

/EFFECTS OF FREEZING AND THAWING
ON SENSORY QUALITY AND THIAMIN CONTENT
OF SPAGHETTI AND MEAT SAUCE
AFTER REHEATING IN CONVENTIONAL OR MICROWAVE OVEN/

by

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B.S., Kansas State University, Manhattan, 1977

A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1985

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Introduction

Food preservation has become important for increasing the food supply throughout the world. The type of preservation method used depends upon many factors including type of food, facilities and labor availability and end use of product. Nutrient retention and product acceptability varies among different food preservation methods. Freezing is used more frequently in home and institutional settings than canning or drying and freeze-drying. Freezing maintains high nutritional value and product acceptability.

Freezing pre-cooked foods is increasing in the food service industry and among convenience food manufacturers. As the number of women working outside the home, single parent households, and single family units increase, more precooked food is frozen. This demands less time for meal preparation and decreases product waste because excess food can be frozen and used when needed.

Although freezing has advantages over other food preservation methods it is not problem-free. All steps in the freezing process must be done using sanitary practices. This is especially important because freezing only retards growth of microorganisms and if food is handled improperly it may not be safe to eat.

"Freezing abuse" often occurs to products in the marketplace. Partial thawing and refreezing may occur several times before products reach final destinations. This may be the result of improper handling or insufficient temperature control during the transportation phase.

It is almost impossible to maintain correct temperatures in freezer display cases in the supermarket. Partial or total thawing of products also may occur after purchase and before transfer to the home freezer. Therefore, it is important to study the effects of freezing and thawing on nutrient retention and product acceptability.

Modern technology has increased the number of ways a product can be heated or reheated. Retortable pouches allow cooking in boiling water with small nutrient losses and high eating quality. Microwave ovens are becoming popular in both private and public sectors. Microwave ovens are considered energy efficient, and often require less time for reheating foods than conventional ovens (Dahl et al., 1981, and Snyder, 1978). Also, few dishes and easy oven cleaning increases microwave oven usage.

Extensive research findings have been published on various food preservation methods. Effects of heating and reheating comparing microwave oven with conventional methods are also popular topics. However, little information is available in the literature concerning the effects of freezing and thawing on various food products.

The objective of this investigation was to evaluate spaghetti with meat sauce after subjecting the product to several freeze-thaw cycles and reheating by a conventional or microwave oven.

REVIEW OF LITERATURE

Food Preservation

Deterioration of food results from chemical and enzymatic reactions within the food system as well as from microbial contaminants (Ley, 1980). The aim of food preservation (Fennema, 1975) is "to prevent undesirable changes in the wholesomeness, nutritive value or sensory quality of food by economical methods which control growth of microorganisms; reduce chemical, physical and physiological changes of an undesirable nature; and obviate contamination."

Food can be preserved through chemical means by adding substances such as sugar, salt or acids to foods. Alcoholic or acidic fermentations preserve foods using biological means. Physical methods are most common and include heating (canning), irradiation, chilling or freezing, drying or freeze-drying.

Canning usually results in severe overcooking, because of the high temperatures and duration of heating required for sterilization. A loss of flavor results, as well as deterioration in texture and general appearance (Rogers and Binsted, 1972). Hellendoorn et al. (1971) reported on the nutritive value of canned meals consisting of meat, vegetables, legumes and potatoes. Considerable losses occurred in vitamin A, thiamin, niacin and pantothenic acid during sterilization and storage. Vitamin E, riboflavin, pyridoxine, vitamin B₁₂, folic acid, choline chloride and inositol were relatively stable. Protein quality also decreased during storage.

Freezing usually is considered superior to canning for long-term food preservation because proper freezing is effective for retaining the flavor, color and nutritive value of food while only moderately altering textural characteristics (Fennema; 1975; 1977).

The freezing process has little effect on the nutritive value of foods. If storage temperatures are maintained at 0°F or below, the nutrients will only deteriorate slightly (Ley, 1980). According to Ley (1980), freezing generally affects nutrients in the following ways:

- (1) Proteins usually are not affected by frozen storage, except during prolonged storage; proteins in fish and shellfish may become less digestible.
- (2) Fats become rancid due to oxidation, and fat-soluble vitamins (A,D,E, and K) will oxidize during storage if not packaged or frozen properly.
- (3) Carbohydrates generally are not affected by frozen storage. The exceptions will be discussed later.
- (4) Although minerals are not destroyed by freezing, they may be lost during blanching or thawing.
- (5) Water-soluble vitamins are the most sensitive to food processing; thiamin and ascorbic acid are frequently studied to determine nutrient retention in foods.

The rate at which molecules move determines the rate at which they interact with others or initiate chemical reactions. Generally, reaction rates double with an 18°F rise in temperature (Ley, 1980).

Detrimental effects that occur during freezing and severity of those effects depends on the product and on the nature of the freezing process (Fennema, 1975). Livingston et al. (1973) cited previous studies concerning the effects of storage, time, temperature and container size. Ascorbic acid in fruits and thiamin and riboflavin in low-acid vegetables were found to be especially sensitive to extended storage at

high temperatures. They concluded that nutrient retention was higher in frozen as opposed to canned foods. However, prolonged storage reduces vitamin content, especially thiamin, regardless of preservation method used.

Methods of preservation result in some undesirable effects on the sensory attributes and nutritional content of foods (Fennema, 1975). For example, thermal sterilization softens food tissues, degrades chlorophylls and anthocyanins, alters flavor and results in loss or degradation of substantial amounts of some nutrients. The advantages almost always outweigh the disadvantages of food preservation, however, research must be continued to decrease the disadvantages while maintaining the advantages.

Lund (1979) summarized effects of moisture removal from studies by others on vitamins A and C. Since both vitamins are heat labile and sensitive to oxidation, the dehydration process resulted in nutrient losses similar to losses from freezing rather than canning.

History of freezing. The frozen food industry was initiated in 1865 using a "weather freezing" system for fish (Ley, 1980). However, it was not until the early 1920's that the first successfully prepared product (chicken a'la king) was marketed by Birdseye Frosted Foods (Tressler et al., 1968). The product was successful because it (a) retained characteristics extremely well after frozen storage, (b) had a long shelf life, (c) could be produced to sell at a reasonable price, and (d) required no special effort by consumers to prepare the product at home.

The frozen food industry prospered until 1944 (Tressler et al., 1968). A drastic decline in frozen food purchases resulted from the industries' ignorance of proper freezing methods, improper selection of raw materials, handling and distribution problems, and consumer ignorance. Initially, a bad experience with one package of frozen food was likely to prejudice the consumer against all frozen foods. After consumer confidence returned, the industry experienced exponential growth resulting in inferior products, because many companies entered the industry without proper knowledge or product experimentation (Tressler et al., 1968). Therefore, in 1947, the industry experienced a 87.5 per cent decrease in frozen food sales.

In 1948 the Western Utilization Research Branch began investigations on how frozen food products behave under conditions of time and temperature such as they may encounter in the commercial distribution system (Van Arsdell, 1957). Researchers found "freezing abuse" (temperature fluctuation) resulted in inferior quality and decreased acceptability of frozen foods. Also, the damage which occurred was progressive and irreparable.

Seafood has been an important component of the frozen food industry almost since its conception. In 1949, Rudy Wagner, owner of Redi Foods, "invented" fish sticks to satisfy the demand in Albany, New York for frozen fish strips that could be fried in roadside stands for sandwiches (Tressler et al., 1968). Since shrimp was available regionally, it became a popular frozen food item and sales increased from 17 million pounds in 1952 to 105 million pounds in 1966.

Birdseye, realizing its potential, added precooked frozen foods to the product line in 1952 (Tressler et al., 1968). Since 1953 frozen dinner sales have increased annually without ever experiencing a decline. The success of precooked frozen foods has been attributed to the fact that these products save time, and make foods available to the consumer which ordinarily require a great deal of skill to prepare (Rogers and Binsted, 1972). However, food which has been precooked is subject to increased chemical changes and deterioration during frozen storage than when the product is frozen uncooked. Also, the delicate flavors and aromas developed during cooking are easily lost during frozen storage, because of the chemical reactions such as oxidation and evaporation.

The success of the frozen food industry is evident from the data in Table 1 (Anonymous, 1979).

Table 1. Frozen foods sales.

	Fruit	Prepared Foods	Dinners	Total
(Millions of dollars)				
1948				292
1958			88	2,320
1968	261	1,927	471	6,690
1978	461	5,511	657	20,442

Effects of Freezing

Although food preservation methods can stop growth of micro-

organisms and retard the rate of chemical reactions, some chemical and physical changes do occur in preserved foods. These changes must be considered if foods are to be frozen successfully.

Physical changes. Supercooling, the first step in the freezing process, is when the temperature of water is lowered below its freezing point before crystallization occurs. Studies indicate that temporary supercooling generally does not impair the quality of foods (Fennema, 1975). Therefore, the undesirable side effects of freezing are attributed to the second step in the freezing process, crystallization of water.

Nucleation, the first phase in water to ice transformation, is the association of molecules into an ordered particle of a size sufficient to survive and serve as a site for crystal growth (Fennema, 1975). The location of ice crystals is a function of freezing rate, temperature and nature of the cells (Fennema et al., 1973). Water crystallization resulting in separation of oil and aqueous phases and breaking of the emulsion occur in frozen foods.

The second step in the crystallization process is the growth of the ice crystals. Unlike nucleation, crystalline growth can occur just below the melting point (Fennema, 1975). Water molecules must move from the liquid phase to the crystal surface while the solute must diffuse away from the crystal.

Slow freezing (cooling at a rate of less than $1^{\circ}\text{C}/\text{min}$) generally allows only a few nuclei to form in extracellular areas, resulting in large ice crystals, maximum dislocation of water, a

shrunken appearance of cells and usually lower food quality (Fennema et al., 1973; Fennema, 1975). As ice forms in extracellular regions, the solute concentration of the unfrozen phase gradually increases and vapor pressure decreases. At relatively high subfreezing temperatures, ice crystals cannot penetrate cellular membranes, therefore, intracellular fluid remains supercooled and vapor pressure exceeds extracellular fluid. This vapor pressure difference causes water to diffuse from the cell and deposit on extracellular ice crystals resulting in cellular dehydration (Fennema et al., 1973). Continued freezing increases shrinkage and ice crystal size.

A uniform distribution of ice crystals results in products frozen rapidly to a low temperature (Fennema, 1975). Rapid freezing favors intracellular ice crystal formation which minimizes cellular dehydration.

Fennema and colleagues (1973) cited studies by Mazur (1966) that suggested cell membranes were effective barriers to crystal growth during slow freezing, but the barrier suddenly disappears at about -10°C during rapid cooling. Possible reasons for the decline in barrier effectiveness as temperature decreases are: (1) low temperatures damage the membrane either directly or indirectly which may be related to solute concentration, or, as Mazur believes (2) membranes are not damaged, but at a certain temperature (approximately -15°C) ice crystals develop which can penetrate the minute water-filled pores of the membrane.

Volume change is another physical change which is associated

with ice formation. Pure water at 0°C expands approximately 9% when water is transformed to ice (Fennema, 1975). The extent of volume changes in a food system depends upon the following factors:

- (1) Composition. The percentage of water and presence of solutes or suspended matter influence volume changes. Since water is responsible for the expansion during freezing, any decrease in water per unit volume decreases the expansion.
- (2) Percentage of free water. Any water that is bound or supercooled does not contribute to expansion during freezing.
- (3) Temperature range.

The following events can contribute to volume changes: cooling prior to freezing (contraction), ice formation (expansion), cooling of ice crystals (contraction), solute crystallization (contraction), cooling of solute crystals (contraction), and crystallization and cooling of nonsolutes such as fat (contraction).

Physical changes that occur during frozen storage include formation of eutectics, freezer burn and recrystallization (Fennema et al., 1973). The percentage of frozen water to free water increases as temperature decreases, for example, the percentage of ice in lean meat is approximately 74% at 23°F, 83% at 14°F and 89% at -22°F. When lean meat is reduced to a temperature range of -58° to -76°F, the eutectic point (where further temperature decrease will not cause additional water solidification) is reached (Ley, 1980). The eutectic point for most foods occurs near -67°F. At temperatures below the eutectic point approximately 8% of the water is unfrozen, but it is bound to proteins.

Freezer burn is initiated by sublimation of ice and results in

inferior food quality. Since ice crystals are not stable, changes can occur in number, size, shape, orientation or perfection of crystals after initial solidification; this is referred to as recrystallization (Fennema et al., 1973).

Chemical changes. Chemical changes that can occur during frozen storage are lipid oxidation, enzymatic browning, flavor deterioration, protein insolubilization, degradation of chlorophyll and vitamins (Fennema et al., 1973). Since food systems are so complex, both chemical and physical changes are responsible for damaging frozen foods. These changes will be discussed in greater detail as they relate to specific products.

Stability of Frozen Foods

Resistance to freezer damage is product dependent. Cell breakage, cell separation and impaired texture are observed frequently in frozen plant tissues. This damage has been attributed to the semirigid, poorly aligned nature of many plant cells (Fennema, 1975). Muscle fibers, however, have parallel arrangements allowing flexibility so muscle fibers usually separate rather than break during freezing, which does not significantly alter meat texture.

Fruits. The quality of fruits and vegetables following the freezing process depends on variety, growing conditions and stage of maturity at harvest (Fennema, 1975). Enzymatic browning is a major problem in fruits. Since heat damages desirable sensory properties of fruit, enzymatic browning usually is retarded through the use of chemical additives. Sulfur dioxide, which chemically interacts with the

enzyme substrate, may be used if the fruit is cooked prior to consumption. Lowering the pH to a value less desirable for enzyme activity is achieved by adding acids such as citric and malic, thus reducing enzymatic browning. A more effective acid is ascorbic acid (Fennema, 1975; Guadagni et al., 1957), which apparently maintains phenolic substances in a reduced and colorless state rather than significantly changing the pH. Although more expensive, 0.1% ascorbic acid is frequently used in sugar syrup (0.3% required for complete effectiveness) to control enzymatic browning, and it is also a valuable nutrient.

Sucrose or sugar syrups often are added to fruit prior to freezing for several reasons: for sweetness; to retain volatile aromas; to decrease the amount of frozen water; and to act as an oxygen barrier, which decreased enzymatic browning (Fennema, 1975; Guadagni et al., 1957). However, sucrose hydrates often crystallize in cold processed frozen fruit spreads during storage causing deterioration in appearance and texture. Studies indicate the appearance of sucrose hydrate crystals was slowest at storage temperatures of -30°F (-34°C) and fastest at -10°F (-23°C) (Tressler et al., 1968).

Thiamin and ascorbic acid routinely are used to measure nutrient retention for several reasons (Fennema, 1977). These vitamins are water-soluble and highly susceptible to chemical dehydration. They are also present in many foods and are essential for the human body. If these nutrients are retained well, it generally is assumed that other nutrients also are retained well.

Ley (1980) reported that frozen strawberries and raspberries, with juice or syrup, contain approximately 80% of their ascorbic acid content after frozen storage. Crushed or sliced fruits experience a greater loss than frozen whole fruits. Since ascorbic acid is added to peaches and apricots during processing to prevent discoloration, a high ascorbic acid content is found in these fruits after frozen storage.

Somer, et al. (1978) found ascorbic acid to be stable under extreme temperature fluctuations (greater than 10°F) in frozen juice concentrate. The B-vitamins were found to be even more stable than ascorbic acid. Researchers in the early 1950's (Bennett et al., 1954) found fruit stored at 0°F and -20°F retained more ascorbic acid after 12 months of frozen storage than those stored at +10°F. Guadagni et al. (1957) found 0° to be a satisfactory storage temperature for peaches with respect to economy and quality retention.

Vegetables. Vegetables are more vulnerable to enzymatic deterioration during frozen storage than any other food group (Ley, 1980). Crystallization of water reduces the turgidity of cells which causes wilting of frozen vegetables (Tressler et al., 1968). Enzymes control chemical changes and will initiate undesirable color and flavor changes if not deactivated. Therefore, heat treatment, or blanching (190°F for 3 minutes or 212°F for 30 seconds) is necessary to control enzyme activity during frozen storage (Fennema, 1975; Ley, 1980). Blanching will inactivate enzymes (approximately 180°F), reduce microbial populations and enhance some flavor and texture characteristics.

Underblanching vegetables can cause greater quality deterioration

than no blanching, because partial heating will disrupt or damage tissues causing enzymes and natural substrates to react more quickly (Ley, 1980). Also, moderate heat can inactivate some enzymes and increase activity of others, producing an imbalance that will accelerate deterioration. Toughness is another result of underblanching.

Overblanching will cause chlorophyll to break down and form pheophytin, giving green vegetables an undesirable color change. Excess heat also softens tissue to an undesirable degree (Ley, 1980). To ensure thorough enzyme deactivation, large, dense food should be warmed to 120°F prior to blanching.

Blanching can be done in hot water or steam. Research indicates hot water deactivates enzymes faster than steam (Ley, 1980). However, when blanching vegetables with a large quantity of cut surfaces, steaming is recommended to prevent leaching of nutrients. Stone and Young (1984) found green beans blanched in a microwave oven greener and firmer when compared to conventional blanching. Off-flavors and a "grassy" aroma were found in green beans blanched in a microwave oven.

Vegetables must be cooled immediately after blanching to stop the heating, thus minimizing texture damage and nutrient loss. Ley (1980) reported 15-30% of vitamin loss occurs during blanching and freezing. Little vitamin loss occurs during storage if temperatures do not rise above 0°F, which prevents oxidation. Blanching must be a compromise between the destruction of enzymes and undesirable textural changes produced by the heat treatment.

Acceptability of cooked and uncooked vegetables prior to freezing was studied by Woodroof and Atkinson, as reported by Tressler et al. (1968). Lima beans, snap beans, soybeans, okra and cream-style corn remained in excellent condition after being stored for one year at 0°F (-18°C) when blanched prior to freezing. However, if these products were precooked, quality was rated fair to poor after storage. These tests indicated that as heating time increased, beyond the recommended blanching time, color, aroma and flavor deteriorated. Cooked puree of pumpkin and sweet potatoes remained in excellent condition after frozen storage, however. The highest quality rhubarb was obtained when blanching was omitted.

Hanson et al. (1950) compared quality attributes of blanched and precooked frozen peas, sweet corn, Kentucky Wonder beans, celery, carrots, lima beans, peppers and Chinese water chestnuts. Cooked peas developed an off-flavor faster than blanched peas, but there was no difference in degree of off-flavor, indicating overcooking was not the cause in the flavor differences. Packing peas in liquid such as cream sauce, kept the air from coming in direct contact with the peas, which prevented the development of off-flavors during storage. Hanson and co-workers also concluded that desired crispness could be obtained by varying cooking times prior to freezing.

Hein and Hutchings (1974) reported that ascorbic acid content in some vegetables decreased as much as fifty percent when the product was frozen and held at 16°F for six months. In another study (Fennema, 1977), several vegetables (asparagus, lima beans, green beans, broccoli

spears, brussel sprouts, cauliflower, whole kernel corn, immature green peas, mashed potatoes and spinach) were cooked after frozen storage. Analysis revealed a 25 percent decrease in thiamin content when frozen and fresh vegetables were compared. However, freezing was found to be superior to canning, because three times more thaimin was retained in the frozen vegetables. Bennett et al. (1954) found ascorbic acid retention was satisfactory when vegetables were stored at -20°F. Higher storage temperatures showed a gradual decrease in the retention of this vitamin.

Reducing agents such as sulfite sometimes are added to water of peeled white potatoes, cabbage and salad greens when food is held before cooking. Van Zante and Johnson (1970) found higher ascorbic acid retention when sulfites were used to inhibit oxidation. However, thiamin, riboflavin, and niacin were reduced slightly.

The nutritional effects of unit operations, such as blanching, deep frying, and dehydrating, in commercial potato processing were investigated by Augustin et al. (1979). French fries and preformed patties were frozen and later freeze-dried. Overall retention ranged from 53% for ascorbic acid to 90% for vitamin B₆, in preformed patties. The lower ascorbic acid retention in preformed patties (53%) as compared to French fries (small fries 61%, large fries 69%) was attributed to the deep-frying operation.

Smaller fries had significantly lower ($p < 0.05$) nutrient retention, except for thiamin and folic acid, probably a result of nutrient leaching. Researchers concluded water blanching was the major

reason for nutrient loss during commercial frozen French fry production, and blanching with steam produced fries with a higher vitamin content.

Eggs and Egg Products. Raw egg white is not affected by freezing and thawing (Davis et al., 1952). However, frozen products containing cooked egg whites are not freeze-thaw stable. Ice crystal formation damages the coagulated protein gel structure, and syneresis occurs during thawing as is evident in frozen custards (Feiser and Cotterill, 1983; Tressler et al., 1968).

Feiser and Cotterill (1983) studied the effect of sodium chloride on the composition, serum and sensory properties of cooked-frozen-thawed scrambled eggs and cooked-frozen-thawed-reheated (CFTR) scrambled eggs. Mean sensory scores of fresh compared to CFTR scrambled eggs were significantly different ($p \leq 0.05$) from 0.6 to 1.0% salt. Sensory scores for unfrozen eggs indicated that no difference could be detected in varying salt treatments to 0.6%, but CFTR scores showed no difference to 0.4% salt. Mean rankings of fresh to CFTR samples were significantly different ($p \leq 0.05$) throughout varying salt treatment. Fresh to CFTR sensory scores were no different with up to 0.4% salt. Results indicate 0.4% is the maximum level of salt that may be used to CFTR egg products to be comparable to freshly cooked scrambled eggs.

Researchers concluded that the addition of salt (0-1.0%) to scrambled egg products decreases the amount of serum loss probably because of the solubilizing effect of salt on the phosphorus-containing

components (phospholipids, ovalabumin, and phosvitin). The CFTR process for scrambled eggs increases salty taste compared to the fresh product. This may be related to the decrease in moisture loss with the increased percentage of salt in CFTR scrambled eggs. Therefore, salt may play an important part by improving moisture retention. They also found that serum volume decreases as salt concentration increases, but total solids, protein, ash, lipids, sodium chloride, potassium, iron and phosphorus levels in the serum increases.

Gossett and Baker (1983) used protein modification to alter the functionality of proteins in egg albumen. The researchers believed that as the pH is raised, the negative charges might cause the increased repulsion among peptide chains, enabling the protein matrix to entrap more water. They theorized that by succinylating the proteins, the amino groups bind to succinate anions with two carboxyl groups causing a net gain in the negative charge. This increased repulsion between carboxyl groups may decrease protein-protein interactions, while increasing the protein-water interaction, thus improving water-retention properties of the gel.

Gosset and Baker (1983) found as pH increased above pH 9.5 the percent of expressible moisture (EM) decreased for both unfrozen and nonfrozen treatments of coagulated egg albumen. As proteins were succinylated up to a certain level, such as 0.4% (g anhydride/g albumen), the succinyl groups and their negative charges contributed to the general expansion of protein allowing greater water retention. Further levels succinylation exhibited no further decrease in percentage EM of

coagulated gel. The cook value did not change. A significant increase in percentage EM was observed in all frozen samples. Raw albumen adjusted to pH 9.5 or greater exhibited significantly ($p \leq 0.05$) decreased percentage EM in coagulated albumen and whole egg gels for frozen and nonfrozen treatments. Raw albumen adjusted to pH 10.5 and 11.0 required less time to attain the same cook value than the pH 9.0 control.

Meat, fish and poultry. Protein denaturation and oxidation are responsible for the major undesirable changes which occur in meat, fish, and poultry after frozen storage. Also, as with all foods, the microbiological aspect of frozen meats is of utmost importance. Frozen storage results in virtually no loss of thiamin or riboflavin for meat, fish, or poultry, (Ley, 1980).

After comparing raw and cooked pork, Watts and Peng (1947) found rancidity increased rapidly as pH decreased (pH 6.5-4.8) in raw ground pork. However, pH had no effect on the rate of rancidification if ground pork was cooked prior to freezing. Therefore, they concluded that precooked frozen pork was superior to raw frozen pork after storage. They also found some salts (sodium chloride, sodium nitrate, sodium acetate, magnesium chloride and potassium nitrate) rapidly increased rancidity in raw ground pork, but not precooked pork during frozen storage. The effects of acids and salts on rancidity development in raw pork was attributed to the activity of a fat peroxidizing enzyme, possibly on hemoglobin. Decomposition of hemoglobin, resulting in meat discoloration, also occurred when meat became rancid. Watts

and Peng attributed the slower rate of rancidification in the cooked pork to the fact that peroxidizing enzymes are inactivated during cooking.

Kraft et al. (1979) studied the influence of meat composition and effects of different freezing methods on microbiological quality of beef patties. After beef patties containing 30% fat, 20% fat, and 20% fat with soy protein were frozen using liquid nitrogen, liquid carbon dioxide, or by mechanical freezing and stored for five months, researchers concluded that all freezing methods were effective in reducing bacteria. However, cryogenic freezing of beef patties containing 20% fat, with or without soy protein had significantly greater reduction in total viable mesophiles and psychrotrophs than patties with 30% fat, mechanically frozen.

Fennema (1975) reported that prompt chilling at 10 - 20°C (below 10°C "cold shortening" occurs) for at least 20 hours slowed the rate of glycolysis of slaughtered animal carcasses, thus reducing microbial growth and decreasing muscle contraction. Although aging of beef enhances flavor; increases tenderness, juiciness and water-holding capacity; and decreases thaw exudate and lipid stability, it is usually not done prior to freezing. Lamb requires little or no aging, and pork should not be aged because of its unstable lipid content.

Fennema (1975) also reported that papain and other proteolytic enzymes are sometimes used prior to freezing to tenderize meat. These enzymes are injected prior to slaughter or by dripping, spraying or injecting the carcass.

Thiamin is used to determine vitamin retention in meat. According to Fennema (1977), thiamin is usually studied because it is water-soluble, highly susceptible to chemical dehydration, present in many foods, required in the diet, and sometimes deficient in the diet. It is generally assumed that if thiamin is well retained, other nutrients are also well retained. Fennema (1977) found thiamin losses to be insignificant in various animal tissues after frozen storage.

The major problems in freezing fish are oxidative deterioration, dehydration, toughening, loss of juiciness and excessive thaw exudate (drip), according to Fennema (1975). Following correct sanitary procedures and freezing as promptly as possible is essential, because fish are especially subject to deterioration by microorganisms. To minimize contraction and lessen toughening during freezing, Fennema suggests completing rigormortis at a low nonfreezing temperature prior to freezing. However, quality is maintained when large pieces of fish are stored at least 2 months at -10°C and thawed slowly to avoid muscle contraction.

Eliminating oxygen, avoiding contamination with oxidative catalysts and irradiation, using antioxidants and low storage temperatures decrease undesirable oxidative changes in fish (Fennema, 1975). According to results reported by Tressler and associates (1968), protein denaturation causes the toughening of cooked lobster, crab and shrimp during prolonged frozen storage. Rapid glycolysis may also increase toughness in poultry as well as fish (Fennema, 1975). Therefore, slaughter and dressing operations

should be done in a manner that does not stimulate the rate of post-mortem glycolysis (chilling and aging poultry for 1-6 hours above 0°C).

To minimize growth of microorganisms, poultry should be cooled quickly to 10°F (50°F) or less. Chilling is done usually in crushed ice and water to avoid moisture loss (Fennema, 1975).

Oxidation and resultant rancidity are chemical changes likely to occur when fatty foods are frozen and stored. Turkey fat is particularly subject to oxidative rancidity (Tressler et al., 1968). Lineweaver et al. (1952) have shown that the addition of an antioxidant to turkey during cooking greatly retards rancidity development.

Baked products and other starch-containing products. Freezing has been a popular way of increasing shelf life of yeast doughs and other baked goods economically while retaining a high quality product. However, as the food system becomes more complex the problems encountered during freezing and frozen storage increase. Each ingredient must be considered independently and then in relation to one another.

Starch is a major constituent of wheat flour which is used in baked products as well as many other products including pasta, gravies and sauces. Therefore, the emphasis here will be placed on the effects of freezing on starch.

Uncooked starch are virtually unaffected by freezing in the presence of water (Tressler et al., 1968). However, if starch granules are gelatinized, various physical changes occur during frozen storage. Most starches contain two types of molecules, amylopectin (branched fraction) and amylose (linear fraction), the former being the major

component. Amylose fractions have a strong tendency to associate with one another through hydrogen-bonding between hydroxyl groups; this is referred to as starch retrogradation (Tressler et al., 1968). This results in an insoluble precipitate and a rigid gel. Retrogradation of linear molecules is virtually irreversible. However, retrogradation of branched molecules can be reversed readily by heating to 122-140°F (50-60°C).

Association of starch molecules increases viscosity or even congelation which causes thickened sauces to lose their smooth, creamy consistency during freezing, and become lumpy or curdled. Reheating only partially restores the original product appearance. Retrogradation also causes a dull opaque appearance to fruit pie-filling when frozen.

The most objectionable effect of linear and branched molecule association is the loss of water-holding capacity resulting in syneresis when frozen food is thawed. Although re cooking will frequently reconstitute a homogenous paste because branched molecules dissociate and expand to reabsorb the water, consumers find syneresis highly objectionable and they associate it with "curdling" and microbiological spoilage. Also, the bottom pie crust will become soggy if syneresis occurs during thawing. Slow freezing increases the starch concentration which promotes associative bonding (Tressler et al., 1968). Rapid freezing is essential, and is important to keep the pie fully frozen until baked. If thawing and refreezing occur, even the most stable food will break down. Slow thawing may be almost as detrimental

to the texture and consistency of starch foods as slow freezing.

Chan and Toledo (1976) studied the extent of starch retrogradation of gelatinized starch gels by measuring the water-holding capacity (WHC). The WHC was found to be primarily dependent upon the resistance where water to ice transformation occurred as well as the freezing process used. Little change in the WHC occurred during pre-cooling to the freezing point or below the freezing temperature. An inverse relationship was observed between the WHC of the frozen starch gel and the extent of reconstitution.

Normal cereal starches (corn, sorghum, wheat and rice) have a high degree of linear retrogradation resulting in products that are prone to form gels, develop opacity and have a decreased water-holding capacity (Tressler et al., 1968). While unmodified root and tuber starches (tapioca and potato) have a lower content of linear fraction, and are less susceptible to retrogradation, they swell extensively when cooked in water, resulting in cohesive, slimy pastes. "Waxy" or amylopectin starches have been developed which contain only branched starch, but are also cohesive; subsequently, they usually are not used in foods.

To alleviate some of the above problems, ungelatinized starch granules are chemically cross-bonded in alkaline medium (trace amounts of ester or ether crosslinking) which protects the granules against excessive swelling (Tressler et al., 1968). However, cross-bonding substantially reduces cold storage and freeze stability of starch. A second modification is done on the cross-bonded starch by introducing

acetate ester groups or ionized phosphate ester groups. This process reduces the alignment of linear chains and linear segments of branched molecules. The result was an improved freeze resistant product while the desired quality attributes of the pasted starch (clarity, viscosity, acid resistance and water-holding capacity) were maintained (Tressler et al., 1968).

Schoch (1968) studied the cold storage stability and freeze resistance of various food starches by subjecting a five percent cooked starch paste to successive freeze-thaw cycles and determining the rate of syneresis or water separation from the pasted starch. Two patterns of instability were observed: (1) a slow progressive syneresis with each successive freeze-thaw cycle, and (2) no water separation for a number of cycles, followed by rapid deterioration. Specific findings by Schoch (1968) include:

- (1) Normal unmodified sorghum starch was highly unstable, having more than 30% water separation after one freeze-thaw cycle.
- (2) Unmodified waxy sorghum and waxy maize starch withstood three freeze-thaw cycles before substantial syneresis occurred.
- (3) Waxy rice flour was very stable, with no syneresis until after seven freeze-thaw cycles.
- (4) Starch stability generally decreases substantially at pH 3.
- (5) Cross-bonding waxy sorghum starch with 0.06% trimetaphosphate considerably decreased stability, probably because the starch is less dispersed, thus in a more concentrated state allowing for more molecular association.
- (6) Freeze resistance of waxy sorghum and waxy maize starch was improved when either phosphate or acetyl ester groups were cross-bonded with the starch.

Gravies and sauces, essential to many precooked frozen meat

products, often curdle and become unappetizing in appearance. Baldwin et al. (1972) investigated the effects of freezing on waxy milo and modified waxy maize starches than for those thickened with waxy rice flour. Also, gravy thickened with new waxy rice flour was more desirable ($p < 0.05$) in texture, mouthfeel, and overall acceptability than the gravy thickened with old waxy rice flour which had been stored at ambient temperatures for five years.

Grains of filtrate, obtained after centrifuging and filtering gravies were greatest in the product containing new waxy flour and at least in that made with cross-bonded waxy milo starch. A significant ($p < 0.01$) positive correlation ($r = 0.678$) was found between viscosity and sensory evaluation for consistency for gravies. A significant ($p < 0.01$) negative correlation ($r = -0.519$) occurred between viscosity and amount of filtrate.

Temperature is an important factor in determining the rate of retrogradation. Wheat starch retrogradation occurs most readily at -4°C (Collison, 1968). At extreme temperatures the Brownian motion of the macromolecules are either too intense or too slow for association to take place.

Freeze-thaw studies conducted on instant dehydrated potato granules by Ooraikul and associates (1974) indicate retrogradation of amylose occurred during the freezing and thawing, which decreased the strength of the cell binding matrix. Surfactants, namely glycerol monostearate and propylene glycol-monostearate, were found to reduce the content of free starch. This resulted in an improvement of

textural quality of the instant dehydrated potato granules.

Escape of carbon dioxide is the major problem in frozen batters. The separation of ice increases the carbon dioxide in the remaining liquid phase until the concentration becomes so high it will not stay in solution (Tressler et al., 1968). Also, coagulation resulting from protein denaturation allows more carbon dioxide to escape.

The longer yeast doughs are stored, the more slowly the dough will rise after it is thawed. Yeast cells gradually lose their viability, and some carbon dioxide is lost because of the separation and growth of ice crystals (Tressler et al., 1968).

Tressler et al. (1968) drew the following conclusions concerning frozen pasted starch systems.

(1) The higher the starch concentration, the more rapid is the association, because the closer the molecules are to one another, the greater the probability of intermolecular combination.

(2) Associative bonding increases as the temperature nears the freezing point, due to slowing kinetic motion.

(3) The longer the pasted starch is held in a near-frozen state, the greater the association. However, no change occurs while in a "deep-frozen" state (-12°F or -25°C).

(4) High initial hydration and dispersion of starch molecules gives more stability to thoroughly cooked starch pastes than under-cooked starch.

(5) The higher the acidity, down to pH 3, the greater the tendency of the starch to associate.

(6) Sugar usually reduces association of starch, but higher concentrations interfere with optimum cooking which limits starch hydration.

(7) Introducing chemical derivative groups (esters or ethers) into starch molecules prevents association between linear chains and linear segments of branched molecules.

Effects of Thawing on Frozen Foods

Unsafe methods have contributed to the recent increases in the incidence of foodborne illness (Ley, 1980). Frozen food is either allowed to thaw in refrigerators, sometimes requiring three or more days to thaw, or thawed at room temperature, which is extremely conducive to increased microbial contamination.

Precooked frozen foods are more vulnerable to contamination than raw frozen products because of additional exposure to 130-145°F danger zone during processing. Therefore, convenience and ready prepared foods that are thawed and served cold, without further heat treatment, present a hazard if they are not thawed properly to restrict microbiological growth (Ley, 1980).

Fluid is drawn out of the cell to form ice crystals during freezing. A controlled thaw of a raw product allows time for the cell to reabsorb a portion of the fluid from the melting ice crystals. This process will yield a moist, reheated end product with less water-soluble nutrient loss. However, a slow rate of thawing increases "drip" or exudation (Livingston et al., 1973).

Damage which occurs during thawing usually is caused by chemical (protein insolubilization or lipid oxidation) or physical changes (recrystallization and volume changes). Microbial growth can cause significant damage, but if recommended sanitary practices are followed

throughout the freezing, thawing and reheating process, this is not a problem.

Fennema (1973) described an experiment using a non-flowable starch gel to compare the different rates of freezing and thawing. Large temperature gradients were found in the outer frozen zone during freezing, and freezing was completed in approximately 26 minutes. The frozen phase rose rapidly to the melting point and remained there for the duration of the thawing process, which was not close to completion after 30 minutes. Twice as much time was required to thaw the center of the starch gel as was needed to freeze it.

Fennema (1973) stated that the additional time required for thawing just below the melting temperature is unfavorable because recrystallization and growth of the microorganisms are both more likely here than at any other subfreezing temperature. Also, many chemical reactions occur rapidly at temperatures just below freezing. Differences in the rates of freezing and thawing would be less than previously stated in foods with a moderately low water content such as meat, or with substantial air content such as fruits and vegetables.

The state of food when cooked or reheated affects quality of the final product. Burr (1971) studied the effects of time and temperature of holding par-fries (partially deep fried before freezing) in thawed condition on the loss of water and uptake of fat during finish-frying, and on retrogradation of the starch in par-fries.

Frozen par-fried French-fry cuts allowed to thaw and held, decreased in weight while fat uptake increased. Finished product

decreased in weight about 7% after holding 3 days at 50°F and fat uptake increased about 25%. Substantial loss in yield occurs in a little as 1.5 hours at 50°F or 5 hours at 40°F. Yield decreases and fat absorption increases as the temperature of the product increases prior to frying. The rate of retrogradation decreases with increasing temperature suggesting that the two phenomena are unrelated.

Langlois et al. (1979) studied the effects of curing frozen hams and thawed (13°C) hams with and without nitrate on the weight loss, visual appearance, eating quality, composition and microbiological characteristics of dry-cured aged hams. Nitrate in the cure had no effect on weight loss. However, weight loss was higher when hams were cured after being thawed as compared to being cured from the frozen state. Subjective evaluations for color, aroma and general appearance revealed no significant differences among the hams. Sensory panel members scored frozen hams more tender than unfrozen hams ($p < 0.01$). However, no significant differences in flavor or overall satisfaction were found. Warner-Bratzler shear values were lower than those usually reported for country hams. Moisture contents of the lean of the frozen hams and unfrozen hams were 57.3 and 56.3, respectively.

Coliforms were detected only from the thawed hams before curing. Both frozen and thawed hams contained detectable levels of Staphylococci, but were not detected when thawed hams were cured with potassium nitrite (KNO_3) and sodium nitrite (NaNO_2). All pre-cure counts were significantly higher for thawed hams than frozen hams at the 1% level, except *Pseudomonas* (7°C) which was significant at the 5%

level. Generally, after curing, counts were higher in thawed hams than frozen ones. However, the only significant difference ($p < 0.01$) not related to KNO_3 was the aerobic count (37°C). Cured, frozen hams had higher counts than hams thawed prior to the curing after 3 months. These higher counts were probably related to lower salt and high moisture content of the frozen hams. Langlois et al. (1979) concluded, dry-cured hams can be produced using frozen hams without affecting quality and without excessive microbial growth.

Thawing problems include (Fennema, 1973):

- (1) Thawing is slower than freezing.
- (2) Maximum temperature differential permissible during thawing (approximately 100°C or less) is much less than that which is feasible during freezing (200°C).
- (3) Thawing is potentially more detrimental than freezing, because much time is spent near the melting point where recrystallization and even microbial growth.
- (4) Thawing of food is often conducted by persons who are unskilled and sometimes unconcerned with correct procedures.

Proper thawing is an important step in the preparation of quality and safe meal components (Ley, 1980).

Temperature Fluctuation

The average distribution time of frozen foods is five and one-half months at an average temperature of 3°F . Many frozen food manufacturers estimate the products may be subjected to as many as five freeze-thaw cycles before it is consumed. Quality and acceptability of frozen foods are eroded away by every experience (i.e. extended storage

or temperature fluctuation). Quality erosion is progressive and irreparable (Van Arsdel, 1957; Michener et al., 1960).

Generally, as temperature increases quality storage life decreases, because a greater amount of free water allows chemical reactions to occur, contributing to spoilage and deterioration (Ley, 1980). Temperature fluctuation during frozen storage will cause more damage than freezing above 0°F, because water is allowed to melt and slowly refreeze, resulting in the formation of larger ice crystals. These larger crystals cause more structural damage, deteriorating original texture characteristics, increasing drip loss and increasing the loss of water-soluble nutrients, flavor and pigments. An example of a textural change is the increase in graininess of ice cream, sherbets and ices after frozen storage, because the ice crystals have increased in size (Tressler et al., 1968). Fluctuating and high storage temperatures accelerate crystal growth.

Michener et al. (1960) reported data from earlier studies on peas, green beans, cauliflower and spinach. When these vegetables were held at 20°F or below, taste test results suggested an inverse relationship between temperature and the time elapsed before appearance of an off-flavor. Flavor deteriorated rapidly at higher temperatures in all cases.

If maximum storage periods are extended or if temperature frequently fluctuates above 0°F, the following changes can occur (Ley, 1980):

(1) Cured meat products lose red color turn brownish gray and change flavor due to oxidative reactions between sodium chloride and fatty acids.

(2) Batters and unbaked goods containing baking powder have a short storage life because the acid and soda slowly react during storage causing carbon dioxide to escape which decreases leavening action.

(3) Since spices are volatile, changes occur in flavor during freezing.

(4) Undesirable flavor changes occur in egg yolks.

(5) Products with fruit that is not immersed in liquid remain exposed to oxidative action from the air.

(6) Cooked egg whites toughen.

(7) Sauces and gravies thickened with wheat flour or corn starch will retrograde causing fluid separation and curdling.

(8) Cooked shellfish toughen because of protein coagulation. Oxidative reactions cause color and flavor changes.

(9) Fried products are subject to oxidative reactions, because most of the fat remains on the food surface which is in direct contact with the air.

(10) Breakdown of chlorophyll to pheophytin changes natural green to olive green in raw, blanched vegetables. Ascorbic acid is oxidized to dehydroascorbic acid and then to diketogulonic acid causing flavor changes.

(11) Red fruits turn brown, because anthocyanins leach into the packing syrup.

(12) Enzymatic reactions turn yellow fruits brown, because of oxidation. Oxidation also reduces ascorbic acid content.

As previously stated, subjecting foods to freeze-thaw cycles usually results in inferior products. However, a freeze-thaw process for production of potato granules has been developed to eliminate or minimize some of the major problems of conventional Add-Back (A-B) process (Ooraikul, 1978). Essential steps in the A-B process are

precooking, mash-mixing and conditioning. Precooking is important because it strengthens the potato cells so they can withstand compression and shear force during the mash-mixing step. Without precooking, potato cells may be damaged resulting in a texturally inferior product. A problem in the A-B process is incomplete final cooking which results in hard lumps causing a high proportion of discard. The major problem occurs during the mash-mixing step where the cooked potato tissue is subdivided by mixing, pressing, rubbing and shearing with recycled dry granules. About 85-90% of the total granule output has to be recycled to the mash-mixer, which leaves only 10-15% of the granules to be packed as product. Most granules go through 8-10 processing cycles. The F-T process eliminates the pre-cooking step and since the process is a "straight-through" one, no recycling of dry granules is necessary. The total output of the F-T process yields 85-90% packaged product (Ooraikul, 1978). Approximately 85-90% of the total granule output must be recycled during the conventional process, compared to 10% when the freeze-thaw process is used. Other advantages of the freeze-thaw process include minimal microbial growth, superior texture and flavor as well as higher nutrient retention, because processing occurs at lower temperatures.

Reheating Frozen Food Products

The final phase of the freezing process is reheating. The first consideration is whether the food should be heated from the

thawed or frozen state. Ley (1980) suggested that convenience and ready prepared foods that are served hot should be thawed prior to reheating to retain quality and reduce surface dehydration and scorching. Reheating in a conventional oven from a refrigerated versus a frozen state will reduce total heating time by as much as 130 percent. A special problem arises when microwave ovens are used to reheat frozen foods, because food mass temperatures will be not uniform. Inconsistent energy distribution within the oven cavity and variations in product densities result in uneven product thawing during heating (Ley, 1980; Glew, 1973). Thawed portions absorb greater amounts of energy, rising in temperature more quickly than unthawed portions. Therefore, controlled thawing is necessary prior to microwave heating to reduce total heating time and to promote uniform product temperatures (Harrison, 1980).

Uncontrolled thawing and rapid heating without prior thawing of many frozen products can result in waste, spoilage, flavor and texture changes, discoloration and increased moisture and nutrient loss (Ley, 1980).

Energy is a limited resource and, therefore, is receiving increased attention in food service operations (Dahl et al., 1981). Twelve per cent of the total energy generated in the United States is used in food systems (Fennema, 1975). In 1910 approximately one calorie of energy output was needed to produce one calorie of food output. In 1970, nine calories of energy output were required per calorie of food output (Fennema, 1975). Since microwave ovens are considered

energy-efficient, their use for reheating has increased dramatically in household as well as food service situations (Dahl et al., 1981).

Snyder (1978) has estimated that microwave ovens can save up to 65% of the energy required to heat small portions of food when compared to convection ovens.

Microwave heating has been used for approximately 30 years, the predominant development has been for cooking and reheating food in domestic and catering situations (Sale, 1976). Characteristics that differentiate microwave heating from conventional heating include (Sale, 1976):

- (1) Microwaves generate heat within the food itself; no heat transfer is involved. Little heat conduction occurs within the food itself, causing the temperature of the food to rise very rapidly.
- (2) Microwaves do not penetrate metal, but pass through plastics, glass and paper, allowing food sealed in these materials to be heated.
- (3) Uneven heating occurs because of the geometry of the food. Edge overheating is a frequent phenomenon associated with microwave heating.
- (4) Thermal runaway occurs during thawing, because water absorbs microwaves more readily than ice.

Microwave cookery has different effects on food quality, depending on the physical and chemical composition of the product. Many vegetables have an exceptionally full flavor and color. Vegetables may be cooked in many cases without water, since the microwave energy will directly cook each unit in its own water content. This results in a minimum of nutrient loss by leaching into the cooking water. Covering the food is also unnecessary, resulting in shorter

cooking times. However, uniformity in food pieces is essential for even heating (Copson, 1962).

The purpose of the investigation by Klein et al. (1979) was to determine the folacin content and retention of conventionally and microwave cooked frozen vegetables (spinach, peas, green beans and broccoli). No significant differences were found in folacin content (78-105%) among the cooking methods, except broccoli (51-59%). The lower folacin content was attributed to the presence of heat labile forms of folacin.

Mabesa and Baldwin (1979) cooked frozen peas with and without water in a domestic microwave oven (115 V, 550 watts) and in an institutional microwave oven (220 V, 1150 watts). Peas cooked without water had a higher ascorbic acid content (95.6 to 100.9%) than peas cooked with water (72.1 to 78.2%) using domestic and institutional microwave ovens, respectively. Conventionally cooked peas had a 79.7% ascorbic acid retention.

If there is any predominant quality factor at issue in precooked foods, it is the freshness of flavor (Copson, 1975). It is probably more difficult to maintain flavor in meat than in vegetables. Copson (1975) made the following suggestions when preparing meats for a microwave meal:

- (1) Select meat (slices of roast, ham or turkey) which is improved by the process of preparation, freezing and reheating.
- (2) Use sauces or seasonings which lend a stable appeal.
- (3) Adjust the amount of precooking into balance with the final heating.

(4) Inhibit flavor deterioration (particularly in the fatty substance during frozen storage) by using suitable antioxidants or use products within a few weeks.

The effects of cooking method, and reheating method on physical, chemical and palatability factors of restructured pork patties were studied by Campbell and Mandigo (1978). Per cent area and thickness were not affected by reheating method. Infrared ovens resulted in higher cooking losses ($p < 0.01$) than microwave and convection oven reheating. Microwave oven reheating resulted in greater cooking losses ($p < 0.05$) than convection oven reheating, which was probably related to surface dehydration. Panel members found microwave reheated patties significantly less juicy ($p < 0.01$) as compared to convection oven reheating, however, color, visual texture, flavor and eating texture were not affected.

After heating frozen bread-soy patties, raw or char-broiled frozen fried breaded chicken parts in a hot air convection oven and holding 0.5, 1.5 or 3 hours; infrared, pressure steam, or microwave oven followed by 30 minute hot holding, Ang et al. (1978) determined riboflavin and thiamin retentions. Thiamin retention was lowest in chicken parts reheated by convection oven and held 3 hours (74%). Infrared heating resulted in 81-84% thiamin retention in beef and chicken, and 80% riboflavin retention in beef. Other heating methods yielded 87-93% riboflavin in chicken and 86-96% thiamin retention in both chicken and fish.

In another study, Dahl and Matthews (1980) found thiamin loss of beef loaf to vary from 5-10% after heating in a microwave oven.

Bowers and Fryer (1972) compared the thiamin and riboflavin retention in cooked, cooked-reheated, and cooked-frozen-reheated turkey muscles using gas and microwave ovens. No significant differences were found (moisture, fat-free basis) in thiamin retention. However, riboflavin content was higher in turkey muscle heated by gas ovens when compared to muscle heated in microwave ovens. In a later study, Engler and Bowers (1975) found turkey breasts suffered a greater ($p < 0.05$) volatile loss, but less ($p < 0.05$) drip loss when reheated in a microwave oven compared to those reheated in an electric oven. No significant differences were observed among treatments when vitamin B₆ was calculated on a cooked weight basis.

No significant differences in ascorbic acid and thiamin retention were found by Kylen et al. (1961; 1964) when fresh and frozen vegetables and meat were cooked in microwave or conventional ovens. However, thiamin retention in pork roasts was significantly greater after microwave cooking (Kylen et al., 1964).

Combination foods, such as in frozen dinners, present additional problems in reheating because of the variations in size, shape and density of the different food components. Copson (1962) stated that hot ovens may overheat foods where contact is made with the hot aluminum plate, resulting in drying or even crusting of the food. Also, a relatively long period in the hot oven may cause flavors to mingle so the distinct qualities of each component are impaired. This is avoided in the microwave oven because the cooking time is generally very short. However, multiple dinners could be cooked simultaneously

in conventional ovens, while only individual or small units could be heated in a microwave oven.

Kahn and Livingston (1970) studied the retention of thiamin in beef stew, shrimp newburg, chicken a la king and peas in cream sauce after freezing and reheating to 194°F (90°C) using either a microwave oven, infrared heating or boiling water immersion. Average thiamin retentions for the four products (based on 100% for freshly prepared foods) were 93.5%, 90%, and 86% for microwave oven, infrared and immersion reheating, respectively.

Ang et al. (1975) evaluated the nutritional quality of several frozen prepared food products after reheating in a high pressure steamer, or convection, infrared or microwave oven. Microwave oven heating tended to retain higher amounts of heat-labile nutrients than other heating methods. However, frequent stirring and resting periods to avoid scorching, in heating bulk foods, was detrimental to ascorbic acid retention. Infrared heating, which required longer reheating times, but fewer disruptions, resulted in similar nutrient retentions as microwave reheating. Convection oven reheating required the longest heating times for bulk frozen foods. Thiamin retention was lower in mashed potatoes and carrots when the convection oven was compared to infrared and microwave ovens for reheating. However, fish portions (2 pounds per pan) reheated in a convection oven required less time and had a higher thiamin content than when reheated in a microwave or infrared oven. High pressure steam reheating in all instances resulted in substantially lower levels of thiamin and riboflavin than other

methods.

Nicholanco and Matthews (1978) evaluated beef stew in a hospital cook/chill foodservice system. Thiamin was reduced from 0.11 mg/100 g in raw ingredients to 0.03 mg/100 g in stew after cooking and chilled storage for 27 hours. No further loss of thiamin was observed when stew was reheated to 145°F in a microwave oven.

Foodservice Industry

The foodservice industry prepares approximately forty per cent of the food consumed away from the home (Van Dress, 1979). The increases in the cost and the decreased number in the labor force have caused centralization of food preparation to increase greatly in popularity. Foodservice operations generally procure large quantities of meat, fish and poultry and chill or freeze until needed. Vegetables are either purchased fresh, canned or frozen (Livingston et al., 1973). Of the more than 20 million dollars spent in 1978 on frozen foods, over 10 million dollars was spent by institutions (Anonymous, 1979).

In the early 1970's hospitals began implementing the cook/chill foodservice concept (Kaud, 1972). This process involves chilling hot foods immediately after preparation, then holding in refrigerators for at least 24 hours prior to serving. The chilled food is then proportioned, placed in refrigerated food carts; transported to patient areas where microwave ovens are used to heat the food to desired temperatures.

Freezing prepared foods has become more popular than the cook/chill method throughout the foodservice industry. Advantages of

freezing on-premise food production include (Ley, 1980; Tressler et al., 1968):

- (1) Individuality may be maintained by using original recipes.
- (2) Reheating food at time of service increases nutritional retention (as opposed to hot-holding).
- (3) Sensory attributes, such as color, flavor, and texture, are better retained when compared to other forms of food preservation.
- (4) Skilled labor, which is expensive, is reduced, because reheating can be done by less experienced personnel.
- (5) Peak activity periods are reduced, resulting in a more relaxed working atmosphere.
- (6) Seasonal foods can be purchased, prepared, frozen and served at a later date, thus reducing cost and increasing menu variety.
- (7) Overproduction is virtually eliminated, because only the amount ordered is removed from storage.
- (8) Food production now allows more flexibility in arranging work schedules.

Although some of the above advantages are true of both cook/chill and cook/freeze systems, freezing increases the magnitude of each advantage.

Pasta Products

Pasta products are economical and well-liked by consumers. Pasta sales tend to increase during economically tight periods (Katz, 1982). These products are also easy to prepare and require little preparation time. Therefore, the use of pasta has been escalating in the foodservice industry. Approximately two billion pounds of pasta was

manufactured in 1981 (Katz, 1982). Approximately three-fourths of the production was sold directly to consumers, however, many manufacturers and restaurants are making their own pasta. A variety of pasta products can be found in frozen food cases in supermarkets, which reflects the trend in marketing frozen convenience foods.

Standardized pasta products must contain semolina, durum wheat flour, farina, flour or a combination of these ingredients (Douglass and Matthews, 1982). Rheological properties and color are superior when semolina and durum flours are used, therefore, these are generally the predominant ingredients.

Enriched pastas, according to federal standards of identity must contain 13-16.5 mg of iron, 4-5 mg of thiamin, 1.7-2.2 mg of riboflavin and 27-34 mg of niacin per pound. Calcium (500-625 mg/lb) and vitamin D (250-1,000 U.S.P. units/lb) enrichment is optional and not common.

Many researchers have tried to develop high-protein pasta products. In 1972 a new standard of identify for fortified macaroni was announced by the Food and Drug Administration (Banasik and Dick, 1982). Wheat must be the main ingredient in enriched, protein-fortified macaroni products and the protein source may be from any edible source. Fortified macaroni must contain 20% protein and have a protein efficiency ratio value equal to 95% casein, as well as be enriched with vitamins and minerals. All noodles must contain at least 5.5% egg or egg yolk solids, and vegetable pastas must contain at least 3% vegetable solids.

The USDA and American Institute of Baking began studies in the late 1960's to determine the nutrient content of wheat and wheat products. Nutrient composition of macaroni, as compared to wheat, is listed in Table 2 (Toepfer et al., 1972).

Table 2. Nutrient concentration in macaroni (durum wheat yield is 100%).

Nutrient	% Yield
Thiamin	48
Riboflavin	86
Niacin	40
Vitamin B ₆	25
Linoleic	42
Reducing sugar	371
Nonreducing sugar	63
Starch	116
Iron	41
Phosphorus	46
Calcium	59
Amino Acid (average)	95

A study to investigate the changes affecting the carbohydrate fraction of durum wheat following pasta processing was undertaken by Lintas and D'Appolano (1973). Their findings include:

- (1) Semolina starch had a higher peak viscosity than starch isolated from spaghetti. The decrease in peak viscosity as a result of processing indicated that starch damage occurred to some extent during processing.
- (2) Water-binding capacity was obtained from the starches isolated from the spaghetti. The starch damage values revealed that during pasta processing, the percentage of damaged starch was increased greatly.
- (3) Change in free sugar content:
 - (a) Maltose increased moderately after mixing (dough), greatly increased after extruding (wet spaghetti), and showed no change after drying.
 - (b) The change in glucose took place mainly during drying.

(4) The yield of water-soluble pentosans was much higher in spaghetti than from semolina. The opposite was true of the water-insoluble pentosans.

Little literature is available on preserved pasta products, however, Douglas and Matthews (1982) reported data on canned pasta mixtures. Canned pasta mixtures are higher in fat and ash, and lower in protein and carbohydrate contents than plain cooked macaroni. Nutrient content of canned pasta is product dependent. As expected, spaghetti with tomato sauce is generally lower in vitamin and mineral content when compared to macaroni and cheese, beef ravioli and lasagna. Two exceptions were copper and ascorbic acid contents. Iron, thiamin, riboflavin and niacin contents were similar in all products because of the enrichment specifications. Thiamin (per 100 g sample) for example yielded 0.17 mg in enriched macaroni cooked to the tender stage, 0.06 mg in spaghetti with tomato sauce, 0.09 in macaroni and cheese, 0.05 mg in beef ravioli, and 0.05 mg in lasagna.

The pasta image is one of high calorie and low nutrition (Katz, 1982). In reality, a cup of cooked spaghetti with tomato sauce yields 179 calories; meatballs add about 120 calories. Spaghetti and meatballs also contain 14 g of protein and 44 g of complex carbohydrates and many vitamins and minerals in a one-cup serving. One cup of plain yogurt made from whole milk yields 151 calories (fruit adds about 130 calories) with approximately the same amount of protein.

Instrumental and Sensory Texture measurements of Pasta Products

Texture influences the acceptability of products. Larmond and

Voisey (1973) investigated quality attributes of eight varieties of spaghetti. A taste panel rated spaghetti for firmness, chewiness, gumminess, adhesiveness, starchiness and flavor. The results were compared with acceptance tests by a consumer panel. Researchers concluded that flavor contributes little in predicting consumer reaction, whereas, firmness and gumminess as rated by the laboratory panel were sufficient to predict consumer acceptance.

Maintaining product texture is important to the foodservice industry, and a great deal of research has been done concerning this quality attribute. Starch is the major component of semolina, and firmness in cooked spaghetti is influenced by gelatinized starch properties as stated previously. Dexter and Matsuo (1979) investigated the effect on spaghetti cooking quality of some starches from various cereals. Differences appeared to be mainly attributable to variations in starch water absorption. Waxy maize and waxy barley starches were detrimental to spaghetti cooking quality, but high amylose corn starch appeared to impart a slight improvement in cooked spaghetti firmness.

Instrumental measurements are important because they are more reproducible than human measurements. However, a correlation between sensory and instrumental measurements must be made in order for instrumental measurements to be meaningful. The Instron Universal Testing Machine (IUTM) is recognized as a sensitive device for measuring texture quality (Lee et al., 1978).

The Ottawa Texture Measuring System developed by Voisey can be adapted to the IUTM for evaluating products of undefined shape (Perry

and Carroad, 1980). Small curd cottage cheese was evaluated by Perry and Carroad (1980). The firmness parameter was measured by determining peak heights in Newtons, or the force required to extrude the curd through the test cell. Cohesiveness was evaluated by the force which could be applied to the curd before it ruptured. Peak heights also were measured to determine the energy required to compress, shear and extrude curd through the test cell. Results showed a correlation between instrumental and sensory measurements for texture. Voisey and Larmond's (1973) use of the Ottawa System with the plate extrusion cell indicated that instrumental measurements were more sensitive to textural differences in firmness than sensory measurements.

A high positive correlation ($r = 0.812$) between taste panel scores and shear test cells using the Ottawa system when measuring spaghetti firmness was evaluated by Walsh and Gilles (1971). Matsuo and Irvine (1974) found differences related to spaghetti quality could be measured. Firmness was judged organoleptically as the force required to penetrate the product with the molar teeth. Chewiness was rated organoleptically in terms of seconds required to masticate a sample at a rate of one chew per second until a satisfactory consistency for swallowing was reached. The multiblade shear tests on the IUTM were used to determine textural characteristics instrumentally. Results showed high correlations between firmness and chewiness and between shear force and shear stress.

MATERIALS AND METHODS

Treatments

Frozen spaghetti with meat sauce, subjected to one, three or five evenly spaced or five immediate freeze-thaw cycles were compared with the fresh product. Two methods of reheating the products after frozen storage also were compared. A randomized complete block design with two reheating methods and five freeze-thaw treatments was used; sensory studies were replicated six times and instrumental data were replicated three times.

Sample Preparation. The North Central-120 regional project of which this project was a part, provided a spaghetti with meat sauce formula which was modified and used in preparing spaghetti samples. Ingredients and specifications are listed in the Appendix, Table A-1. Ingredients in sufficient quantities for the entire study were procured at the beginning of the study. Locally purchased ground beef was frozen until needed. Preliminary work showed that cooking spaghetti until the "thread" at the core of the strand disappeared produced a mushy product after preparation and reheating. Therefore, cooking was terminated after 15 minutes.

Fresh samples were tested immediately after preparation. Remaining product was divided into approximately 750 g portions before freezing in covered, moisture-proof, plastic containers. Temperature was maintained at $-29^{\circ} \pm 4^{\circ}\text{C}$ throughout the 39 day storage period. Each sample was frozen and thawed one, three or five times evenly spaced according to the schedule in Table 3.

Table 3. Freezing and thawing schedule.

No. Freeze-Thaws	Freeze-Thaw Days ^a
1	-
3	9, 21
5	5, 12, 19, 27
5 Immediate	2, 3, 4, 5

^aThawed for 8 hours at room temperature and returned to freezer.

The five freeze-thaw cycles immediately (hereafter designated 5-I) were included in this study to determine if the time of freezing and thawing during frozen storage affected the quality attributes of this product.

Large ice crystals remained in the interior of the product after thawing at room temperature (approximately 21°C) for eight hours. On day 39, each sample was removed from the freezer 12 hours before reheating in microwave ovens because ice reflects and transmits microwaves resulting in uneven, incomplete heating (Glew, 1973).

Spaghetti samples were reheated to an internal temperature of 74°C \pm 2° in a 1 1/2 quart, covered glass casserole using a conventional electric (Whirlpool, Model REF950P) or Sharp Carousel microwave oven (Model R-8200). Samples designated to be reheated in a conventional oven were reheated approximately 30 minutes to 165°F internal temperature at 350°F (176°C). The roast setting on the microwave oven was used to reheat the remaining samples for nine minutes, turning the samples 180 degrees after five minutes. Following reheating, all samples were kept warm in a Blick-Built Selective-Menu food conveyor,

(Model no. ALS-44324) for approximately five minutes until sensory evaluation.

Instrumental Evaluation of Spaghetti with Meat Sauce

Texture. Spaghetti firmness was evaluated using the Instron Universal Testing Machine (Model 1122). A back extrusion cell was used with a 500 kg load cell to compress 100 g of samples of spaghetti after manually removing all meat particles. Crosshead and chart speeds of 20 mm/min and 50 mm/min, respectively, were used. Previous studies (Christensen, 1981) concluded that evaluating time and temperature influenced results. Therefore, all samples were covered, held at approximately 22°C and evaluated two hours after reheating. Peak heights represented the amount of force (kg) required to compress the spaghetti.

Color. Spaghetti and meat sauce color was evaluated using the HunterLab spectrophotometer, Model D54-P. The Waring blender was used to prepare a slurry from 100 g of spaghetti and 10 ml of water for 90 seconds on the blend setting. Six centimeter diameter, optically clear cups were filled to a depth of approximately 1.5 cm. Using Illuminant C, four readings per sample were taken and mean L, a, b and CIE L, a, b values were reported. Instrumental values were used to calculate hue angle ($\tan^{-1} b/a$) and saturation index $(a^2 + b^2)^{1/2}$ (Little, 1976), representing hue (color) and intensity, respectively.

Analysis of Data

Instrumental and chemical data for five treatments and two

reheating methods were analyzed by ANOV as follows:

<u>Source of Variance</u>	<u>D/F</u>
Replication	2
Method	1
Replication x Method	2
Treatment	4
Method x Treatment	4
Error	<u>16</u>
Total	29

When differences were indicated, least significant differences ($p < 0.05$) were determined.

Sensory Evaluation of Spaghetti with Meat Sauce

To ensure food safety of the product, microbiological tests were made prior to the sensory evaluations. These tests revealed very low bacterial counts, approximately 15 viable counts per gram (Appendix, Table A-4).

Panel Selection. Faculty and graduate students from the Foods and Nutrition Department who were experienced in sensory methodology comprised the eight member panel to evaluate the spaghetti with meat sauce for appearance, mouthfeel, texture and flavor.

Panel Training. Four training sessions were held before the study commenced to familiarize the panelists with the product and sensory evaluation procedures of this study. The scorecard was introduced and terminology discussed. During these sessions the scorecard developed by NC-120 project members was revised in order to better evaluate the characteristics of interest in this particular study. Examples of product extremes similar to those which would be evaluated during the

study were presented to panelists during training. Aroma bottles were available to panel members to aid in the recognition of spices used in the spaghetti and meat sauce. Several procedures were modified as a result of those training sessions to better ensure repeatability among panel members and reproducibility of results. The length of time required for frozen storage made it necessary to hold two retraining sessions prior to evaluation of reheated samples. At this time the panel members were again presented with product extremes.

Scorecard. A 15 cm standard unstructured descriptive rating scale with anchors and descriptive terms 1 cm from each end was adopted by the NC-120 Committee. Those scales were used for the characteristics important to this study. The scales for the characteristics evaluated are shown in the Appendix (Figure A-1).

Panel Evaluation Sessions. Four samples coded with random three-digit numbers, were evaluated at each of the two sessions per day with a fifteen minute break after each two samples. Order of presentation of each pair of samples was randomized among panelists. Spaghetti remained in the casserole while panelists evaluated moistness under the MacBeth skylight. Each panelist evaluated remaining characteristics from individual, approximately 50 g samples in heated glass custard cups. Preliminary studies indicated greasiness was influenced by temperature, therefore, thermometers were provided and panelists were requested to evaluate this characteristic at 49°C. Deionized, distilled water and unsalted crackers were provided for use between samples. After evaluations were completed, numerical values were

assigned to each panelist's assessments for statistical analysis.

Nutrient Measurements of Spaghetti and Meat Sauce

Thiamin. After blending 100 g of spaghetti for one minute in a Waring blender with 100 g 0.1N hydrochloric acid, the thiochrome method (AOAC 43.024, 1980) was followed to determine thiamin content (wet weight basis) of spaghetti with meat sauce.

Analysis of Data

Data for the six replications of the sensory data were analyzed by analysis of variance (ANOVA) as follows:

<u>Source of Variance</u>	<u>D/F</u>
Replication	5
Method	1
Replication x Method	5
Treatment	4
Method x Treatment	4
Error	<u>36</u>
Total	55

RESULTS AND DISCUSSION

Significant differences were found by ANOV (Tables 4 and 5) among the five freeze-thaw treatments for moistness, strand separation, mouth-feel, sensory texture, spice intensity, ($p < 0.001$); off-flavor ($p < 0.01$) and thiamin content ($p < 0.05$). Reheating method resulted in significant differences in sensory texture ($p < 0.01$), HunterLab b values ($p < 0.05$), the 1976 CIE b values, and saturation index using the CIE 1976 values ($p < 0.01$). An interaction between reheating method and freeze-thaw treatments was found for moistness and thiamin content.

Effects of Treatments on Appearance Factors

Strand Separation. The only sensory factor related to appearance affected by the freezing and thawing treatments was strand separation. All samples which were frozen had more clumping ($p < 0.05$) than the freshly prepared spaghetti. Strand separation, or the absence of clumping of strands, is an important characteristic related to product acceptance by consumers. When starch freezes, water is crystallized, resulting in increased pressure within the cell causing the cells to rupture. This breakdown in the starch molecules is partially responsible for strand clumping in frozen samples. Significant differences were found for strand separation between fresh and all samples which had been frozen and thawed ($p < 0.05$), as expected. Once the product was frozen, individual strands were less apparent when compared to the fresh product. Previous work done by Glew (1973) found repeated freeze-thaws exaggerated the rupturing of cells, however, no differences were noted among the

Table 4. Mean squares and F values^a from analysis of variance of sensory properties for spaghetti and meat sauce.

Source of variation	df	Moistness	Separation	Separation	Mouthfeel	Greasiness	Texture	Spice	Off-Flavor
Replication	5	3.12 (0.93)	5.64 (2.28)	4.35 (1.96)	7.76 (6.50)*	4.02 (4.20)	3.94 (7.93)*	4.32 (2.49)	3.20 (1.93)
Method	1	0.06 (0.02)	5.20 (2.10)	1.88 (0.85)	3.51 (2.94)	4.71 (4.93)	11.42 (22.96)**	2.19 (1.26)	6.78 (4.08)
Replication X Method (Error) ^b	5	3.34 (4.20)	2.47 (1.21)	2.22 (1.92)	1.19 (0.69)	0.96 (1.35)	0.50 (0.61)	1.73 (0.77)	1.66 (0.63)
Treatment	4	28.25 (35.47)**	3.81 (1.86)	27.06 (23.36)***	9.24 (5.32)***	0.50 (0.71)	47.07 (57.87)***	17.88 (7.99)***	10.30 (3.90)**
Method x Treatment	4	2.12 (2.66)*	1.89 (2.66)*	0.89 (0.92)	1.04 (0.77)	0.68 (0.60)	0.57 (0.69)	1.01 (0.46)	3.89 (1.47)
Error b	36	0.80	2.05	1.16	1.74	0.71	0.81	2.24	2.64

df values are in parentheses; levels of significance designated as follows: *, $p \leq 0.01$; ***, $p \leq 0.001$.
^bUsed to test first two sources of variation listed.

Table 5. Mean squares and F values^a from analysis of variance for chemical and instrumental tests on spaghetti and meat sauce.

Source of variation	df	Thiamin	Instron Firmness (kg)	L	a	b	Hue Angle ^b	S.I. ^c	L*	a*	b*	Hue Angle ^b	S.I. ^c
Replication	2	0.03 (4.90)	20.48 (0.78)	13.80 (13.79)	5.79 (4.35)	3.33 (92.44)*	0.01 (1.24)	7.23 (2.36)	13.54 (16.83)	4.08 (54.92)*	24.88 (4664.25)***	0.00 (0.26)	28.82 (2.18)
Method	1	0.00 (0.53)	30.83 (1.17)	0.71 (0.71)	3.07 (2.30)	0.97 (27.00)*	0.00 (1.15)	2.61 (7.00)	0.39 (0.48)	0.48 (6.48)*	3.54 (633.06)**	0.00 (0.16)	4.03 (454.96)***
Replication X Method (Error a) ^d	2	0.01 (0.48)	52.69 (18.30)***	1.00 (0.35)	1.33 (0.63)	0.04 (0.02)	0.00 (0.93)	0.37 (0.12)	0.80 (0.28)	0.07 (0.05)	0.01 (0.00)	0.00 (0.35)	0.01 (0.00)
Treatment	2	0.04 (3.44)*	1.64 (1.14)	2.09 (0.74)	3.11 (1.47)	0.24 (0.12)	0.01 (1.57)	1.44 (0.47)	2.00 (0.69)	1.42 (1.02)	3.87 (0.32)	0.00 (0.46)	5.30 (0.40)
Method X Treatment	3	0.04 (3.44)*	1.03 (0.72)	1.11 (0.39)	1.99 (0.94)	0.49 (0.24)	0.00 (1.06)	1.14 (0.37)	0.82 (0.28)	0.42 (0.30)	1.07 (0.09)	0.00 (1.06)	1.12 (0.08)
Error ^b	12	0.10	1.44	2.84	2.12	2.01	0.004	3.06	2.89	1.40	12.26	0.0005	13.25

^aF values are in parentheses; levels of significance designated as follows: *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$.
^bcalculated by formula: $\frac{1}{b/a}$
^ccalculated by formula: $(a^2 + b^2)^{1/2}$
^dused to test first two sources of variation listed.

four frozen-thawed treatments in this study (Table 6 and Figure A-2).

Fat Separation. Subjecting spaghetti with meat sauce to several freeze-thaw cycles had no significant effect on fat separation when compared to the fresh product (Table 6 and Figure A-2). The product which was frozen and thawed once had the highest level of fat separation with a gradual decrease in amount of fat separation noted as the number of freeze-thaw cycles increased. However, none of those differences were significant. Some fat separation might have been expected after freezing since cell destruction occurs during freezing and allows fat to escape the cell.

HunterLab Color Values. Color data for spaghetti with meat sauce are presented in Tables 5, 6, 7 and Figures A-3, A-4 and A-5. Anthocyanins, xanthins, and carotenoids are stable pigments and no significant differences for any of the measurements, among fresh and frozen samples resulted, as expected. The calculated hue angles and saturation indexes did not vary significantly among sample treatments. However, fresh samples had higher saturation index values than frozen samples indicating a slightly duller product, but not significantly so, after freezing. Dehydration which occurs during freezing may have contributed to this difference. The method of reheating had a significant difference, $p < 0.05$, and $p < 0.01$ on the b and b^* values, respectively, indicating more yellowness in the product reheated in a microwave oven than in the conventional oven (Table 7 and Figure A-5). Also, conventional reheating yields a duller product than one which is reheated in a microwave oven; this is apparent from the higher saturation index values.

Table 6. Least square means for appearance factors for varying freeze thaw cycles.

Characteristic	Fresh	Freeze-Thaw Cycles ^a				LSD _{0.05}
		1	3	5	5I	
Sensory ^b						
Fat separation ^c	7.78	8.72	7.66	7.49	7.25	NS
Strand separation ^d	9.18a	4.97b	5.59b	4.08b	4.78b	1.046 ^e 0.89 ^f
Color ^g						
L	47.92	48.77	49.45	48.73	49.23	NS
a	11.13	10.38	10.40	10.18	9.13	NS
b	17.22	16.80	16.95	16.85	16.68	NS
Hue Angle ($\tan^{-1}b/a$)	1.00	1.02	1.02	1.03	1.08	NS
Saturation Index [(a+b) ^{1/2}]	20.51	19.75	19.89	19.69	19.14	NS
L*	55.02	55.77	56.55	55.83	56.23	NS
a*	13.02	12.07	12.07	11.95	11.77	NS
b*	26.80	25.05	25.17	25.15	24.78	NS
Hue Angle*	1.11	1.12	1.12	1.13	1.13	NS
Saturation Index*	29.81	27.81	27.91	27.85	27.44	NS

^aEvenly spaced during 39 day period except 5I which were all immediately after initial freezing.

^bSix replications; means in the row sharing a common letter are not significantly different ($p \leq 0.05$).

^cScale: 0, no fat separation; 15, much fat separation.

^dScale: 0, strands clump together; 15, individual strands apparent;

^eFresh vs all frozen treatments.

^fAmong frozen treatments.

^gMeasured with HunterLab D-54P spectrophotometer; three replications 1976 CIE values (Little, 1976).

Table 7. Least square means for significantly different appearance factors for spaghetti and meat sauce.

Reheating Method	ba	Color b*b	SI*b
Conventional	17.08a	25.73a	28.53a
Microwave	16.72b	25.05b	27.78b

a $p \leq 0.05$.

b $p \leq 0.01$; SI calculated as follows: $(a^2 + b^2)^{\frac{1}{2}}$

This difference may be attributed to a greater moisture loss in conventional as compared to microwave oven reheated spaghetti and meat sauce.

Effects of Treatments on Mouthfeel and Texture

Mouthfeel: Dryness. A significant difference ($p < 0.05$) in moistness was found between fresh spaghetti with meat sauce samples and those samples which were frozen (Table 8 and Figure A-6). The frozen ones were less moist in every instance. The difference may partially result from overcooking the spaghetti during reheating. Undercooking the spaghetti during initial preparation may decrease the moisture loss after subjecting the spaghetti with meat sauce to frozen storage and freezer abuse. In this study we found the differences between 1 freeze-thaw and 3 freeze-thaw cycles to be significant. Products subjected to 3 freeze-thaw cycles were the driest. The differences were not significant among samples subjected to 3, 5 or 5-1 freeze-thaw cycles. These results were expected because of the freezing phenomena where water expands, forcing it out of the cell. However, once the water leaves the molecule it cannot return, even after thawing. This study substantiates that phenomena by showing a change which occurred only due to the freezing process. The number of freeze-thaws had little effect on product dryness.

Greasiness. No significant difference was found in product greasiness (Table 8 and Figure A-6). Cellular destruction probably contributed to a slightly less greasy fresh product than frozen products. A pattern was not shown in the amount of greasiness found in the product as the number of freeze-thaw cycles increased. Therefore, the freezing

process itself appears to be responsible for the slight but insignificant increases in greasiness detected by the sensory panelists.

Sensory Evaluation for Firmness. Significant differences in sensory firmness were found. Firmness is a characteristic important in consumer acceptance for many products including spaghetti and meat sauce. The results presented in Table 8 and Figure A-6 indicate the fresh product is firmer than the frozen products, as expected.

Table 8. Least square means for mouthfeel and texture evaluation of spaghetti for effect of increasing (zero to five) freeze-thaw cycles^a.

Characteristic	Fresh	Freeze-Thaw Cycles ^a				LSD _{0.05}	
		1	3	5	5I		
Sensory							
Mouthfeel ^b						A	B
Dryness ^c	4.73a	6.45b	7.56c	6.62bc	6.98bc	1.28	1.09
Greasiness ^d	6.66	7.29	7.17	7.26	7.16	NS	
Firmness ^e	8.61a	4.44b	3.68c	2.53d	2.95cd	0.88	0.74
Instron							
Firmness, kg ^f	25.36a	22.13b	21.73b	22.66b	21.46b	1.44	NS

^aEvenly spaced during 39 day period except 5I which were all immediately after initial freezing.

^bMeans in a row sharing a common letter are not significantly different, $p \leq 0.05$.

^cScale: 0, very wet and 15, very dry.

^dScale: 0, not greasy and 15, very greasy.

^eScale: 0, extremely soft and 15, extremely firm.

^fBack extrusion cell on Instron Universal Testing Machine

A Fresh vs frozen

B Among frozen treatments

Glutenin and gliadin are wheat proteins most responsible for spaghetti textural characteristics. Water is an intrinsic part of

protein structure, therefore, water removal which occurred during freezing undoubtedly caused denaturation of protein. Protein denaturation and starch retrogradation probably caused structural changes in cells leading to the textural changes and resulting in a softer product after freezing. Undercooking spaghetti prior to freezing would eliminate overcooking during reheating, probably resulting in a firmer end product.

Fresh pasta products were two to three times firmer than frozen products. The product became progressively softer as the number of freeze-thaw cycles increased. With increasing number of freeze-thaw cycles the potential for further denaturation occurs. Therefore, as expected, this study showed an inverse relationship between spaghetti firmness and number of freeze-thaw cycles. The 5-I samples were firmer than those frozen and thawed 5 times spaced throughout the study; however, those differences were not significant. These results suggest that the time of freezing and thawing during the storage period has no effect on the firmness of the product.

Instrumental Values for Firmness. No significant differences were found among the frozen treatments according to instrumental texture data, however, fresh samples required more force than frozen samples, supporting the sensory data (Table 8 and Figure A-7). The 5-I samples had the lowest Instron values and suggest a slightly less firm product than the other frozen samples. This was not entirely consistent with the sensory evaluation which indicated the five evenly spaced freeze-thaw cycles resulted in the softest product. However, since none of the differences were significant, the data are in agreement.

Table 9. Least square means for sensory flavor evaluations for effect of increasing the number of freeze-thaw cycles.

Characteristic	Fresh	Freeze-Thaw Cycles ^a				LSD _{0.05}	
		1	3	5	5I		
Sensory Flavor ^b						A	B
Spice ^c	7.66a	4.44b	4.11c	4.13bc	4.23b	1.45	1.24
Off-flavor ^d	2.19a	3.33ab	3.77abc	5.09c	4.04bc	1.58	1.35

^aEvenly spaced during 39 day period except 5I which were all immediately after initial freezing

^bMeans in a row with same letter are not significantly different ($p \leq 0.05$).

^cScale: 0, spice intensity weak and 15, strong.

^dScale: 0, no off-flavor and 15, strong off-flavor.

^AFresh vs frozen

^B Among frozen treatments

Flavor

Flavor: Intensity of Spice. Spices are volatile, resulting in diminished spice intensity. Therefore, the sensory panel, as expected, indicated a stronger spice intensity in the fresh pasta product than in the frozen samples. Those differences were significant ($p < 0.05$) and are found in Table 9 and Figure A-8. Little difference was found in spice intensity among various frozen treatments.

Off-flavor. Two major off-flavors were detected by panel members. The stale off-flavor and a "cardboard" off-flavor detected by the panel members was probably caused by hydrolytic rancidity (Tressler et al., 1968). This type of rancidity results because fats are cleaved and yield individual fatty acids which causes strong off-flavors. When cells are ruptured, the excreted lipids are exposed to oxygen which could result in a pronounced "cardboard" off-flavor. No significant differences were noted for off-flavor when fresh or frozen samples were subjected to one or three freeze-thaw cycles and evaluated by panelists. As the number of freeze-thaw cycles increased, the off-flavor became more pronounced. Results showed a significant difference between the fresh sample and those subjected to 5 and 5-I freeze-thaw cycles (Table 9 and Figure A-8), which one might expect because accelerated temperatures increase oxidative rancidity. As stated earlier, oxidation occurs more rapidly at -20°C than at ambient temperature (Glew 1973). Pasta products during this study frequently were recorded near the most vulnerable temperature. Temperatures noted during the study ranged from -25° to 33°C . However, no significant differences in products were noted between 1, 3

or 5-I freeze-thaw cycles. The strongest off-flavors were detected by the sensory panelists in spaghetti and meat sauce after 5 freeze-thaw cycles spaced evenly throughout frozen storage. These samples were significantly different ($p < 0.05$) from all treatments except those having experienced 5-I freeze-thaw cycles.

Effects of Reheating Method with Freeze-Thaw Treatments on Spaghetti and Meat Sauce

The method used to reheat the spaghetti and meat sauce resulted in no significant differences in the quality attributes evaluated in this study, except for moistness and thiamin retention.

Moistness. A significant difference ($p < 0.05$) was found between samples reheated in a conventional oven and those reheated in a microwave oven (Table 10 and Figure A-9). No differences were found after the spaghetti and meat sauce was frozen and thawed once. However, the product was more moist when reheated in the microwave oven after three and five freeze-thaws. Conventional oven reheating produced a moister product after 5-I freeze-thaws cycles.

Nutrient Analysis

Thiamin. Generally, thiamin content of this pasta product was not affected adversely or significantly by the various treatments (Table 11) in this study. However, spaghetti which had 5-I freeze-thaw cycles contained less thiamin ($p < 0.05$) than the fresh spaghetti with meat sauce. Little difference was found in thiamin retention between microwave and conventional oven reheating (Table 10 and Figure A-10), unless the product had experienced five freeze-thaw cycles, either evenly

spaced or immediately. The greatest thiamin loss was found after 5-1 freeze-thaw cycles when spaghetti with meat sauce was reheated in a conventional oven.

When microwave ovens were used in this study to reheat products which had been frozen and thawed, the thiamin content is equal or superior to samples reheated in conventional ovens. Samples reheated in a microwave oven were subjected to heat for a shorter time than samples reheated in a conventional oven, therefore, the thiamin contents found in this study were expected.

Table 10. Least square means for reheating^a by conventional and microwave ovens and freeze-thaw treatments^{b,c} on moistness and thiamin content (wet weight basis) of spaghetti and meat sauce.

Characteristic	Fresh	Freeze-Thaw Cycles ^d				LSD _{0.05}
		1	3	5	5T	
Moistness ^d						
Conventional oven	8.6ax	5.3by	3.9cy	3.0cy	5.1by	1.7c
Microwave oven	8.1ax	5.0by	5.16y	3.8cy	4.2bcy	1.046d
Thiamin, mcg/g						
Off-flavor ^d	0.91a	0.68bx	0.74aby	0.56bc	0.49c	0.00245c
	0.68ax	0.74by	0.70a	0.68ax	0.69a	0.1893d
						0.029e

^aAll means within a row sharing a common letter are not significantly different, $p < 0.05$.

^bFor comparisons among freeze-thaw treatments; a, b, c, are used.

^cFor comparing fresh vs. freeze-thaw treatments; a, b, c, are used.

^dScale: 0 to 15 ; 0, low, 15, high.

Table 11. Least square means for chemical measurement for spaghetti and meat sauce.

Characteristic	1 Freeze-thaw	3 Freeze-thaw	5 Freeze-thaw	5 Immediate Freeze-thaw	Fresh	LSD _{0.05}
Thiamin	0.71ab	0.72ab	0.62ab	0.59ab	0.79a	0.1893

^aMeans with the row sharing the same letters are not significantly different, $p \leq 0.05$.

SUMMARY

Freeze-thaw stability of spaghetti with meat sauce was investigated. The pasta product was subjected to 1, 3, or 5 evenly spaced or 5-immediate freeze-thaw cycles and reheated in a conventional or microwave oven. Products were evaluated for selected chemical, physical and sensory attributes.

Based on the conditions of this study, the following conclusions can be made:

1. Appearance. Strand separation decreased after spaghetti with meat sauce was frozen. Freezing treatment and/or reheating method produced no significant differences in fat separation or product color.

2. Mouthfeel. Freezing produced less moist and less greasy samples compared to fresh pasta. Spaghetti with meat sauce was driest after 3 freeze-thaw cycles. Reheating method also affected product moistness. Generally, pasta reheated in the microwave oven was more moist, however, spaghetti which had 1 or 5-1 freeze-thaw cycles reheated in the conventional oven was as moist as spaghetti with meat sauce with 1 or 3 freeze-thaw cycles when reheated in a microwave oven. No differences in greasiness were found among frozen samples.

3. Texture. Sensory evaluation indicated fresh spaghetti with meat sauce was two to three times firmer than frozen products. Firmness was inversely related to the number of freeze-thaw cycles to which the product was subjected. Instrumental readings indicated fresh pasta was firmer ($p \leq 0.05$) than frozen pasta; however, no significant

differences were found among treatments.

4. Flavor. Spice intensity decreased significantly after spaghetti with meat sauce was frozen, but no difference appeared among the frozen-thawed treatments. Off-flavors such as stale, rancid and "cardboard" were detected in samples exposed to freeze-thaw cycles. Off-flavors generally increased as the number of freeze-thaw cycles increased.

5. Thiamin. Thiamin loss was nominal unless the spaghetti with meat sauce experienced 5-I freeze-thaw cycles. Conventional reheating of the pasta product after 5-I freeze-thaws resulted in greater thiamin loss than microwave oven reheating.

References

- Ang, C.Y.W., Chang, C.M., Fey, A.E. and Livingston, G.E. 1975. Effects of heating methods on vitamin retention in six fresh or frozen prepared food products. *J. Food Sci.* 40:997.
- Ang, C.Y.W., Basillo, L.A., Cato, B.A. and Livingston, G.E. 1978. Riboflavin and thiamin retention in frozen beef-soy patties and frozen fried chicken heated by methods used in foodservice operation. *J. Food Sci.* 43:1024.
- Anonymous. 1979. Frozen foods almanac. *Quick Frozen Foods.* 42:101.
- Assoc. of Official Analytical Chemists Method 43.024, 1980.
- Augustin, J., Swanson, B.G., Teitzel, C., Johson, S.R., Pometto, S.E., Artz, W.E., Haug, C.P. and Schomaker, C. 1979. Changes in the nutrient composition during commercial processing of frozen potato products. *J. Food Sci.* 44:807.
- Baldwin, R.E., Moody, D., Cloninger, M. and Korschgen, B. 1972. Stability of gravies to freezing. *J. Am. Diet. Assoc.* 60(3):218.
- Banasik, O.J. and Dick, J.W.. 1982. Extruded products from durum wheat. *Cereal Foods World.* 27(11):553.
- Bennett, G., Cone, J.F., Dodds, M.L., Murphy, J.F., Nicholas, J.E., Perry, J.S., Pierce, R.T. and Shaw, M.D. 1954. Some factors affecting the quality of frozen food II. *Penn. Agr. Expt. Sta. Bull.* 580.
- Bowers, J.A. and Fryer, B.A. 1972. Thiamin and riboflavin in cooked and frozen, reheated turkey: Gas vs. microwave ovens. *J. Am. Diet. Assoc.* 60:399.
- Burr, H.K. 1971. Frozen french-fried potatoes. Effect of thawing and holding before finish frying and their nonrelation to starch retrogradation. *J. Food Sci.* 36:392.
- Campbell, J.F. and Mandigo, R.W. 1978. Properties of restructured pork patties as affected by cooking method, frozen storage and reheating method. *J. Food Sci.* 43:1648.
- Chan, W.S. and Toledo, R.T. 1976. Dynamics of freezing and their effects on the water-holding capacity of a gelatinized starch gel. *J. Food Sci.* 41:301.
- Christensen, J.M. 1981. Effects of hot-holding time on spaghetti and meat sauce. MS Thesis, Iowa State University, Ames, IA.

- Collison, R. 1968. Swelling and gelation of starch in "Starch and Its Derivatives," 4th Ed. Radley, J.A. Chapman and Hall, Ltd., London.
- Copson, D.A. 1962. Microwave Heating in Freeze-Orying, Electronic Ovens and Other Applications. AVI Publ. Co., Inc. Westport, Conn. p. 309-345.
- Copson, O.A. 1975. Microwave Heating. AVI Publ. Co., Inc. Westport, Conn. 2nd edition p. 324-327.
- Dahl, C.A. and Matthews, M.E. 1980. Cook/chill foodservice system with a microwave oven: Thiamin content in portions of beef loaf after microwave heating. J. Food Sci. 45:608.
- Dahl, C.A., Matthews, M.E. and Lund, O.B. 1981. Energy balance for heating beef loaf, effect of microwave heating in cook/chill foodservice system. J. Am. Diet. Assoc. 79(3):
- Davis, J.G., Hanson, H.L. and Lineweaver, H. 1952. Characterization of the effect of freezing on cooked egg white. Food Res. 17:393-401.
- Dexter, J.E. and Matsuo, R.R. 1979. Effect of starch on pasta dough rheology and spaghetti cooking quality. Cereal Chem. 56(3): 190.
- Douglass, J. and Matthews, R.H. 1982. Nutrient content. Cereal Foods World. 27(11):558.
- Engler, P.P. and Bowers, J.A. 1975. Vitamin B₆ in reheated, held, and freshly cooked turkey breast. J. Am. Diet. Assoc. 67(7):42.
- Feiser, G.E. and Cotterill, O.J. 1983. Composition of serum and sensory evaluation of cooked-frozen-thawed scrambled eggs at various salt levels. J. Food Sci. 48:794.
- Fennema, O.R., Powrie, W.D. and Marth, E.H. 1973. Low-Temperature Preservation of Foods and Living Matter. Marcel Dekker, Inc., N.Y. pp. 86-193, 202-207, and 22-227.
- Fennema, D.R. 1975. Principles of Food Science, Part II. Physical Principles of Food Preservation. Marcel Dekker, Inc., N.Y. pp. 5-7 and 173-190.
- Fennema, O. 1977. Loss of vitamins in fresh and frozen foods. Food Technol. 23(12):32.
- Glew, G. 1973. Cook/Freeze Catering. Faber and Faber, London. pp. 32-38 and 48-82.

- Gossett, P.W. and Baker, R.C. 1983. Effect of pH and of suc-cinylation on the water retention properties of coagulated, frozen and thawed egg albumin. *J. Food Sci.* 48:1391.
- Guadagni, D.G., Nummo, C.C. and Jansen, E.F. 1957. The time-tempera-ture tolerance of frozen foods. II. Retail packages of frozen peaches. *Food Technol.* 7(1):33.
- Hanson, H.L., Winegarden, H.M., Horton, M.B. and Lineweaver, H. 1950. Preparation and storage of frozen cooked poultry and vegetables. *Food Technol.* 4:430.
- Harrison, D.L. 1980. Microwave versus conventional cooking methods: Effects on food quality attributes. *J. Food Protection.* 43:633.
- Hein, R.E. and Hutchings, I.J. 1974. Influence of processing on vitamin-mineral content and biological availability in processed foods. In "Nutrients in Processed Foods, American Medical Association". Publishing Sciences Group, Inc., Acton, Mass. p. 59-93.
- Hellendoorn, E.N., deGroot, A.P., Vander Mijldekker, L.P. and Williams, J.J.L. 1971. 1971. Nutritive values of canned meals. *J. Am. Diet. Assn.* 58:434.
- Kahn, L.M. and Livingston, G.E. 1970. Effect of heating methods on thiamin retention in fresh or frozen prepared foods. *J. Food Sci.* 35:349.
- Katz, F. 1982. Pasta-changing images. *Cereal Foods World.* 27(11):552.
- Kaud, F. 1972. Implementing the chilled food concept. *Hospitals.* 46 (Aug.,1):97.
- Klein, B.P., Lee, H.C., Reynolds, P.A. and Wangles, N.C. 1979. Folic acid content of microwave and conventionally cooked frozen vegetables. *J. Food Sci.* 44:286.
- Kraft, A.A., Reddy, K.V., Sebranek, J.G., Rust, R.E. and Hotchkiss, D.K. 1979. Effect of composition and method of freezing on microbial flora of ground beef patties. *J. Food Sci.* 44:305.
- Kylen, A.M., Charles, V.R., McGrath, B.H., Schleter, J.M. and Van Duyne, F.D. 1961. Microwave cooking of vegetables. *J. Am. Diet. Assn.* 39:321.
- Kylen, A.M., McGrath, B.H., Hallmark, E.L. and Van Duyne, F.D. 1964. Microwave and conventional cooking of meat. *J. Am. Diet. Assn.* 45:139.

- Langlois, B.E., Kemp, J.O. and Fox, J.O. 1979. Microbiology and quality attributes of aged hams produced from frozen green hams. *J. Food Sci.* 44:505.
- Larmond, E. and Voisey, P.W. 1973. Evaluation of spaghetti quality by a laboratory panel. *J. Inst. Can. Sci. Technol. Aliment.* 6(4):209.
- Lee, C.I., Imoto, E.M. and Rha, C. 1978. Evaluation of cheese texture. *J. Food Sci.* 43(5):1600.
- Ley, S.J. 1980. Foodservice Refrigeration. CBI Publ. Co. Inc., Boston, Mass.
- Lineweaver, H., Anderson, J.O. and Hanson, H.L. 1952. Effect of antioxidant on rancidity development in frozen creamed turkey. *Food Technol.* 4:98.
- Lintas, C. and D'Appolonia, B.L. 1973. Effect of spaghetti processing on semolina carbohydrates. *Cereal Chem.* 50:563.
- Little, A.C. 1976. Physical measurements as predictors of visual appearance. *Food Technol.* 30(10):74, 76-77, 80 and 82.
- Livingston, G.E., Ang, C.Y.W. and Chang, C.M. 1973. Effects of foodservice handling. *Food Technol.* 19:28.
- Lund, O.B. 1979. Effect of commercial processing on nutrients. *Food Technol.* 33(2):28.
- Mabesa, L.B. and Baldwin, R.E. 1979. Ascorbic acid in peas cooked by microwaves. *J. Food Sci.* 44:932.
- Matsuo, R.R. and Irvine, G.N. 1974. Relationship between the GRL spaghetti tenderness tester and sensory testing of cooked spaghetti. *J. Inst. Can. Sci. Technol. Aliment.* 7(2):155.
- Mazur, P. 1966. In "Cryobiology", ed. by H.T. Meryman, Academic, N.Y. pp. 213-215.
- Michener, H.D., Thompson, P.A. and Dietrich, W.C. 1960. Time-temperature tolerance of frozen foods. XXII. Relationship of bacterial population of temperature. *Food Technol.* 14(6):290.
- Nicholanco, S. and Matthews, M.E. 1978. Quality of beef stew in a hospital chill food-service system. *J. Am. Diet. Assoc.* 72(1):31.
- Ooraikul, B., Packer, G.J.K. and Hadziyev, D. 1974. Starch and pectic substances as affected by a freeze-thaw potato granule process. *J. Food Sci.* 39:358.

- Ooraikul, B. 1978. Some characteristics of the freeze-thaw process for potato granule production. *Am. Potato J.* 55:171.
- Perry, C. and Carroad, P. 1980. Instrument for texture of small curd cottage cheese and comparison of sensory evaluation. *J. Food Sci.* 45:798.
- Rogers, J.L. and Binsted, R. 1972. *Quick-Frozen Foods. The Commerce and Technology of Processing, Packaging and Distribution.* Food Trade Press, Ltd. London, 2nd ed. pp. 327-332.
- Sale, J.H. 1976. A review of microwaves for food processing. *J. Food Technol.* 30:319.
- Schoch, T.J. 1968. Effects of freezing and cold storage on pasted starches. In "The Freezing Preservation of Foods", ed. by O.K. Tressler, W.B. Van Arsdel and M.J. Copley. AVI Publ. Co. Inc. vol. 4 pp. 44-56.
- Snyder, O.P. 1978. The role of the microwave oven in reducing energy consumption in commercial food service. *J. MW Power* 13:262.
- Somer, I.I., Farrow, R.P. and Reed, J.M. 1978. Influences of storage and distribution upon vitamin-mineral content and biological availability in processed foods. In "Nutrients in Processed Foods, American Medical Association", Publ. Sci. Group, Inc., Acton, Mass. pp. 72-76.
- Stone, M.B. and Young, C. 1985. Effects of cultivars, blanching techniques and cooking methods on quality of frozen green beans as measured by physical and sensory attributes. *J. Food Quality* (in press).
- Toepfer, E.W., Polansky, M.W., Eheart, J.F., Slover, H.T., Morris, E.R., Hepburn, F.N. and Quackenbush, F.W. 1972. Nutrient composition of selected wheats and wheat products. XI. Summary. *Cereal Chem.* 49:173.
- Tressler, D.K., Van Arsdel, W.B. and Copley, M.J. ed. 1968. *The Freezing Preservation of Foods. Vol. 4-Freezing of precooked and Prepared Foods.* AVI Publ. Co. Inc., Westport, Conn. 4th ed. pp. 1-22, 33-56 and 213-555.
- Van Arsdel, W.B. 1957. The time-temperature tolerance of frozen foods. I. Introduction: the problem and the attack. *Food Technol.* 7(1): 28.
- Van Dress, M. 1979. An overview of the foodservice industry. *National Food Review*, Summer.

- Van Zante, H.J. and Johnson, S.K. 1970. Effect of electronic cooking on thiamin and riboflavin in buffered solutions. J. Am. Diet. Assoc. 56:133.
- Voisey, P.W. and Larmond, E. 1973. Exploratory evaluation of instrumental techniques for evaluating some textural characteristics of cooked spaghetti. Cereal Sci. Today. 18:126-133 and 142.
- Walsh, D.E. and Gilles, K.A. 1971. The influence of protein composition on spaghetti quality. Cereal Chem. 48:544.
- Watts, B.M. and Peng, D. 1947. Rancidity development in raw versus precooked frozen pork sausage. J. Home Econ. 39:88.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Dr. Carole Setser for her guidance and encouragement during the course of this study. She always made herself available whenever help was needed, and I appreciate all the time and energy she gave me.

I would also like to thank Jean Craig for her invaluable assistance for the thiamin analysis, and Dr. Daniel Fung for his microbiological assays. I am also grateful to the faculty, staff and fellow graduate students of the Foods and Nutrition Department for their support, and especially to Dr. Martha Stone and Dr. Faith Roach for their continued assistance and encouragement.

The panel members deserve special recognition for their participation and assistance in this study: Dr. Jane Bowers, Dr. Carole Setser, Dr. Martha Stone, Kenneth Prusa, Anna Kuzniar, Karan Dalgas, Laura Lee Keller and Faustina Bohannon.

A very special thank you is extended to my husband, David, and our son, Travis, for their patience, understanding, encouragement and help during my graduate studies.

APPENDIX

Table A-1. Spaghetti and Meat Sauce Formula.

Ingredient	Amount	Procedure
Spaghetti, uncooked (R & F brand - Ravarino and Freshci, 100% semolina, approx 54 cm strands)	2 lb. 3.2 oz.	1. Break spaghetti into 12-14 cm lengths.
Salt	12.5 g	2. Measure water and salt into 5 gal steam-jacketed kettle.
Water.....	11.25 kg	3. Bring water to boil. Add spaghetti all at once, while stirring.
		4. Boil approx 15 min. ^a Drain in colander for 2 min. ^b
Onions, dehydrated (Sexton).....	3/4 oz.	5. Sauté rehydrated onions in oil in steam-jacketed kettle.
Oil (Mazola).....	3 Tbsp.	6. Add meat and seasonings to steam kettle.
Beef, ground (approx 10% fat)	4 lb.	7. Cook at moderate heat, stirring frequently until meat has lost its pink color
Oregano, ground (McCormik).....	1/2 tsp.	
Onion salt (French's).....	1/2 tsp.	
Salt.....	2 1/2 tsp.	
Sugar, granulated.....	1 Tbsp.	
Tomatoes, canned (Hunt's).....	10 cups	8. Crush tomatoes; add tomato paste to mixture.
Tomato paste (Hunt's).....	0.625 lb.	9. Cook, with heat low, stirring occasionally, for 30 min. or until sauce has thickened.
		10. Add cooked, drained spaghetti; mix thoroughly.
		11. Reheat to 165°F before serving.

^aThe test for doneness is the disappearance of white "thread" of starch in spaghetti strands, 15 minutes in this study.

^bSpaghetti was rinsed in hot running water for approximately 1 1/2 minutes in colander then drained for 2 minutes. ^cChopped in Waring blender approximately 3 seconds, approximately 10 tomatoes at a time, without juice.

APPENDIX

FIGURE A-1. Scorecard for evaluating spaghetti and meat sauce.

Please evaluate the samples in the following order:

Appearance

(1) Moistness



(2) Fat Separation



(3) Spaghetti

Mouthfeel

- (1) Dryness—gives sensation of a reduction in free fluids in oral cavity (wetness is the sensation of an increase in free fluids in oral cavity). Use approximately 1 tsp. of sample.



- (2) Greasiness - gives lips a sensation of thick immiscible (greasy) coating in mouth or on lips. Evaluate at 120°F.



Figure A-1. Scorecard for evaluating spaghetti and meat sauce (continued).

Spaghetti Texture

- (1) Firmness - force required to penetrate the spaghetti with the molar teeth.



Flavor

- (1) Intensity of spice



- (2) Intensity of off-flavor



Describe off-flavors and indicate which samples have these flavors:

Figure A-2.

Effect of freeze-thaw cycles on fat and strand separation. Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

FAT AND STRAND SEPARATION FOR VARIOUS FREEZE-THAW CYCLES

INCREASING SEPARATION

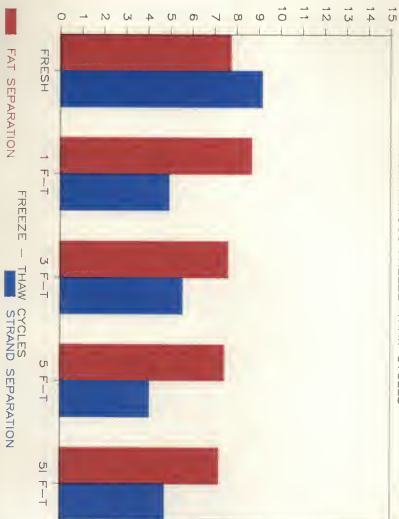


Figure A-3.

Effect of freeze-thaw cycles on instrumental L, a, b color values. Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

LEAST SQUARE MEANS FOR COLOR

Lab VALUES

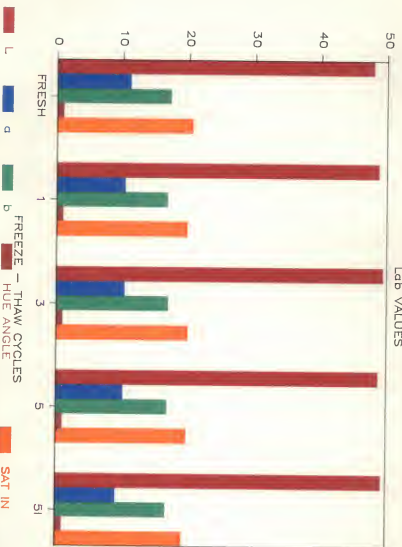


Figure A-4.

Effect of freeze-thaw cycles on instrumental CIE L, a, b color values. Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

LEAST SQUARE MEANS FOR COLOR

-CIE Lab VALUES

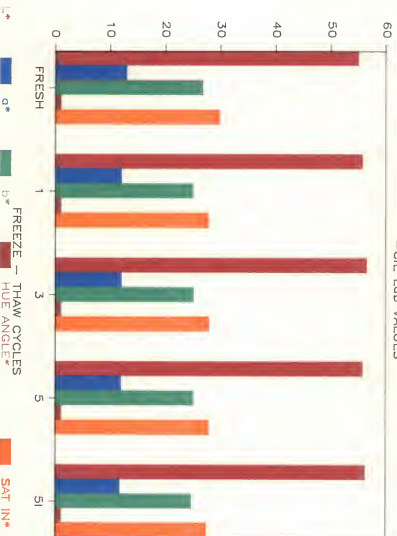


Figure A-5. Effect of reheating method on instrumental color values.

SIGNIFICANTLY DIFFERENT APPEARANCE FACTORS FOR SPAGHETTI AND MEAT SAUCE

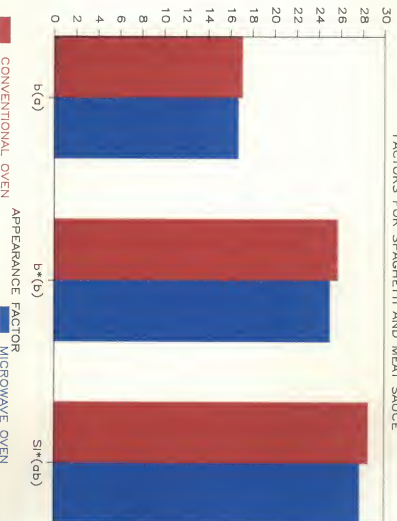


Figure A-6.

Effect of freeze-thaw cycles on moistness, greasiness and firmness. Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

MOUTHFEEL AND TEXTURE EVALUATION WITH INCREASING FREEZE-THAWS

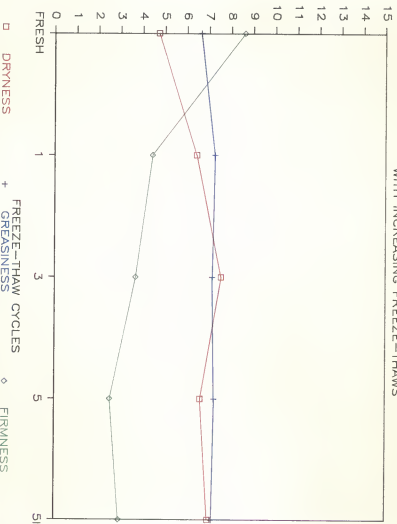


Figure A-7.

Sensory versus instrumental firmness values.

Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

INCREASING FIRMNESS

FIRMNESS SENSORY VS INSTRUMENTAL

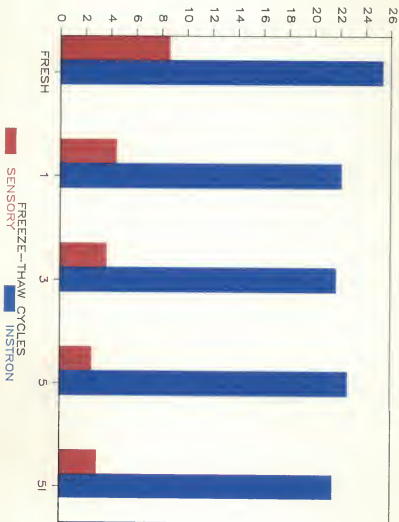


Figure A-8.

Effect of freeze-thaw cycles on spice intensity and off-flavor. Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-I indicates 5 freezing and thawing periods during the first 5 days of a 30 day storage.

SENSORY SCORES VS FREEZE THAWS

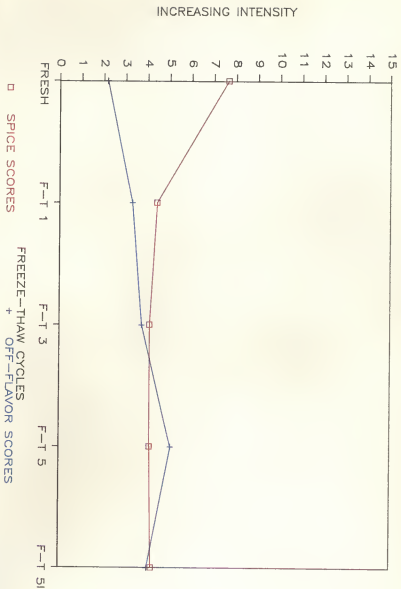


Figure A-9.

Effect of reheating on moistness.

Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

LOSS OF MOISTNESS FROM REHEATING METHOD

INCREASING MOISTNESS

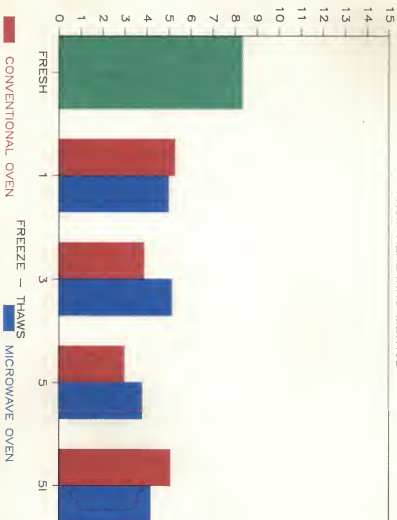
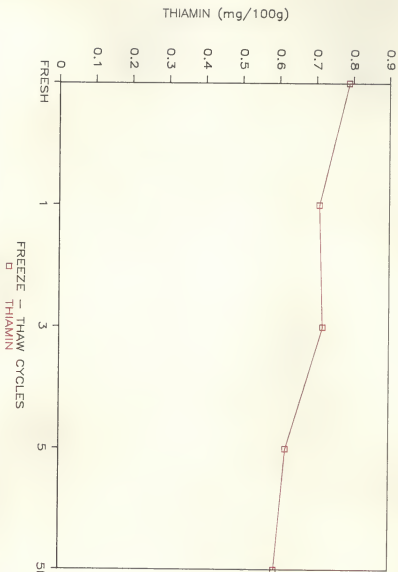


Figure A-10.

Effect of freeze-thaw cycles on thiamin retention.

Freeze-thaw cycles are designated for 1, 3 or 5 evenly spaced freezing and thawing periods during a 39 day storage; 5-1 indicates 5-freezing and thawing periods during the first 5 days of a 30 day storage.

THIAMIN LOSS WITH FREEZE - THAW CYCLE



APPENDIX

Table A-2. Least square means comparing reheating by conventional and microwave ovens and freeze thaw treatments for sensory attributes of spaghetti and meat sauce

Characteristic	Fresh	Freeze-Thaw Cycles ^a			
		I	3	5	5I
Fat Separation ^b					
Conventional oven	7.74	9.70	7.70	7.80	7.62
Microwave oven	8.01	7.74	7.61	7.19	6.87
Strands ^c					
Conventional oven	9.15	4.45	5.22	4.60	4.97
Microwave oven	9.22	5.49	5.96	5.01	4.60
Mouthfeel ^d					
Conventional oven	4.64	5.80	7.40	6.70	6.50
Microwave oven	4.83	7.10	7.72	6.53	7.46
Greasiness ^e					
Conventional oven	6.86	7.64	7.20	7.94	7.41
Microwave oven	6.47	6.93	7.14	6.59	6.92
Texture-Firmness ^f					
Conventional oven	8.56	4.04	3.01	1.85	2.40
Microwave oven	8.66	4.83	4.34	3.21	3.50
Spiciness ^g					
Conventional oven	6.82	4.47	3.92	4.10	4.22
Microwave oven	8.49	4.40	4.31	4.15	4.23
Off-flavor ^h					
Conventional oven	2.11	3.33	4.19	6.45	4.14
Microwave oven	2.67	3.33	3.35	3.74	3.94

^aEvenly spaced during 39 day period except 5I which were all immediately after initial freezing.

^bScale: 0, no fat separation; 15, much fat separation.

^cScale: 0, strands clump together; 15, individual strands apparent.

^dScale: 0, very moist; 15, very dry.

^eScale: 0, not greasy; 15 very greasy.

^fScale: 0, extremely soft; 15, extremely firm.

^gScale: 0, weak spice flavor; 15, strong spice flavor.

^hScale: 0, no off-flavor; 15, strong off-flavor.

APPENDIX

Table A-3. Least square means comparing reheating by conventional and microwave ovens and freeze-thaw treatments on color of spaghetti and meat sauce.

Characteristic	Fresh	Freeze-Thaw Cycles ^a			
		1	3	5	5I
L					
Conventional oven	47.80	49.40	49.07	48.83	49.77
Microwave oven	48.03	48.13	49.83	48.63	48.70
a					
Conventional oven	11.40	10.53	10.50	9.97	10.43
Microwave oven	10.87	10.23	10.30	10.40	7.83
b					
Conventional oven	17.03	17.17	17.07	16.90	17.23
Microwave oven	17.40	16.43	16.83	16.80	16.13
Saturation Index					
Conventional oven	20.50	20.14	20.04	19.62	20.15
Microwave oven	20.52	19.36	19.74	19.76	18.13
Hue Angle					
Conventional oven	0.98	1.02	1.02	1.04	1.03
Microwave oven	1.01	1.01	1.02	1.02	1.13
L*					
Conventional oven	54.90	56.30	56.20	55.90	56.67
Microwave oven	55.13	55.23	56.90	55.77	55.80
a*					
Conventional oven	13.33	12.20	12.23	11.63	12.10
Microwave oven	12.70	11.93	11.90	12.27	11.43
b*					
Conventional oven	26.67	25.47	25.53	25.23	25.77
Microwave oven	26.93	24.63	24.80	25.07	23.80
*Saturation Index					
Conventional oven	29.84	28.24	28.31	27.79	28.47
Microwave oven	29.78	27.37	27.51	27.91	26.41
*Hue Angle					
Conventional oven	1.10	1.12	1.12	1.14	1.13
Microwave oven	1.12	1.12	1.12	1.12	1.12

^aEvenly spaced during 39 day period except 5I samples which were freeze-thaw cycled immediately after initial freezing.

APPENDIX

TABLE A-4. Bacterial counts in spaghetti.

Sample	Viable cell counts/g
1	18
2	1170
3	21
4	15
439 A	15
439 B	Non detectable
100 A	21
100 B	93
1224 A	Non detectable
1224 B	9
1230 A	12
1230 B	12
17 A	15
17 B	9
115 A	12
121 A	15
121 B	18

EFFECTS OF FREEZING AND THAWING
ON SENSORY QUALITY AND THIAMIN CONTENT
OF SPAGHETTI AND MEAT SAUCE
AFTER REHEATING IN CONVENTIONAL OR MICROWAVE OVEN

by

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B.S., Kansas State University, Manhattan, 1977

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1985

ABSTRACT

Frozen spaghetti with meat sauce was subjected to one, three, or five evenly spaced or five immediate freeze-thaw cycles during a 39 day frozen storage period and compared with the fresh product. Spaghetti samples were reheated to 74°C in a conventional or microwave oven after thawing at room temperature for eight hours. Physical measurements for color and firmness were obtained using the HunterLab spectrophotometer and Instron Universal Testing Machine (IUTM), respectively. The chemical measurement for thiamin also was determined. An eight member trained panel evaluated the spaghetti and meat sauce for appearance, mouthfeel, texture and flavor using a 15 cm descriptive rating scale.

Analysis of variance (ANOVA) of sensory data indicated that treatment significantly influenced strand separation. Significant differences ($p < 0.05$) resulted between fresh and all samples which had been frozen and thawed. No significant differences were found in fat separation or greasiness among the various treatments. A significant difference ($p < 0.05$) in moistness was found between fresh and frozen samples. The frozen spaghetti and meat sauce was consistently less moist than fresh samples. The fresh product was significantly ($p < 0.001$) more moist than the frozen product, and the firmness decreased as the number of freeze-thaw cycles increased. Stronger spice intensity ($p < 0.05$) was found in the fresh pasta as opposed to the frozen samples. These differences were significant ($p < 0.05$). However,

little difference was found among various frozen treatments. A pronounced stale and "cardboard" off-flavor was detected by panel members after 5 evenly spaced freeze-thaw cycles. These samples were significantly different ($p < 0.05$) from all treatments except those subjected to 5 immediate freeze-thaw cycles. Moistness was the only sensory attribute significantly ($p < 0.05$) affected by the reheating method. The spaghetti and meat sauce was more moist when reheated in a microwave oven rather than a conventional oven after three or five freeze-thaw periods.

ANOVA of physical measurements for texture indicated treatment had no significant effect on product firmness, however, fresh samples were firmer than frozen ones. Color measurement data indicated treatment had no significant effect on hue, however, the saturation indices were higher for fresh samples than frozen samples, indicating a slightly duller product after freezing. The reheating method did have a significant effect on the b ($p < 0.05$), and b^* ($p < 0.01$) values which were higher (yellowier) after reheating in a microwave oven. Also, the product which was reheated conventionally was duller than the one reheated in the microwave oven.

ANOVA indicated freezing treatment and reheating method did not significantly ($p < 0.05$) decrease the thiamin content except when the product was subjected to 5-immediate freeze-thaw cycles. The greatest thiamin loss was found after conventionally reheating the spaghetti and meat sauce subjected to 5-immediate freeze-thaw cycles.