DEVELOPMENT OF A CANNED WHOLE WHEAT PRODUCT

by

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1.0 INTRODUCTION

1.1 Background

In 1960, the Agricultural Research Service of the U.S. Department of Agriculture developed a process for cooking and canning debranned whole kernel wheat (Umstott and Hollen, 1962). This product was to provide an easy-to-prepare convenient form of wheat to compete with rice as a side dish, as a vegetable or as an ingredient in main course dishes.

Bulgar, or parboiled wheat, was the incentive for the canned product developed by the Agricultural Research Service. Bulgar has been used for centuries as a staple food in the Middle East and Near East.

1.2 Preparation

Traditionally, bulgar has been made by separating the wheat from the chaff, then washing in cold water and placing in a cauldron. Cold water is then added to cover the wheat and the mixture is heated to a boil. Heating continues for three hours until water has penetrated into the kernel. The excess water is either evaporated or absorbed so that only moist wheat remains. The wheat is then

spread out in the sun to dry, which requires two to three days. The dried bulgar is then packed in porous bags to save during the winter rainy season. Bulgar is stone ground before cooking and then may be prepared like rice or mixed with meat (Shammas, 1954).

Bulgar is reported to be more stable than raw wheat (Haley, 1960): 1) it is and remains edible and palatable almost indefinitely, and 2) it is highly resistant to insects, vermin, and microorganisms. Because bulgar is stored in porous bags, the rancid flavors and odors diffuse from the product. The resistance to reinfestation is due to sterilizing the bulgar by cooking, drying and storing under dry conditions not suitable to reinfestation (Haley et al., 1960).

In 1965, the Western Regional Research Laboratory of the U.S. Department of Agriculture developed a product which they named "WURLD WHEAT." This is a bulgar made by lye-peeling the wheat creating a light colored, low-fiber product (Sheppard, 1965).

The process of WURLD WHEAT involves a brief treatment of the cooked wheat with hot lye solution followed by a thorough washing. This process was developed because of limited acceptance of bulgar in the United States and in countries where it was shipped in the Food for Peace Program, the main objection being the dark color and the bran content.

Nutritional attitudes have changed since these

studies were conducted. Some people are skeptical of the increasing use of food additives and over-refined foods. More demand is being placed on "natural" foods which are believed to be more nutritious.

In the previous studies, the bulgar was either partially, or wholly debranned as in WURLD WHEAT, to create an acceptable product. Attention has been drawn lately to a theory which maintains that Americans are not getting sufficient bulk or fiber in the form of cellulose in their diets because of increased consumption of refined products (Burkitt, 1971). Burkitt (1971) also suggested that wheat bran was the best form of fiber for reducing occurrences of colon cancer, diverticulitis, polyps, and other intestinal disorders. Since minerals and most of the vitamins are in the bran, the process as described in El Molino Best Recipes Book (1953) leaves the bran intact. People usually prepare cooked wheat by boiling it all night, or by canning it possibly in an unsafe manner.

1.3 Objectives

The objectives of this experiment are as follows:

1) to develop a safe thermal process for a wheat product containing all of its natural fiber,

2) to test the varietal differences (2 wheat varieties--Soft Red Winter and Hard Winter) on texture after thermal processing.

3) to test the effect of salt on texture and thiamine retention of the processed wheat,

4) to test the effect of thermal sterilization on texture and thiamine retention, and

5) to test the effects of salt and thermal sterilization on moisture absorption.

2.0 REVIEW OF LITERATURE

2.1 Preparation

This study was undertaken to determine the validity of a process as described in El Molino Best Recipes book (1953) for canning of wheat. For the recommended process, three-quarters of a cup (150g) of red cereal wheat is placed in a pint jar. One-third of a teaspoon (3g) of table salt is added and boiling water is added to provide one-inch headspace. The jars are to be processed for one hour at ten pounds pressure in a pressure cooker.

A preliminary test of the canned raw wheat gave a pH value of 6.35 to 6.8. The requirement of a process for acid foods, with a pH of 4.6 or less, is usually the temperature that must be reached at the center of the can without regard to the length of time required to reach that temperature. The minimum process is that which brings the temperature of every particle of food to 82°C(180°F) (Ball, 1957). This condition is due to the low heat resistance of spoilage microorganisms in acid foods and to the inhibition of spore growth at pH 4.6 and lower, thus a mild process of boiling water may be used (Ball, 1957).

Low acid products of pH greater than 4.6 require a more severe process of higher temperatures attained by

pressure cooking. This is necessary to destroy pathogenic bacteria and spoilage bacteria which grow above pH 4.6 and may cause spoilage under normal conditions of storage of the food (Ball, 1957).

The author knows of no other published information for canned whole wheat, whereas considerable work has been done with canned bulgar, a similar product (Haley, 1960). There was concern with the canned wheat product--was the process safe? How nutritious was it after canning, and what was the relationship between processing and texture? The process described in El Molino implies that the resultant product is nutritious and tender. Preliminary tests showed that the absence of salt made a considerable difference in the texture of the product.

2.2 Texture

The addition of salt had a noticeable textural effect upon canned bulgar products. Umstott and Hollen (1962) in their market research report found the most frequent criticism of canned bulgar was that it was too chewy as it came from the can and needed additional cooking to soften it. They used a commercial bulgar with salt added as an unseasoned product. Ferrel (1963) stated that addition of salt to the soak water had an adverse effect on soaking time and texture. Soaking grains in a 3-5% salt solution increased the soak time by 30%. He also reported that adding

salt at the end of the soak also toughened the kernel and reduced the moisture content, probably due to osmosis.

Roberts et al. (1953, 1954), Ferrel (1959a, 1959b) and Ferrel et al. (1960) showed that cooked milled rice could be canned if the moisture content is controlled. Copley et al. (1960) described a similar process for canning bulgar by partial debranning and soaking to 50-55% moisture before canning under a high vacuum. The proper moisture level is critical because if it is higher than 55%, there is excessive kernel rupture making the product pasty and gummy. Below 50% moisture the bulgar remained chewy and tough even if additional water is used for home preparation (Ferrel, 1963). Because of this critical moisture content of canned bulgar, Heid (1972) suggested packing the uncooked bulgar with the optimum amount of water and seasonings directly in the can, then sealing and retorting. This method eliminated many preparatory steps. An agitating retort was necessary to keep the wheat from settling in a gummy mass in the bottom of the can. According to Heid, this method worked very well. Ferrel et al. (1963) claims that soft white wheats and hard red wheats work equally well in making canned bulgar.

2.3 Nutritional Aspects

The nutritive value for bulgar has been investigated by several workers. Shammas (1954) reported that more than

60% of the thiamine and 100% of the niacin were retained in the bulgar process. However, very low retention values for riboflavin were obtained due to destruction by sunlight during drying. Haley and Pence (1960) found that the nutritional value for bulgar is nearly equivalent to that of the whole wheat. Rohrlich et al. (1960) and Haley and Pence (1960) showed that vitamins and minerals of the bran layer pass from the outer layers to the endosperm during the parboiling process. Haley and Pence (1960) reported two-thirds as much thiamine and niacin retained from the whole wheat after boiling. Pence et al. (1964) reported that losses of thiamine in bulgar prepared in the laboratory averaged 15%; riboflavin, 12%; and niacin, 7%. Losses caused by hot air expansion or puffing of bulgar increased to 53% for thiamine, and losses for riboflavin and niacin were less than 10%. Partially debranned raw wheat canned under vacuum at 55% moisture lost 72% of the original thiamine and 30% of the riboflavin. Sabry and Tannous (1961) showed that thiamine losses increased steadily with time of boiling and the boiling step accounted for nearly all of the thiamine losses.

Kohler (1964) and Milner and Carpenter (1969) found that the bulgar process reduced the total lysine by 25%, but the PER was increased, probably due to the fact that the test animals were able to eat more of the cooked bulgar than the raw wheat. El Lakany et al. (1969) reported that the metabolizable energy (ME value) of whole wheat was

increased by autoclaving. Hutchinson et al. (1964) suggested that heat treatment of wheat may increase the digestibility by destroying the ability of the proteins gliadin and glutenen to form gluten.

2.4 Thiamine

Pure thiamine is a white crystalline powder usually combined with hydrogen chloride. It is extremely soluble in water and alcohols on the order of 100g/100 ml. Thiamine is insoluble in ethers, benzene and other fat solvents. Stability to dry heat is one of its characteristics, but it can be easily destroyed by autoclaving. In solution, the vitamin is sensitive to Oxidation Reduction Potential. According to Joslyn (1970) thiamine is extremely stable in acid solutions, and may withstand sterilization at temperatures of 120°C(248°F) for 30 minutes. However, neutral or alkaline pH causes rapid destruction at the above temperature and time. This rapid decline is probably due to the destruction of the thiazole ring (Assoc. Vit. Chem., 1951).

Farrer (1955) described the factors which influenced the rate of thiamine destruction as follows:

1. Temperature--increases in temperature increases destruction of thiamine.

2. Time--destruction of thiamine increases as length of time of heating increases.

3. pH--increases in pH value cause more rapid destruction.

4. Electrolyte System--rate of destruction changes as ionic concentration of buffer changes with rising pH value. NaCl and KCl have no effect on thiamine destruction (Watenabe et al., 1949). However, Ache and Ribeiro (1945) claim that NaCl accelerates decomposition and Simeonova (1968) states that NaCl inhibits loss of water soluble vitamins.

5. Heavy Metals--presence of heavy metals decreases thiamine content (Farrer, 1947a).

6. Concentration of Electrolytes--(salt effect)--increased concentration of buffer salts decreases thiamine retention (Farrer, 1947b, 1949b).

7. Non Electrolytes--Sucrose, lactose, and glucose produced a slight acceleration of destruction while fructose, invertase, and inositol may retard decomposition.

8. Form of Vitamin--depending on the form found in greatest amount of foodstuff; free thiamine-HCl--stable; cocarboxylase--not as stable; thiamine mononitrate--more stable than thiamine-HCl.

9. Concentration of Thiamine--at high concentrations (100 µg/ml) rate of destruction decreases. However, most foods contain less than 10 µg/ml so this is not applicable to food systems.

10. Oxygen--very susceptible to oxidizing solutions.

11. Moisture Content--dilution effect--drying out will concentrate thiamine.

Of these factors, the first three of time, temperature and pH are the most important (Feaster et al., 1948; Farrer, 1955). Melnick and Field (1939) found 89% of thiamine in wheat is of the free hydrochloride form. Atkin et al. (1943) supports the statement that starch slows the destruction of thiamine in wheat cereal grains when cooked.

Farrer (1955) and Feliciotti and Esselen (1957) showed that thermal destruction of thiamine progressed in a unimolecular reaction following a first order reaction rate.

It is now common knowledge that processing at a higher temperature for a shorter time will improve the quality of most canned foods (Feliciotti and Esselen, 1957; Harris and Von Loesecke, 1960). Feliciotti and Esselen (1957) characterized thiamine with a $D_{250} = 154$ and a $z = 46$. Clostridium botulinum has a $D_{250} = 0.1\text{-}0.21$ and a $z = 18$ (Stumbo, 1973). The disparity between these values is large. The greater D_{250} value and z value as exhibited by the thiamine enables it to withstand higher temperatures of processing than C. botulinum (Stumbo, 1973). Bendix et al. (1951) and Cameron (1955) also showed an increase in thiamine retention from high temperature, short time processing of vegetables. Cameron (1955) has demonstrated that a 10°C (18°F) rise in temperature doubles the rate of thiamine

destruction while the rate of bacteria destruction over the same temperature, increased by ten-fold. Weir (1948) states that for peas, the rate of thiamine destruction is 2.5 times for every 10°C(18°F) rise in temperature in the range of 100°C(212°F) to 147°C(298°F). Feaster (1947) shows that high temperature, short time processing results in better thiamine retention than conventional methods. Simeonova (1968) states that during the boiling cycle the loss of thiamine is less in enameled cans than in glass jars.

2.5 Fiber

Kohler (1964) stated removal of the bran layer in the bulgar process would result in only 1% loss in protein but would remove 55% of cellulose and 20% of the pentosans. Neither are digested by man, so by removing them from the wheat, the bulgar is substantially improved.

The above statement exemplifies the concern to produce processed, refined convenience foods and a lack of appreciation for fiber content of foods. Recent evidence (Burkitt, 1972) has shown that a fiber deficient diet may be a factor in a number of colo-rectal diseases including colon cancer. The major components of dietary fiber are cellulose, hemicellulose, lignin and pectins (Scala, 1974). Burkitt *et al.* (1972) estimated that dietary fiber has decreased from 8.1 gram/person/day in 1880 to 5.3 gram/person/day in 1970 while refined carbohydrates have increased.

Several workers (Brenner et al., 1970; Painter and Burkitt, 1971; Burkitt, 1971) have shown a relationship between the decrease in dietary fiber and a rise in the incidence of colon cancer, appendicitis, diverticulosis, polyps and colitis. Burkitt (1971) postulated that carcinogens may be produced by the action of abnormal intestinal flora when held in concentrated form in contact with the bowel mucosa lining.

Painter and Burkitt (1971) stated that if the lack of fiber causes diverticular disease, then the symptoms may be alleviated by replacing fiber, in the form of bran, in the diet. Painter et al. (1972) stated that the more economical way to include fiber is by eating unprocessed bran as its effects exceed that of fruit and vegetable fiber. Painter and Burkitt (1971) contend that diverticular disease is a deficiency disease and, like scurvy, can be prevented.

Rolled oats have been shown to reduce serum cholesterol levels in man (deGroot et al., 1963). If only canned whole wheat product was consumed, 2-1/3 303 x 406 cans would be necessary (due to hydration of the wheat) to obtain a diet of 8.1g fiber/day. Addition of 2g fiber per day was suggested by Painter and Burkitt (1971) to increase the daily intake of fiber to an optimum level. This would amount to approximately 250g of canned wheat or about 1 cup serving. The canned whole wheat product produced in this study is very high in fiber.

2.6 Taste Panel

Because of their subjective nature, taste panel results are influenced by human psychological factors. The conditions of the taste panel must favor a completely independent response for each individual, and each sample must be presented under similar conditions (Kramer and Twigg, 1970). A taste panel can be used as a laboratory instrument to detect a difference. A small number of skilled panelists, from 3 to 5 members, should be adequate and a scoring or ranking system is sufficient for statistical analysis (Kramer and Ditman, 1956). It is important to provide each panelist with sufficient privacy so results are not influenced by other panelists. The panelist should not receive any instructions which may indicate the sample's identity (Kramer and Twigg, 1970). Harrington and Pearson (1962) suggested that for chew count, the panel should be instructed to chew the sample to a consistency which would normally be swallowed. If instructions are given to score a particular attribute, other differences should be ignored, but these other factors will undoubtedly have an effect on the results (Kramer et al., 1961).

Samples should be prepared carefully before presentation, with each panelist being provided a similar aliquot. The samples may be presented cafeteria style, which is an advantage to the panel operator, and also each panelist observes the same unit so there is little error from variations

among units of the same sample. The disadvantage of cafeteria style is that it is difficult to prevent communication among panelists (Kramer and Twigg, 1970). This may be overcome by setting out two samples, one for viewing and one for tasting. This procedure is limited to situations where large numbers of samples must be tasted at a single session (Kramer and Twigg, 1970).

Opinions vary as to the number of samples to be tasted per sitting. Some psychologists (Bayton, 1956) say only one, to two, treated as pairs (Beyer and Abrams, 1953) or three in triangular (Peryam, 1950), to larger numbers for the sake of economy and optimizing memory (Kramer and Ditman, 1956). Kramer et al. (1961) concluded that for the purpose of obtaining significant differences a single sample is inefficient, and the optimum number handled at any one sitting depends on the nature of the product. If the substance is bland, more samples (9-18) can be handled (Kramer and Twigg, 1970).

Kramer and Twigg (1970) stated that the shear press could be correlated with taste panel evaluation. The action of the shear press test simulated the action of the teeth, which first compress, then shear the food (Kramer and Twigg, 1970). Harrington and Pearson (1962) used actual chew counts to measure tenderness of pork loins. The shear press forces may be read directly from gauges or from a recorder to obtain time-force curves instead of just a maximum reading

(Decker et al., 1957). In general, deformation is shown by the distance from the beginning of the curve to the first peak and firmness by the height of the curve (Kramer and Twigg, 1970).

The degree of correlation obtained between panel scores and the instrument method may indicate the accuracy of the instrumental procedure provided the following conditions are met (Kramer and Twigg, 1970):

1. the sample submitted to the panel and instrument must be identical,

2. the number of samples must be adequate, and

3. the samples cover all conditions and variations.

If these conditions are met, then a correlation coefficient of 0.90 or higher indicates that the instrument is sufficient to accurately measure the quality attribute. If an attribute of quality is defined, it is desirable to use an instrument capable of measuring the same attribute directly; thus, chewiness of lima beans could be more reliably measured by shear and compression than by bean color (Kramer and Twigg, 1970).

Chewing breaks up food and increases surface area for enzyme action, and a continued release of flavor is desirable (Oldfield, 1960). An impulse to spit out the food may be signaled if flavor disappears before chewing is completed (Amerine et al., 1965).

Factorial experiments are designed to give a set of independent comparisons of a type dependent on the choice of treatments (Steel and Torrie, 1960).

2.7 Experimental Design

A "factor" is a treatment and in a factorial experiment, it will supply several treatments. The term "level" refers to the amount or state of a factor. Main effects are averages over a variety of conditions, whereas simple effects are differences of one factor from level to level of the other factor. When simple effects for a factor differ by more than can be attributed to chance, this is called "interaction" (Steel and Torrie, 1960).

A hypothesis is tested by using the "F" test. Such a test is used so that two independent variances may be compared as if they were simple variances from populations with the same variance (pooled variance). Using this test, the hypothesis that all population means are equal may be validated (Steel and Torrie, 1960).

3.0 EXPERIMENTAL

3.1 Apparatus

3.11 Analytical Balance

All weighings for moisture determinations and for reagents were performed on a Mettler Model B Gram-atic analytical balance with an accuracy of ± 0.02 mg.

A Sartorius Model 2204 top loading balance with an accuracy of ± 0.1% was used for bulky samples.

3.12 Can Closing Machine

All experimental cans were sealed on a Canco Model 423-IES-00 steam flow closing machine.

3.13 Thermocouples

Ecklund copper-constantan thermocouples for 303x406 cans were used in the heat penetration study. The thermocouple has the capacity for plug in coupling with lead in wires. When installed, these thermocouples are recessed so they may be run through a can closing machine.

3.14 Multiswitch

A General Electric 10 point thermocouple transfer switch was used to read thermocouples in sequence for determining heat penetration data.

3.15 Potentiometer

Heat penetration data was taken from a Honeywell-

Brown Portable Single Range Pyrometer Potentiometer-Series 126 W2P, with auto reference junction-compensation. The Potentiometer was graduated in degrees Fahrenheit on the instrument's scale. When used with copper-constantan thermocouples, the reading range is from -100°F to +400°F with an accuracy of 0.2% of the scale span.

3.16 Vacuum Oven

Moisture determinations were performed by drying in a Precision Scientific Vacuum Oven with a heating capacity of 180°C(356°F). The oven is capable of attaining a vacuum of 25 inches of mercury (635.0 Torr).

3.17 Shear-Press

The Allo-Kramer shear press Model S2HE was used to evaluate the texture of the canned product. The 1000 pound ring was used in conjunction with the CS-1 Standard Shear Compression cell and shear blades. The shear press was coupled with a recorder to generate time-force curves for analysis.

3.18 Fluorometer

Thiamine content as determined by thiochrome fluorescence was assayed on a G. K. Turner Model 430 Spectrofluorometer with excitation and emission monochromaters to control wave length instead of filters. Wave length for excitation was set at 365 nm and the wave length for emission was 435 nm. All measurements were made with the polarizer filter in place as suggested by the manufacturer.

3.2 Materials

3.210 Wheat Varieties

Initially four varieties of wheat were used in order to determine heat penetration data and process time. From these four, two different varieties were chosen for the main experiment. These four varieties were:

1. Soft Red Winter (Arthur)--hereinafter referred to as SRW wheat.
2. Kansas Hard Red Winter--hereafter referred to as HRW wheat.
3. Spring.
4. Soft White Winter.

The above varieties were obtained from Roanoke City Mills, Roanoke, Virginia.

For the main factorial experiment, only HRW wheat and SRW wheat were used. HRW wheat was then obtained from Piedmont Mills in Lynchburg, Virginia.

3.211 Cans

Cans used in this experiment were #303x406 C-enameled with C-enamel ends.

3.212 Salt

Salt used in the pack was non-iodized salt (NaCl) with trace of yellow prussiate of soda added as an anti-caking agent.

3.213 Water

Tap water was used for the pack which gave the cans

an initial temperature of 29.4°C(85°F).

Distilled, deionized water was used in dilutions for thiamine determinations.

Triple distilled, deionized water was used for preparation of stock reagents for thiamine determinations.

3.214 Sodium Sulfate

Sodium sulfate, anhydrous, certified A.C.S. grade in granular form from Fisher Scientific Co., Chemical Manufacturing Division, Fairlawn, New Jersey was used to clear isobutyl-thiochrome solution of excess water before reading the sample in the fluorometer. The granular form was used because of its ease in handling.

3.215 Potassium Ferricyanide

Fisher certified A.C.S. grade potassium ferricyanide was used to make up 1% potassium ferricyanide solution by weighing 1.0g on the analytical balance and diluting to 100 ml with triple distilled, deionized water. This solution is stable for one month if kept at 5°C (41°F) in a brown bottle.

3.216 Sodium Hydroxide

Certified A.C.S. grade sodium hydroxide in pellet form (Fisher) was used to prepare 15% sodium hydroxide solution. The solution was prepared by weighing 15g of the pellets on the analytical balance and dissolving in distilled, deionized water. The concentrated solution was

cooled in a refrigerator, and diluted with distilled, deionized water to 100 ml before using.

3.217 Hydrochloric Acid

Concentrated (37.4%) hydrochloric acid A.C.S. reagent grade (Fisher) was used to prepare 0.1N and 0.01N hydrochloric acid solutions. For the 0.1N solution, 8.5 ml of concentrated acid was pipetted into a 1000 ml volumetric flask and diluted to 1000 ml with distilled, deionized water. The 0.1N solution was prepared by pipetting 0.85 ml of concentrated hydrochloric acid into a 1000 ml volumetric flask and diluting to 1000 ml with triple distilled, deionized water.

3.218 Alkaline Potassium Ferricyanide

The oxidizing agent, alkaline potassium ferricyanide was prepared by pipetting 3 ml of the 1% potassium ferricyanide solution into a 100 ml volumetric flask and diluting to 100 ml with 15% sodium hydroxide at 5°C(41°F). This solution was prepared fresh daily.

3.219 Sulfuric Acid

Fisher reagent grade, concentrated sulfuric acid was used. An approximate 0.1N solution was prepared by pipetting 2.8 ml of sulfuric acid into a 1000 ml volumetric flask and diluting to 1000 ml with triple distilled, deionized water.

3.220 Sodium Acetate

Fisher certified reagent, A.C.S. certified sodium acetate was used. a 2.5 M solution was prepared by weighing

345g on the top loading balance and diluting to 1000 ml in a volumetric flask with triple distilled, deionized water.

3.221 Isobutyl Alcohol

A.C.S. reagent grade isobutanol (Fisher) was used, the fluorescence of which should not exceed 10% of the standard. Fluorescence was reduced by shaking with 1.5g activated charcoal for every 100 ml alcohol, then filtering through a Whatman #4 filter paper over a Whatman #1 filter paper filter stack.

3.222 Stock Thiamine Solution

Thiamine hydrochloride from Eastman Kodak Company, Rochester, New York was used. The stock thiamine solution was prepared by drying the powdered thiamine over P_2O_5 in a disiccator for 24 hours. Then 100 mg of thiamine was weighed on the analytical balance and then dissolved in 0.01N hydrochloric acid. The solution was diluted to 1000 ml in a volumetric flask with triple distilled, deionized water. The final concentration was 100 µg/ml. The solution is stable for several months if stored in a brown bottle at 5°C(41°F).

3.222.1 Intermediate thiamine solution

An intermediate thiamine standard solution was prepared by pipetting 5 ml of the stock solution into a 100 ml volumetric flask and diluting to 100 ml with distilled deionized water. Final concentration was 5 µg/ml. This solution was prepared fresh daily.

3.222.2 Working thiamine solution

The working thiamine standard solution was prepared by pipetting 4 ml of the intermediate thiamine standard into a 100 ml volumetric flask containing 75 ml of 0.1N sulfuric acid and 5 ml of 2.5 M sodium acetate. This solution was diluted to 100 ml with distilled, deionized water. Final concentration of the working solution was 0.2 µg/ml. This solution was prepared fresh daily.

3.223 Enzyme Preparation

Taka-Diastase enzyme from Parke-Davis Pharmaceuticals, Detroit, Michigan was used. The enzyme suspension was prepared fresh daily by weighing 6g of the dry enzyme and dispersed with 2.5 M sodium acetate buffer to 100 ml in a volumetric flask.

3.3 Procedures

3.31 Potentiometer Calibration

Thermocouples and the Potentiometer used in heat penetration were calibrated against a mercury thermometer for the temperature range of 37.7°C(100°F) to 121°C(250°F) by 5.5°C(10°F) increments. Glycerine was used to obtain temperatures over 100°C(212°F).

3.32 Heat Penetration

3.321 Cold point determination

Thermocouples were placed at 1/4-inch intervals from the midpoint of the can to the bottom, one each in

seven #303 cans. The thermocouple tip was positioned in the geometric center of the 303x406 tin cans. One hundred fifty grams of wheat were weighed into a can and water was added to within 1/8-inch from the top of one initial can. The amount of water was weighed, and an equal amount was weighed into each can thereafter.

The cans were sealed, placed in the retort, and the lead-in wires were connected to the can thermocouples making sure the numbers on the can corresponded with the number on the multiswitch. The retort was vented for four minutes. The thermocouples were read in sequence at one minute intervals until near retort temperature was reached. This procedure was repeated three times to determine the position within the can having the slowest rate of heat penetration (hereafter called cold point). Temperature vs. time was plotted on semi-logarithmic paper. In this manner, as described by Ball (1957), the cold point was located. After location of the cold point, all subsequent cans had the thermocouples positioned accordingly.

3.222 Heat penetration data

For heat penetration data collection, the thermocouples were placed in the cans, the cans tared, and 150g of a single known variety of wheat was placed in five cans. An equal weight of 340g water was added to each can, producing a 1/8-inch headspace. With the same variety, the same procedure was followed except 3g salt was added to

each can. The cans were sealed with an initial temperature of 29.4°C(85°F).

In recording the rate of heat penetration, the temperatures were read directly from the Potentiometer in degrees Fahrenheit, once every minute for the heating phase, and once every two minutes for the cooling phase. The time period for the heating phase was governed by the time taken for the temperature to stabilize or when temperatures near retort temperature were recorded (Ball, 1957). At that time, the steam to the retort was shut off, and the cooling phase begun.

Heat penetration curves were prepared according to Ball (1957) and Stumbo (1973) by turning semi-logarithmic graph paper upside down and numbering the top line of the log scale one degree below retort temperature and labeling the temperature in log cycles. The time was labeled along the linear axis and the data recorded from the heat penetration was plotted. From these graphs, the slope of the heating and cooling curves, the corrected zero of the process, and the shape of the heating curve were determined. This information was then used in calculation of the sterilizing value (F_o) and the process time (B).

Calculation of processing times from the heat penetration curves was done manually using the Ball Formula Method (Ball, 1957; American Can Co., 1970) and verified by using the Simplified Ball Formula Method program on the

computer (Anon. 1972). The formula method was used instead of the general or nomographic method, because these two methods do not lend themselves to variable conditions as does the formula method.

Processing times of 8, 16, 32, and 64 minutes were arbitrarily chosen as variables in the factorial experiment to cover a range of sterilizing values as calculated. The 8-minute time corresponds to a F_o value of 1.2 which would be the lowest end of a range of D_{250} values (Stumbo, 1973) for a 12D reduction of Clostridium botulinum spores. The 16-minute process was chosen to represent the minimum safe process. A time of 32 minutes established a middle point between the minimum process and the 64 minute time approximating that recommended in El Molino (1953).

3.33 Physical Determinations

3.331 Drained weight

Drained weight was measured by opening and inverting the can, emptying its contents onto a Number 10 U.S. Standard Sieve (tare weighed). The can and lid was left inverted on the sieve and the sieve was tilted at a slight angle to allow better drainage of the liquid. A time of 2-1/2 minutes elapsed before the sieve was reweighed without the can and lid. The difference between the tare and full weight of the sieve is the drained weight of the contents.

3.332 Moisture

The percent moisture was determined by the AOAC (1970)

method of weighing a suitable sample size on an analytical balance and placing in a covered dish, with cover ajar, in a vacuum oven. The samples were dried to a constant weight at 98-100°C(208-212°F) at 25 in. mercury vacuum. After drying, the covers to the dishes were immediately secured after opening the door, and the dish was placed in a desiccator. The material left after drying is the total solids, and the loss in weight is moisture.

3.333 Taste panel

A taste panel study was conducted to gain a correlation between human response and that of the shear press. Chew count was used as a measure of tenderness to correlate with the shear press values. Two cans of each process variable were tested in duplicate. One set for each process was tested on one day and the second set on the following day. A three member panel was selected for the test.

Four cans of a treatment block were tested at each sitting. The cans were opened and drained, as in the drained weight procedure, before presentation to the panel. A level teaspoon of wheat was then weighed in a portion control cup and found to weigh 6g. All other samples were weighed accordingly. A sample form is illustrated in the Appendix.

The order of sample presentation was changed from the first day to the second, each four can sample was from the same block of variety and salt for the four process

times. Two plates of samples were presented to each taster, one plate containing four portion control cups containing the weighed samples of the four different processes. The second plate contained their duplicates in random order (See Appendix) (Harrington, 1961).

Panel members were instructed to chew the entire portion, and count the number of chews necessary to reach the consistency at which the sample could normally be swallowed.

Wheat samples remaining after material for the taste panel was removed, were evaluated by the shear press immediately after tasting was completed to assure the same moisture of the product and to reduce error in the evaluation.

3.334 Shear press

After the can contents had been drained and weighed, duplicate 100g samples were weighed for testing texture with the Allo-Kramer shear press. The weighed sample was placed in the standard shear compression cell and dispersed evenly and level in the cell.

Results were recorded on the recorder to give time-force curves for analysis. The range was set at full scale for recording the measurements with a 15 second stroke.

When the shear cycle was completed, the wheat sample was collected from the cell and placed in a polyethylene bag. A number of these smaller bags were placed in a larger

plastic bag and stored in the freezer for later thiamine determinations.

3.335 Split grains

The percent of wheat grains split open by water imbibition was related to the effects of process time and texture. A sample from the drained weight sieve was placed in a white tray and two, fifty grain portions were counted as to split vs. unsplit. This ratio was then expressed as a percent of split grains.

3.336 Thiamine (Vitamin B_1)

The procedure followed for determination of thiamine was that of the Association of Vitamin Chemists (1951).

a. Sample Preparation:

Raw wheat to be assayed for thiamine was ground in a Wiley Mill through a 20 mesh sieve top delivery tube. A five gram sample of wheat was weighed on the analytical balance and placed in a graduated Erlenmeyer flask for extraction. Canned wheat was blended in a mini-blender for 1 minute with 60 ml 0.1N hydrochloric acid.

b. Extraction:

A sample of 10 grams of canned wheat product was weighed into a graduated 125 ml Erlenmeyer flask. This sample was then blended in a small volume blender cup with 60 ml of 0.1N HCl for one minute. The cup was then rinsed with approximately 15 ml of the acid to make a total of approximately 75 ml. The sample was then placed in a boiling

water bath for 45 minutes stirring every 5 minutes to avoid lumping. After heating, the sample was cooled in air to 50°C(122°F) or lower. Samples should not be cooled by placing in a cold water bath as this will lower readings considerably and give erratic results. When cooled, five ml of the enzyme solution was added and the mixture then incubated at 50°C(122°F) for two hours or at 37°C(98.6°F) overnight. The sample was cooled to room temperature and diluted to 100 ml with distilled water, mixed thoroughly and filtered. When the procedure could not be completed in one day, it was stopped after filtering.

c. Conversion to thiochrome

Five ml of filtrate was pipetted into a round bottom capped centrifuge tube. The standard solution was filtered and also pipetted into a centrifuge tube at this time. All procedures were performed from this point on in absence of direct fluorescent light or daylight as the thiochrome compound is sensitive to light. Three ml of alkaline ferricyanide solution was added and mixed gently for 15 seconds. Immediately afterward 15 ml of isobutyl alcohol was added and vigorously shaken for 60-90 seconds. A standard blank was prepared by adding, to a tube containing 5 ml of the standard, three ml of 15% NaOH solution following the same procedure as for the other tubes.

d. Separation

The tubes were centrifuged at 250 G for one to

three minutes. The bottom aqueous layer was siphoned with a pipet and discarded. Two to three grams of sodium sulfate (1/4 teaspoon) were added to the alcohol layer and shaken gently for thirty seconds until clear. It was not necessary to weigh an accurate amount of sodium sulfate; however, it was necessary for all tubes to receive a precise amount. The tubes were then centrifuged for one to three minutes.

e. Measurement of thiochrome

Approximately 10 ml of the alcohol layer was decanted into a 1/2-inch diameter cuvette, and care was taken not to decant any sodium sulfate crystals. The cuvette was placed into the sample compartment and the deflections recorded. The fluorometer range knob was set at 10X, blank at low, sensitivity control at high, and monochromators set at wavelengths of 365 nm for excitation and 435 nm for emission. The sensitivity control knob was then adjusted to obtain a reading of 100 with the standard. The standard blank was read next, then the unknowns. After reading the unknown samples, their thiochrome content was destroyed by the addition of 1-2 drops of concentrated hydrochloric acid. This action in effect made the assay solution a reagent blank to provide a baseline fluorescence for the chemicals added. These blanks were read and recorded.

f. Calculations

$$\frac{\mu g \text{ thiamine}}{\text{gram}} = \frac{U-UB}{S-SB} \times \frac{1}{5} \times \frac{100}{\text{sample wt.}}$$

U = unknown deflections

UB = unknown blank deflections

S = standard deflections

SB = standard blank deflections

$\frac{1}{5}$ = converts µg/5 ml to µg/ml. This is the standard concentration = 0.2 µg/ml.

3.4 Experimental Design

The experimental design involved six cans for each variety and treatment for a total of 96 cans. Duplicate samples from each can were taken for shear press and thiamine determinations. The other measurements of drained weight, moisture and split grains were single samples. This procedure was necessary to reduce error within treatments. The sample cans were then assigned a random number and coded to make the experiment blind to reduce bias on the part of the experimenter.

3.5 Analysis of Research Data

Research data were accumulated and analyzed both graphically and statistically. A factorial analysis of variance statistical design was chosen to analyze the resultant data.

Statistical analysis was conducted using the computer SAS program (Barr and Goodnight, 1972) and manual calculations for interactions. The purpose of the analysis was to detect the level of significance of differences among variables.

4.0 RESULTS AND DISCUSSION

4.1 Preliminary Functions

4.11 Cold Point Location

The initial step in the study was the determination of a safe thermal process for whole wheat. To accomplish this, a cold point in the type of can used was located.

From Figure 1, the cold point was found to be 3/4-inch from the bottom of the can. The internal can temperature approached the retort temperature within 12 minutes. Because of the large proportion of water to raw wheat (345g: 150g), and also the fact that the wheat was added to the can without soaking, the water heated rapidly and the wheat starch did not gelatinize during this time.

4.12 Heat Penetration Data

On the basis of cold point determination as discussed in Section 4.11, thermocouples were installed and heat penetration data were collected on four varieties of wheat, with and without salt added. The results are shown in Figures 2-4. Spring wheat (see Appendix) and SRW wheat exhibited a straight line heating curve when plotted on semi-logarithmic paper. The addition of salt to these varieties did not alter the shape of the curve, but did increase the slope of the curve.

HRW wheat and SRW wheat varieties showed evidence of a "reverse" broken curve where the slope of the 2nd curve increased after the break instead of the customary decrease. An explanation for this behavior may be that the wheat stayed immobile on the bottom of the can until the temperature reached a certain point and then the wheat was carried in the convection currents. Another explanation may be in the interpretation of the least squares fit of the line through the data points.

For all varieties, the rate of heat penetration was similar with a rapid rise to near retort temperature within the first ten to twelve minutes of heating.

4.13 Determination of Process Lethality

The results are plotted for sterilization value (F_o) versus process time (B) in Figures 5-7. For a safe minimum process, the 12D concept is normally employed. It has been established that the minimum thermal process should be sufficient to reduce any population of the most heat resistant spores of C. botulinum to 10^{-12} (Stumbo, 1973).

The most heat resistant botulinum spores are types A and B with a D_{250} value of 0.21. The minimum process is calculated as follows (Stumbo, 1973):

$$t = F_s = D (\log a - \log b)$$

$$F_s = .21 (\log 1 - \log 10^{-12})$$

$$F_s = .21(12) = 2.5$$

Thus a minimum process for a safe product would require a sterilizing value of 2.5. From the graphs of sterilizing value versus process time (Fig. 5-7) a time for sterilization of SRW wheat is 9.5 minutes and HRW wheat is 11.5 minutes.

A commercially sterile canned food may contain viable spores of thermophilic anaerobes, which will not develop under normal conditions of storage (Ball, 1957). He further states some of these spores are so highly heat resistant that to destroy them may overcook the food to such an extent that it would be unsuitable to consume.

Low-acid canned foods are processed beyond the minimum safe process because of the presence of spoilage bacteria with higher heat resistance. Because these bacteria are not of public health significance, the minimum process is based on economic consideration (Stumbo, 1973). For mesophilic spore formers (i.e. PA3679) a reduction in population to 10^{-5} is normal.

This computed to a F value of 5.00 which yields a process time of 12.5 minutes for SRW wheat and 14 minutes for HRW wheat.

4.14 Varietal Selection for Factorial Experiment

Two of the four varieties were chosen for the main factorial experiment. In the preliminary tests there were two sets of similar responses for heat penetration. Spring

and SRW wheat showed duplicate responses and Soft White Winter wheat and HRW wheat were also similar to each other.

Other factors influencing the selection were that HRW wheat was reported (Watt and Merril, 1962) to have the highest thiamine content. HRW wheat has a harder texture than the soft wheats due to an increase in protein and the nature of the starch in the endosperm. According to Pomeranz (1970), hard wheat starch will swell initially at a lower temperature (23.9°C--75°F) than soft wheat varieties (29.4°C--85°F). No explanation was given by Pomeranz for this action. Neither did he state if the type of starch was different in soft or hard wheat varieties.

The above statement may explain the lag in heating of HRW wheat for the first 7 minutes . The kernels may have swelled initially making them larger and physically impeding convection currents. The kernels of HRW wheat may be more dense than those of SRW wheat staying on the bottom of the can longer, and requiring a stronger convection current for mobilization.

When the internal can temperatures reach near retort temperatures, convection currents cease and the product then essentially heats by conduction (Ball, 1957).

4.15 Test with Tap and Distilled Water

Shear press values and thiamine assays were obtained for wheat canned in tap water or distilled water. No

difference was found between the samples, therefore tap water was used in the main pack.

4.16 Taste Panel Evaluation

A correlation coefficient of 0.9 or higher is required to replace human evaluation with an instrument designed for texture analysis (Kramer and Twigg, 1971). Correlation of chew count as a measure of tenderness exceeded the above requirement and was significant at the 5% level of confidence (See Appendix). Since the Shear Press showed an ability to reproduce texture measurements, the taste panel was dropped for further texture analysis in favor of the Shear Press.

4.17 Thiamine Preliminaries

Thiamine assays were performed on the raw wheats (Table 1) used in the experiment which were used later for determination of percent thiamine retention. Values for thiamine for HRW wheat were 0.347 mg/100g and 0.414 mg/100g for SRW wheat. The value for HRW wheat thiamine content is lower than the literature data which could result from growing conditions (Harris and von Loesecke, 1960).

Recovery experiments for thiamine were conducted using fortified samples. Thiamine recovery through extraction and incubation was 95% for a 10g initial sample.

A standard curve for thiamine was plotted using standards of 0.01 µg/ml, 0.05 µg/ml, 0.10 µg/ml, 0.15 µg/ml and 0.20 µg/ml. The standards were used to check the linearity of

the instrument and also to assist in choosing an appropriate sample size that would fit on the linear portion of the curve. The curve was a straight line through all concentrations and a sample size of 10g of cooked wheat was most suitable for assay.

Percent moisture for the raw wheat was analyzed for later calculations on a dry weight basis. SRW wheat contained 14% moisture and HRW wheat contained 10% moisture.

4.2 Statistical Analysis of the Factorial Experiment

4.21 Shear Press

From the analysis of variance for shear press values in Table 2, the three main effects of variety, salt, and process time are all significant at the 1% level. However, significant interactions of variety x process, salt x process, and variety x salt x process were detected by the analysis proving that the main effects are not independent of one another. Certain conclusions implicated by the main effects would be erroneous without qualifying with statements of the interactions.

The interaction of variety x salt is non-significant, meaning that the factors of variety and salt are independent of each other. Therefore, the difference in toughness between HRW wheat and SRW wheat is not affected by the presence of salt.

Variety x process interactions showed that HRW wheat

was significantly tougher than SRW wheat for 8, 16, and 32 minutes of process time; however, these differences were not significant at the 64 minute time.

Salt x process interactions averaged over all process times and varieties indicate that wheat canned with salt was significantly tougher than wheat canned without salt.

Toughness was not decreased as fast in the presence of salt due to the inhibition of gelatinization. The length of processing time would have to be increased to obtain a product of tenderness equal to wheat with no salt added. Process time, when salt is added, must be almost four times that of no salt to achieve similar shear press values.

These results confirmed the hypothesis that salt would adversely affect the tenderness of the product. Pomeranz (1971) stated that HRW wheat had a tougher texture than SRW wheat. Ferrell and Pence (1961) noticed that salt added to bulgar before cooking increased the soak time required to reach a certain moisture content and the wheat remained tough. Increasing process time allows enough time for the gelatinization of the wheat starch and results in a decrease in the shear value.

Pomeranz (1971) stated that gelatinization occurs when starch is heated in an aqueous medium. Changes in the starch occur as a result of water entering the starch granule. These changes are hindered if sufficient water is

not present to be freely available to the granule. The hindrance of swelling can be caused by the presence of other substances such as salt or sugar which compete for the water. Such an action would leave the grain of wheat fairly intact and would result in a product which remains tough. As the temperature increases after the initial swelling, the starch (wheat) granules continue to swell. This theory of salt competition for water may explain the reason why wheat with salt added was tougher than the wheat canned with no salt.

The above theory may help explain the faster heat penetration rate for samples with salt added. Since the wheat kernels do not swell as much in the presence of salt, they offer less resistance to convection currents. Another explanation may be that the denser salt water buoys up the wheat grains allowing more freedom of movement in the convection currents. This action would also generate a faster rate of heat penetration.

4.22 Thiamine Retention Based on Wet Weight

Thiamine was analyzed to evaluate the nutrient change due to treatment effects and also as an indicator of sufficiency of process.

Analysis of variance on thiamine data presented in Table 3 showed the main effects of salt and processing and interactions of salt x process and variety x salt x process to be significant. No significant difference was detected

between HRW wheat and SRW wheat when averaged over all salt and processing levels (See Appendix).

The significant salt x process interactions means that the salt differences are not the same for all levels of process time. Analysis of the salt x process interaction (see Appendix) indicates that salt significantly increased thiamine retention only at 16 minutes and 64 minutes processing time. The significant 3-way interaction implies that the salt x process may be affected by the variety. The overall trend is for salt to result in product with slightly higher thiamine content on a wet weight basis.

The decrease in thiamine content as the processing time increases is an expected result. Thiamine is a heat labile nutrient, and destruction follows the rate equation for first order kinetics. Thus, both time and temperature are critical for thiamine retention.

4.23 Thiamine Content as Based on Dry Weight of Grain

Analysis of variance for thiamine content as calculated on a dry weight basis is presented in Table 4. Variety is now a significant factor as well as process time, salt x process and variety x process interactions.

Variety x salt interaction are non-significant and the simple effects of variety are the same for all levels of process time. Variety differences are not significant at either salt level when averaged for all processing times.

The factors are independent and the differences are due to the main effects.

Interactions for variety x process are not significant, therefore the differences due to variety are the same for all levels of process time. The simple effects of a non-significant interaction are similar to the main effects and the difference between varieties of HRW wheat and SRW wheat are not affected by process time and the difference in thiamine retention between process times is not affected by the variety (see Appendix).

The salt x process interaction (see Appendix) is significant which means that the effect of salt is not uniform for all levels of process time. Further analysis reveals that there is a significant difference at the 8 minute process time only. The significant 3-way interaction of variety x salt x process implies that there was an effect of variety for this salt x process interaction.

By calculating thiamine on a dry weight basis, salt did not significantly increase thiamine retention. The higher retention of thiamine exhibited by SRW was probably caused by the higher amount of thiamine in SRW wheat initially. As the process time increased, the thiamine content decreased when averaged over all variety and salt levels. The addition of salt generally decreased the retention of thiamine when averaged for all times of process, but only

at the 8 minute level was the decrease significant, and this was probably due to variety--as implied by the 3-way interaction.

Actual thiamine destruction was not as rapid as it appeared to be. The thiamine present in the wheat grain was diluted as water was absorbed by the wheat grain. The lower rate of thiamine destruction (wet basis) with salt compared to no salt was probably caused by inhibition of water absorption by the wheat. Expressing results on a dry weight basis negates this dilution effect. When expressed on a wet or "as eaten" basis dilution is a factor in addition to destruction.

Ache and Ribeiro (1945) claimed that sodium chloride accelerates decomposition of thiamine and Farrer (1947) states that the concentration of buffer salts in some instances will influence destruction of thiamine. However, Simeonova's (1968) findings did not bear out this observation nor did this study. The percent of original thiamine present on a wet weight basis present after processing ranged from 20% for the 8 minute process time to 5-6% thiamine for the 64 minute process time. These values are very low for thiamine in heat processed foods. Harris and von Loesecke (1960) give a range in thermal treatment losses from 0-80% for thiamine. Cain (1967) gave an average of 13-37% retention for canned beef, 40% retention for canned sweet potatoes, 55% for canned lima beans, 19-42%

for canned corn, and 97% for canned tomato juice. Farrer (1955) stated an average of 40% thiamine loss from canning.

The content of thiamine in the canned wheat on first inspection seems very low. However, the amount of moisture which wheat gains as process time increases is considerable and this probably causes a dilution of thiamine, thus lowering the percent thiamine on wet weight basis. Calculation on a dry weight basis (Table 1) improves the percent thiamine retention from 20% to 51% for 8 minutes and 5% to 19% for 64 minutes making it more comparable to canned lima beans and beef.

Thiamine is very readily destroyed on heating in neutral or alkaline pH media (Farrer, 1955). Farrer (1955) stated that an increase in the velocity coefficient for thiamine destruction occurred between pH 6.2 and 6.9. Values for pH of the canned wheat were between pH 6.35 and pH 6.8. This fact helps explain why more thiamine was not retained at the shorter process times. Thiamine retention as calculated by the method of Stumbo (1973) should produce a retention of approximately 89%.

Bendix (1957) indicated that only peas adhere to the unimolecular theory. Other food systems did not follow a first order rate reaction. Therefore, calculations on thiamine retention must be verified by analysis.

4.24 Analysis of Variance for Percent Moisture Absorption

The analysis of variance for percent moisture is

presented in Table 5 which indicates a statistical significance for all three main effects of salt, variety and process as well as a significant salt x process interaction.

SRW wheat absorbed more water than HRW wheat; however, the soft wheats contain more moisture when raw than the hard wheats. For this reason, canned SRW wheat may have more moisture than canned HRW wheat.

Variety x salt interactions were not significant, therefore, the differences of the means for variety were the same for all levels of salt, and vice versa. The factors of salt and variety are independent of each other.

Variety x process interactions (see Appendix) were also not significant. The difference in variety means were the same for all levels of processing time. The differences of HRW wheat and SRW wheat were not affected by process time, and the process time values for percent moisture were not affected by varietal differences.

The significant salt x process (see Appendix) interaction means the factors do not operate independently of one another. Thus, a change in one factor depends on the level of the other factor in the interaction term. The effect of salt significantly inhibited the absorption of water for all levels of processing time when averaged over both HRW wheat and SRW wheat.

4.25 Analysis of Variance for Percent Split Grains

The percent of split grains is related to appearance

and was performed to visually assess the effect of water absorption by the wheat grains. The main effects of the analysis of variance were all significant (Table 6). None of the interactions was significant, which is ideal in a factorial analysis. Without interactions present, the main effects are all independent of each other, and all differences in percent split grains are caused by the main variables of the experiment.

Canned SRW wheat contained more split grains than HRW wheat when averaged for both salt levels and all process times. This follows the pattern of moisture absorption as presented in the preceding section.

Salt significantly inhibited the swelling of the wheat starch resulting in fewer grains split. Increased processing time resulted in an increased number of split grains due to water absorption and gelatinization of the starch.

4.26 Analysis of Drained Weight as a Factor in Canned Wheat

The main effects of salt and process time and the salt x process interaction were the only significant factors for drained weight (Table 7). Drained weight of the canned wheat was not affected by variety.

No difference was found between drained weight for either level of salt when averaged for both varieties (see Appendix) and the difference in means of variety did not change significantly with a change in process time. However,

salt added did increase free liquid and lower actual drained weight for all levels of process time except at the 64 minute time (see Appendix). Longer processing times allowed the wheat to absorb more water even with the inhibitory effect of salt.

5.0 SUMMARY AND CONCLUSIONS

Thiamine destruction, texture measurement, and a minimum calculated process were determined for thermally processed, canned whole grain wheat. The minimum process as calculated should be validated by an inoculated pack before the product could be marketed. The minimum process was computed for 303 x 406 tin cans at 121°C(250°F) and would differ if glass jars were used, or another temperature was employed. Variables of variety, salt and process times were analyzed for effect on thiamine content and texture.

The main conclusions follow:

1. A minimum safe process time for canning wheat requires a sterilizing value (F_o) of 2.5. This yields a process time of 9.5 minutes for SRW wheat and 11.5 minutes for HRW wheat, at 121°C(250°F) in 303 x 406 cans.

2. The addition of salt in the canning process resulted in a tougher product when compared to canned wheat with no salt added. This effect was due to the salt inhibition of starch gelatinization.

3. SRW wheat was significantly more tender than HRW wheat for processing times of 8, 16, and 32 minutes; however, at 64 minutes these differences disappeared.

4. The wheat became more tender as the process time increased.

5. Retention of thiamine was not affected by salt added in the process when calculated on a dry weight basis. This procedure corrects for the dilution of thiamine with water.

6. Increase in process time decreased the thiamine content significantly and progressively for all process time intervals tested.

7. Percent moisture of the canned wheat was significantly lower when salt was added.

8. Percent moisture increased progressively in the four process times.

9. The percent of split grains and drained weight were directly related to the percent moisture.

The process of canning wheat recommended by El Molino did not produce an acceptable quality product. The addition of salt produced a tougher wheat product than that without salt. When salt was added, increased processing time was required and resulted in a reduced thiamine content. Although the processing times of 8 minutes and 16 minutes had a higher thiamine content, the wheat was not cooked to the tender stage. The minimum calculated process sufficient to produce commercial sterility did not result in acceptable tenderness. From a health food standpoint, wheat is being boiled or canned for extended cooking times by health

conscious consumers in an effort to obtain a nutritious product. This prolonged processing is not conducive to optimum retention of nutrients.

If a softer textured canned whole wheat product is desired, a soft variety of wheat should be chosen and processed for 32 minutes at 121°C(250°F) without salt addition. This process gives an acceptable product for tenderness and eye appeal. Further processing without salt results in complete gelatinization of the starch producing 95% split grains. Even though it is tender, the 64 minutes was judged unacceptable due to the resultant gummy texture.

HRW wheat should be chosen for canning if more protein is desired, but composition varies with growing conditions.

Retention of thiamine in canned whole wheat on a dry weight basis was equivalent to that found in canned lima beans and peas.

For a more acceptable product which is more nutritious, it is recommended that salt for flavoring should not be added until after processing when the can is opened for serving.

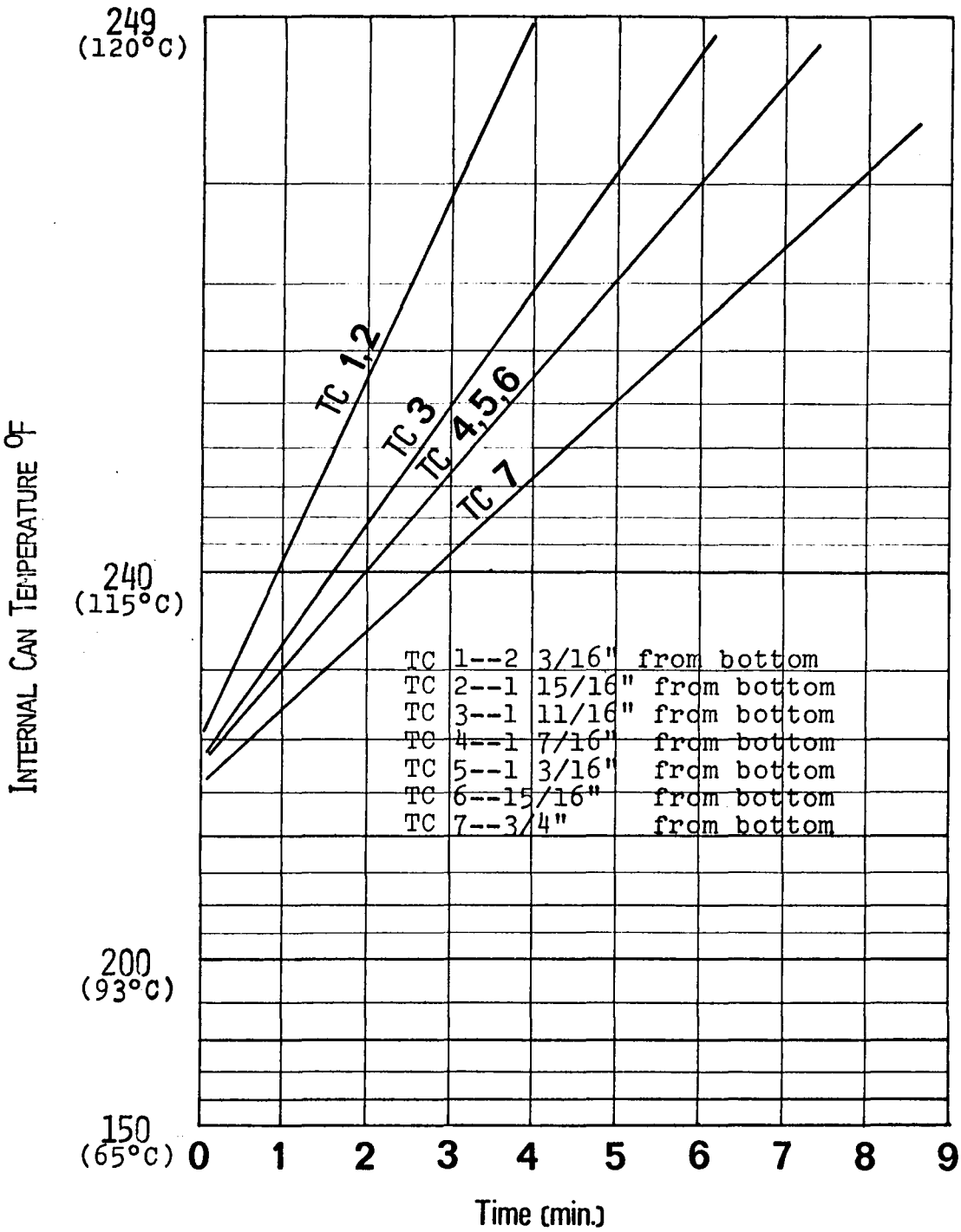

Fig. 1. Cold point determination for canned wheat processed in 303 x 406 cans at 250°F(121°C).

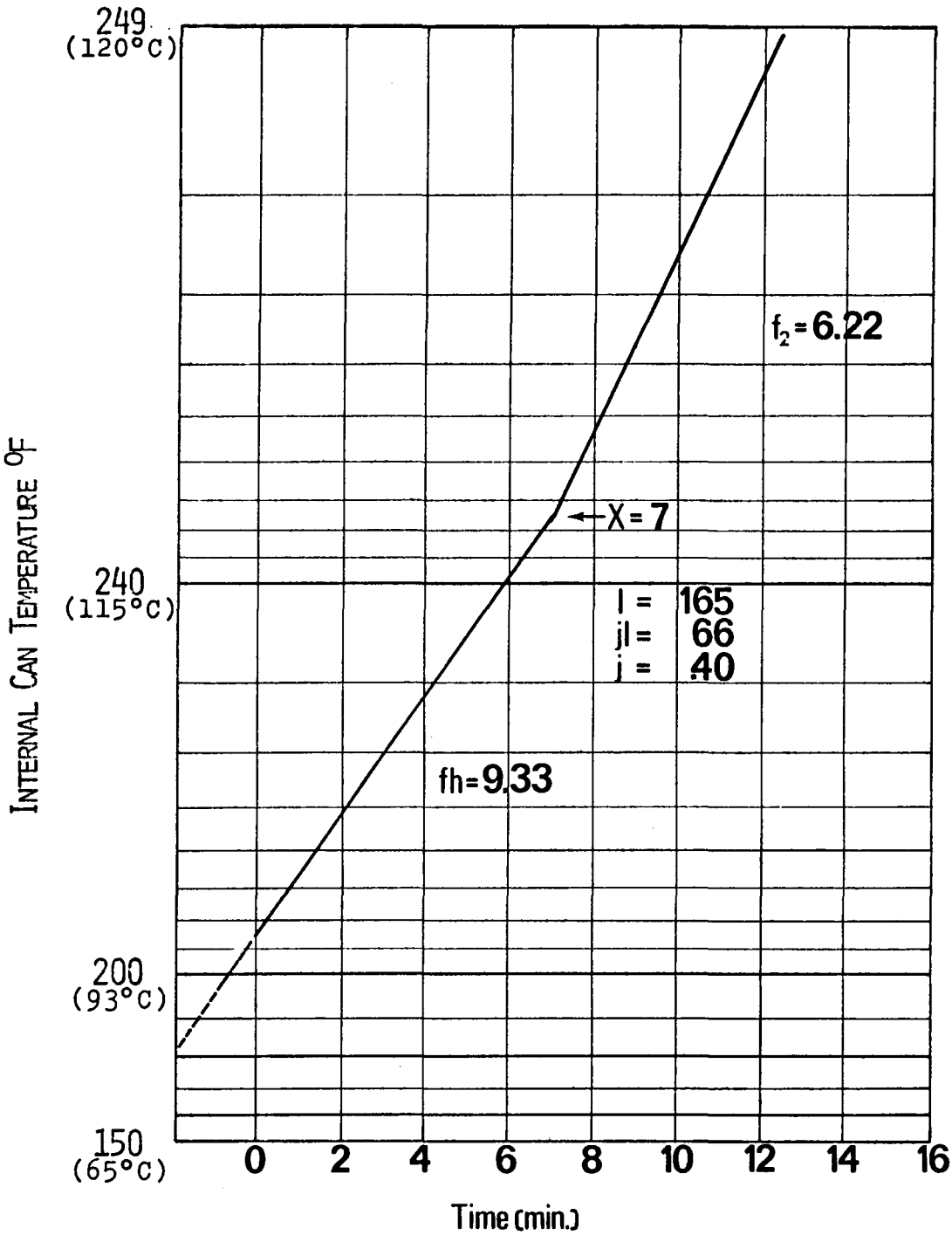

Fig. 2. Heat penetration curve for Hard Red Winter Wheat processed in 303 x 406 cans at 250°F(121°C) with values the same for no salt and salt added.

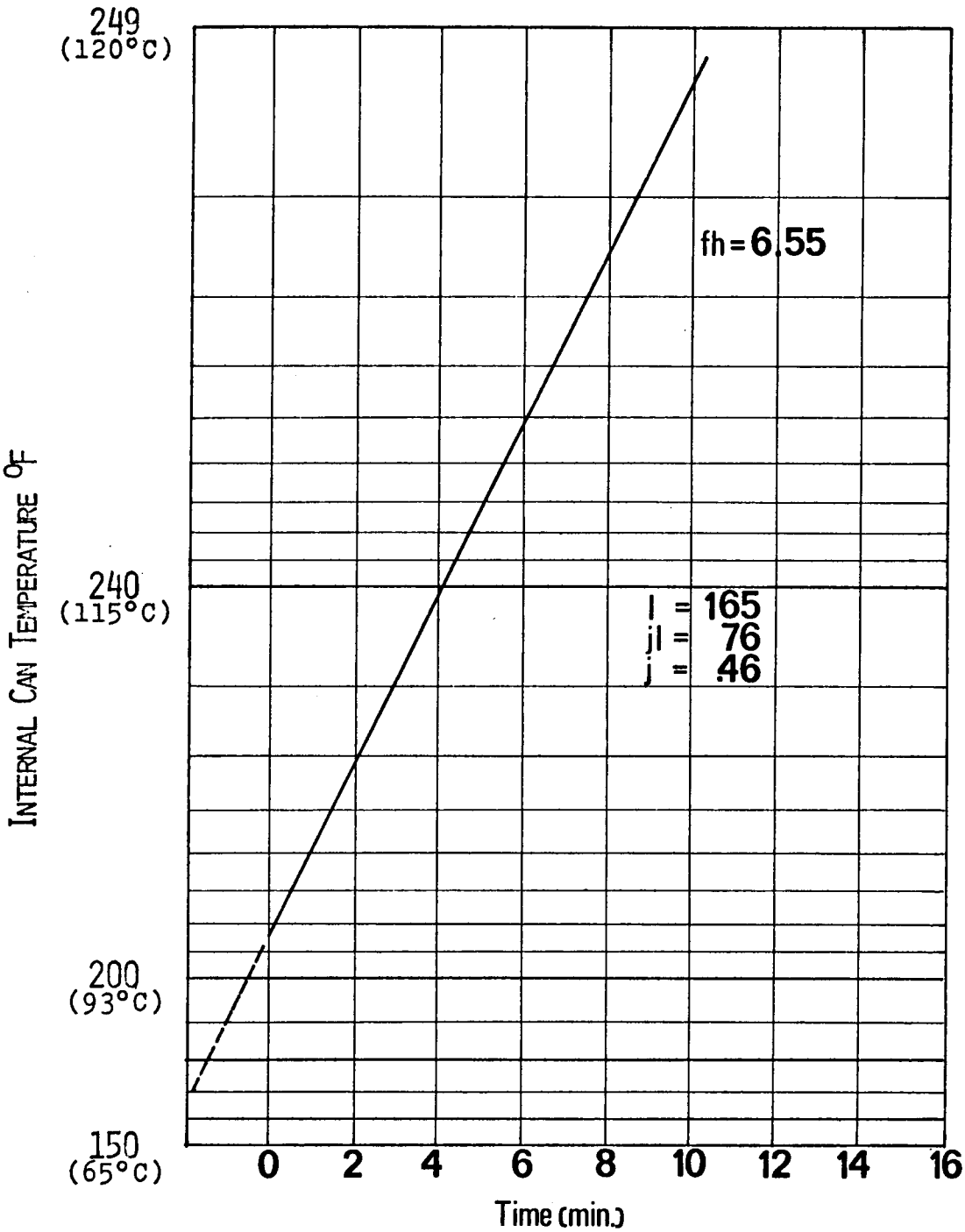

Fig. 3. Heat penetration curve for Soft Red Winter wheat processed in 303 x 406 cans at 250°F(121°C) with no salt added.

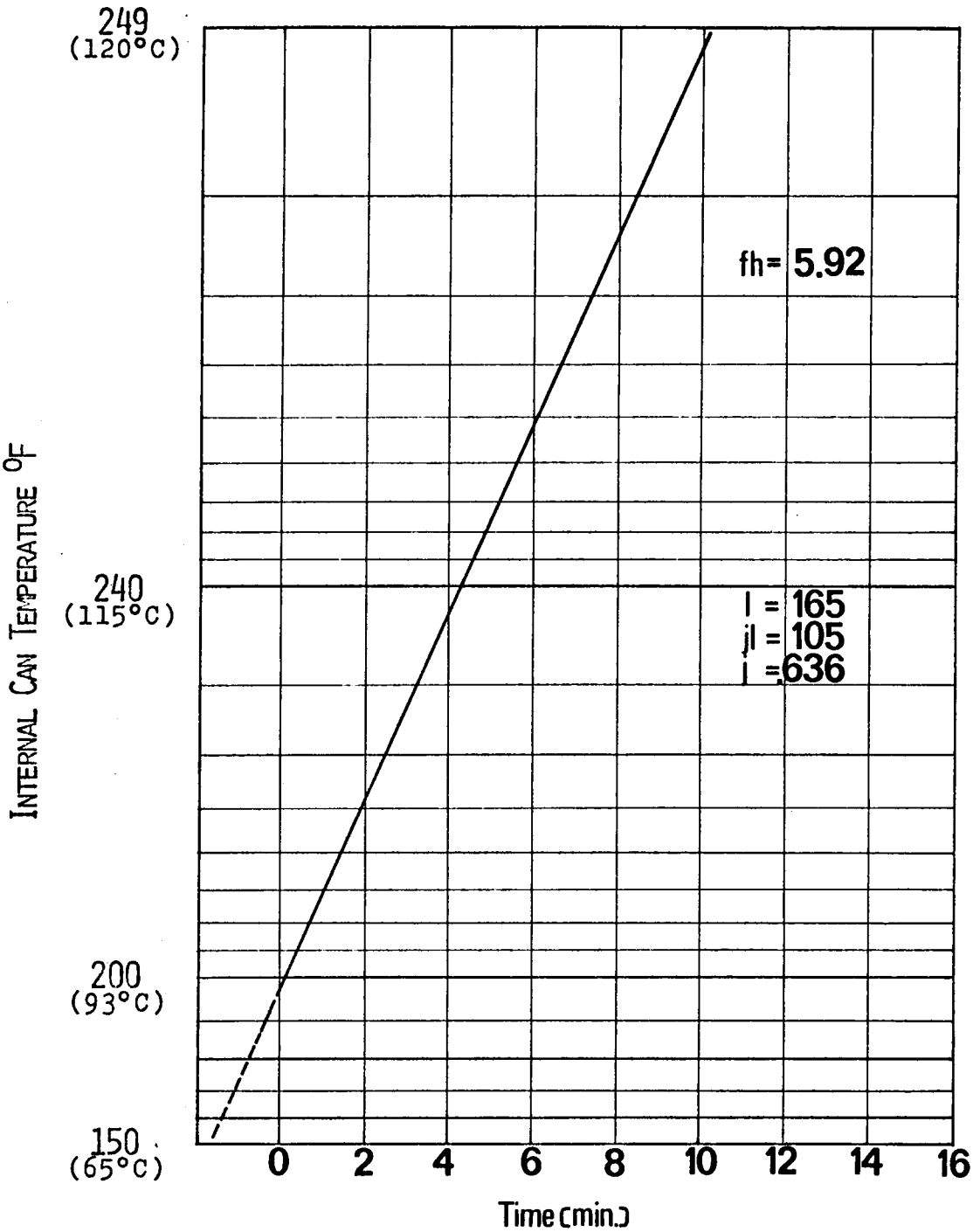

Fig. 4. Heat penetration curve for Soft Red Winter wheat with 3g NaCl added, processed in 303 x 406 cans at 250°F(121°C).

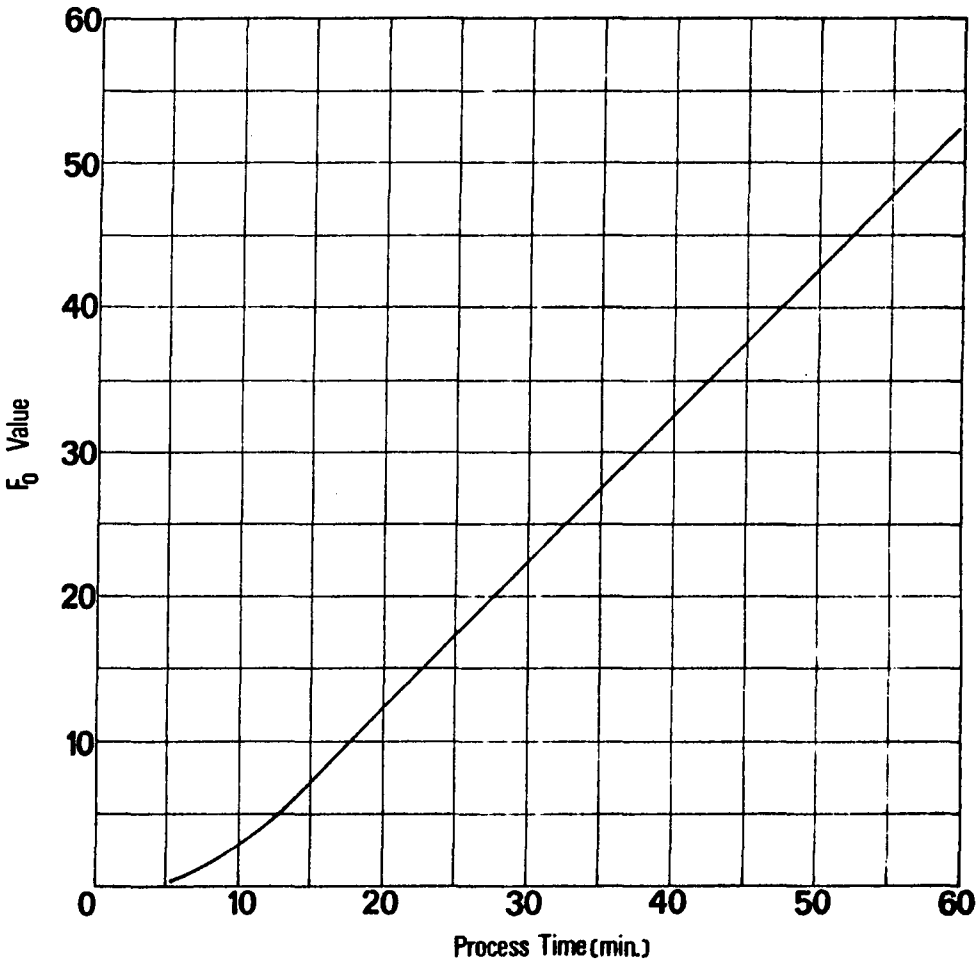

Fig. 5. Process times at 250°F(121°C) for various sterilizing values for Soft Red Winter wheat with no salt added.

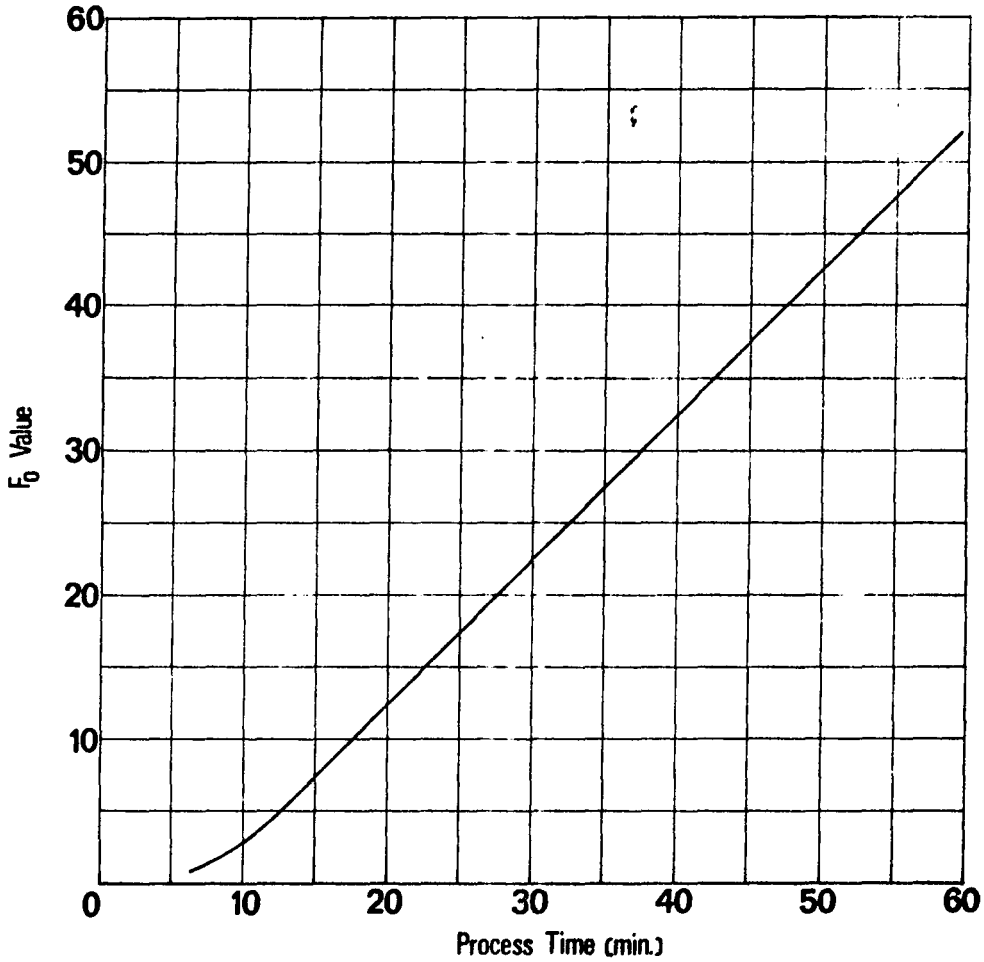

Fig. 6. Process times at 250°F(121°C) for various sterilizing values for Soft Red Winter wheat with 3g salt added.

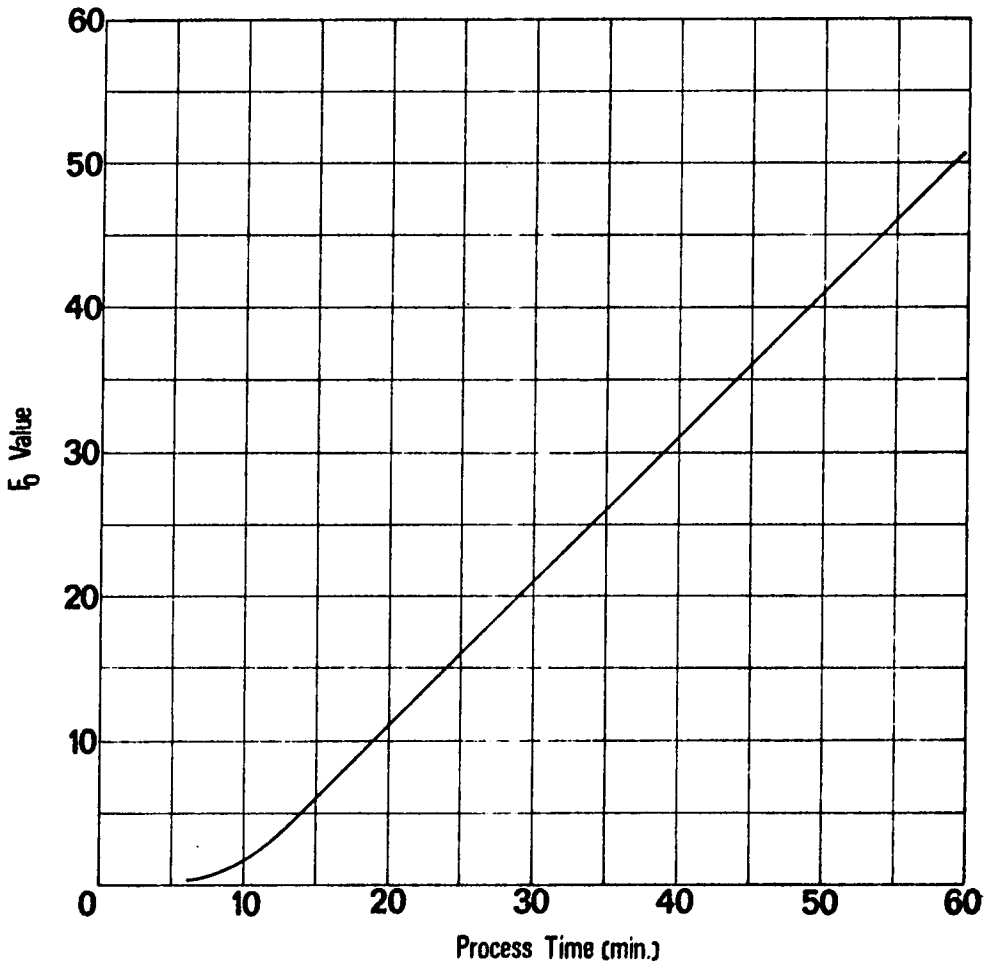

Fig. 7. Process times at 250°F(121°C) for various sterilizing values for Hard Red Winter wheat with values the same for no salt and salt added.

Table 1. Effect of variety, salt, and process time on thiamine content of raw and canned wheat

Variety	Salt	Process Time (Minutes)	Thiamine (mg/100g) wet basis[a]	% of orig.	Thiamine (mg/100g) dry basis[a]	% of orig.
HRW wheat	raw none	---	0.347	---	0.385	---
		8	0.068	19.8	0.197	51.2
		16	0.064	18.4	0.198	51.3
		32	0.039	11.5	0.141	36.5
		64	0.019	5.6	0.075	19.6
HRW wheat	salt added	8	0.066	19.0	0.172	44.8
		16	0.066	19.0	0.176	45.8
		32	0.052	14.8	0.152	39.4
		64	0.032	9.2	0.111	28.9
SRW wheat	raw none	---	0.414	---	0.470	---
		8	0.073	17.6	0.218	46.5
		16	0.053	12.9	0.175	37.3
		32	0.052	12.6	0.193	41.2
		64	0.026	6.3	0.098	20.9
SRW wheat	salt added	8	0.069	16.8	0.181	38.5
		16	0.070	16.9	0.192	40.9
		32	0.047	11.4	0.155	33.1
		64	0.027	6.6	0.096	20.5

[a]All values are averages of 12 observations.

Table 2. Statistical analysis of research data for shear press values

Analysis of Variance				
Source	df	ss	ms	F
variety	1	836.04	836.04	147.59**
salt	1	6635.81	6635.81	1171.49**
process time	3	9513.24	3171.08	559.82**
variety x salt	1	18.46	18.46	3.26
variety x process time	3	174.92	58.30	10.29**
salt x process time	3	611.51	203.83	35.98**
variety x salt x process time	3	99.17	33.05	5.83**
Error	80	453.15	5.66	
Total	191	18608.58		

**Significant at 1%

Table 3. Statistical analysis of research data for thiamine values as expressed on a wet weight basis

Analysis of Variance				
Source	df	ss	ms	F
variety	1	0.00010	0.00010	.93
salt	1	0.00081	0.00081	7.44**
process time	3	0.05332	0.01777	161.98**
variety x salt	1	0.00011	0.00011	1.06
variety x process time	3	0.00044	0.00014	1.33
salt x process time	3	0.00107	0.00035	3.27*
variety x salt x process time	3	0.00171	0.00057	5.21**
Error	80	0.00877	0.00011	
Total	191	0.06977		

*Significant at 5%

**Significant at 1%

Table 4. Statistical analysis of research data for thiamine as expressed in dry weight of wheat

Analysis of Variance				
Source	df	ss	ms	F
variety	1	0.0030	0.0030	5.00*
salt	1	0.0013	0.0013	2.25
process time	3	0.1431	0.0047	77.48**
variety x salt	1	0.0022	0.0022	3.63
variety x process time	3	0.0020	0.0007	1.13
salt x process time	3	0.0085	0.0028	4.64**
variety x salt x process time	3	0.0082	0.0027	4.45**
Error	80	0.0492	0.0006	
Total	95	0.2179		

*Significant at 5%

**Significant at 1%

Table 5. Statistical analysis of research data for percent moisture absorption after processing

Analysis of Variance				
Source	df	ss	ms	F
variety	1	28.8313	28.8313	15.94**
salt	1	401.4335	401.4335	222.02**
process time	3	1021.0320	340.3440	188.23**
variety x salt	1	8.0099	8.0099	4.43
variety x process time	3	4.9177	1.6392	.90
salt x process time	3	66.3465	22.1155	12.23**
variety x salt x process time	3	3.8853	1.2951	.71
Error	80	144.6462	1.8080	
Total	95	1679.1027		

**Significant at 1%

Table 6. Statistical analysis of research data for percent split grains

Analysis of Variance				
Source	df	ss	ms	F
variety	1	546.2604	546.2604	4.74*
salt	1	8951.3437	8951.3437	77.73**
process time	3	32037.1979	10679.0650	92.74**
variety x salt	1	49.5937	49.5937	0.43
variety x process time	3	751.8645	250.6215	2.17
salt x process time	3	681.7812	227.2604	1.97
variety x salt x process time	3	839.5312	279.8437	2.43
Error	80	9211.8333	115.1479	
Total	95	53069.4062		

*Significant at 5%

**Significant at 1%

Table 7. Statistical analysis of research data for drained weight of canned wheat

Analysis of Variance				
Source	df	ss	ms	F
variety	1	464.3320	464.3320	1.61
salt	1	60547.7444	60547.7444	210.98**
process time	3	197535.4383	65845.1430	229.44**
variety x salt	1	470.8647	470.8647	1.64
variety x process time	3	2193.5496	731.1832	2.54
salt x process time	3	14800.0311	4933.3436	17.19**
variety x salt x process time	3	1667.2213	555.7404	1.93
Error	80	22958.0601	286.9757	
Total	95	300637.2418		

*Significant at 5%

**Significant at 1%

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LIST OF APPENDICES

No. 1: Interactions of Variety x Salt x Process Time for Shear Press Determinations[a] (lbs x 10) of canned wheat

Variety	Salt	Process Time (min) 8	16	32	64	Means
HRW wheat	None	43.14	36.46	29.75	24.33	33.42
	Added	53.08	51.83	42.69	30.62	44.56
	Means[x]	48.11	44.15	36.22	27.48	38.99
SRW wheat	None	34.16	30.99	25.83	23.51	28.63
	Added	49.95	47.62	36.96	29.48	41.00
	Means[y]	42.06	39.31	31.39	26.49	34.82
	y - x	-6.05**	-4.84**	-4.83**	-.99	-4.17

[a]All values are the average of 12 observations.

**Differences significant at 1% level for variety x process at 64 min process time.

No.2: Interactions of Salt x Process Time for Shear Press Determinations[a] (lbs x 10) of Canned Wheat.

Factor		Salt None [x]	Salt Added[y]	Means	y - x
Process Time	8	38.65	51.52	45.09	+12.87**
	16	33.73	49.72	41.73	+15.99**
	32	27.79	39.82	33.81	+12.03**
	64	23.92	30.05	26.99	+ 6.13**
	Means	31.02	42.78	36.90	

[a]Values for Shear Press are averaged for 24 observations

**significant at 1% level.

No. 3: Interactions of Variety x Salt x Process for Thiamine Content of Wet Weight Grain (mg/100g)[a]

Variety	Salt	Process Time (min) 8	16	32	64	Means
HRW wheat	None	0.0688	0.0640	0.0398	0.0197	0.0481
	Added	0.0658	0.0662	0.0515	0.0317	0.0538
	Means[x]	0.0673	0.0651	0.0456	0.0257	0.0509
SRW wheat	None	0.0728	0.0532	0.0525	0.0259	0.0511
	Added	0.0697	0.0703	0.0472	0.0276	0.0537
	Means[y]	0.0712	0.0618	0.0498	0.0268	0.0524
	y - x	+0.0039	-0.0055	+0.0042	+0.0011	+0.0015

[a]Values for Thiamine are averages of 12 observations.

No. 4: Interaction of Salt x Process for Thiamine Content of Wet Weight Grain (mg/100g)[a]

Process Time (min)	Salt		Means	y - x
	None[x]	Added[y]		
8	0.0708	0.0678	0.0693	-0.0030
16	0.0586	0.0682	0.0634	+0.0096**
32	0.0462	0.0494	0.0478	+0.0032
64	0.0228	0.0296	0.0262	+0.0068*
Means	0.0496	0.05375	0.051675	

[a]Values are averages of 24 observations

**Significant at 1%, *Significant at 5%.

No. 5: Interactions of Variety x Salt x Process for Thiamine Content of Canned Wheat on a Dry Weight Basis (mg/100g)[a]

Variety	Salt	Process Time (min) 8	16	32	64	Means
HRW wheat	None	0.1964	0.1960	0.1409	0.0709	0.1511
	Added	0.1734	0.1766	0.1513	0.1111	0.1531
	Means[x]	0.1849	0.1863	0.1461	0.0910	0.1521
SRW wheat	None	0.2188	0.1755	0.1947	0.0991	0.1720
	Added	0.1819	0.1943	0.1452	0.0978	0.1548
	Means[y]	0.2003	0.1849	0.1699	0.0984	0.1634
	y - x	+0.0154	-0.0014	+0.0238	+ 0.0074	+0.0113

[a]All values are averages of 12 observations.

No. 6: Interactions for Salt x Process Time for Thiamine Content of Canned Wheat on a Dry Weight Basis (mg/100g)[a]

Process Time (min)	Salt		Means	y - x
	None[x]	Added[y]		
8	.2076	.1776	.1926	-.03*
16	.1858	.1854	.1856	-.0004
32	.1678	.1482	.1580	-.0196
64	.0850	.1045	.0948	+.0195
Means	.1615	.1539		

[a]Values are averages of 24 observations.

*Significant at 5% level.

No. 7: Interactions for Variety x Salt x Process Time for Percent Moisture of Canned Wheat[a]

Variety	Salt	Process Time (min)[a] 8	16	32	64	Means
HRW wheat	None	64.96	67.28	71.64	72.20	69.02
	Added	61.84	62.56	66.04	71.59	65.51
	Means[x]	63.40	64.92	68.84	71.89	67.27
SRW wheat	None	66.70	69.62	72.91	73.55	70.69
	Added	61.58	63.64	67.48	71.42	66.02
	Means[y]	64.14	66.63	70.19	72.48	68.36
	y - x	+0.74	+1.71	+1.35	+0.59	+1.09

[a]All values are averages for 6 observations.

No. 8: Interaction for Salt x Process Time for Percent Moisture of Canned Wheat[a]

Process Time (min)	Salt		Means	y - x
	None[x]	Added[y]		
8	65.83	61.71	63.77	-4.12**
16	68.46	63.10	65.77	-5.36**
32	72.28	66.76	69.52	-5.52**
64	72.87	71.51	72.19	-1.36**
Means	69.86	65.77	67.81	

[a]All values are averages of 12 observations.

**Significant at 1% level.

No. 9: Interactions of Variety x Salt x Process Time for Percent Split Grains of Canned Wheat[a]

Variety	Salt	Process Time (min) 8	16	32	64	Means
HRW wheat	None	36.33	65.33	83.67	98.00	70.83
	Added	32.67	37.00	62.33	79.83	52.96
	Means[x]	34.50	51.17	73.00	88.92	61.89
SRW wheat	None	60.50	70.66	82.33	94.64	77.04
	Added	34.33	45.40	60.33	85.33	56.29
	Means[y]	47.42	57.91	71.33	90.00	66.66
	y - x	+12.92	+6.74	-1.67	+1.08	+4.77

[a]All values are averages for 6 observations

No. 10: Interactions of Salt x Process Time for Percent Split Grains of Canned Wheat[a]

Process Time (min)	Salt		Means	y - x
	None[x]	Added[y]		
8	48.42	33.50	40.96	-14.92
16	68.00	41.08	54.54	-26.92
32	83.00	61.33	72.16	-21.67
64	96.33	82.58	89.46	-13.58
Means	73.94	54.62	64.28	

[a]All values are averages for 12 observations.

No. 11: Interactions of Variety x Salt x Process Time for Drained Weight (g) of Canned Wheat[a]

Variety	Salt	Process Time (min) 8	16	32	64	Means
HRW wheat	None	417.37	422.35	472.00	493.63	451.34
	Added	348.90	368.66	414.25	490.36	405.54
	Means[x]	383.14	395.50	443.12	491.99	428.44
SRW wheat	None	387.68	437.10	485.00	495.69	451.37
	Added	337.39	358.98	406.66	483.82	396.71
	Means[y]	362.54	398.04	445.83	489.76	424.04
	y - x	-20.60	+2.54	2.71	-2.23	-4.40

[a]All values are averages of 6 observations.

No. 12: Interactions of Salt x Process Time for Drained Weight (g) of Canned Wheat[a]

Process Time (min)	Salt		Means	y - x
	None[x]	Added[y]		
8	402.52	343.15	372.84	-59.37**
16	429.72	363.82	396.77	-65.90**
32	478.50	410.45	444.48	-68.05**
64	494.66	487.09	490.86	- 7.57
Means	451.35	401.13	426.24	

[a]All values are averages of 12 observations.

**Significant at 1% level.

No. 13. Sample Form of Score Sheet for Taste Panel Evaluation of Texture

Name _____ Date _____

Code _____

Taste the sample, and count the number of chews it takes to reach the consistency at which the sample would normally be swallowed.

Plate 1. a. _____ b. _____ c. _____ d. _____

Plate 2. a. _____ b. _____ c. _____ d. _____

Rate the chewiness of each sample according to the scale given below:

1	2	3	4	5
soft				tough

Plate 1	Sample	Plate 2
_____	a.	_____
_____	b.	_____
_____	c.	_____
_____	d.	_____

Comments or preferences -

Name _____ Date _____

Code _____

Using the scale below -

20%	40%	60%	80%	100%

Estimate the percent of open grains for each sample and circle your preference.

Sample a. _____ b. _____ c. _____ d. _____

Appendix No. 14

Plate 1

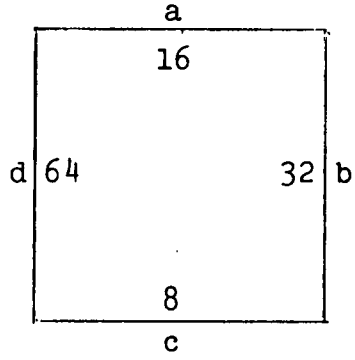
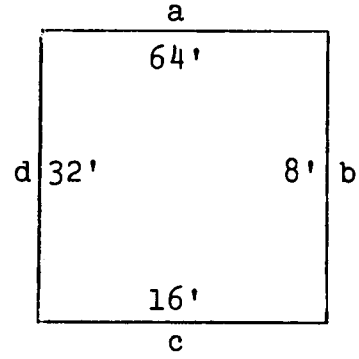


Plate 2

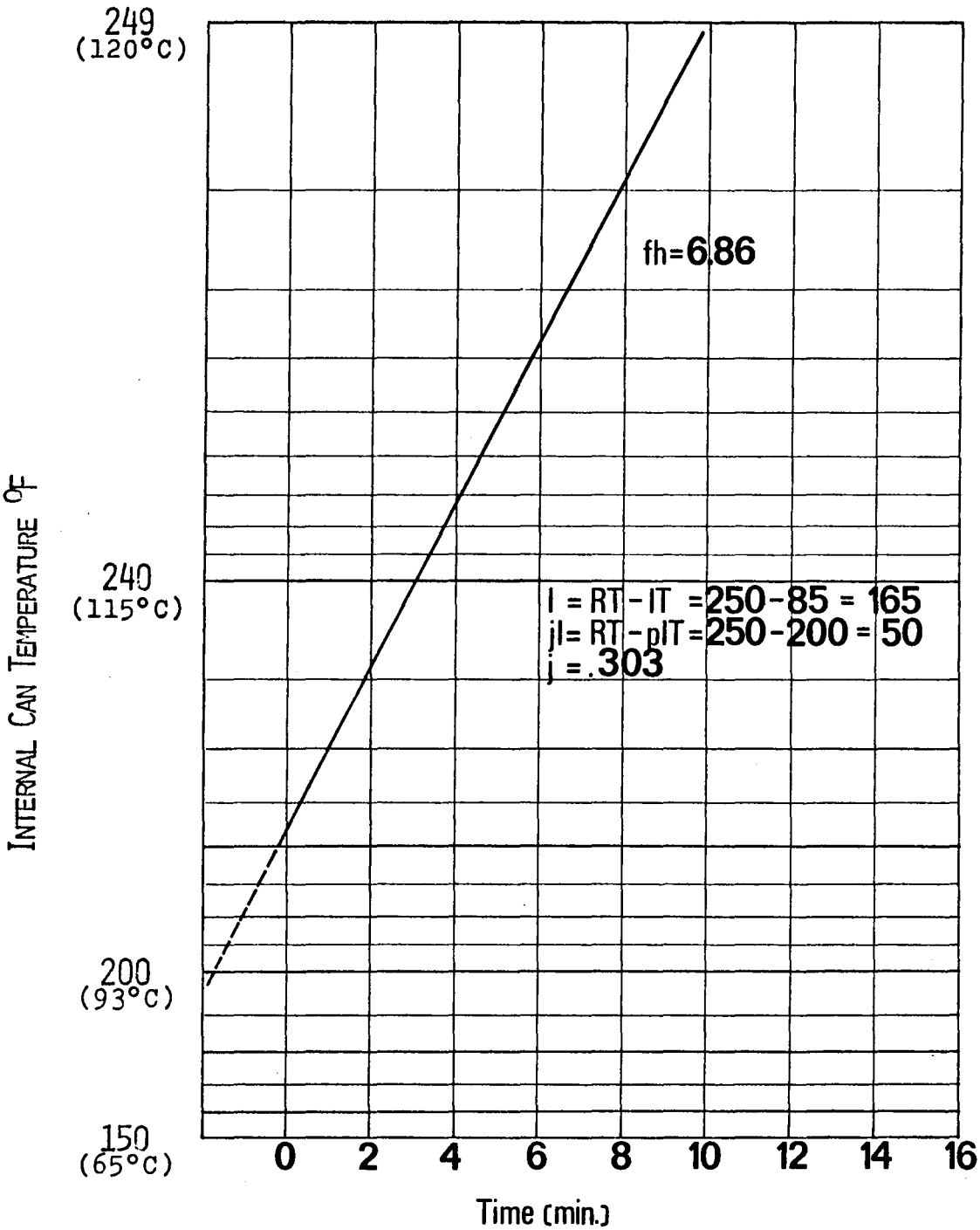


Sample Order			Time
1.	HRW	ns	9:00
2.	SRW	s	10:30
3.	SRW	ns	1:30
4.	HRW	s	3:00

Sample Order			Time
1.	SRW	ns	9:00
2.	HRW	s	10:30
3.	HRW	ns	1:30
4.	SRW	s	3:00

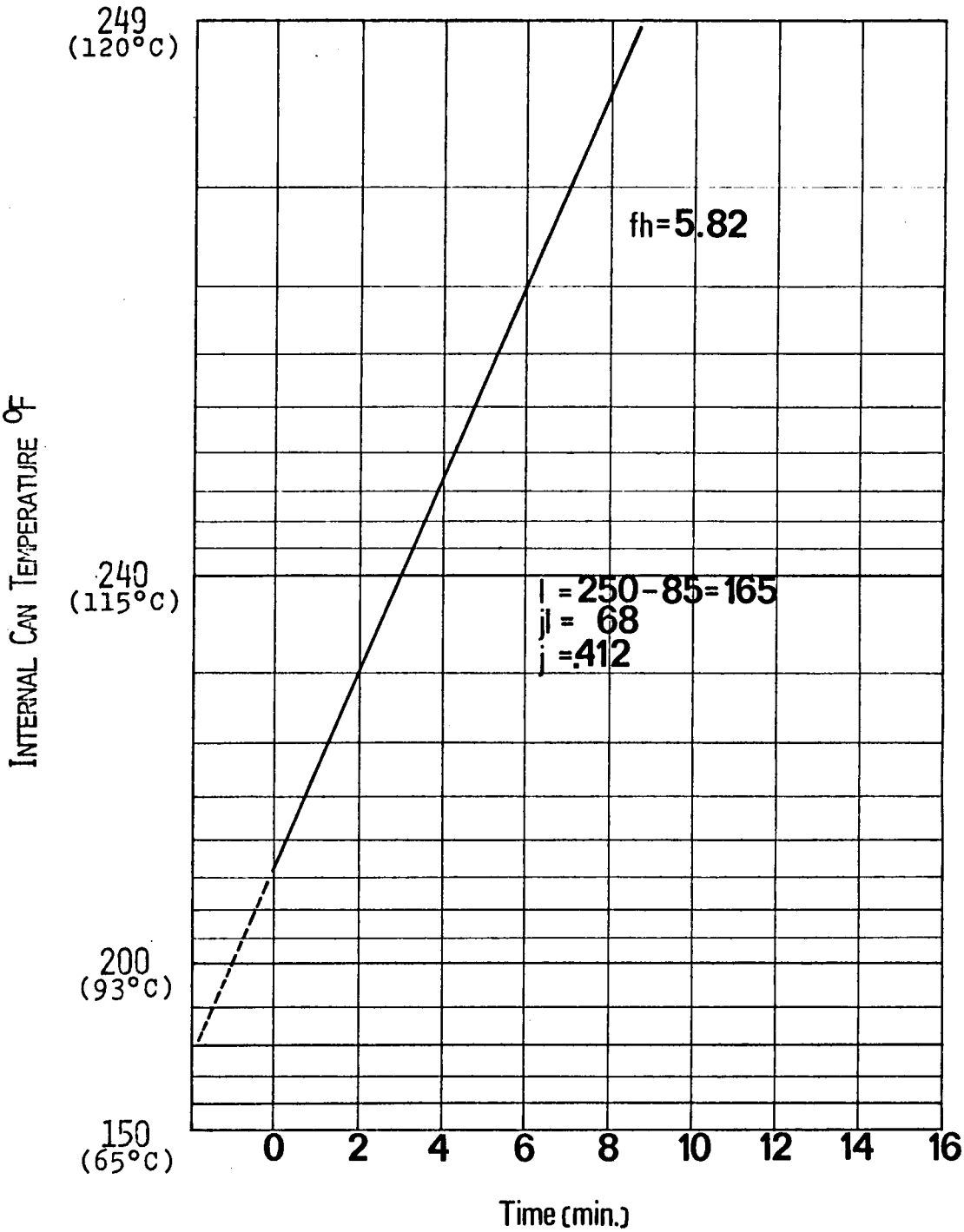
Order of Presentation of Samples for Taste Panel Evaluation of Texture.

Appendix No. 15



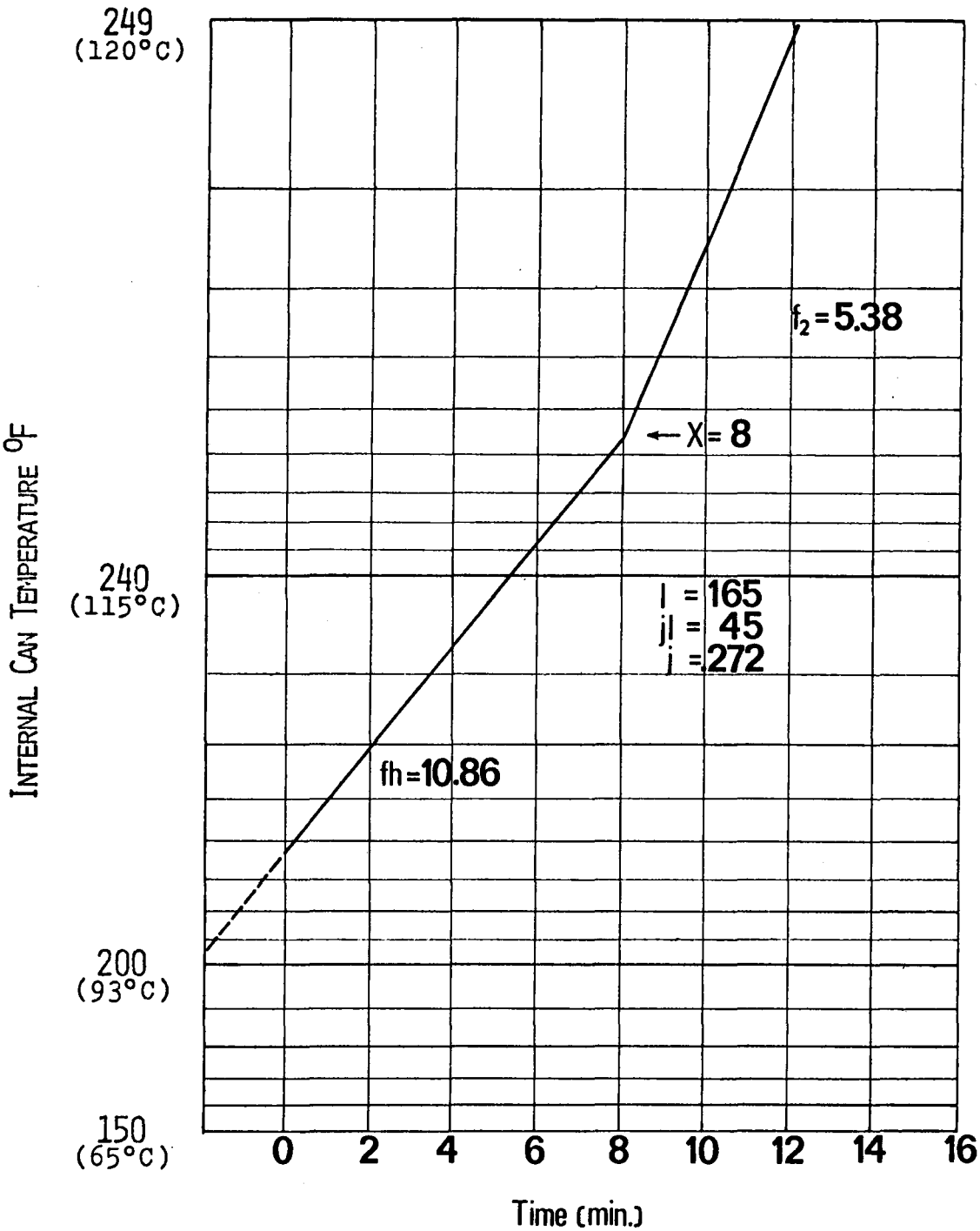
Heat penetration curve for Spring wheat processed in 303 x 406 cans at 250°F(121°C) with no salt added.

Appendix No. 16



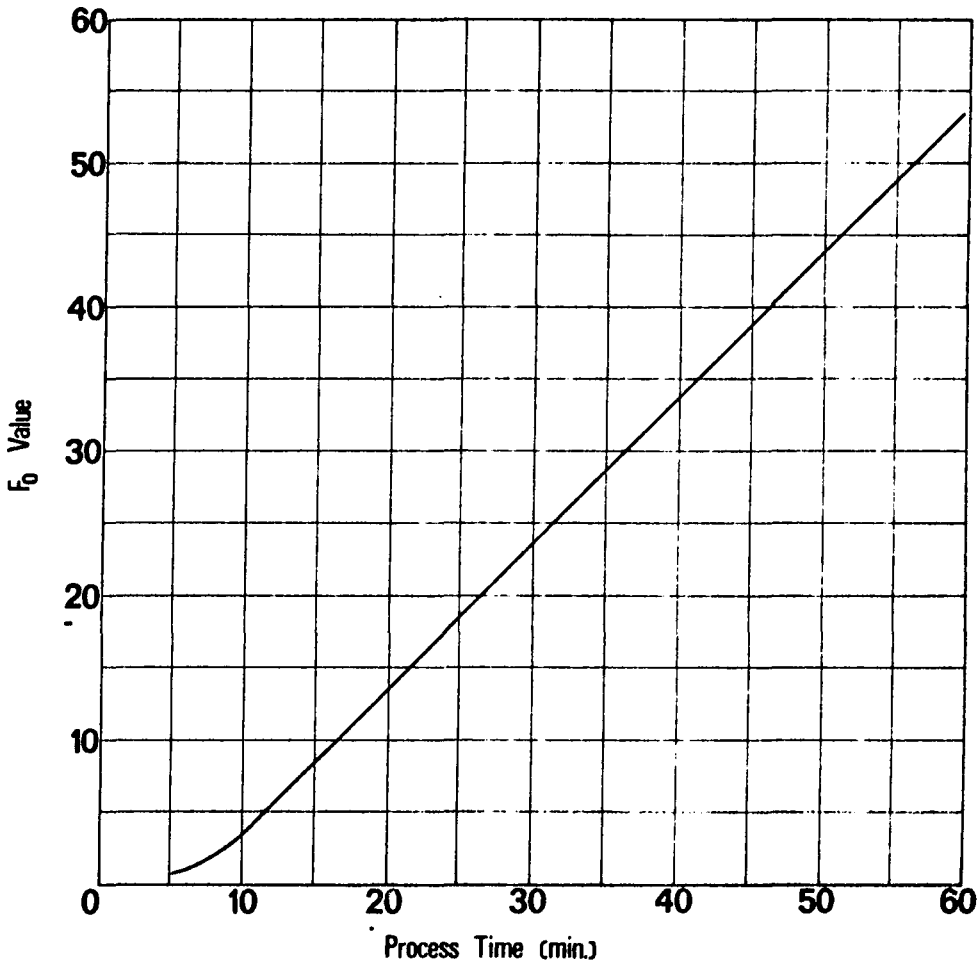
Heat penetration curve for Spring wheat with 3g NaCl added, processed in 303 x 406 cans at 250°F(121°C).

Appendix No. 17



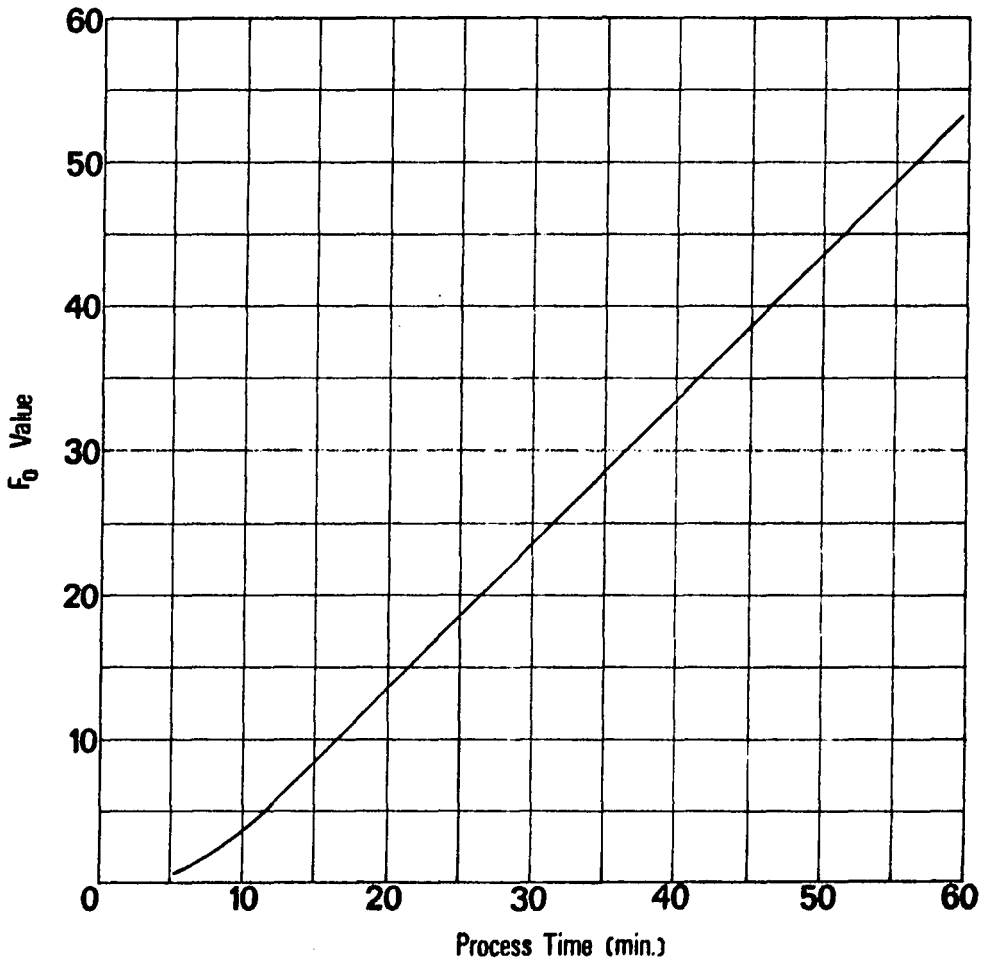
Heat penetration curve for Soft White Winter wheat, processed in 303 x 406 cans at 250°F(121°C).

Appendix No. 18



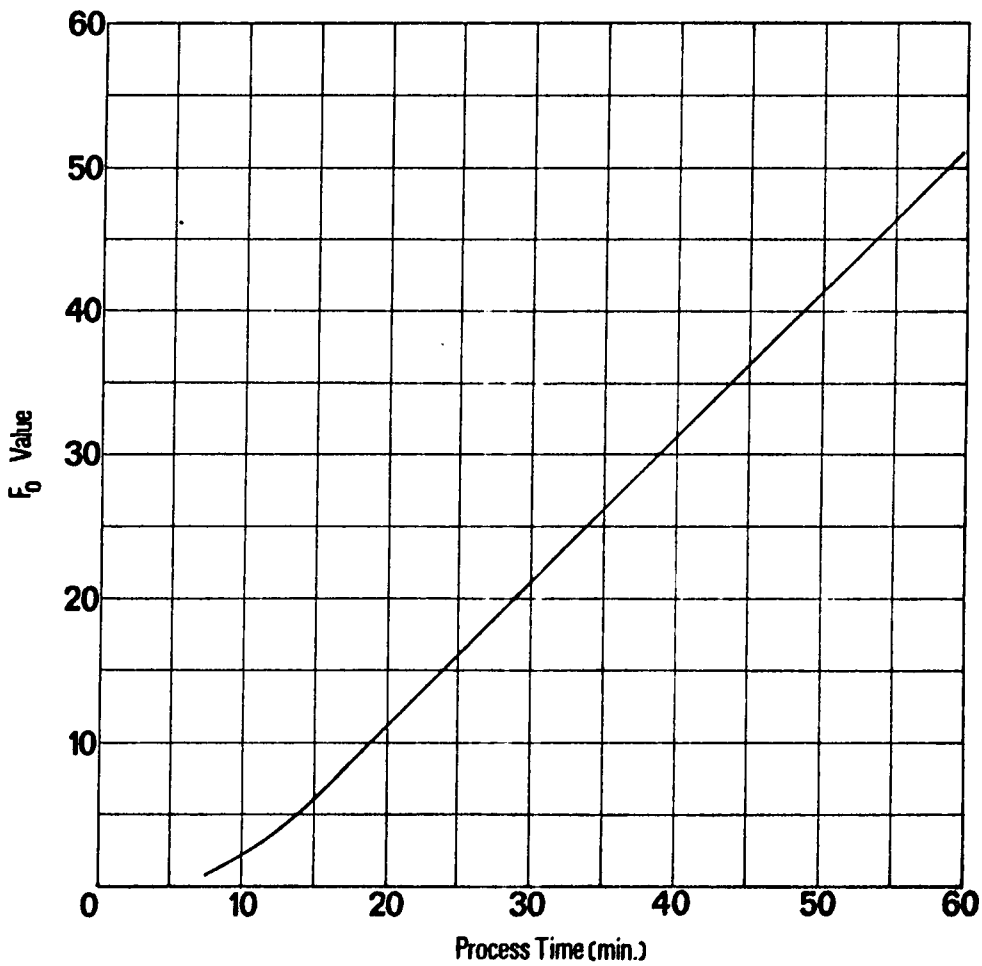
Process times at 250°F(121°C) for various sterilizing values for Spring wheat with no salt added.

Appendix No. 19



Process times at 250°F(121°C) for various sterilizing values for Spring wheat with 3 g NaCl added.

Appendix No. 20



Process times at 250°F(121°C) for various sterilizing values for Soft White Winter wheat with values the same for no salt and salt added.

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DEVELOPMENT OF A CANNED WHOLE WHEAT PRODUCT

by

Todd Franklin Davis

(ABSTRACT)

A canned whole wheat product was developed. The effects of variety, salt and process time on texture, thiamine content and percent moisture were investigated. A minimum safe process was determined. A safe process was calculated to be 9.5 minutes and 11.5 minutes at 121°C (250°F) for Soft Red Winter (SRW) wheat and Kansas Hard Red Winter (HRW) wheat, respectively.

The SRW wheat exhibited a more tender texture, higher thiamine content after processing and a higher percent moisture than the HRW wheat. Salt added during canning increased the toughness of the wheat as compared to no added salt and required an increased process time to achieve a texture similar to the no salt added wheat. Thiamine content was not affected by added salt when calculated on a dry weight basis. Length of process time was directly related to thiamine destruction. Water absorbed by the wheat was found to have a diluting effect on thiamine content of canned wheat. Salt had an inhibiting effect on moisture absorption and the percent moisture was related to

toughness. Increased moisture tenderized the product. Excessive moisture at the 64 minute process time resulted in a gummy, unappealing product.

Thiamine content of the canned wheat compared favorably with values for other food products such as canned lima beans and peas.