THE EFFECT OF KIND AND CONCENTRATION OF SUGAR ON GLUTEN FORMATION AND CHARACTER

Thesis for the Degree of M. S.

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Donna Poland Meiske

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This is to certify that the

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Donna Poland Meiske

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Evelyn M. Jones
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by

Donna Poland Meiske

AN ABSTRACT

Submitted to the College of Home Economics of Michigan
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AN ABSTRACT

DONNA POLAND MEISKE

The effects of various sugars on gluten formation and character were studied before and after heat denaturation. An all-purpose flour was used throughout the study.

Two experimental procedures were employed. In the first procedure 5% levels of D (-) fructose C.P., D (-) glucose C.P., beta-lactose 98%, D (+) technical maltose, or sucrose (cane sugar) were incorporated in: (a) a dough in the preparation of gluten, (b) gluten prepared from the above method, and (c) gluten prepared from only a flour-water dough. The effects of the three methods of adding the sugars and the effects of each sugar on gluten were determined by measuring the amount of resulting drip loss obtained from raw gluten, and the volumes and crushing forces of baked gluten balls. Gluten which had had no sugar additions served as a control for each method.

Drip losses of gluten were greater when sugars were incorporated in gluten after preparation. These drip losses in addition to containing some of the added sugar in solution were shown to include nitrogenous material (positive ninhydrin test) presumably protein, peptones, peptides or alpha-amino acids. It was concluded that the sugars exerted a peptizing or solvent action on the gluten protein.

The volumes of the baked gluten balls were not altered significantly, except when lactose or maltose were incorporated in lots of gluten prepared by method (c).

The crushing forces of the baked gluten balls were significantly decreased when a sugar was added to prepared gluten.

In the second experimental procedure 5% increments of D (-) fructose C.P., D (-) glucose C.P., D (+) technical maltose, D (+) maltose C.P., beta-lactose 98%, sucrose (cane sugar) or D (+) lactose C.P. were incorporated in a dough until gluten formation was negligible. The effect of each sugar was followed by measuring gluten yields and the volumes and crushing forces of baked gluten balls.

No gluten was obtained when the following sugars were added at these "critical levels of concentration": fructose, glucose, and sucrose, 55-65%; D (+) maltose C.P., 45%; beta-lactose, 40-45%; and D (+) technical maltose 30%. The D (+) lactose seemingly did not effect gluten yield, even at the 70% concentration.

The technical maltose had the most detrimental effect on gluten formation and character after heat denaturation. Beta-lactose resembled the technical maltose in its effects. The D (+) lactose did not significantly affect gluten yields and the volumes and crushing forces of baked gluten balls. This behavior was related to the insolubility of this sugar.

It was concluded that all of the sugars used in this study, except D (+) lactose, either exerted a solvent or peptizing action on the gluten proteins, or decreased their water absorptive power.

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As sugar concentration increased, the yields of gluten diminished. The volumes of the gluten balls at the lower levels of a sugar were greater than the controls, and thus indicated that the sugar probably weakened the structure of the baked gluten balls. Crushing forces also were less as the concentrations of sugars were increased. However, at higher levels of concentration, smaller amounts of gluten were obtained and hence the volumes and the crushing forces of the baked gluten balls were less.

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INTRODUCTION

Wheat gluten is primarily responsible for providing structure in bread and most other baked products. The exclusiveness of wheat as a bread-making cereal is accounted for by the special and distinctive characteristics of a protein substance that is intermixed with the starchy endosperm of the grain. It is only by virtue of the unique properties of this protein material that carbon dioxide produced during dough fermentation is retained by the dough in a manner which provides the familiar porous and spongy structure of bread. This substance, recognized as the "gluten protein" of wheat, can be readily and conveniently separated from the bulk of the wheat starch. The gluten, itself, is recovered as a coherent, extensible, and rubbery mass, merely by the thorough kneading (or similar physical manipulation) of flour dough under a stream of water (9).

Sugar, too, is an important component of many baked products having gluten structure. By increasing sugar to an optimum point, there is increased volume and tenderness in these baked products (17, 18, 39, 41). An excessive amount of sugar produces a product with a very coarse texture and often a collapsed structure (17).

In 1911 and again in 1921, Jago and Jago (27, 28) reported that the physical condition of a flour-water dough

was noticeably affected by the presence of sucrose. A sufficient concentration of sucrose decreased the dough viscosity, which indicated weakening of the gluten structure. They postulated that sucrose had a solvent effect on the flour proteins and that it also affected the water-absorptive power of the flour proteins.

Since that time little work has been done to determine the effects of sugars on gluten formation and character. The experiments reported in this paper include studies of the effects of various sugars on gluten formation and character, both before and after heat denaturation. Fructose, glucose, lactose, maltose, and sucrose were included in this study because they commonly occur in baked products.

REVIEW OF LITERATURE

Historical

Beccari, an Italian scientist, is credited with the first separation of gluten and starch from wheat flour in 1728. Beccari's method is as follows, taken from Bailey's translation (2) of Beccari's lecture "Concerning Grain" (7):

> Flour is obtained from the best wheat, moderately ground, so that bran will not pass through a sieve; from this it follows therefore, that the product is of the cleanest with impurities removed. This is mixed with the purest water and is kneaded. The residue obtained in this operation is accomplished by washing. The water, therefore, carries away all portions that can be dissolved; the other portions it leaves behind intact.

Beccari called the glue-like portion "glutinosum" and the other starch-like portion "amylaceum."

Since that time, the proteins of flour have been repeatedly investigated. Accounts of the early studies are primarily of interest historically and have been reviewed by Osborne (42) and by Bailey (3).

The "modern period" of flour protein research is recognized as beginning with the work of Osborne and associates (3). In 1907, Osborne (42) published a report of studies on flour proteins done over a period of 15 years. He characterized the proteins of wheat flour on the basis of differing solubility characteristics. The five main fractions based on solubility were as follows: gliadin, a prolamine soluble

in 70% ethyl alcohol; glutenin, soluble in dilute acid and dilute alkali; a neutral salt-soluble globulin; a water-soluble, heat-coagulable albumen; and an ill-defined "proteose". Osborne concluded that the gluten protein constituted more than 80% of the wheat flour protein, and was composed essentially of glutenin and gliadin.

Method of Preparation

The method of extracting gluten from flour by the physical manipulation of a flour dough under water has remained essentially the same as that used by Beccari (7).

When gluten was prepared from a flour dough by the usual washing process, Blish (9) reported both the amount and nature of the product were influenced by a number of individual factors. These factors included the character of the flour itself, and the kind of wheat from which it was milled. Flours of higher total protein content usually yielded larger quantities of gluten. It was noted that as the total protein content of the flours increased, the ratio of gluten to non-gluten protein was higher. The author stated that it was frequently difficult to effect proper agglomeration of gluten particles in flours of low protein content, inferior grade, or both. As a result low or negligible yields of gluten were obtained unless special precautions and very careful handling were used.

Dill and Alsberg (20) listed ten factors to consider in extracting gluten from dough: length of the period the dough was allowed to set, length of the period the gluten was allowed to set, temperature, length of wash time, mechanical manipulation, nature of the wash water, hydrogen ion concentration of the flour, gluten quality, concentration and kinds of electrolytes in the flour, and gluten quantity.

Studies reported by Blish (9) and by Udy (59) indicated that soft water dissolved more gluten protein than hard water. Fisher and Halton suggested that a 0.1% sodium chloride solution be used for washing gluten in cases where sufficient hardness of tap water was lacking. Dill and Alsberg (20) proposed the use of dilute sodium phosphate solution adjusted to pH 6.8. Fisher and Halton (23) cited other factors to consider in washing gluten, namely, the temperature of the wash water, length of the rest period between preparation of dough and washing process, and personal peculiarities of the operator. Tague (58) stated that a pH range of 4.5 to 7.0 was important in gluten formation.

Many mechanical devices have been invented to cut down on the hand labor of washing gluten (3). The electric mixer has been used in fractionation studies (8). Sollars (50) reported a method of extracting gluten from wheat flour with dilute acetic acid. He concluded, however, that the acid extraction process required more time than separations made by kneading the dough under water. The use of the acid extraction method was suggested for low-protein flours and flours with damaged gluten.

Due to the presence of substantial quantities of starch, fat, and mineral matter, which cannot be removed by the conventional washing process, the term "crude gluten" should be commonly applied to the proteinaceous material recovered by washing a flour dough under water. Blish (9) stated that crude gluten as isolated by the washing-out procedure contained an average water content of 65%, while its dry substances contained 70-80% protein, 5-15% residual carbohydrates (chiefly starch), 5-10% lipids, and a small quantity of mineral salts. Sullivan (53) reported the composition of gluten to be 85% protein, 8.3% lipid, 6.0% starch, and 0.7% ash (dry weight basis).

Protein and Amino Acid Composition of Gluten

In 1907, Osborne (42) concluded that gluten was composed of two proteins, glutenin and gliadin. Subsequent studies have supported the view that gluten is composed of several if not many components. Osborne's terminology has been retained for convenience until the identity of the protein components of gluten can be more definitely established.

Sandstedt and Blish (46) and Stockelbach and Bailey (51) reported fractionation studies which indicated that gluten was composed of three fractions, namely, gliadin, glutenin, and an intermediate they termed mesonin. Sandstedt and Blish (46) stated that the glutenin fraction was soluble in very concentrated acetic acid and that gliadin was soluble in 50-70% alcohol or dilute acetic acid. Mesonin was less soluble in neutral (50-70%) alcohol, but was highly soluble in dilute acetic acid.

Krejci and Svedberg (29), determined the molecular weight of gliadin by ultracentrifugation and concluded that the protein was not homogeneous with respect to molecular weight. There was probably a mixture of whole and half molecules with weights of 34,500 and 17,500, respectively. Lamm and Polson (32) found that gliadin was heterogeneous, as shown by differences in diffusion constants of several fractions. However, the most soluble fraction appeared homogeneous. They estimated that the molecular weight of gliadin was 27,500. Burk (13) determined the molecular weight of gliadin by osmotic pressure measurements in different solvents. The molecular weight values of gliadin varied from 40,000 to 75,000 depending on the solvent used.

McCalla and Gralen (35, 36) investigated the molecular characteristics of gluten in sodium salicylate solution. Using methods of sedimentation and diffusion they found that the molecular weight of the most soluble fraction ranged from 35,000 to 44,000. Schwert _et al_. (48) reported that gliadin was not an electrophorectically homogeneous protein and consisted of at least two components. These workers determined

that the isoelectric point of one fraction was pH 5, while that of the other fraction was pH 7.

Fractionation experiments were conducted by McCalla and Rose (37) on gluten in sodium salicylate dispersion. The gluten fractions were reprecipitated by varying quantities of magnesium sulphate. Successive fractionations of the precipitated gluten protein contained progressively more amide and less arginine nitrogen. None of the fractions were similar to gluten, but when they were redispersed, combined, and reprecipitated as a whole, a gluten was obtained. The most soluble 10-15% of the gluten protein appeared distinct, but the remainder was probably a single protein complex, which could be progressively fractionated.

McCalla and Gralen (35, 36) stated that gluten was a protein system which showed progressive and regular changes in solubility.

Sullivan (53) reported that the "so-called" glutenin fraction was ill-characterized and non-homogeneous, and furthermore that it could not be dispersed in any solvent sufficiently well enough to permit ultracentrifugation, electrophoresis, or other usual physical techniques.

Barmore (6) fractionated gluten into components which differed progressively in viscosity and solubility. The differences in viscosity were interpreted to indicate differences in axial ratio of ellipsoidal molecules. Gliadin appeared to be the most symmetrical and most soluble, yet some of these

molecules appeared twice as unsymmetrical as others. Glutenin molecules likewise varied in symmetry and were less symmetrical than those of gliadin. Symmetry and solubility in several solvents appeared to be related; the more symmetrical the molecule, the greater the solubility or dispersibility. Barmore believed this evidence further supported the theory that gliadin and glutenin were a part of a complex protein system differing systematically in physical and chemical properties with no clear distinction between the two.

Kuhlmann (30) proposed that gliadin consisted of two fractions, alpha and beta-gliadin. Experiments indicated that glutenin consisted of the longest and most stable micelles. Gliadin consisted of shorter micelles which were less stably built and more flocculent than those of glutenin. The beta-gliadin fraction was similar in swelling, peptization, and length of micelle, to glutenin.

Blish (9) summarized the evidence supporting the individual protein components and homogeneity of gluten protein as follows:

1. Gluten protein is definitely inhomogeneous and probably consists of several, if not many components, instead of two as postulated by Osborne (42).

2. Non-homogeneity appears to increase with a decrease in solubility of the various protein fractions.

3. Evidence of non-homogeneity may however be due, in considerable measure, to aggregation, and to component interaction with "complex formation," rather than to the actual existence of numerous individual components.

4. The solubility characteristics of gluten present unique difficulties and complexities when attempts are made to apply and interpret modern physical methods for studying protein individuality and molecular properties.

5. Convincing solution of the problem of gluten structural composition and homogeneity apparently must await discovery and application of appropriate solvents, or of new methods and criteria, or a combination of these developments.

The amino acid composition of gluten prepared from seventeen different flours was determined by Pence and co-workers (43). The amino acids present in gluten (as percent of protein with a theoretical average nitrogen content of 17.5%) were as follows: alanine 2.2%, arginine 4.7%, aspartic acid 3.7%, cystine plus cysteine 1.9%, glutamic acid 35.5%, glycine 3.5%, histidine 2.3 %, isoleucine 4.6%, leucine 7.6%, lysine 1.8%, methionine 1.9%, phenylalanine 5.4%, proline 12.7%, serine 4.7%, threonine 2.6%, tryptophane 1.1%, tyrosine 3.1%, and valine 4.7%.

Gluten Structure

When water is mixed with wheat flour in proper proportions, gluten is formed.

Osborne (42) suggested that glutenin formed the nucleus to which the gliadin adhered and this bound the gluten protein in one coherent elastic mass.

Bungenberg de Jong (11) theorized that gluten was not just a physical mixture of gliadin and glutenin, but that its existence was dependent upon an interaction between these two components. This interaction was a result of the opposition

of charges on the two components in the complex. In the region of the complex formation, gliadin was always the positive component, and glutenin the negative component. The glutenin-gliadin ratio, therefore, was thought to influence, to some extent, the physical properties of the gluten. Particle size, and presence of other proteins (albumins, globulins, and peptones) were also thought to alter the amount of gluten formed.

Kuhlmann (30) suggested that gluten be considered as a high polymer representing a complex of proteins, forming micelles of various lengths.

Sullivan et al. (54) proposed that gluten strands are coiled fibrils of proteins with main or side chains containing disulfide bonds. Laitinen and Sullivan (31), in studying the oxidation-reduction systems in flour, found the presence of possible sulfhydryl linkages in gluten.

Cunningham (16) postulated that gluten might be formed by four types of bonding: peptide bonds, hydrogen bonds, salt linkages, and disulfide bonds. The basic pattern of gluten structure was probably due to polypeptide chains. The relatively high amount of the amino acid proline was thought to fix the configuration of the polypeptide chains in one particular way. Hydrogen bonds, salt linkages, and disulfide bonds were thought to be interchain linkages. Hydrogen bonds were easily ruptured and easily reformed. Salt linkages were shown to be present by the ready solubility of gluten in dilute acid or alkali. The disulfide bonds probably had their origin in cysteine, which was found to be relatively abundant in gluten.

It has been emphasized that gluten is a colloidal system (12, 16, 45, 56, 57). Swanson (56, 57) suggested a three-dimensional gluten network in dough. When dough was formed from a flour and water mixture it was probable that the protein particles which formed gluten united into filaments or strands. In a well-mixed dough these strands had a three-dimensional network which permeated the whole dough and thus formed a continuous phase system. The amount of protein determined the density of the network and the quality determined the behavior. The starch granules were enmeshed in this network. The layers of water which were adsorbed on the protein particles and on the starch also formed a continuous phase or system.

Baker et al. (4) studied the distribution of water in dough and proposed that the hydrated gluten in a dough was largely fluid in its action. The gluten had elastic properties due to its cohesions and thus rendered the dough slightly elastic by bonds between gluten micelles dispersed throughout the dough. Dough properties were modified, however, by an approximately equal volume of suspended starch which added putty-like properties to the dough.

Dempster et al. (19) studying the relaxation of internal stresses in non-fermenting bromated and unbromated doughs, supported the three-dimensional network theory. Since dough was partially elastic, it was postulated that it contained flexible, long-chain molecules (presumably protein) with some cross-links between neighboring molecules, creating a three-dimensional network. The cross-links were probably points of strong intermolecular or secondary valence forces between polar groups of adjacent molecules, rather than primary covalent bonds. Sections of the long molecules between the cross-links were thought to assume randomly kinked or crumpled configurations. The structure was probably dynamic and the shape and degree of kinking in the individual molecular segments changed readily.

It was further stated in this report (19), that in a rested dough, the length of the molecular segments between the cross-links of the postulated network structure were randomly oriented with respect to each other. A certain minimum number of polar groups were considered to be involved in labile intermolecular cross-links which changed in position but remained essentially the same in number. When the rested dough was shaped by comparatively mild manipulations involved in rounding and rolling, the mean length of the molecular segments was increased by mechanical unkinking. Previously non-bonded polar groups in adjacent molecules were also brought into adjacent position by this manipulation. Intermolecular forces between these groups established additional cross-linkages in the network. Internal stresses were thus set up in the dough by working and a considerable force was required to stretch the dough. Upon standing, the dough again reached equilibrium between the numbers of bonds breaking and reforming, internal stresses relaxed, and less force was needed to stretch the dough.

Udy (59) reported that glutens became more resistant to stretching after resting as contrasted to doughs which mellow and soften as a result of relaxation of their internal stresses during resting. It was suggested that new associations between protein molecules accounted for the increase in strength during the resting or mechanical working of the "purified gluten".

Heat Denaturation of Gluten

Neurath *et al*. (40) defined denaturation as, "any non-proteolytic modification of the unique structure of a native protein giving rise to definite changes in chemical, physical or biological properties."

Limited work has been done on the heat denaturation of gluten. Alsberg and Griffing (1) heated disks of gluten in water in a water bath. Ability to swell in dilute acetic acid was used to measure the extent of denaturation. They concluded that heating gluten alters its power to swell. The swelling diminished as the temperature increased from 50°C. to 80°C. Denaturation seemed to take place over the whole range between 50°C. to 80°C., but seemed to be most rapid between 60°C. to 65°C.

Pence *et al*. (44) studied the effect of time, temperature, moisture content, pH, and salt concentration on the denaturation of gluten by heat. The denaturation of wet-gum gluten was found to have an activation energy of approximately 35,000 calories per mole when measured by a baking test method, and 44,000 calories per mole when measured by a solubility method. The rates of denaturation at both 80°C. and 90°C. were negligible at low moisture contents but rose rapidly to an optimum point between 35 to 40 % moisture. At higher moisture levels the rates declined slightly toward intermediate levels. Denaturation was slow at pH 4, but became more rapid at higher pH levels. The relations among pH, temperature, and rate of denaturation were found to be quite complex. At low pH values, damage to the baking properties of gluten occurred which was not due to heat. Variation in salt concentrations had no effect on the rate of denaturation.

Pence *et al*. (44) and Cook (14) found that the denaturation of the gliadin fraction was much slower than that of the whole gluten complex and was characterized by a definite induction period. The studies of Cook (14) indicated that when gluten proteins were subjected to elevated temperatures, the glutenin fraction was first affected, next the gliadin fractions of low solubility, and finally under severe conditions all of the gliadin was denatured.

The Effect of Sugar on Baked Products

It has been noted that the addition of too great a quantity of sugar in baked products produced undesirable results; fallen structure and decreased volume. Experiments varying the proportion of sugar (sucrose) in cake led to the conclusion that increasing sugar up to a certain point improves texture, tenderness, and volume. It was not possible to increase the quantity much above an optimum point without causing the cake to fall (10, 15, 17, 39, 41, 52).

de Goumois and Hanning (18) reported that there were increases in volume and compressibility of yellow cakes when the total sugar content of the cake formula was increased 15 or 30% by the additions of sucrose, glucose, alpha-lactose or beta-lactose. The increase in volume and compressibility were always greater at the 30% level of any of the sugars. The cakes which had additions of beta-lactose and sucrose had the largest volumes, and those with beta-lactose were more compressible throughout the storage period of five days.

Sandstedt and Blish (47) reported the effects on loaf properties of bread produced by variations of added sucrose over a range of 2.5 to 5.5 g. per 100 g. of flour. Effects were unimportant when shortening was ommitted. When shortening was included in the formula and the sugar was increased from 2.5 to 5.5%, a significant volume increase was noted.

Barham and Johnson (5) studied the influence of sucrose, glucose, fructose, and invert sugar on bread and dough properties. They found that bread made from a dough containing 2 to 4% sugar had minimum crumb firmness. In samples containing more than 4% sugar, the crumb firmness (measured twenty-four hours after baking) increased to a greater extent than could be accounted for by volume differences. They proposed that sugar might have served as a bonding force and hence created a firmer less resilient crumb.

Larmour and Brockington (33) reported the effects of variation in formulas of bread made from three flours. They observed that with one flour that loaf volume increased as the sugar content of the formula was raised. This result was not noted in the volumes of bread made from the other two flours.

Micka and Child (38) stated that there was a decrease in adsorption of a dough as the sucrose content of a bread formula was increased. They also noted that a dough made with flour, water, and sugar was slacker directly after mixing than a dough made with flour and water which became still slacker on standing.

The Effect of Sugar on Gluten

Limited work has been done on the effect of sugars on gluten formation and character. Jago and Jago (27, 28) reported a study on the effect of adding sucrose to a flour and water dough. They noted that when sugar was added to the dough, the dough became softer and stickier than dough to which no sugar had been added. If the sugar-dough was to attain the same viscosity as the flour-water dough, water had to be reduced. The results of this study are summarized in Table I.

Jago and Jago (27, 28) further studied doughs made from two different kinds of flour, with and without the addition of 20 parts of sugar. Wet gluten was determined after washing the flour dough. Dry gluten was determined after the wet gluten was air dried and finely ground. The protein of the true gluten was estimated by nitrogen analysis (Kjeldahl method) on the dry gluten. Gliadin was found by dissolving wet gluten with 70% alcohol, filtering, and estimating the protein of the filtrate by nitrogen analysis. Glutenin was found by subtracting gliadin from true gluten. In all cases the sugar caused a diminution in the quantity of gluten recovered, except in the case of the dry gluten of one flour. The results of this study are summarized in Table II.

When extracted with alcohol, much more gluten was dissolved by sugar-spirit (20% sucrose in 70% alcohol) than by the 70% alcohol alone. The experimenters concluded that sugar had a marked solvent action on the wet gluten. The total protein of the two flours was directly estimated by nitrogen analysis. The proteins soluble in water were determined by directly treating the flour, filtering, and estimating the protein of the filtrate by nitrogen analysis. The proteins soluble in 70% alcohol were estimated by direct treatment of the flour, and estimating the protein of the filtrate by

TABLE I (27, 28)

THE EFFECT OF SUGAR ON DOUGH VISCOSITY

Weight in Grams				Viscosimeter Time
I.	Flour 100,	water 50		106 seconds
II.	Flour 100,	sugar 20,	water 50	9 seconds
III.	Flour 100,	sugar 20,	water 48	16 seconds
IV.	Flour 100,	sugar 20,	water 46	28 seconds
V.	Flour 100,	sugar 20,	water 44	50 seconds
VI.	Flour 100,	sugar 20,	water 42	64 seconds
VII.	Flour 100,	sugar 20,	water 40	86 seconds
VIII.	Flour 100,	sugar 20,	water 38	364 seconds

Sucrose was the sugar used in this experiment.

TABLE II (27, 28)

THE EFFECT OF ADDITION OF TWENTY PARTS SUGAR ON GLUTEN, GLIADIN, AND GLUTENIN RECOVERED FROM DOUGHS MADE FROM TWO KINDS OF FLOUR

Constituents	Flour A		Flour B	
	Ordinary	Sugar-dough	Ordinary	Sugar-dough
	g.	g.	g.	g.
Gluten, wet	37.2	35.9	26.7	23.9
Gluten, dry	11.3	11.7	8.2	7.7
Gluten, true	10.4	10.0	7.5	7.2
Gliadin, ex gluten	3.6	7.2	3.0	5.6
Glutenin	6.8	2.8	4.5	1.6

Sucrose was the sugar used in this experiment.

nitrogen analysis. The proteins similarly dissolved by the sugar-spirit were also determined. The results of this study are summarized in Table III.

Jago and Jago (27, 28) assumed that water and sugar-water, respectively, did not dissolve the same proteins as did the alcohol and sugar-spirit, but that there was probably some overlapping. It was noticed in every case that an increased solvent power was exerted when sugar was present. In all cases the sugar-spirit dissolved considerably more protein than 70% alcohol alone. Sugar diminished rather than increased the absorptive power of the flour proteins. It was thought that small quantities of sugar exerted a solvent action on the gluten and effected sufficient softening which increased the gas-retaining power of doughs and thus indirectly increased the strength of the flour.

McAuley (34) studied the effect of sucrose on sodium salicylate dispersions of gluten. It was found that the sugar decreased the intrinsic viscosity of the gluten dispersion. This decrease was thought to indicate a decrease in the particle size or axial ratio of gluten. This assumption was based on the theory that gluten molecules were coiled chains which were free to react with other molecules. Changes in attractions within the molecule or between molecules would be reflected by change in viscosity. It was therefore assumed that sucrose brought about these changes.

TABLE III (27, 28)

THE EFFECTS OF AQUEOUS SUGAR SOLUTION, SUGAR-SPIRIT, AND ALCOHOL ON THE SOLUBILITY OF FLOUR PROTEINS

Constituents	Flour A		Flour B	
	%	%	%	%
Total proteins	11.6	11.6	9.9	9.9
Proteins soluble in water	1.0		0.5	
Proteins soluble in sugar-spirit		1.5		2.5
Gliadin and glutenin	10.6	10.1	9.4	7.4
Soluble in alcohol, gliadin	6.4		4.6	
Soluble in sugar-spirit, gliadin		7.5		5.7
Insoluble glutenin	4.2	2.6	4.8	1.7

Sucrose was the sugar used in this experiment.

Frang (24) studied the effects of sugars on heat denaturation and coagulation of gluten. The effect of glucose or sucrose on gluten was determined by measuring the change in sulfhydryl groups and the soluble nitrogen of the filtrate from lactic acid dispersions of gluten during heat and pH change. Glucose, fructose, maltose, lactose, invert sugar, and sucrose were incorporated in gluten and the volumes of the baked gluten balls were determined. Soluble nitrogen was determined on part of the latter series. The results of the study indicated that the presence of either glucose or sucrose decreased slightly the amount of oxidizable sulfhydryl groups, and increased the soluble nitrogen in the filtrate. It was concluded that these two sugars interfered with the denaturation process and brought about a peptization of the coagulum.

From the results of the experiments on baked gluten balls Frang (24) noted that an increase in per cent soluble nitrogen might be caused by sugars other than glucose or sucrose. Gluten was prepared from two kinds of flour and the following sugars were added in amounts equivalent to 5 or 10% of the flour used to prepare the gluten: sucrose, glucose, lactose, maltose, fructose, and simulated invert sugar. There was usually an increased solubilization of nitrogen at the higher concentration. Separate determinations of nitrogen in the crust and crumb of baked gluten balls showed that there was a greater concentration of soluble nitrogen in the crust than in the crumb of the gluten ball. From the volume of the baked gluten balls measured by seed displacement, it was concluded that at the 5% level, fructose, invert sugar, and maltose had the greatest beneficial effect on volume; and at the 10% level, they had the least detrimental effect. Lactose always had the most detrimental effect at either level.

Hlynka and Bass (26) studied the reaction of dough and gluten with 5% glucose. It was found that a storage period was necessary to bring about the glucose-protein interaction. It was also shown that the reducing value of gluten was unchanged by washing the gluten to remove the added reacted glucose. This evidence was believed to support the hypothesis that reducing carbohydrates in dough and gluten act as cross-linking agents between protein chains to form a three-dimensional network.

Similar studies were reported by Hlynka and Anderson (25) on the glucose-protein interaction on material prepared from high, medium, and low-protein flours of five different varieties of wheat. High-protein flours gave the lowest initial reducing values and also the greatest increase in reducing values after a storage of six months. When glucose was added and intimately mixed with water, and moisture removed to the original level, reducing values increased several fold. The same general trend was obtained from analogous experiments with gluten prepared from high, medium, and low-protein flours.

However, gluten from low-protein flour showed a greater reactivity toward the added glucose than gluten from high-protein flour.

EXPERIMENTAL PROCEDURE

General Plan

Two experimental procedures were employed in this study. An all purpose flour (Gold Medal All-Purpose Flour) was used throughout the study.

In the first procedure a 5% level, based on the water weight, of either D (-) fructose, D (-) glucose, D (+) technical maltose, beta-lactose, or sucrose were added: (a) to a flour-water dough in the preparation of gluten, (b) to gluten prepared from the preceding method, and (c) to prepared gluten made from only a flour-water dough. Weights of the gluten lots (plus the weight of the sugar, if sugar were added) were recorded before and after mixing. The amount of drip loss of the gluten lots as affected by the presence or absence of each sugar was determined in this way. The gluten obtained from these three methods was baked in the form of balls. The extent to which each sugar affected the gluten structure was determined by comparing the volumes and crushing forces of baked gluten balls.

In the second experimental procedure, increasing percentages of each sugar (based on the flour weight) were added to a flour-water dough until gluten formation was negligible. The sugars used were : D (-) fructose, D (-) glucose, D (+) technical maltose, D (+) maltose C.P., beta-lactose, D (+)

lactose, or sucrose. The yield of gluten obtained after each increasing addition of each sugar indicated the amount of gluten formation. The amount of gluten obtained for each increasing level, was baked in the form of a ball. Volume and crushing force of these balls were compared to those with no sugar added. In this way the extent to which each sugar affected the gluten structure was tested.

Preparation of Gluten

Procedure I

Methods (a) and (b). Wet gum gluten was prepared from 355 g. of flour, 288 ml. tap water, and 14.4 g. of sugar (5% of the water weight). The sugars used were either D (-) fructose, D (-) glucose, D (+) technical maltose, beta-lactose, or sucrose (Table IV). The study consisted of four replications of each sugar and the control. The flour, sugar, and water were mixed 5 minutes in a Kitchen Aid Mixer (Model K 5-A). The dough was scraped down at the end of the second and fourth minutes. At the end of the mixing period the dough was rested for 30 minutes at room temperature. After this resting period the dough was immersed in a sink of tap water and was washed to obtain gluten. The water was changed every 2 minutes for the first 10 minutes of washing and thereafter whenever it appeared necessary. The washing was continued until the starch-iodine test indicated that there was no starch in the wash water (usually about 1-hour).

TABLE IV

SUGARS USED IN PROCEDURE I AND PROCEDURE II

Description on Label		Company
* Sucrose ǂ Cane sugar Extra-fine granulated		American Sugar Refining Company
* D (-) Glucose (Anhydrous) ǂ Molecular Weight	 180.16	Eastman Organic Chemicals
* D (-) Fructose, C.P. Special ǂ Molecular Weight Specific Rotation Ash Moisture	 180.13 -92° 0.05% 0.1 %	Pfansteihl
* Beta-Lactose 98% ǂ Ash Free Moisture Beta-lactose Alpha-lactose	 1.10% 0.07% 98.5 % 1.0 %	Pfansteihl
ǂ D (+) Lactose C.P. (hydrate) Molecular Weight Specific Rotation Ash Sucrose or Glucose Dextrin or Starch	 360.19 +52.2-52.5° 0.05% 0.1 % none	Pfansteihl
* D (+) Maltose, technical ǂ (hydrate) Specific Rotation Dextrin	 +125-135° 12-15%	Pfansteihl
ǂ D (+) Maltose, C.P. (hydrate) Molecular Weight Specific Rotation Ash Moisture	 360.20 +130.4° 0.05% 0.1 %	Pfansteihl

* Indicates sugars used in Procedure I.

ǂ Indicates sugars used in Procedure II.

At the end of the wash period, the gluten was placed in an aluminum colander and was allowed to drain for 30 minutes. After draining, the gluten was divided into two equal lots (60-g., more or less, depending upon the amount of gluten obtained). To one of these lots of gluten 7.2 g. of the same sugar used in the flour-water dough was again added [method (b)]. The sugar and gluten were mixed 10 minutes in a Kitchen Aid Mixer (Model 3-C). The gluten and sugar were blended at speed 1 for 1-minute, the bowl was scraped down and mixing continued for 9 more minutes at speed 4.

No sugar was added to the other lot of gluten which was mixed in the same manner [method (a)].

The control for this series was gluten made from 355 g. flour and 288 ml. tap water. No sugar was added at any time. The gluten was washed, drained, and mixed in the same manner as the gluten to which sugar had been added.

The lots of gluten were weighed, before and after mixing, to the nearest tenth of a gram and were divided into four portions. Each of these portions was given 10 folding strokes to shape them into balls which were baked 15 minutes at 232°C. and 35 additional minutes at 149°C. [Sutherland and Nelson (55)].

The gluten balls were cooled at room temperature for two hours before volumes and crushing forces were determined.

Method (c). Dough was made in two lots in a Kitchen Aid Mixer (Model K 5-A). To make each lot of dough 1000 g.

of flour and 800 ml. of tap water were used. The dough was mixed 5 minutes at low speed, the total dough mixture being scraped down at the end of the second and fourth minutes. The dough was rested 30 minutes before it was washed to obtain the gluten.

After the dough had rested for 30 minutes, the first lot of dough was washed 10 minutes (the wash water was changed every 2 minutes) and was placed in a pan of water for 10 minutes while the second lot was washed for the same period of time. The two lots were then pooled and washing was continued until the starch-iodine test was negative (usually about $1\frac{1}{2}$ to 2 hours). The wash water was changed whenever it appeared necessary.

After washing, the gluten was placed in an aluminum colander and drained for 30 minutes.

After draining, the gluten (about 675 g.) was divided into 60-g. lots. (The five lots of gluten 7.2 g. of either D (-) fructose, D (-) glucose, D (+) technical maltose, beta-lactose or sucrose were added.) The amount of sugar added was equivalent to 5% of the weight of water required to obtain 60-g. of gluten. Two of the lots had no sugar added and were used as controls. Methods for mixing the lots of gluten with each sugar, dividing the lots and shaping the lots into balls, and baking were the same as those cited in the procedure used in making gluten balls in methods (a) and (b). The controls, to which no sugar was added, received the same treatment.

Volumes and crushing forces of the gluten balls were determined two hours after removal from the oven.

Procedure II

A dough was made from 30 g. flour, 24 ml. of tap water, and varying percentages of sugar based on the flour weight. Sugars used were: D (-) fructose, D (-) glucose, D (+) technical maltose, D (+) maltose C.P., beta-lactose, D (+) lactose, or sucrose (Table IV). Increasing increments of each sugar were added to the flour-water mixture until no gluten was formed. This was determined by passing the first wash water through a wire sieve. When gluten was formed it remained in the sieve, while solubles, starch, and other particles in dispersion passed through. When no gluten was formed the total mixture passed through the sieve. Three replications were made for each level of each sugar. A dough made of 30 g. flour and 24 ml. tap water served as the control for each replication. All lots of flour for each replication were weighed a day ahead, while the sugar was weighed on the day of preparation.

The flour and sugar were placed in a glass mixing bowl and water was added. The mixture was mixed at speed 1 for 2 minutes, scraped down; mixed 2 minutes, scraped again; and mixed 1 more minute. Kitchen Aid Mixer (Model 3-C) was used.

The total mixture was scraped from the bowl onto Saran Wrap, which had been sprinkled with water, and was rested 30 minutes at constant temperature (25°C.).

The dough was scraped from the Saran Wrap into glass mixer bowls containing 750 ml. of tap water at 25°C. (± 1°C.) and was washed at speed 1 for 2 minutes. The wash water was poured through a wire sieve (20 mesh). The gluten obtained was squeezed 10 times under running tap water to remove more starch at this time. The gluten was again placed in a bowl of water and received three more 2-minute washings at speed 2. The wash water was changed at the beginning of each 2-minute washing. The pH of the tap water was taken every day.

The washing completed, the gluten was placed in an aluminum colander and drained for 30 minutes at constant temperature (25°C.). The gluten was then weighed, placed in a mixer bowl and mixed 10 minutes. Mixing consisted of beating the gluten for 1-minute at speed 1 and 9 minutes at speed 4. The gluten was again weighed after mixing, and was shaped into a ball with ten folding strokes. The baking procedure was the same as that used in Procedure I. (When gluten yields of less than 3 g. were obtained, the mixing times and baking times were shortened. Mixing, in this case, consisted of beating the gluten for 1-minute at speed 1 and 4 minutes at speed 4. The ball was baked 10 minutes at 232°C. and 20 minutes at 149°C.).

Volumes and crushing forces were determined 1-hour after the gluten balls were removed from the oven.

Objective Tests

Volume Measurement

The volumes of the gluten balls made by Procedure I were determined by a Volumemeter (Fig. 1). The volumemeter is a standard laboratory instrument which measures the volume of a given object by rape seed displacement. It consists of a hollow box at the bottom of a column of rape seeds. To determine the volume of the gluten balls, the rape seeds were first allowed to fill the box when the gate was released. The volume of the box was registered on a scale on the front of the volumemeter. The whole cylinder was then turned upside-down, and the seeds fell into a reservoir at the top of the volumemeter. The gate was shut and four gluten balls were placed in the hollow box. The seeds were again released and the scale on the front indicated the volume when it contained the gluten balls. The volume of the gluten balls was obtained by difference.

Since only one gluten ball was obtained for each level of sugar in Procedure II, an instrument was devised to measure the volume of the ball (Fig. 2). The volume of the gluten ball was determined by measuring the volume of seeds displaced from a box by the gluten ball. The volume of a square plastic box was determined by pouring seeds from a uniform height through a glass funnel (approximately 10 cm. diameter) at a uniform rate. The seeds were poured into the box until it was

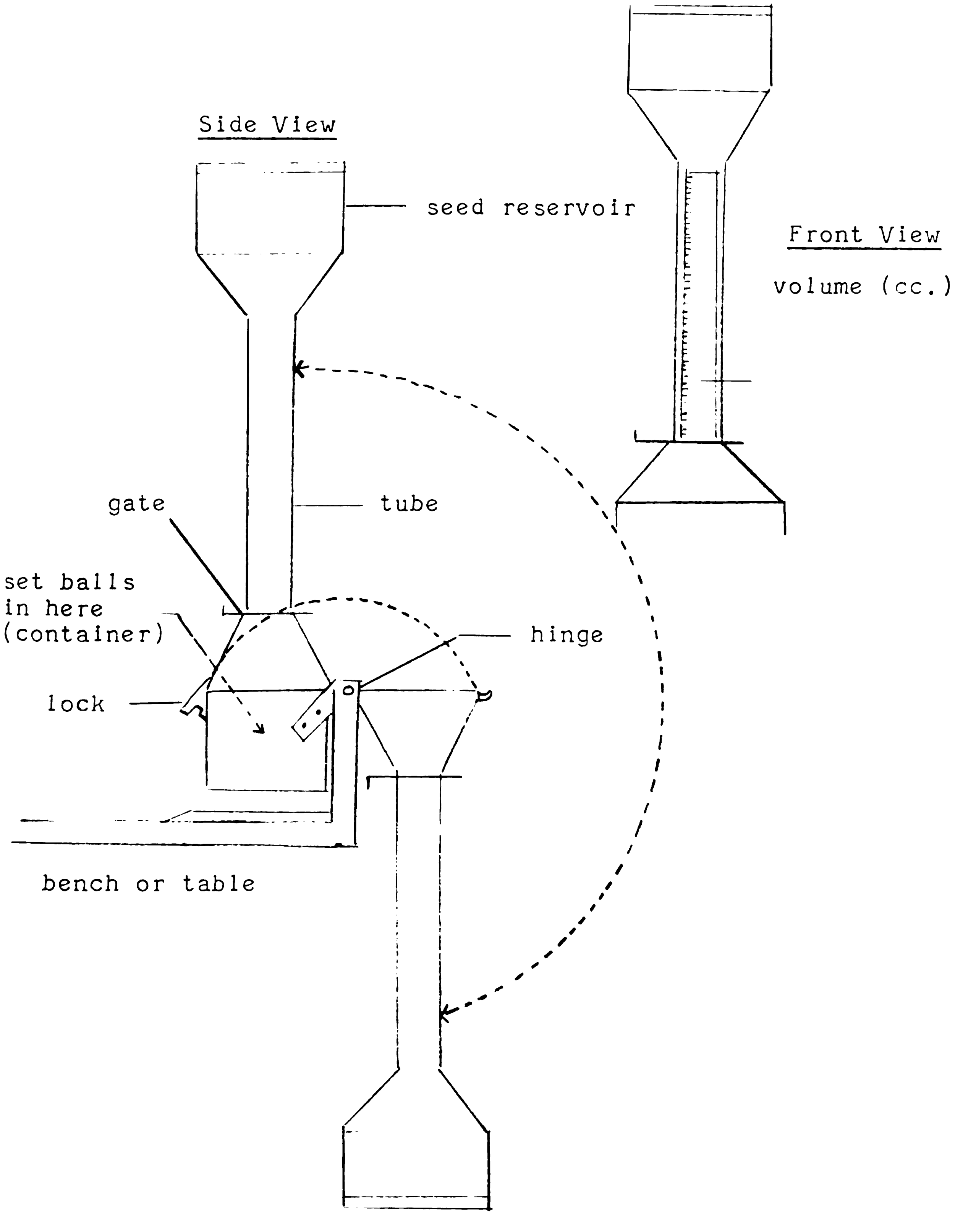

Fig. 1. Loaf Volumemeter (National Manufacturing Company, Lincoln, Nebraska).

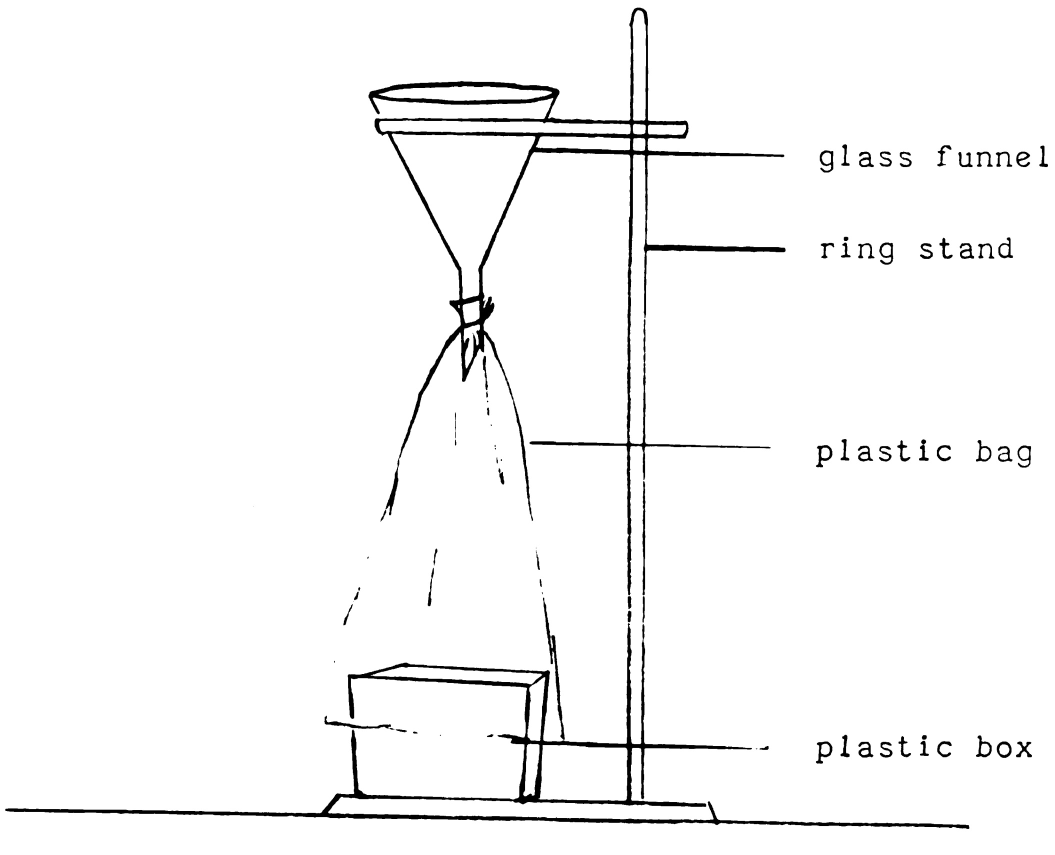

Fig. 2. Apparatus used for measuring the volume of one gluten ball.

over-flowing and the excess scraped off. The seeds were then poured from a uniform height at a uniform rate through a glass funnel into a 500-ml. graduated cylinder. When needed an additional 100-ml. graduate was used. The volume of the gluten ball was measured by pouring seeds into the box until the bottom was covered. The gluten ball was then placed in the box and seeds were poured into the box until it was overflowing. The volume of the seeds was measured in the same manner as before. The volume of the gluten ball was determined by difference. (A plastic bag extended from the funnel to the plastic box. This prevented the seeds from scattering.)

Crushing Force

Since no laboratory instrument was available to measure the amount of force needed to crush a gluten ball, the following device was improvised (Fig. 3). It consisted of a ring stand on which was mounted a glass funnel (approximately 19 cm. diameter). A piece of rubber tubing fitted with a spring clamp was placed on the end of the funnel. The funnel was filled with lead shot. A stiff cardboard can with metal rims and bottom which fitted exactly inside a 1-liter glass beaker was placed directly below the funnel. (Stockingette was used to cover the can. This insured closeness of fit and cushioned the fall of the metal bottom on the glass beaker.) To measure the tenderness of the gluten ball, the ball was placed inside the beaker with the can on top. The spring clamp was released

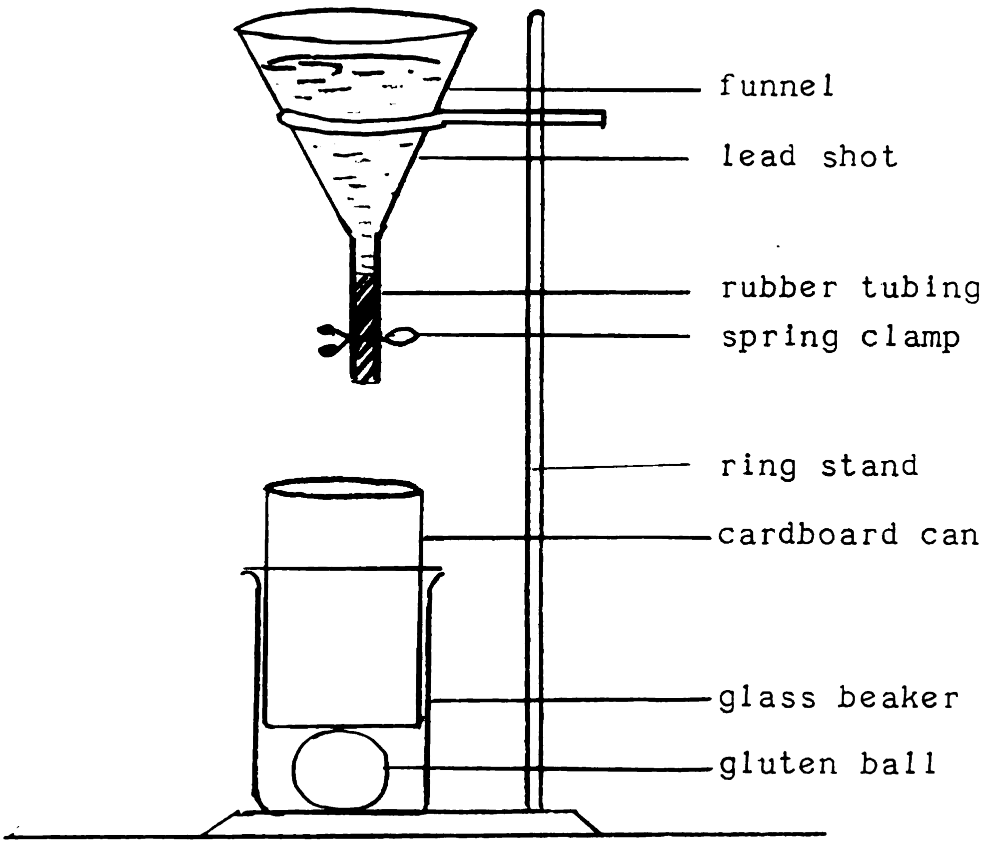

Fig. 3. Apparatus used for measuring the crushing force of gluten balls.

and the shot fell from the funnel into the can at a uniform rate until the gluten ball was completely crushed. The can and shot were then weighed. In this way the amount of force needed to crush a gluten ball was measured.

RESULTS AND DISCUSSION

Procedure I.

The drip losses of the raw gluten, and the volumes and crushing forces of the baked gluten balls as affected by the three methods of adding the sugars were analyzed by an analysis of variance (49) and studentized range (21). In the same manner, each method was analyzed individually to detect differences among the various sugars and controls in their effect on the drip losses of raw gluten, and the volume and crushing forces of baked gluten balls.

Drip Loss

The drip losses of gluten are presented in Table V.

It was found by analysis of variance and studentized range that methods of adding a sugar were significantly different in their effect on the drip loss of gluten. When a sugar was added to a flour-water dough in the preparation of gluten and again to the gluten obtained [method (b)], and to gluten prepared from only a flour-water dough [method (c)] there was a significantly higher drip loss than when each of the sugars was added only to a flour-water dough in the preparation of gluten [method (a)]. The analysis of variance of the drip losses of the three methods is presented in Table VI.

TABLE V

PROCEDURE I. THE INFLUENCE OF 5% LEVELS OF SUGARS AND METHODS OF INCORPORATING SUGARS ON THE DRIP LOSSES OF GLUTEN

	Drip Loss (g.)					
Methods of Preparation	Sucrose	D (-) Fructose	D (+) Technical Maltose	Beta-Lactose	D (-) Glucose	Control
(a)	3.5[1]	4.9	4.6	2.5	3.8	2.9
	2.0	3.2	5.4	0.8	2.9	3.2
	5.4	5.6	5.3	4.1	4.5	2.8
	3.6	4.4	4.9	7.1	3.5	3.1
Mean	3.8	4.5	5.1	3.6	3.7	3.0
(b)	13.5	15.0	8.3	13.8	12.1	2.9
	13.6	13.0	15.0	14.8	14.4	3.2
	15.0	12.8	13.8	15.0	13.8	2.8
	11.5	14.9	7.4	14.1	12.0	3.1
Mean	13.4	13.9	11.1	14.4	13.1	3.0
(c)	12.6	13.5	14.0	14.3	13.1	3.6
	14.4	14.1	13.6	15.1	13.3	3.5
	14.4	14.2	11.1	14.9	13.8	4.2
	14.4	12.8	12.7	14.6	14.7	4.1
Mean	14.0	13.7	12.9	14.7	13.7	3.8

[1] Amount of drip loss obtained from 60 g. of gluten.

TABLE VI

ANALYSES OF VARIANCE OF THE EFFECT OF METHODS AND TREATMENTS OF DRIP LOSSES OF GLUTEN (PROCEDURE I)

Characteristic Tested	Source of Variation	Degrees of Freedom	Mean Square
All Methods	Treatments	5	102.30 **
	Methods	2	500.60 **
	Treatments X Methods[1]	10	20.69 **
	Error	54	1.91
	Total	71	
Method (a)	Treatments	5	2.18
	Replications	3	3.61
	Error	15	1.43
	Total	23	
Method (b)	Treatments	5	74.34 **
	Replications	3	5.00
	Error	15	2.99
	Total	23	
Method (c)	Treatments	5	67.18 **
	Replications	3	0.25
	Error	15	1.40
	Total	23	

* Significant at 5% level of probability.

** Significant at 1% level of probability.

[1] Since the interaction of treatments x methods was significant, this mean square was used as the "error" term to test the significance of the treatments and methods.

Each method of addition was analyzed individually to determine differences in the drip losses of the lots of gluten to which a sugar had been added and the control lots of gluten to which no sugar had been added (Table VI). In both methods (b) and (c), the lots of gluten to which a sugar had been added were significantly higher in drip losses than the control lots of gluten. In method (a) there were no significant differences in the drip losses of the lots of gluten prepared from a sugar-containing dough and the control lots.

The drip losses of the gluten lots to which a sugar had been added after the preparation of the gluten contained some of the added sugar in solution. These same drip losses were also tested for the presence of protein. The ninhydrin test was positive in all cases when either D (-) fructose, D (+) technical maltose, sucrose, D (-) glucose or beta-lactose was added to prepared gluten. The drip losses were thus shown to contain protein, peptones, peptides, or alpha-amino acids. These results suggest the sugars actually exerted a solvent or peptizing action on the gluten protein.

No significant drip losses were obtained from the gluten prepared by method (a). This was probably due to the fact that in this method the sugars were only added to the flour-water dough in the preparation of gluten.

Volume

The volumes of baked gluten balls are presented in Table VII.

TABLE VII

PROCEDURE I. THE INFLUENCE OF 5% LEVELS OF SUGARS AND METHODS OF INCORPORATING SUGARS ON THE VOLUMES OF BAKED GLUTEN BALLS

	Gluten Ball Volume (ml.)					
Methods of Preparation	Sucrose	D (-) Fructose	D (+) Technical Maltose	Beta-Lactose	D (-) Glucose	Control
(a)	575[1]	500	600	550	600	617
	675	500	525	500	575	617
	600	665	540	655	580	667
	650	625	725	615	625	592
Mean	625	573	598	580	595	623
(b)	550	425	750	425	450	617
	550	550	500	500	500	617
	575	565	440	530	630	667
	575	675	675	615	550	592
Mean	563	554	591	518	533	623
(c)	600	500	525	475	575	500
	425	500	400	375	450	575
	480	560	335	380	380	572
	500	625	475	450	450	538
Mean	501	546	434	420	464	546

[1] Volume of four gluten balls.

Gluten balls made from lots of gluten to which a sugar had been added to a flour-water dough in the preparation of gluten [method (a)], and the gluten balls made from lots of gluten to which a sugar had been added both in the preparation of the gluten and again to the gluten obtained [method (b)], had significantly greater volumes than did gluten balls made by method (c). (Gluten balls prepared by method (c) had had a sugar added to lots of gluten prepared from a flour-water dough.) The analysis of variance of the gluten ball volumes of the three methods is presented in Table VIII.

Each method of preparation also was analyzed individually (Table VIII). No significant differences were found among the volumes of the gluten balls prepared by method (a). Also there were no significant differences in the volumes of any of the gluten balls prepared by method (b).

It is apparent that the volumes of the baked gluten balls were not significantly altered by the inclusion of a 5% level of sugar in the preparation of gluten [method (a)]. The volumes of the gluten balls prepared by method (b) were also unaltered by the double sugar additions. However, there does seem to be a trend toward decreased volume in the gluten balls prepared by method (b). Perhaps a longer period of experimentation would have established a significant decrease in the volumes of the gluten balls which had had a double sugar addition in contrast to the volumes of control gluten balls.

TABLE VIII

ANALYSES OF VARIANCE OF THE EFFECT OF METHODS AND TREATMENTS ON THE VOLUMES OF BAKED GLUTEN BALLS (PROCEDURE I)

Characteristic Tested	Source of Variation	Degrees of Freedom	Mean Square
All Methods	Treatments	5	11,763.60
	Methods	2	81,190.00 **
	Treatments X Methods	10	4,089.70
	Error	54	5,274.48
	Total	71	
Method (a)	Treatments	5	1,876.40
	Replications	3	7,406.67
	Error	15	3,289.93
	Total	23	
Method (b)	Treatments	5	6,010.60
	Replications	3	8,059.33
	Error	15	7,363.53
	Total	23	
Method (c)	Treatments	5	12,056.00 *
	Replications	3	9,002.00
	Error	15	3,441.06
	Total	23	

* Significant at 5% level of probability.

** Significant at 1% level of probability.

In method (c) significant differences were found among the volumes of gluten balls. Studentized range analysis indicated that the volumes of gluten balls prepared from lots of gluten to which either lactose or maltose had been added were significantly smaller in volume than both the control gluten balls and gluten balls which had had additions of fructose. The volumes of gluten balls made from lots of gluten which had had glucose or sucrose additions were intermediate. These gluten balls were not significantly different in volume from control gluten balls, or gluten balls to which fructose, lactose, or maltose had been added.

These findings agree, in part, with the results reported by Frang (24) who added 5% levels of sugars to gluten prepared from a flour-water dough. She found that fructose and maltose had the greatest beneficial effect on the volume of gluten balls; lactose had the most severely detrimental effect; and glucose and sucrose were also intermediate. The technical maltose (which contained 10-15% dextrins) may have caused the decreased volumes of the gluten balls prepared in method (c) of this study, and would account for the differences in the results of this study when compared to those reported by Frang (24).

Crushing Force

The average forces needed to crush gluten balls are presented in Table IX.

TABLE IX

PROCEDURE I. THE INFLUENCE OF 5% LEVELS OF SUGARS AND METHODS OF INCORPORATING SUGARS ON THE CRUSHING FORCES OF BAKED GLUTEN BALLS

Method of Preparation	Sucrose	D (-) Fructose	D (+) Technical Maltose	Beta-Lactose	D (-) Glucose	Control
	Crushing Force per Gluten Ball (g.)					
(a)	3078[1]	2741	3270	2014	3565	3464
	3131	2954	3173	3108	3027	3249
	3515	2899	3597	3210	3246	3042
	2994	3357	2602	3148	3303	3654
Mean	3180	2998	3161	2870	3285	3352
(b)	2095	2715	1646	1977	2642	3464
	1934	1572	2624	3156	1899	3249
	2006	1930	1783	2487	1772	3042
	2521	2026	2364	2458	2256	3654
Mean	2139	2061	2104	2520	2142	3352
(c)	2350	2046	2911	2879	2689	3081
	2973	2224	2564	2840	2917	2622
	2157	2255	2434	2560	2360	1903
	2432	2258	2678	2252	2266	2803
Mean	2478	2197	2647	2633	2558	2602

[1] Mean of four determinations.

An analysis of variance of the crushing forces indicated that gluten balls made from lots of gluten to which a sugar had been added to the flour-water mixture in the preparation of the gluten [method (a)] were significantly less tender than gluten balls made from lots of gluten to which a sugar had been added in the preparation of the bluten and again to the gluten obtained [method (b)]. The gluten balls of method (a) were also significantly less tender than the gluten balls made from lots of gluten to which a sugar had been added after the gluten had been prepared from a flour-water dough [method (c)]. The analysis of variance for the three methods is presented in Table X. Therefore, it is believed that the addition of a sugar to prepared gluten is more critical in its effect in weakening the structure of baked gluten balls than the addition of a sugar to a flour-water dough in the preparation of gluten.

Individual analyses of each method (Table X) revealed that there were no significant differences in the tenderness of the gluten balls prepared according to method (a) or method (c). However, in method (b), forces needed to crush control gluten balls were significantly higher than the forces needed to crush the gluten balls to which a sugar had been added.

These findings suggest that the double sugar addition of method (b) apparently affected the gluten to such an extent that the baked gluten balls were weaker in structure and hence, less force was needed to crush these balls.

TABLE X

ANALYSES OF VARIANCE OF THE EFFECT OF METHODS AND TREATMENTS ON THE CRUSHING FORCES OF BAKED GLUTEN BALLS (PROCEDURE I)

Characteristic Tested	Source of Variation	Degrees of Freedom	Mean Square
All Methods	Treatments	5	617,292.00
	Methods	2	3,875,831.00 **
	Treatments X Methods[1]	10	317,087.70 *
	Error	54	128,534.80
	Total	71	
Method (a)	Treatments	5	131,363.60
	Replications	3	57,525.67
	Error	15	129,828.33
	Total	23	
Method (b)	Treatments	5	1,005,643.40 **
	Replications	3	148,367.67
	Error	15	164,811.80
	Total	23	
Method (c)	Treatments	5	114,460.60
	Replications	3	224,476.33
	Error	15	75,344.60
	Total	23	

* Significant at 5% level of probability.

** Significant at 1% level of probability.

[1] Since the interaction of treatments x methods was significant, this mean square was used as the "error" term to test the significance of the treatments and methods.

Procedure II.

In the second experimental procedure increasing percentages of various sugars were added to a flour-water dough until gluten formation was negligible. The pH of the tap water used for washing the dough was recorded every day and ranged between 7.4 to 7.55.

Gluten Yield

When the following concentrations of the various sugars were added to the flour and water in the preparation of the gluten, no gluten was obtained: D (-) fructose, 60-65% (Table XI); D (-) glucose, 60-65% (Table XII); sucrose, 55-60% (Table XIII); D (+) maltose, C.P. 45% (Table XIV); D (+) technical maltose 30% (Table XV); and beta-lactose 40-45% (Table XVI). The D (+) lactose did not affect gluten yield even at the 70% concentration (Table XVII).

The D (+) lactose seemed extremely insoluble in the water present in the dough. No more of this sugar was added above the 70% level, due to this insolubility, as the dough became increasingly more viscous and was impossible to mix. All of the other sugars, except the D (+) lactose, seemed to be soluble in the water present in the dough. As the concentration of each sugar was increased, the dough became less viscous. At the "critical concentration" of each of these sugars (when no gluten was obtained), the dough was actually very thin. However, no measurements of dough viscosity were made.

TABLE XI

EFFECTS OF INCREASING PERCENTAGES OF D (-) FRUCTOSE ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

% D (-) Fructose	Yield of gluten (g.)				Volume of one gluten ball (ml.)				Amount of force needed to crush one gluten ball (g.)			
	Replications				Replications				Replications			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
0	10.9	11.2	11.2	11.1	60	90	70	73.3	5448	2351	4696	4165
5	10.6	10.6	10.4	10.5	60	90	110	86.7	5544	2738	2214	3499
10	10.4	10.2	10.3	10.3	75	85	75	78.3	3648	3314	4452	3805
15	10.7	10.8	10.5	10.7	60	65	75	66.7	4780	3133	2764	3559
20	10.6	10.4	10.8	10.6	95	75	80	83.3	2821	2776	3332	2976
25	10.6	9.9	10.0	10.2	70	75	70	71.7	3738	2426	3465	3210
30	10.7	9.3	9.9	10.0	80	70	75	75.0	3472	1988	3120	2860
35	9.8	8.2	9.5	9.2	90	80	75	81.7	2398	1210	2586	2065
40	8.1	7.4	9.3	8.3	45	65	70	60.0	2997	1112	2171	2093
45	2.0	1.7	6.9	3.5	15	10	60	28.3	586	745	1275	869
50	0.3	1.0	1.2	0.8	1	6	15	7.3	520	552	485	519
55	-	-	0.4	0.1	-	-	4	1.3	-	-	679	226
60	-	-	0.3	0.1	-	-	2	0.7	-	-	395	132
65	-	-	-	-	-	-	-	-	-	-	-	-

TABLE XII

EFFECTS OF INCREASING PERCENTAGES OF D (-) GLUCOSE ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

% D (-) Glucose	Yield of gluten (g.)				Volume of one gluten ball (ml.)				Amount of force needed to crush one gluten ball (g.)			
	Replications 1	2	3	Mean	Replications 1	2	3	Mean	Replications 1	2	3	Mean
0	10.6	10.9	11.4	11.0	65	70	75	70.0	3626	3888	3707	3740
5	10.0	10.0	10.2	10.1	100	80	85	88.3	2682	3385	3368	3145
10	11.0	11.1	11.3	11.1	80	70	90	80.0	3443	4152	3745	3780
15	10.4	10.8	11.3	10.8	75	90	80	81.3	2312	2493	3796	2867
20	10.1	10.7	10.8	10.5	65	85	60	70.0	3063	2152	4148	3121
25	9.9	9.2	9.2	9.4	75	80	75	76.7	3211	1888	1553	2217
30	9.3	9.1	7.7	8.7	50	50	60	53.3	3664	2046	2458	2723
35	8.2	5.7	6.9	6.9	50	45	50	48.3	1817	1095	1363	1425
40	2.8	4.0	3.5	3.4	15	30	20	21.7	805	1328	1072	1068
45	0.8	2.0	3.5	2.1	4	15	15	11.3	771	472	2254	1165
50	0.4	1.3	2.2	1.3	2	10	10	7.3	371	619	540	510
55	0.3	0.3	0.1	0.2	2	5	1	2.7	538	384	368	430
60	0.1	-	-	0.1	1	-	-	0.3	-	-	286	95
65	-	-	-	-	-	-	-	-	-	-	-	-

TABLE XIII

EFFECTS OF INCREASING PERCENTAGES OF SUCROSE ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

	Yield of gluten (g.)				Volume of one gluten ball (ml.)				Amount of force needed to crush one gluten ball (g.)			
	Replications				Replications				Replications			
% Sucrose	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
0	10.5	11.9	10.7	11.1	75	75	60	70.0	4808	4526	4975	4770
5	10.6	11.8	10.1	10.8	100	70	95	88.3	2642	3917	2789	3116
10	10.9	11.1	10.3	10.8	90	100	80	90.0	4078	2736	4105	3639
15	10.2	11.1	10.9	10.7	65	100	75	80.0	3883	2621	4134	3546
20	10.1	11.1	11.0	10.7	85	100	70	85.0	2638	3194	4751	3527
25	10.5	10.9	10.4	10.6	100	80	60	80.0	2833	3632	3691	3385
30	10.2	9.4	9.7	9.8	100	80	75	85.0	2554	2324	3647	2842
35	9.8	9.3	9.3	9.5	75	60	90	75.0	2804	3184	2183	2724
40	8.3	8.9	6.7	8.0	70	55	65	63.3	2721	2448	2787	2652
45	3.7	3.9	6.3	4.6	30	20	45	31.7	1138	1746	1399	1427
50	0.8	0.7	0.8	0.8	8	5	3	5.3	255	1221	1006	827
55	0.4	-	0.7	0.4	4	-	3	2.3	265	-	305	190
60	-	-	-	-	-	-	-	-	-	-	-	-

TABLE XIV

EFFECTS OF INCREASING PERCENTAGES OF D (+) MALTOSE C.P. ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

% D (+) Maltose C.P.	Yield of gluten (g.)				Volume of one gluten ball (ml.)				Amount of force needed to crush one gluten ball (g.)			
	Replications				Replications				Replications			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
0	9.7	10.5	10.1	10.1	60	75	65	66.7	4774	3176	4750	4333
5	10.0	10.0	10.1	10.0	70	95	85	83.3	4118	3524	4054	3899
10	9.8	9.4	9.7	9.6	85	70	85	80.0	4267	3446	3473	3729
15	9.8	10.0	9.8	9.8	75	80	75	76.7	3512	1756	2509	2592
20	9.0	9.3	9.8	9.4	70	80	80	76.7	2183	2659	2362	2568
25	8.8	9.7	9.0	9.2	70	85	60	71.7	1593	2222	1860	1892
30	8.0	3.8	8.7	6.8	60	45	75	60.0	3074	1116	3068	1519
35	5.7	1.7	4.4	3.9	30	7	35	24.0	1559	515	1111	1062
40	1.8	0.2	0.7	0.9	20	1	2	7.7	546	250	736	511
45	-	-	-	-	-	-	-	-	-	-	-	-

TABLE XV

EFFECTS OF INCREASING PERCENTAGES OF D (+) TECHNICAL MALTOSE ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

% D (+) Technical Maltose	Yield of gluten (g.)				Volume of one gluten ball (ml.)				Amount of force needed to crush one gluten ball (g.)			
	Replications				Replications				Replications			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
0	11.5	10.8	11.9	11.4	70	85	75	76.7	4643	3428	3886	3986
5	10.4	10.3	9.5	10.7	90	95	60	81.7	2696	2390	3538	2875
10	9.6	10.1	10.0	9.9	70	100	85	85.0	2754	2364	1639	2252
15	8.1	8.5	9.0	8.5	60	85	80	75.0	1563	1310	1587	1487
20	4.4	6.2	6.5	5.7	15	45	35	31.7	1008	2192	2381	1860
25	4.0	2.4	5.8	4.1	20	10	30	20.0	1175	751	2758	1561
30	-	-	1.2	0.4	-	-	6	2.0	-	-	928	309
35	-	-	-	-	-	-	-	-	-	-	-	-
40												

TABLE XVI

EFFECTS OF INCREASING PERCENTAGES OF BETA-LACTOSE ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

% Beta-Lactose	Yield of gluten				Volume of one gluten ball (ml.)				Amount of force needed to crush one gluten ball (g.)			
	Replications				Replications				Replications			
	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
0	11.9	11.5	11.7	11.7	70	100	45	71.7	4973	2964	4417	4118
5	10.6	10.9	11.0	10.8	80	95	70	81.7	3324	2897	4378	3533
10	10.7	10.1	10.5	10.4	70	70	95	78.3	2942	3158	2809	2969
15	10.6	10.0	10.2	10.3	100	80	85	88.3	1564	2313	3284	2054
20	8.5	7.1	10.0	8.5	80	35	90	68.3	1029	2029	2984	2014
25	5.3	6.1	6.7	6.0	30	20	55	35.0	1261	2319	2647	2076
30	2.7	2.3	3.5	2.8	10	15	20	13.0	447	469	705	540
35	0.3	0.4	0.6	0.4	1	1	4	2.0	746	591	1183	640
40	-	-	0.2	0.1	-	-	2	0.7	-	-	662	221
45	-	-	-	-	-	-	-	-	-	-	-	-

TABLE XVII

EFFECTS OF INCREASING PERCENTAGES OF D (+) LACTOSE ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS

% D (+) Lactose	Yield of gluten (g.) Replications 1	2	3	Mean	Volume of one gluten ball (ml.) Replications 1	2	3	Mean	Amount of force needed to crush one gluten ball (g.) Replications 1	2	3	Mean
0	10.6	10.6	10.7	10.6	65	80	90	78.3	4477	3388	3817	3894
5	10.5	10.0	10.0	10.2	65	80	75	76.7	4738	2674	3690	3700
10	10.3	10.3	10.0	10.2	80	70	90	80.0	3271	4234	3001	3502
15	10.7	10.9	10.2	10.6	70	100	100	90.0	3281	1963	3207	2750
20	9.6	10.5	9.8	10.0	85	80	90	85.0	3686	2865	2511	3020
25	9.5	10.6	9.6	9.9	90	80	75	81.7	2788	3321	2381	2830
30	10.0	9.9	9.5	9.8	80	70	95	81.7	2337	3394	3116	2949
35	10.4	9.8	9.7	10.0	70	75	100	81.7	2552	3760	2887	3066
40	10.0	10.2	10.0	10.1	65	80	70	71.7	3421	3074	3721	3045
45	10.0	10.2	10.3	10.2	80	90	75	81.7	3203	2622	4333	3386
50	9.4	10.2	10.0	9.9	70	75	70	71.7	2885	3463	3788	3379
55	10.0	9.7	9.6	9.8	60	100	75	78.3	2116	1878	3558	2517
60	10.0	10.1	9.9	10.0	70	95	90	85.0	3296	2735	2837	2956
65	9.6	10.4	10.2	10.1	75	80	75	76.7	3392	4251	4146	3930
70	10.2	10.0	10.4	10.2	75	70	95	80.0	3443	2365	3880	3229

TABLE XVIII

EFFECTS OF INCREASING PERCENTAGES OF D (+) LACTOSE-IN-SOLUTION, ON GLUTEN YIELDS AND VOLUMES AND CRUSHING FORCES OF BAKED GLUTEN BALLS*

% D (+) Lactose-in-solution	Yield of Gluten (g.)	Volume of one gluten ball (ml.)	Amount of force needed to crush one gluten ball (g.)
0	10.6	90	3819
5	10.8	85	3834
10	10.2	85	2880
15	9.6	90	1653
20	9.9	105	1811
25	6.5	40	1897
30	5.6	50	622
35	1.2	11	510
40	0.6	5	492
45	-	-	-

* One replication.

One replication was made of D (+) lactose-in-solution in the preparation of gluten. (Increasing increments of D (+) lactose were dissolved in 24 ml. of tap water by heating. Each solution was then cooled to room temperature before being added to 30 g. of flour in the preparation of gluten. Methods of mixing each solution with flour, washing the dough, mixing the gluten, and baking the gluten balls were the same as the methods used in Procedure II.) The yields of gluten obtained from doughs containing increasing levels of D (+) lactose-in-solution (Table XVIII) closely resembled the gluten yields obtained from doughs containing increasing levels of beta-lactose. The D (+) lactose-in-solution prevented gluten formation at the 45% level of concentration.

Averages of the gluten yields which were obtained as the levels of the various sugars were increased are illustrated in Figs. 4 and 5. A probit analysis (22), based on the total gluten yield of three replications is shown in Figs. 6 and 7. Glucose, fructose and sucrose exerted similar effects on gluten yields. Technical maltose and C.P. maltose were different from one another. The technical maltose exerted a more detrimental effect on gluten formation at lower levels than did the C.P. maltose or any of the other sugars. Beta-lactose and D(+) lactose-in-solution exerted similar effects on gluten formation. The D (+) lactose did not seem to significantly affect gluten yield at any level of concentration.

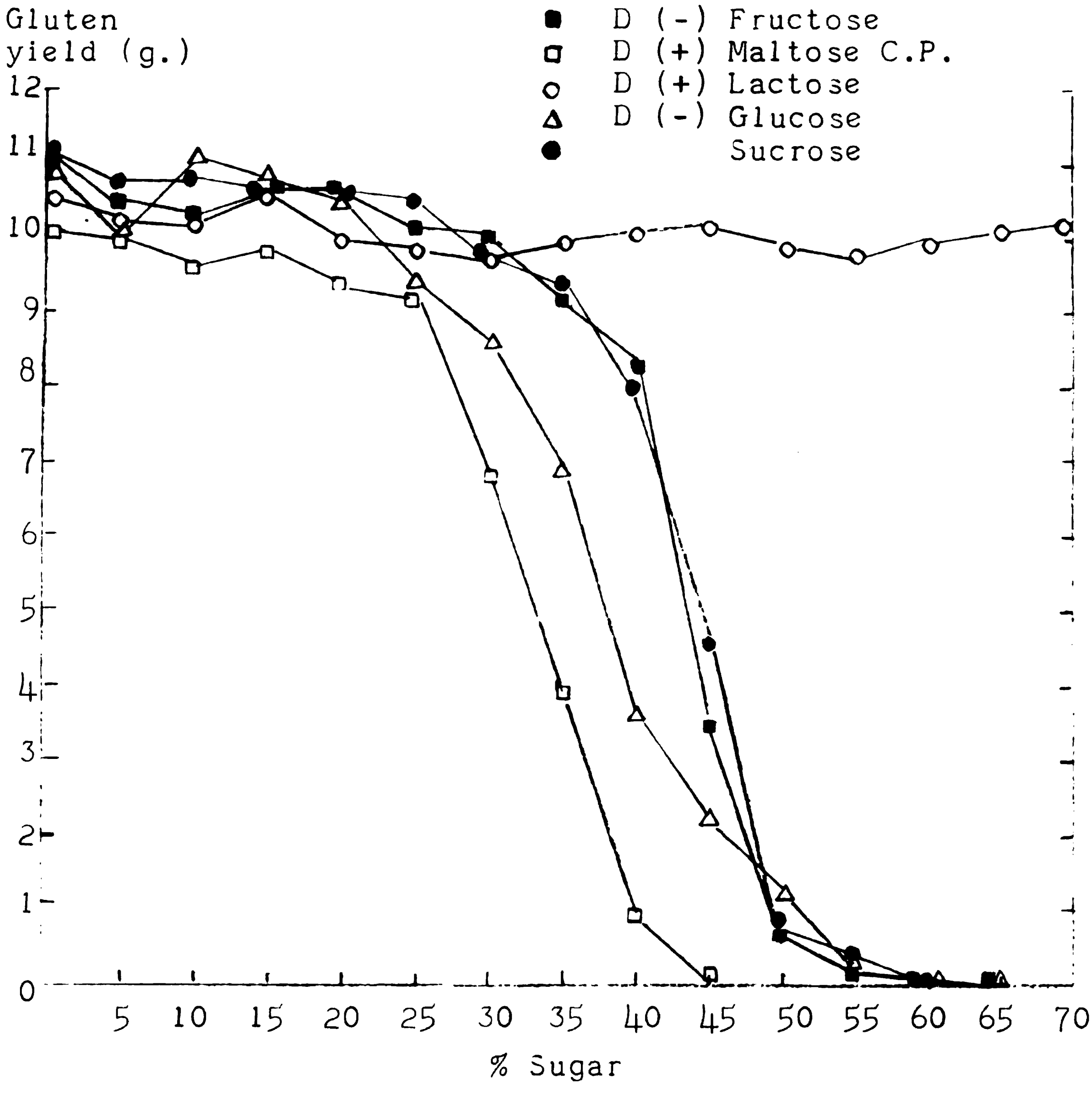

Fig. 4. Effects of increasing percentages of D (-) fructose, D (+) maltose C.P., sucrose, D (-) glucose, and D (+) lactose, on gluten yields. Each point is the average of three replications.

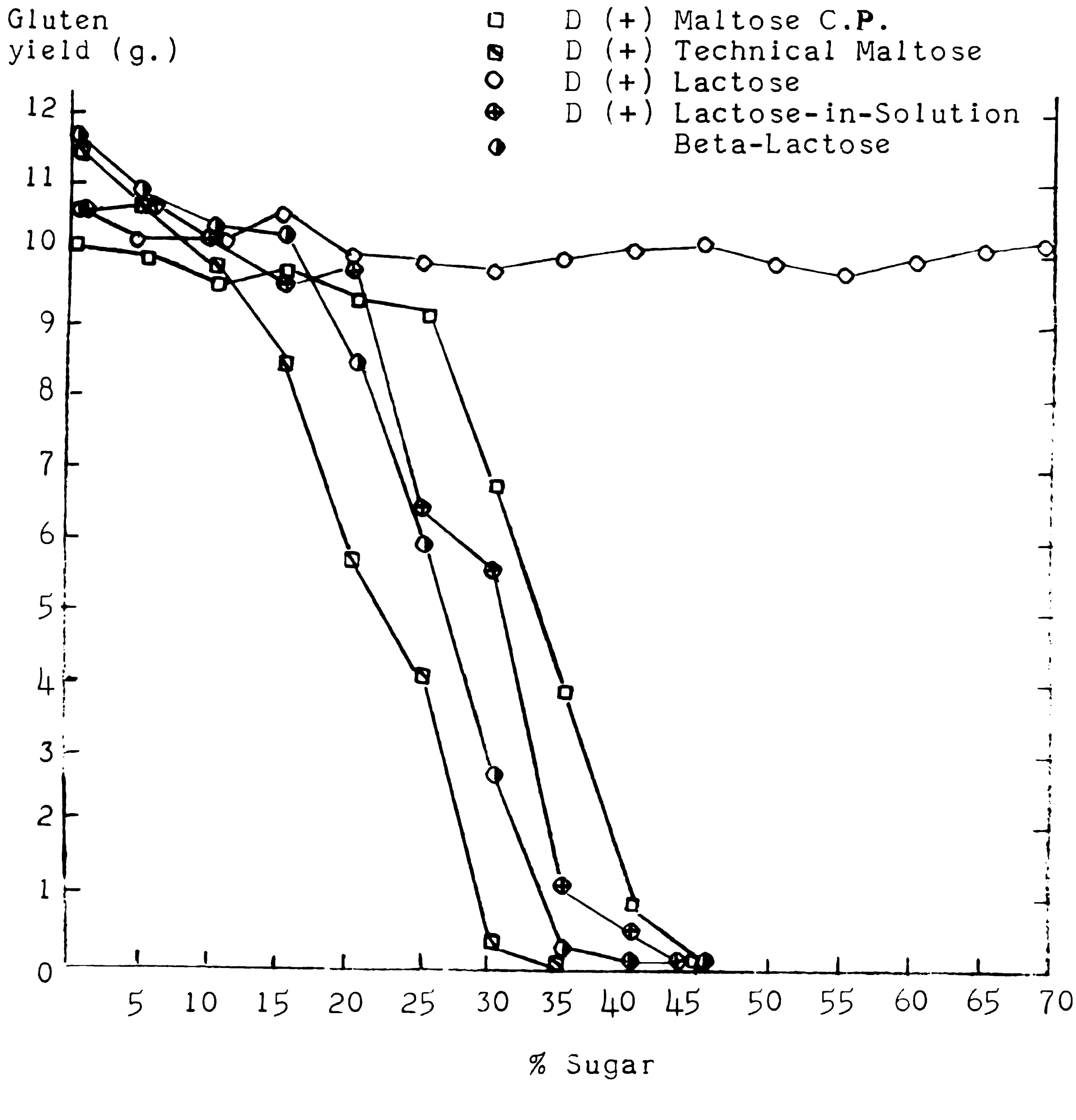

Fig. 5. Effects of increasing percentages of D (+) maltose C.P., D (+) technical maltose, beta-lactose, D (+) lactose, and D (+) lactose-in-solution, on gluten yields. Each point is the average of three replications.

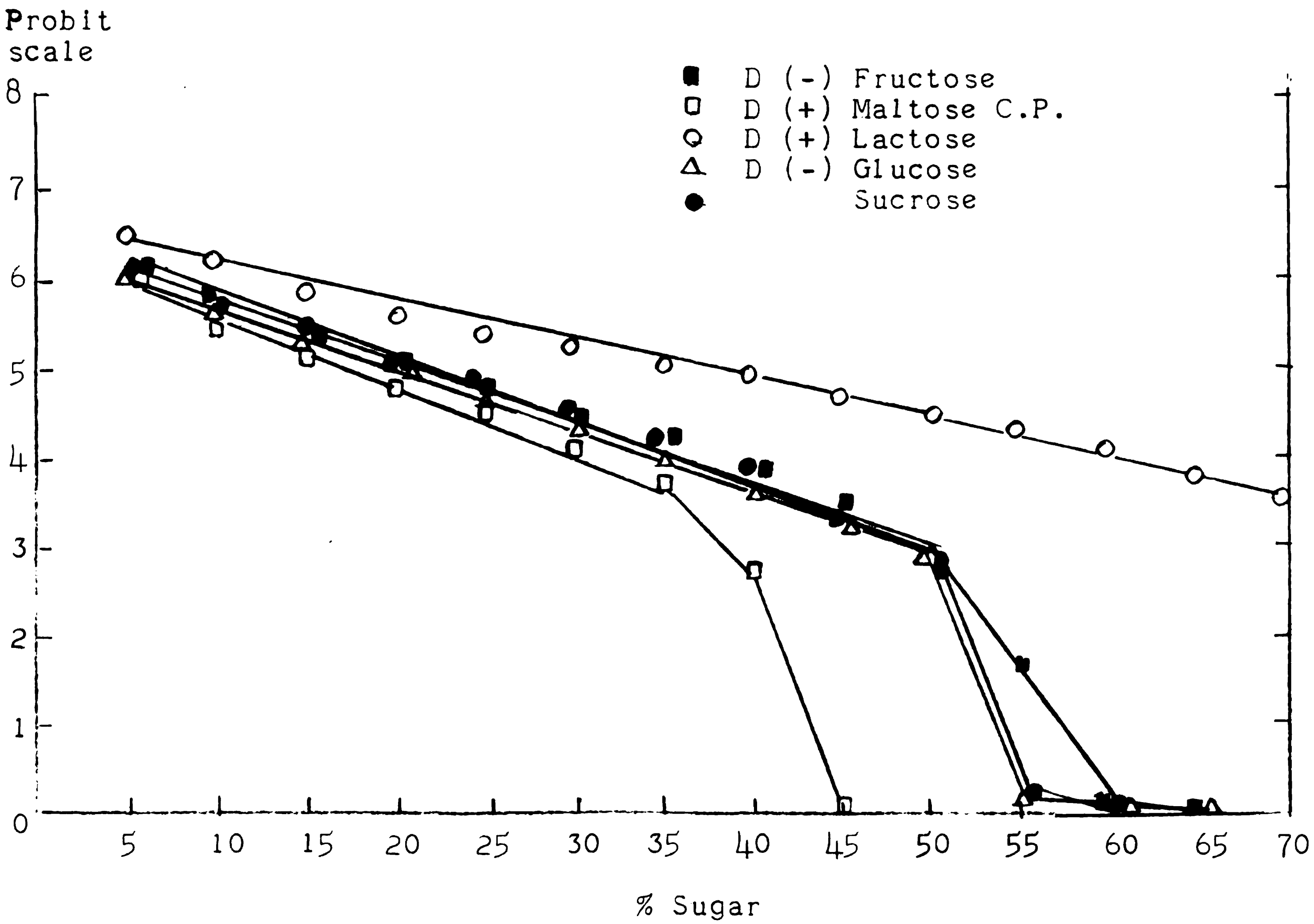

Fig. 6. Probit Analyses of the effects of increasing percentages of D (-) fructose, D (+) maltose C.P., sucrose, D (-) glucose, and D (+) lactose on gluten yields. Probits are based on the total yield of three replications.

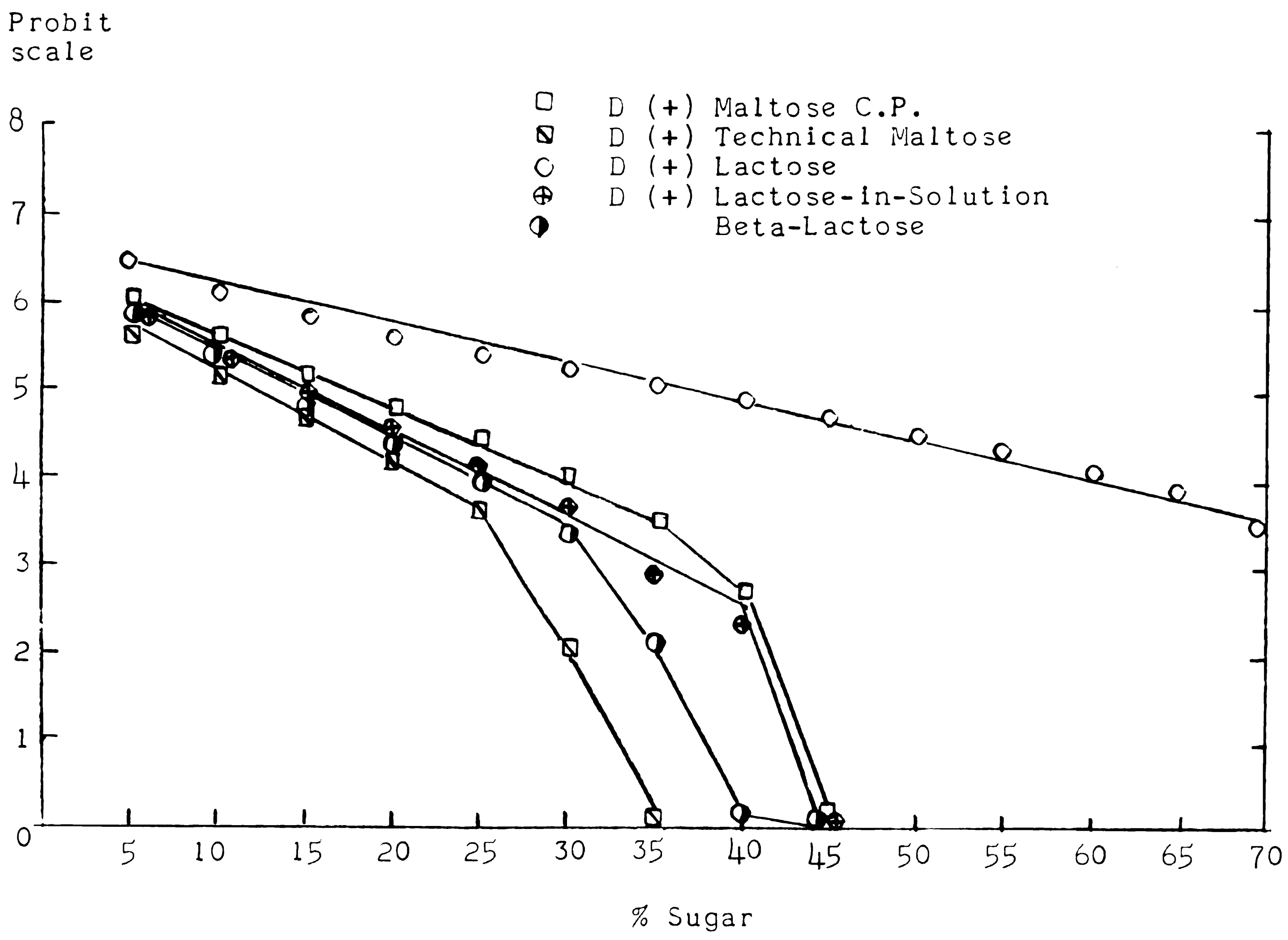

Fig. 7. **P**robit analyses of the effects of increasing percentages of D (+) maltose C.P., D (+) technical maltose, beta-lactose, D (+) lactose, and D (+) lactose-in-solution on gluten yields. **P**robits are based on the total yield of three replications, except D (+) lactose-in-solution.

Volume

The volumes of gluten balls are tabulated in the same tables discussed under gluten yield. It was noted that after initial concentrations of each sugar had been added, the gluten yields were smaller than the yields of gluten which had had no sugar addition, yet the volumes of these same gluten balls were usually greater than the volumes of the controls. Average volumes for each level of addition of the various sugars are shown in Figs. 8 and 9. However, as the concentration of the sugars became higher, the volumes of the gluten balls obtained were smaller. .These decreased volumes were attributed to smaller gluten yields at the higher concentrations of each sugar. Probit analysis (22) of the gluten yields are shown in Figs. 10 and 11. Glucose, fructose, and sucrose exerted similar effects on gluten ball volume. The volumes of gluten balls made with D (+) technical maltose were usually smaller than the volumes of the gluten balls made from the same concentration of all of the other sugars used in this study. The effects exerted by beta-lactose and D (+) lactose-in-solution were similar. The D (+) lactose did not affect the volumes of gluten balls to any extent.

Crushing Force

The crushing forces of the gluten balls of the various sugars are presented in the same tables discussed in gluten yield. In general, as the level of concentration of a sugar

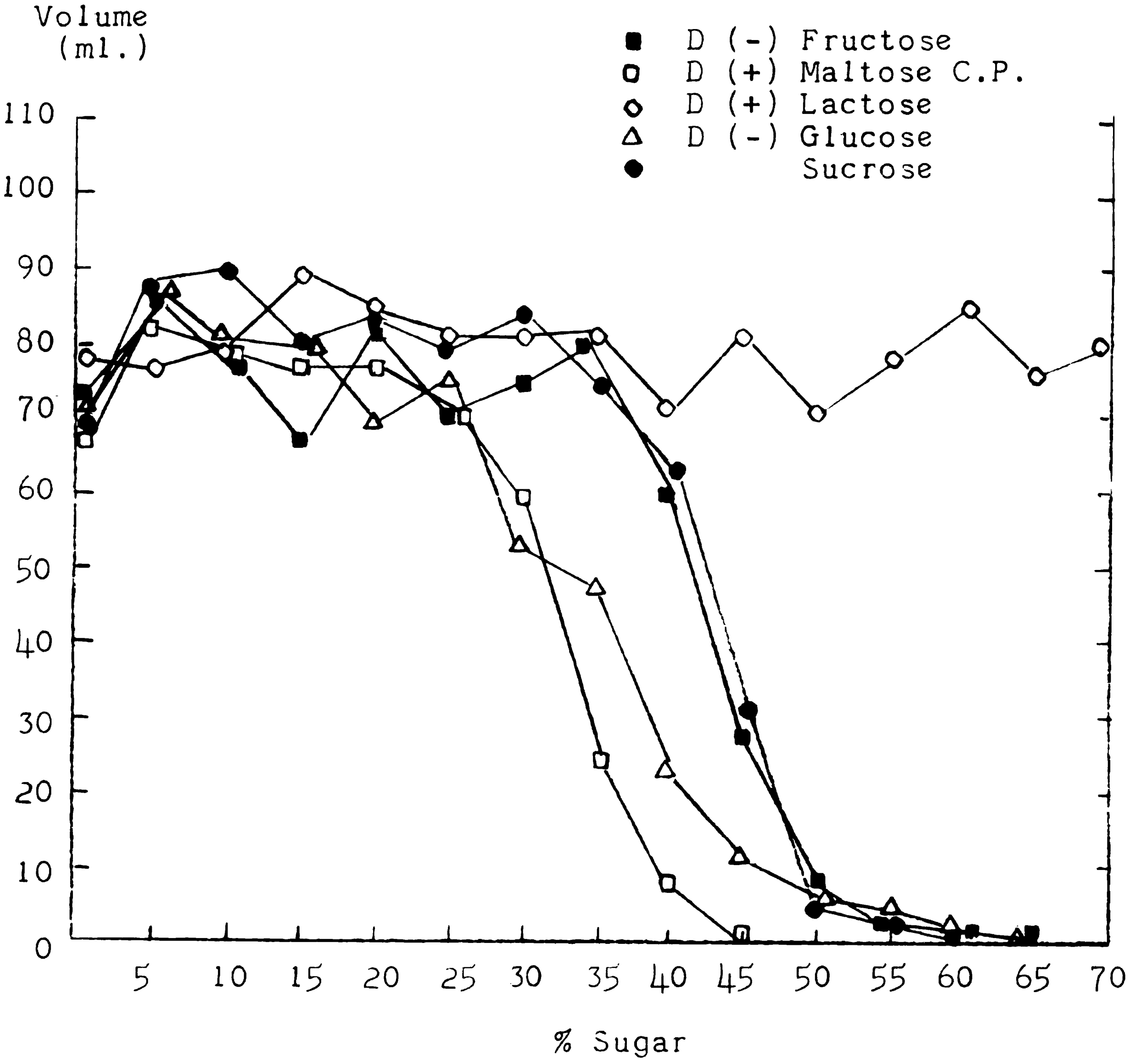

Fig. 8. Effects of increasing percentages of D (-) fructose, D (+) maltose C.P., sucrose, D (-) glucose, and D (+) lactose on gluten ball volumes. Each point is the average of three replications.

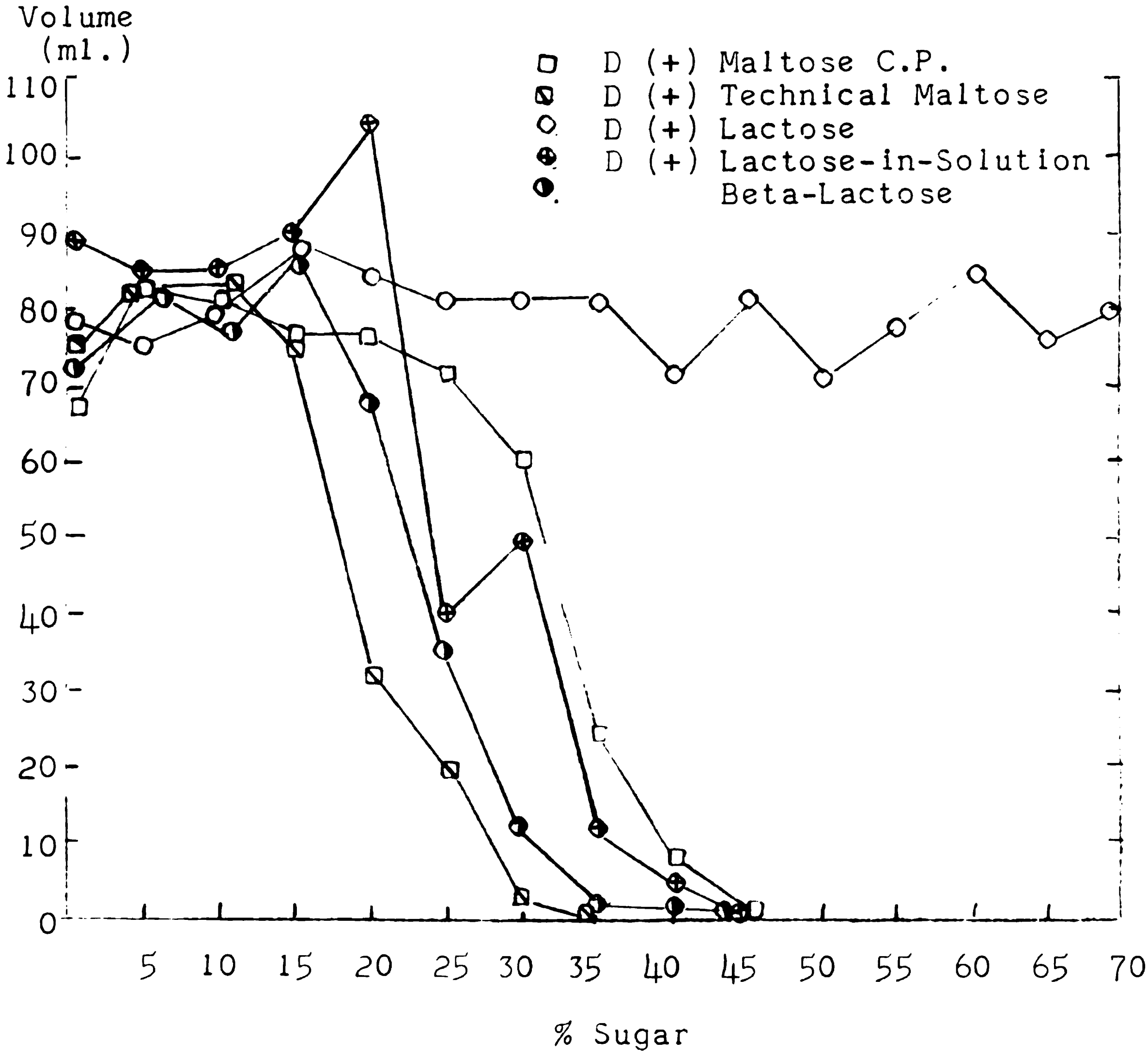

Fig. 9. Effects of increasing percentages of D (+) maltose C.P., D (+) technical maltose, beta-lactose, D (+) lactose and D (+) lactose-in-solution on gluten ball volumes. Each point is the average of three replications, except D (+) lactose-in-solution.

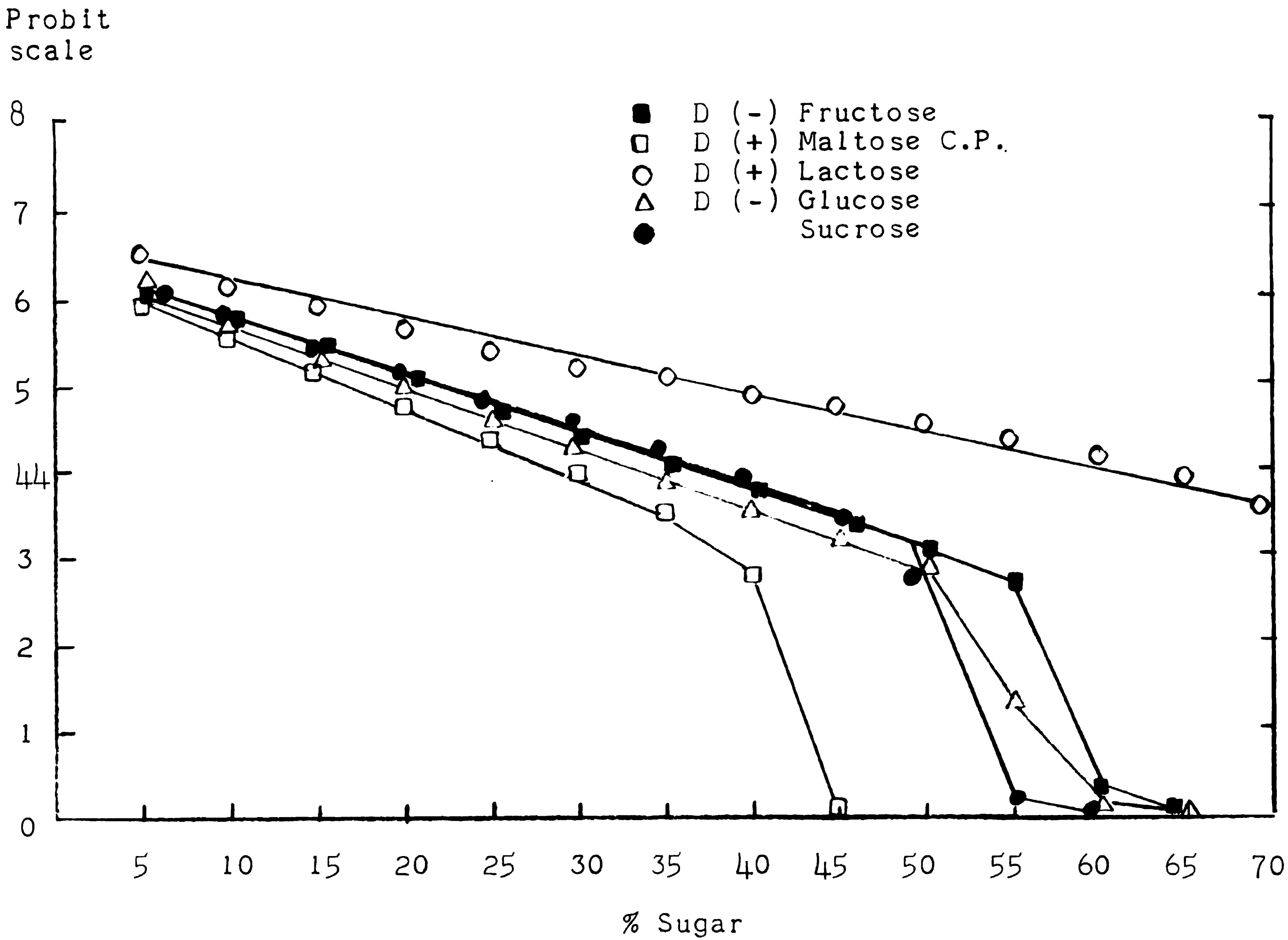

Fig. 10. Probit analyses of the effects of increasing percentages of D (-) fructose, D (+) maltose C.P., sucrose, D (-) glucose, and D (+) lactose on gluten ball volumes. Probits are based on the total volume of three replications.

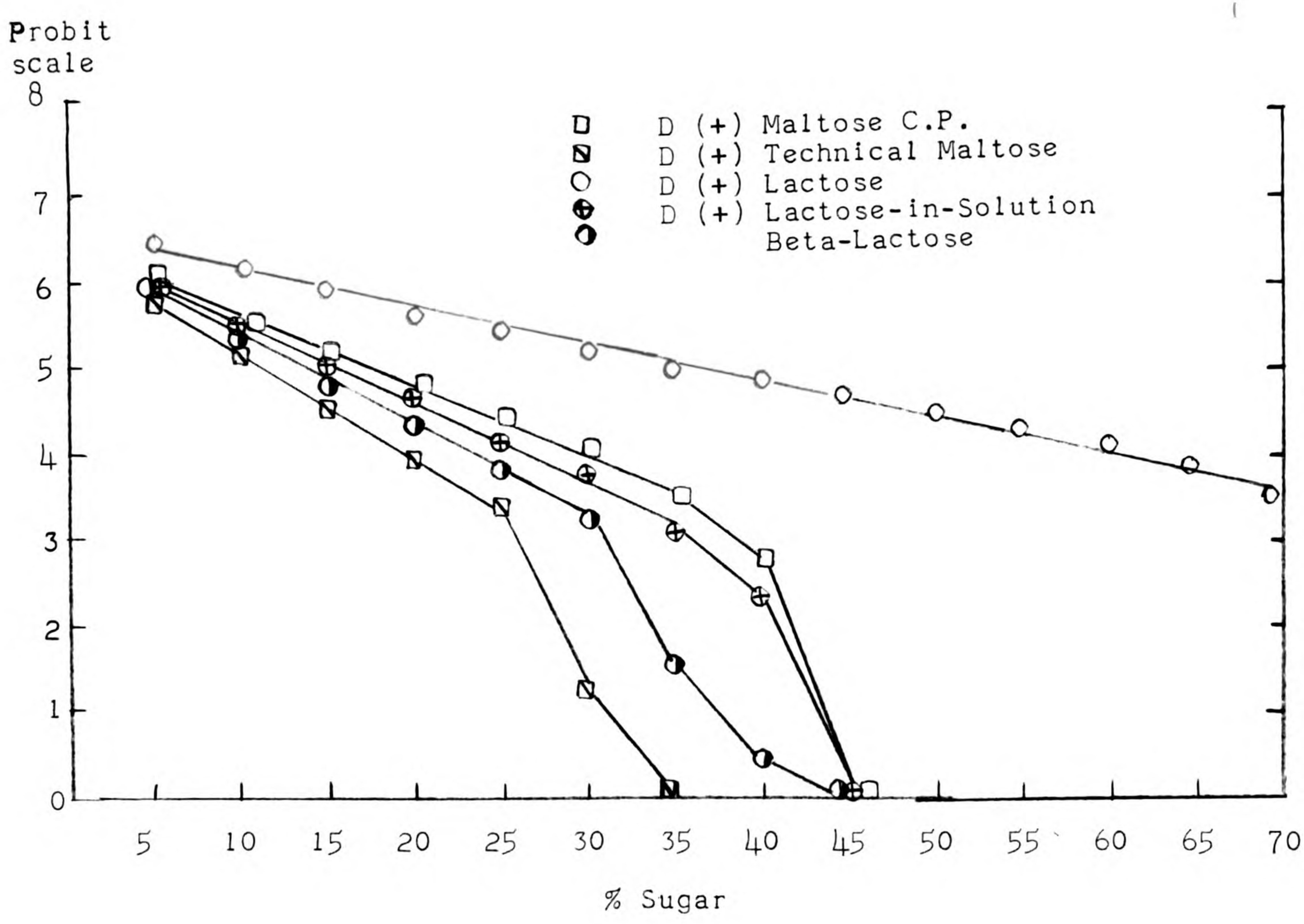

Fig. 11. Probit analyses of the effects of increasing percentages of D (+) maltose C.P., D (+) technical maltose, beta-lactose, D (+) lactose, and D (+) lactose-in-solution on gluten ball volumes. Probits are based on the total volume of three replications, except D (+) lactose-in-solution.

increased the amount of force needed to crush a gluten ball became less (except in the case of D (+) lactose). Part of the decrease in the amount of force needed to crush gluten balls might have been due to the effect of the sugar used actually weakening gluten structure; however, at the higher levels, less gluten was obtained and hence, less force was needed to crush the gluten balls. Figs. 12 and 13 illustrate the decreases in crushing forces as sugar concentrations were increased. Probit analyses (22) of the crushing forces are shown in Figs. 14 and 15. Gluten balls which had had additions of glucose, fructose and sucrose were similar in crushing forces. The gluten balls, to which D (+) technical maltose had been added, had lower crushing forces at lower levels of concentration than gluten balls to which comparable concentrations of the other sugars had been added. The gluten balls made from beta-lactose and D (+) lactose-in-solution had similar crushing forces. The D (+) lactose seemed to have no significant effect on the crushing forces of gluten balls when added at any level of concentration.

General Discussion of Procedure II

Technical maltose, which contained 10-15% dextrins, seemed to have the most detrimental effect on gluten formation, and the volumes and crushing forces of baked gluten balls. The dextrin content of this sugar is thought to limit gluten formation to some extent as the C.P. maltose did not

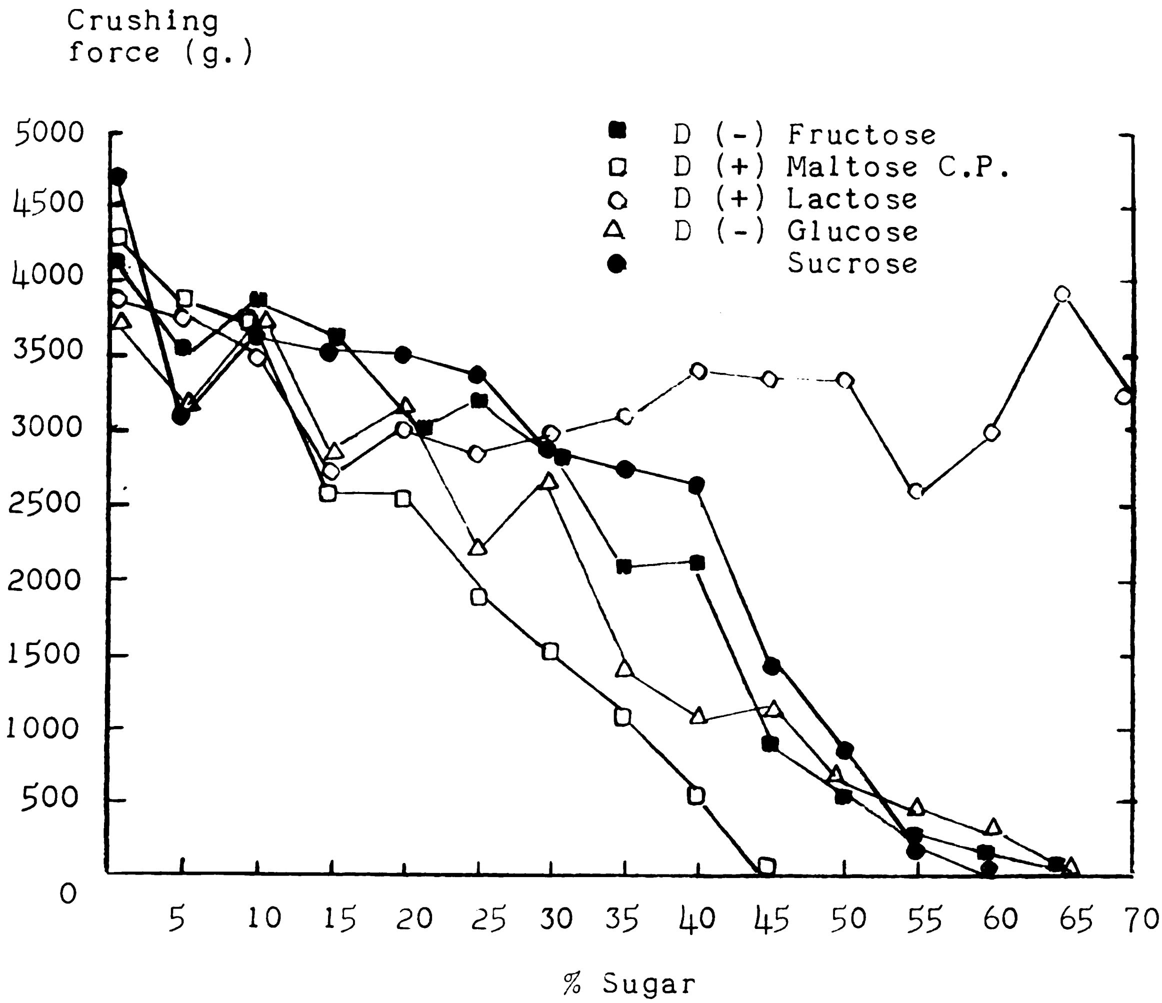

Fig. 12. Effects of increasing percentages of D (-) fructose, D (+) maltose C.P., sucrose, D (-) glucose, and D (+) lactose on the crushing forces of gluten balls. Each point is the average of three replications.

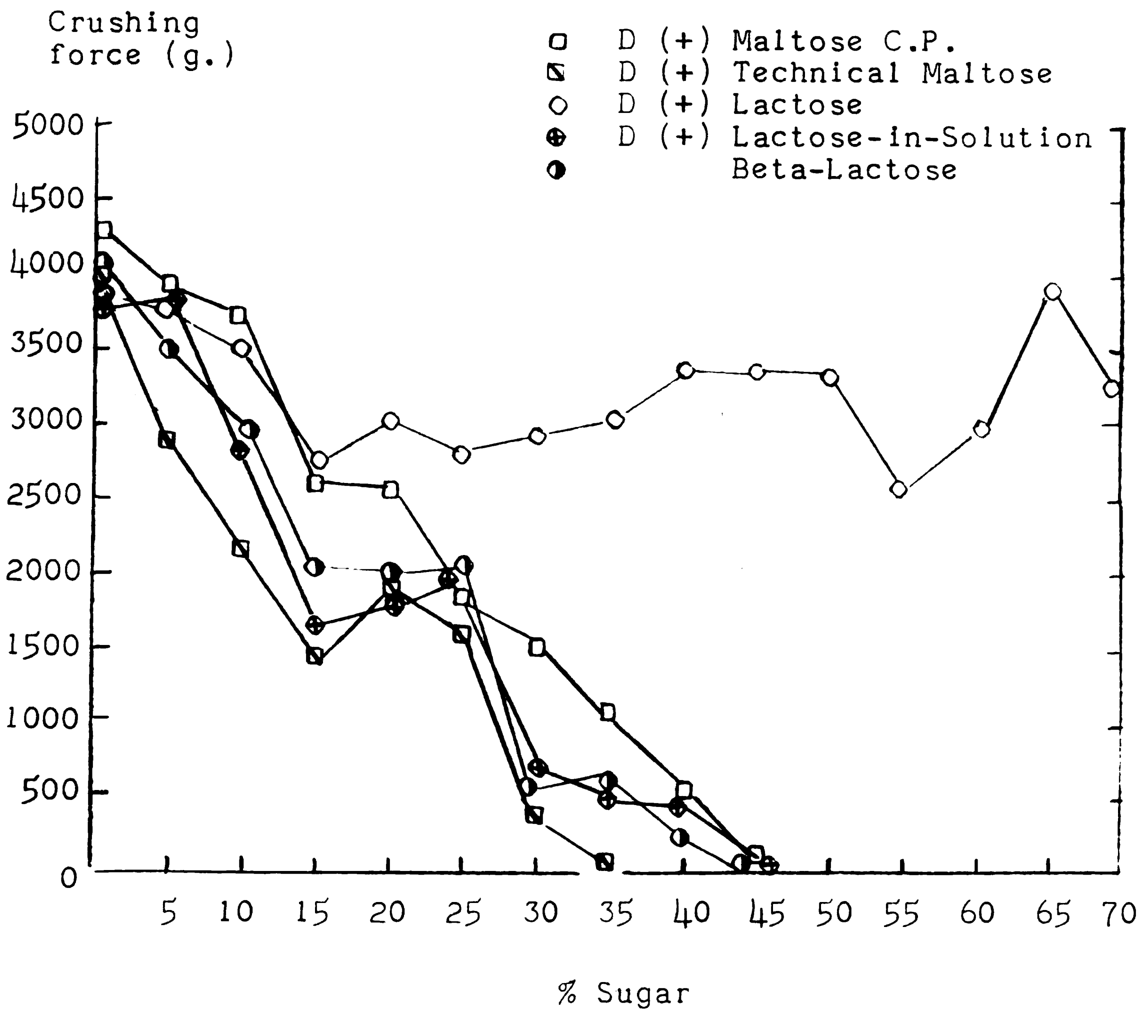

Fig. 13. Effects of increasing percentages of D (+) maltose C.P., D (+) technical maltose, beta-lactose, D (+) lactose, and D (+) lactose-in-solution on the crushing forces of gluten balls. Each point is the average of three replications, except D (+) lactose-in-solution.

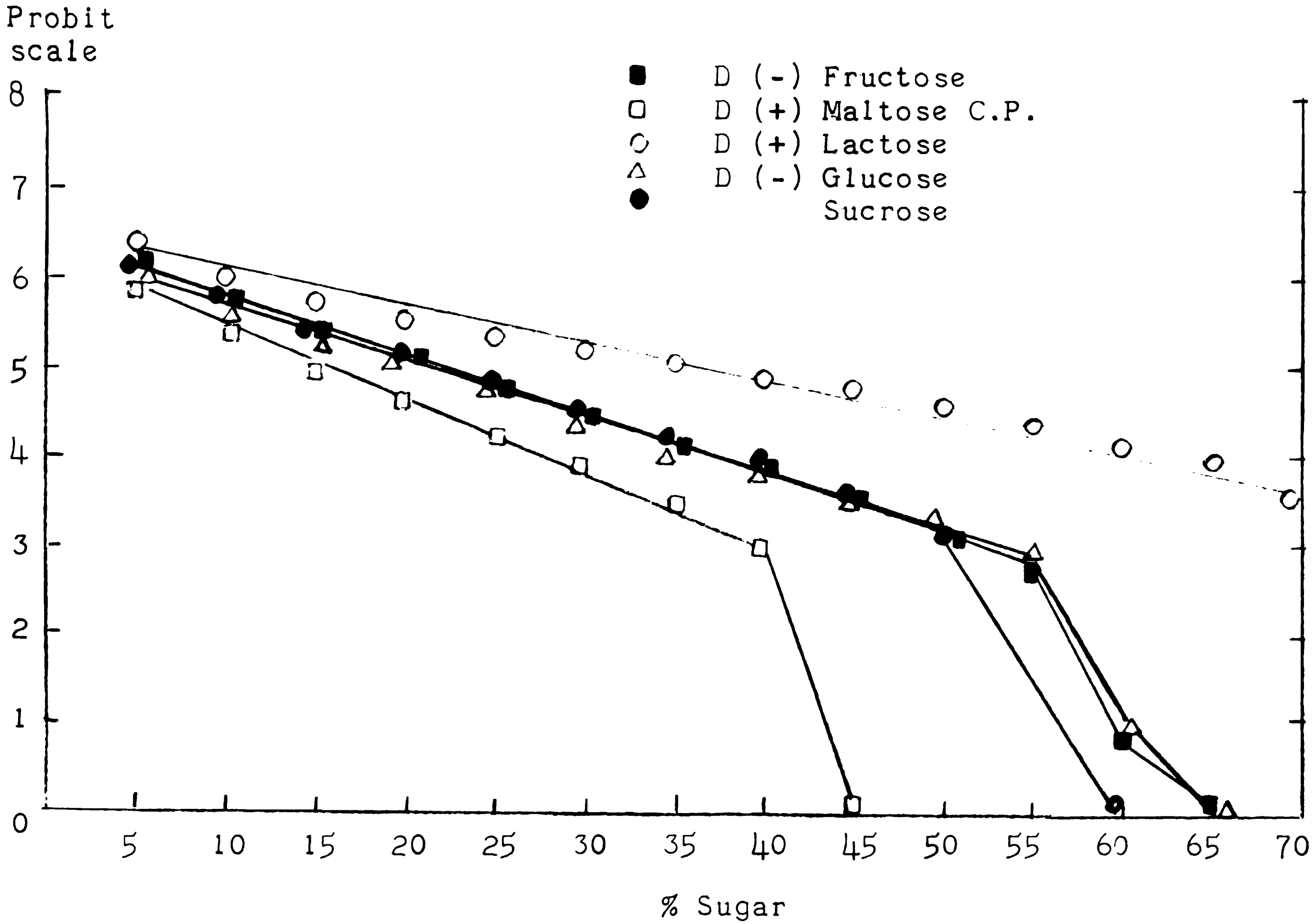

Fig. 14. Probit analyses of the effects increasing percentages of D (-) fructose, D (+) maltose C.P., sucrose, D (-) glucose, and D (+) lactose on the crushing forces of gluten balls. Probits are based on the total crushing force of three replications.

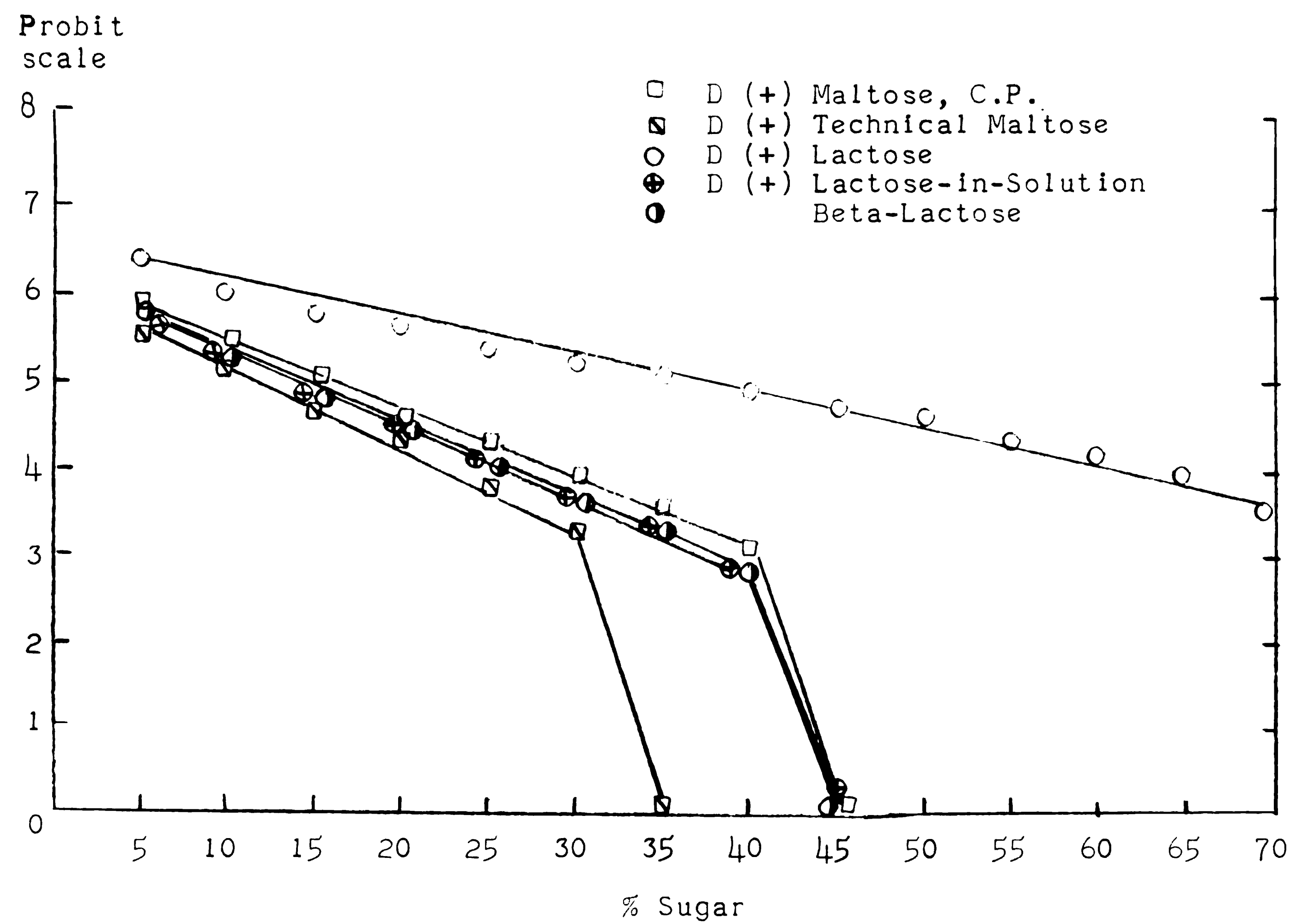

Fig. 15. Probit analyses of the effects of increasing percentages of D (+) maltose, C.P., D (+) technical maltose, beta-lactose, D (+) lactose D (+) lactose-in-solution on the crushing forces of gluten balls. Probits are based on the total crushing forces of three replications, except D (+) lactose-in-solution.

effect gluten formation, and the volumes and crushing forces of the gluten balls as much as did the technical maltose. The C.P. maltose, however, had a more detrimental effect on gluten yields and the volumes and crushing forces of baked gluten balls than did glucose, fructose, sucrose, or D (+) lactose. The D (+) lactose did not significantly affect the gluten yields, and the volumes and tenderness of baked gluten balls. The beta-lactose and D (+) lactose-in-solution exerted similar effects on gluten yields, and the volumes and crushing forces of baked gluten balls.

The data suggest that the effects of sugars on gluten formation may be related to the solubility of sugars. The D (+) lactose seemed to be insoluble in the water present in the dough and exerted no significant effects on gluten yields and on the volumes and crushing forces of the gluten balls. Whittier (60) stated that beta-lactose is more soluble than alpha-lactose. He also reported that a lactose which had a + 55.5 rotation was an equilibrium mixture of the alpha and beta forms, and that the alpha-form may be converted to the beta-form if crystalization takes place above 93°C. The D (+) lactose used in this study had an optical rotation of + 52.2-52.5° and, therefore, probably consisted of a near equilibrium mixture of alpha and beta-lactose. Thus when the D (+) lactose was mixed with water and heated to form a solution, the alpha-form was probably converted to the beta-form. The similarity of the effects of beta-lactose and the D (+) lactose-in-solution may be explained in this manner.

Jago and Jago (27, 28) reported that as the concentration of sucrose in a sugar-flour-water dough was increased, the dough viscostiy decreased. They further studied the effects of sucrose in water solution or in alcohol solution on gluten protein. They concluded that the sucrose might have had a solvent effect on the flour proteins and that it also affected the water absorptive power of the flour proteins.

McAuley (34) found that sucrose decreased the viscosity of sodium salicylate dispersions of gluten and concluded that this decreased viscosity was due to the fact that the particle size or the axial ratio of the gluten molecules was decreased. She suggested that sugar peptized the molecules of gluten.

Thus, the fact that a decreased amount of gluten was obtained as the levels of concentration of each sugar, except D (+) lactose, were increased may be due to: the sugars actually dissolving gluten protein; a decreased absorptive power of the flour proteins due to the presence of a sugar, particularly at the "critical concentration levels"; or the sugars exerting a peptizing action on the gluten protein.

It is thought that the sugars did affect the structure of gluten balls as shown by increased volumes of the gluten balls when the sugars were added at the lower levels of concentration. The crushing forces of the gluten balls were also noted to be smaller at these lower levels and would further indicate weakening in the structure of gluten. However, as the concentrations of the sugars were increased, gluten yields became smaller and hence, the volumes and crushing forces of these baked gluten balls were less.

SUMMARY AND CONCLUSIONS

Two experimental procedures were employed in this study. An all-purpose flour was used throughout the study. In the first procedure 5% levels of D (-) fructose C.P., D (-) glucose C.P., beta-lactose 98%, D (+) technical maltose, and sucrose (cane sugar) were incorporated in: (a) a dough in the preparation of gluten, (b) gluten prepared from the preceding method, and (c) gluten made from only a flour-water dough. The effects of the three methods of adding the sugars and the effects of each sugar on gluten were determined by measuring the amount of resulting drip loss from the raw gluten, and the volumes and crushing forces of baked gluten balls. Gluten which had had no sugar additions served as a control for each method.

Drip losses of gluten were greater when sugars were incorporated in the gluten after preparation. These drip losses, in addition to containing some of the added sugar in solution, were also shown to include nitrogenous material (positive ninhydrin test) presumably proteins, peptones, peptides or alpha-amino acids. It was concluded that the sugars exerted a peptizing or solvent action on the gluten proteins when added to prepared gluten.

Volumes of the gluten balls prepared by methods (a) or (b) were greater than the volumes of gluten balls prepared by method (c). Individual analysis of the volumes of the gluten balls within each method revealed that the volumes of gluten balls prepared by methods (a) and (b) were not altered significantly by sugar additions. In method (c), the gluten balls to which lactose or maltose had been added had significantly smaller volumes than control gluten balls or gluten balls to which fructose had been added. The volumes of gluten balls to which glucose or sucrose had been added did not differ significantly from control gluten balls or gluten balls which had had additions of fructose, lactose or maltose.

The crushing forces of gluten balls prepared by method (a) were significantly greater than the crushing forces of gluten balls prepared by methods (b) or (c). It was concluded that a sugar addition to prepared gluten weakened the structure of the baked gluten balls and hence, these gluten balls were more tender. The double sugar additions of method (b) weakened the structure of gluten balls to a significant extent.

In the second experimental procedure 5% increments of D (-) fructose C.P., D (-) glucose C.P., D (+) technical maltose, D (+) maltose C.P., beta-lactose 98%, D (+) lactose C.P., or sucrose (cane sugar) were added to a flour dough in the preparation of gluten. The effect of each sugar was followed by measuring gluten yields, and the volumes and crushing forces of baked gluten balls.

No gluten was obtained when the following sugars were added at these "critical levels of concentration": fructose, glucose and sucrose, 55-65%; D (+) maltose C.P., 45%; beta-lactose, 40-45%; and D (+) technical maltose 30%. The D (+) lactose seemingly did not affect gluten yield, even at the 70% concentration.

The technical maltose had the most detrimental effect on gluten yields and on the volumes and crushing forces of baked gluten balls. Beta-lactose closely resembled the technical maltose in its effects. The C.P. maltose was not as detrimental in its effect on the gluten yields and the volumes and crushing forces of baked gluten balls as the technical maltose, but it was more detrimental in its effect than was glucose, sucrose, fructose or D (+) lactose. The D (+) lactose did not affect gluten yields or the volumes or crushing forces of baked gluten balls.

Results of the second experimental procedure indicate that the effect of a sugar on gluten formation may be related to the solubility of the sugar. The D (+) lactose seemed to be less soluble and, therefore, exerted no significant effects on gluten yields, and the volumes and crushing forces of baked gluten balls.

It is suggested that all of the sugars, except D (+) lactose, either exerted a solvent or peptizing action on the gluten protein or decreased the water absorptive power of the gluten proteins. Hence, as increasing increments of the sugars were added less gluten was obtained and at "critical levels of concentration," no gluten was obtained.

The volumes of gluten balls were greater than controls when the sugars were added at initial levels of concentration. The crushing forces of the gluten balls also decreased as increasing levels of sugars were added. These results indicated that the presence of a sugar in the dough from which the gluten was prepared had actually weakened the structure of baked gluten balls. However, as the concentration of the sugars increased, the yields of gluten were less and hence, the volumes of gluten balls were much smaller and forces needed to crush these gluten balls were less.

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