-heat puffed volume based on dry fish paste weight prior to puffing is about 5 c.c./gm. as compared to about 4.4 c.c./gm of fat-fried product. The texture of both products are comparable but the radiant-

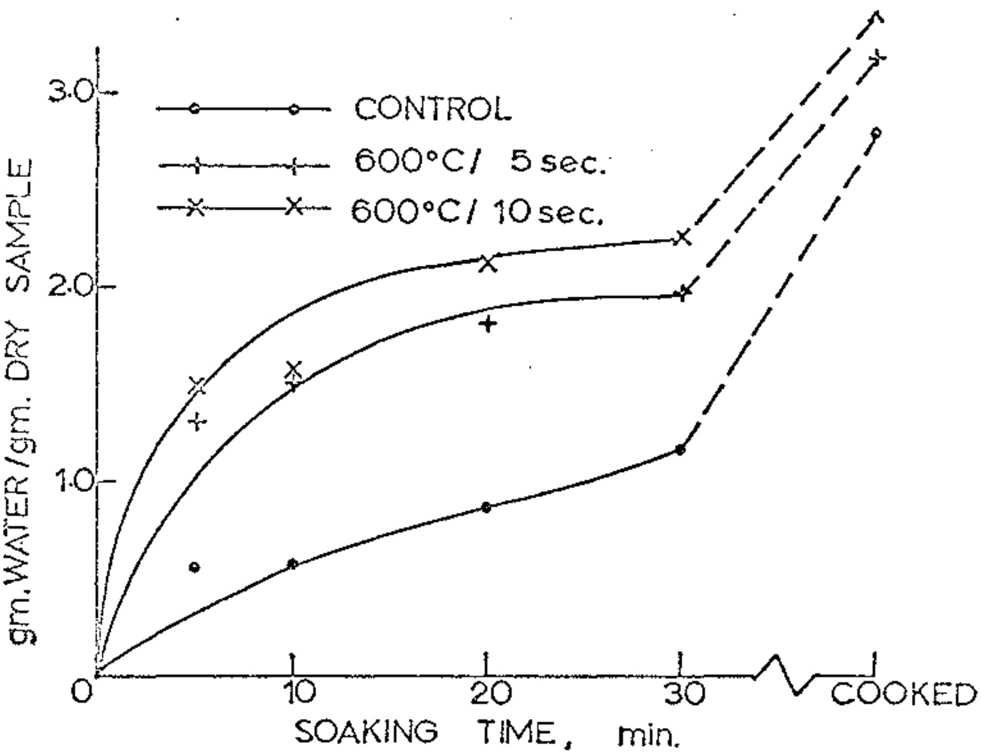


FIG. 24A Rehydration of starch gel.

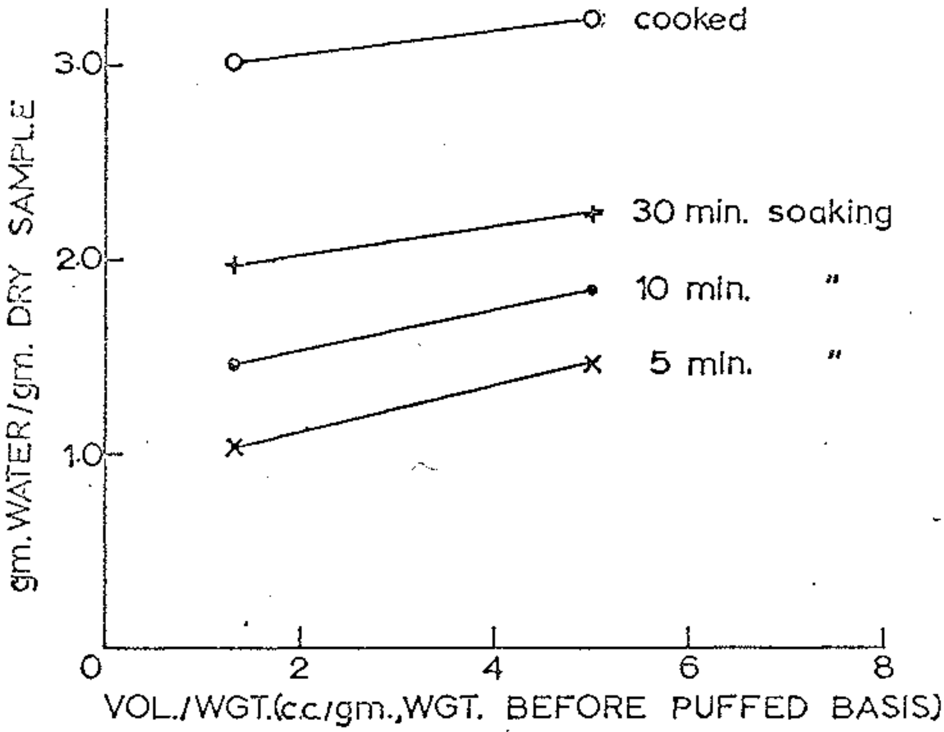


FIG. 24B Puffed volume and rehydration of starch gel.

heat puffed one gives a softer and mealier sensation in the mouth. Hence, it is more pleasant to eat and appears to have less of the grittiness due to the tough broken fish muscle fibres which seem to be more pronounced in the fat-fried product.

ii) Rehydration characteristics: Rehydration rates of the puffed products are largely affected by the extent of puffing, and hence the volume of the puffed products. The method used for the determination of rehydration rates is somewhat arbitrary but it indicates relative values to show variations within one product or to compare products of a similar nature.

The rehydration rates of starch gels puffed to various extents are typified by Fig. 24A. The fully puffed product (600°C/10 sec.) reconstitutes the fastest, the lightly puffed product (600°C/5 sec.) reconstitutes the second fastest, and the control (unpuffed) reconstitutes the slowest. In all cases the rehydration rates are most rapid in the first 10 minutes after which the re-absorption of water slows down. After 20 minutes the fully puffed gel absorbs twice its weight of water, while the control absorbs only about 0.9 of its weight. This implies that the rate of rehydration is significantly increased by the puffing process. When the products are fully rehydrated, i.e. after subjecting to boiling for 10 minutes the puffed products also show their capability to absorb more water than the control. The fully puffed gel, when fully reconstituted absorbs 3.25 times its weight of water; the

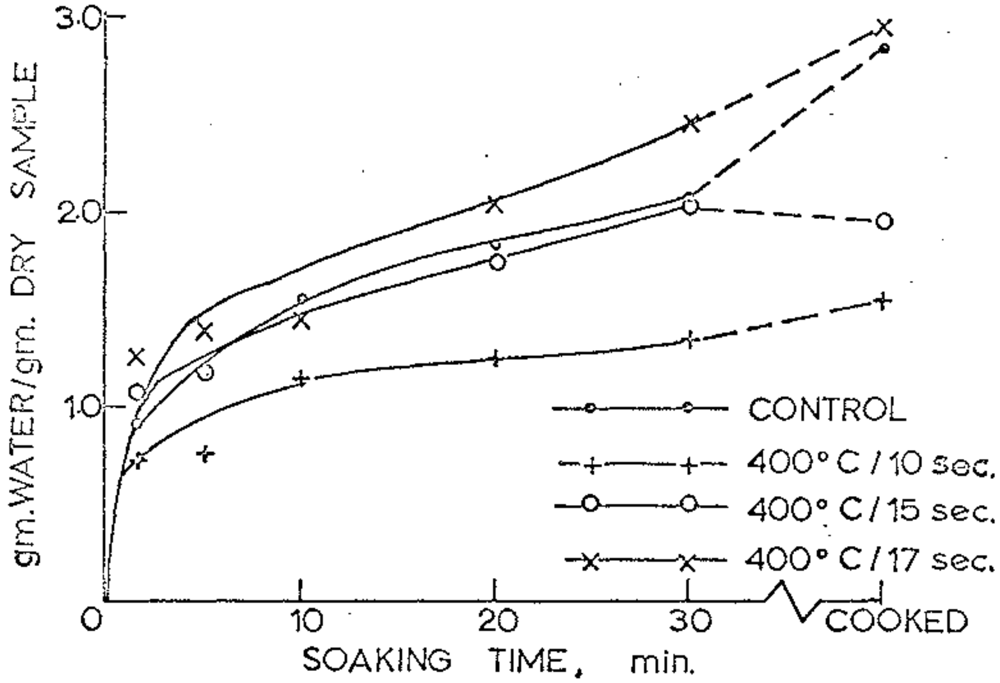


FIG.24C Rehydration of fish product.

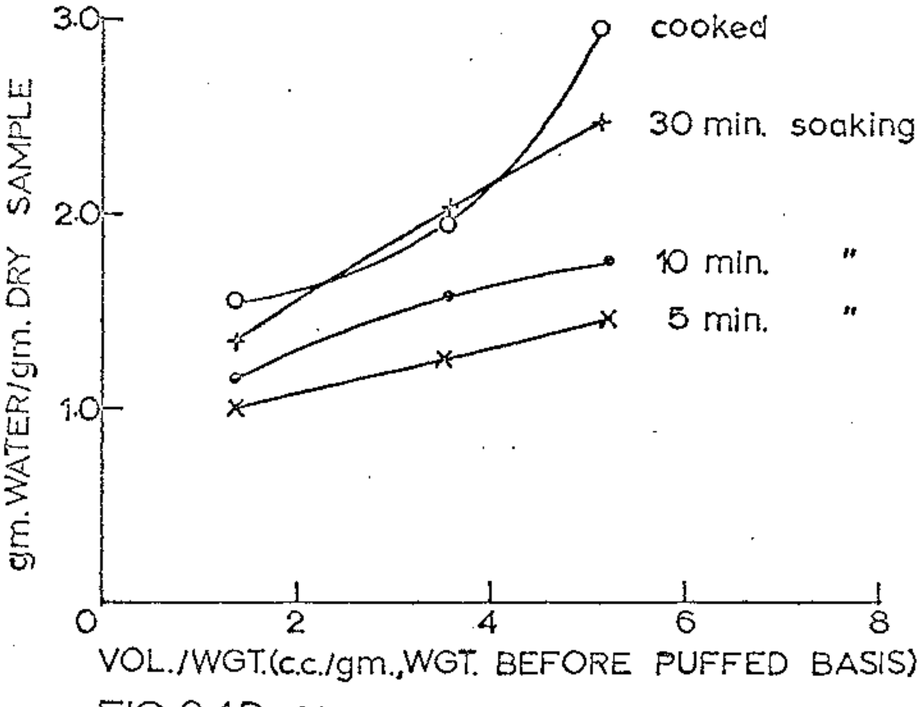


FIG.24D Puffed volume and rehydration of fish product.

half-puffed absorbs 3 times, and the control absorbs about 2.75 times its weight of water.

Fig. 24B shows the increase in water absorbed by the products with increase in their puffed volumes. This again shows that at every stage of reconstitution process the product with a bigger puffed volume is superior in absorption of water.

A somewhat similar trend is experienced in the case of fish products which is illustrated in Fig. 24C and 24D. The fully puffed product shows its superiority over the control at every stage of the rehydration process, but the products puffed to lesser extents, however, show their inferiority in water absorption. This may be explained by the fact that in the less puffed products the heat inflicts two types of quality damage. (a) It merely dries the product further while the characteristics of its texture remain the same or the porosity of the product is not sufficiently increased to efficiently aid the rehydration. (b) The high temperature denatures the protein to an appreciable extent and causes the product to lose its original water-holding capacity. Hence, when these products are reconstituted it is extremely difficult for water to diffuse into their structure, i.e. in the case of the product puffed at 400°C for 10 seconds. When the water manages to diffuse through some open texture, as in case of the product puffed at 400°C for 15 seconds, the absorption of water levels off very quickly after the initial high rate of absorption because the product loses its water-holding capacity. In fact, when this product is boiled for 10 minutes (fully rehydrated) it tends to lose some of its previously absorbed moisture (Fig. 24C).

In case of the fully puffed product (400°C/17 sec.), the product texture is extremely porous with numerous pores throughout the structure. Hence the product possesses a greater surface to absorb water. The product exhibits very rapid initial rate of rehydration in first 10 minutes of immersion under water. This is due to the large amount of water being carried into the product by the capillary action of the pores. Due to large surface area exposed to the water, a larger amount of water can then be held by the fully puffed product than that by the control, even after full rehydration.

The plots in Fig. 24D illustrated similar trends to those in Fig. 24B, i.e. the products of larger puffed volumes show higher capacities to absorb the moisture at all stages of rehydration. The increase in volume seems to have more effect on the increase in absorbed water in this case, however, than in puffed starch gels.

Connell (13) showed that in air-dried (30°C) cod, vacuum contract plate dried (V.C.D.) cod, and freeze-dried cod, the freeze-dried cod rehydrated the fastest, the V.C.D. cod the second - slightly inferior to the freeze-dried product, and the air-dried cod was the worst product

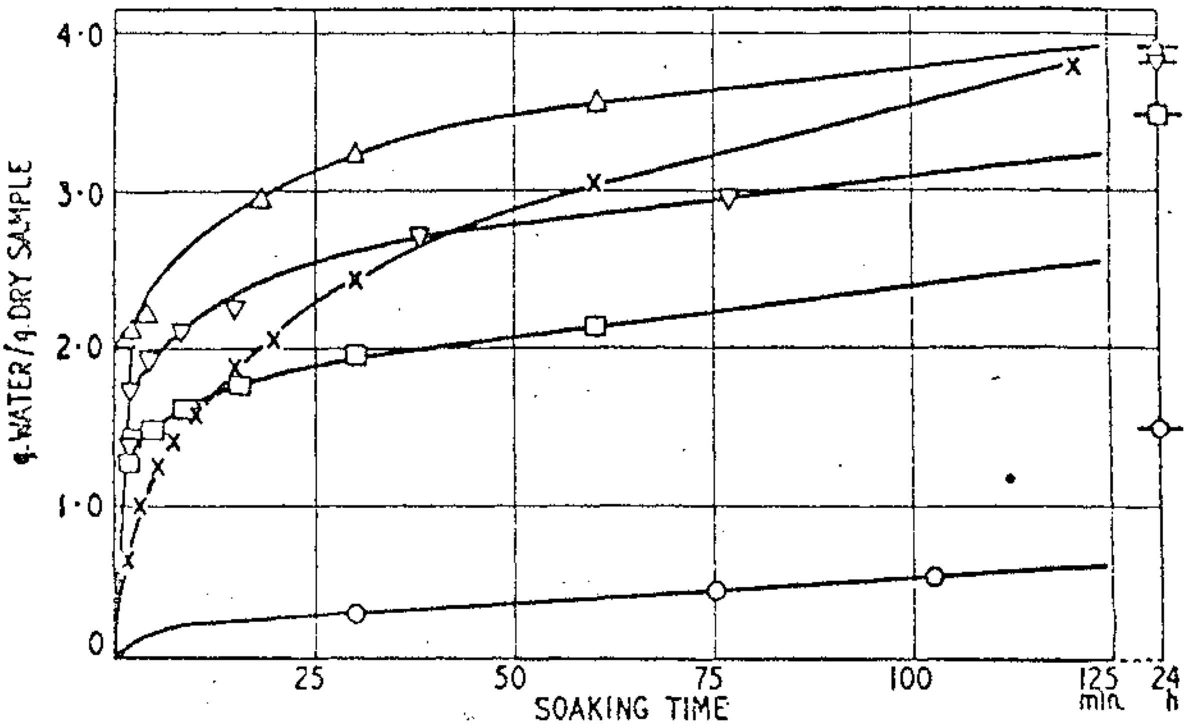


FIG.25 Reconstitution of dehydrated cod (Connell,1957).

∘ air-dried at 30°C

▿ V.C.D. 131/55

+ V.C.D. 342/53

▵ freeze-dried from air-blast(-30°)frozen cod

□ " " " CO_2-ethanol(-80°)" "

with respect to rehydration (Fig. 25). He advocated that this was due to the "micro-structural" differences among the products. All the samples showing freeze-dried characteristics exhibit an enormously rapid initial rate of rehydration. This is due to water being carried deep into the piece by the capillarity of an extensively ramifying system of spaces permeating the whole structure. With a compact tissue like air-dried cod, water penetrates mostly to the centre of large pieces by diffusion through the protein of the fibre itself. This process is very slow in the case of dried muscle protein resulting in very slow rate of rehydration. He also stated that the micro-structural differences accord with the general textural experience of the palate. A highly compacted product like air-dried cod feels tougher than a less compact one like V.C.D. cod and in turn this is more tough than a very finely structured product like freeze-dried cod. The tenderness experienced in fresh cooked fish is lost in most dehydrated products. Even the freeze-dried cod felt more fibrous and dry in the mouth, presumably because the individual fibres of the dried product were less soft and less completely hydrated than those of fresh fish. This, he stated, was due not only to the differences in microscopical structure, but also to the differences in water-binding capacity of the products caused by denaturation of the muscle proteins.

Cooked puffed-fish, though not particularly dry and tough, was rather spongey. This is presumably due to the fact that the individual fibres of the fish have been nearly completely destroyed during the process but are reunited together again into one continuous piece by the gelation process brought about by pH adjustment and drying.

The rehydration rates of the puffed-fish products as shown in Fig. 24C are closely comparable with that of the dehydrated cod as shown on Fig. 25. The smaller overall values of water absorbed by the puffed product (compared with those of dehydrated cod) can be attributed to the fact that the method for rehydration rate determination employed by Connell is slightly different from the method employed in this experiment. Connell lightly blotted his rehydrated samples with filter paper before re-weighing them, while in this experiment the rehydrated samples were dried by centrifuging for a standard time before being re-weighed. Hence the excessive re-absorbed water would be expressed out more by this method resulting in lower values for water of rehydration.

The other difference between our experiments on puffed-fish product and those undertaken on dehydrated cod concerns the thickness of the product. The puffed product is very thin, i.e. about 2 - 3 mm. thick as compared to 1.5 x 5 x 10 cm blocks of the cod flesh as used by Connell. The thin puffed product would be expected to show more rapid absorption in the initial stages of rehydration as it has less depth for water to penetrate through, and hence requiring less time to attain complete hydration.

Considering the product as a whole, the puffed products may be considered as in the same or comparable category as freeze-dried, or V.C.D. products as far as rehydration characteristics are concerned. However, the final rehydrated products are quite different. The conventional fried-dried, or V.C.D. products can be in either raw or cooked state, while the puffed products are always cooked after the process. Hence their utilization may be different.

Puffed foods may be ground and used as a constituent for other types of foods such as soups, or may be used as a protein supplement or flavouring material. The rehydrated puffed foods might be used in a variety of recipes for consumer use and would be quite acceptable to Asian taste. Rehydrated puffed fish, for example, is very much like one of the rehydrated ingredients used for Chinese noodle dishes.

(d) Conclusion: The combination of temperature and time must be decided for each type of food gel to obtain the best radiant-heat puffed product with optimum rehydration characteristics. The best rehydration rate is usually obtained from the fully puffed product. However, care must be taken in the case of protein foods that the denaturation of the proteins does not occur at too great an extent such that the proteins lose most of their original water-holding capacity and resulting in dry and tough rehydrated products.

The radiant heat puffed fish products rehydrate at comparable rates as do freeze-dried, or V.C.D. products but the final products obtained may be quite different.

New ways of utilization of rehydrated puffed foods may have to be devised, however, but their prospect is good as a rehydrated ingredient for Asian dishes, and for some European types of dishes.

APPENDIX

Analytical methods employed in experiments:

I. Moisture Determination:

Aluminium moisture dishes were heated in a hot air oven to 105°C for at least one hour, then cooled in a silica gel desiccator to room temperature. Approximately 2 gm. samples were weighed accurately into the dishes. The samples were dried in the oven at 105°C overnight, cooled in the desiccator and re-weighed. The moisture content was expressed in percentage of the wet weight of the samples.

II. Measurement of Volume of Unpuffed and Puffed Products:

The volumetric measurements were made in a graduated 250 ml. cylinder by displacement in petroleum ether.

The product was submerged into the known volume of the petroleum ether by the aid of a thin rod with a circular head loosely fitting the size of the cylinder. The volume of the rod and its head was previously calibrated. The increase in volume when the sample was submerged was noted. The volume was firstly expressed as the ratio of c.c. of the volume to the weight in gm of the sample (c.c./gm). This is called the volume "as is". Then, in the case of the puffed samples, the volume was also expressed as the ratio of c.c. of the volume to the weight in gm of the sample prior to puffing. This is called the volume "wgt. before puffed basis".

The latter expression was chosen so that:

1) The increase in puffed volumes with the same type of product could be compared between themselves reasonably accurately as they all were calculated on the basis of the original volumes prior to puffing and which were found to be quite consistent in each product.

2) The problem in the discrepancy in the weight of fat pick-up, and in the varying levels of moisture contents of the puffed product which arose in the expression of "as is" volumes could be avoided.

By this expression comparison of the puffed volumes of different types of product could also be made satisfactorily allowing for their difference in unpuffed volumes.

III. Moisture Equilibration of the Food Gels prior to Puffing:

The dried food gels were kept in the closed "humidity jars" for 5 - 6 days at the temperature of 30°C. The saturated solutions of the salts used and the relative humidity they exert at 30°C listed below are taken from : Carr, D. and Harris, B. (9) and Perry, J.H. (61).

Saturated Solution:	Relative Humidity:
$CaCl_2.2H_2O$	32.0%
$K_2CO_3.2H_2O$	43.6%
NaCl	74.9%
KCl	84.5%

It was found that after 5 days in the jars equilibration was complete in all food gels used in the experiments.

When samples were taken out of the jars and used in subsequent experiments such as volume determination, moisture determination and puffing, delay was avoided to ensure that no moisture was lost to or gained from the atmosphere.

IV. Method of Deep Fat Frying:

A small, electrically heated deep fat fryer was used. The fat used was a commercial hydrogenated oleo oil under the trade name "Chefade".

The temperature of the fat could be raised to 500°F, and was thermostatically controlled. However, the fat temperature was checked, against that registered on the on/off switch, by a standard mercury-in-glass thermometer whose temperature range was 0 - 600°F.

The food gels of known weight and volume were fried in a stainless steel basket immersed in fat. A few puffing trials were conducted for each type of food before the actual experiments were carried out, to decide the most suitable length of time of product immersion in the hot fat. This was to ensure that fully puffed, but not burnt, products were obtained. Subsequent puffing trials were done under conditions representing the selected combination of temperature and time.

When the product was fully puffed, it was immediately taken out of the fat in the basket. Excessive fat was drained or shaken out before being tipped out onto a tray. When the product cooled down to room temperature subsequent tests, such as volume measurement and moisture determination, were proceeded with immediately and before the product could take up significant amounts of atmospheric moisture.

V. Determination of Rehydration Rates:

Immediately after being radiant-heat puffed, rehydration rates for products were determined as follows:-

The puffed product of know weight was immersed in 500 ml. tap water (70°F) in a beaker and the immersion period was determined with a stop watch.

The product was immediately taken out of the water after the set time ended and was wrapped up in a nylon net and centrifuged for 1 minute in a "Debonair Spindryer" to get rid of excessive water on the surface.

The product was then reweighed. The rehydration rate was expressed in terms of

$$\frac{\text{weight of water absorbed}}{\text{weight of the product before rehydration}}.$$

The rehydration rate of the control (unpuffed product) was also determined in parallel for comparison purposes.

The product which was immersed under water for the longest period was further employed to determine the amount of water absorbed when fully rehydrated. This was done by immersing the product in boiling water for 10 minutes before it was taken out to be centrifuged and reweighed.

Some products were so light that they floated on the surface of the water. In these cases a small weight was placed on top of the product in the beaker so that it was fully submerged over the whole period of time.

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