Process Modifications for Producing a Superior Instant Rice.

Durward A. Smith

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A SUPERIOR INSTANT RICE

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in

The Department of Food Science

by

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ABSTRACT

Consumer preference studies in various areas of the country have indicated the need for better quick-cooking rice and rice products. Therefore, an investigation was designed to develop methods for the production of a quick-cooking rice with preselected chemical, physical and nutritional properties. The end product should have the normal appearance of presently available commercial rice with grains not appreciably different in size from unmodified rice. Such rice should have substantially the same characteristics of swelling as natural rice, and when finally cooked should have flavor, texture, taste and appearance very similar to ideally cooked conventional milled rice. It was also necessary to make equipment modifications in the laboratory with the assurance that such changes would be applicable to industrial production of the product.

A process which fulfills these requirements for producing a superior quick-cooking rice has been developed, and involves chemical treatment (1, 3.5 and 7% of a 50-50 mixture of sodium citrate and calcium chloride) of both enriched and non-enriched samples of raw, white, long-grain Bluebonnet rice of known history, followed by pressure cooking, freeze-drying and convective air drying.

Laboratory operations for the preparation of optimal quality instant rice included five major steps: (1) soaking (in four aqueous media--distilled water, and water containing 1, 3.5 and 7% of a 50-50
mixture of sodium citrate and calcium chloride—together with two levels of water temperature, 70° and 122°F, and two periods of elapsed time, one minute and 15 minutes); (2) cooking (heating in an autoclave at 250°F and 15 psig for 2 elapsed time periods—2 and 3 minutes, and heating in water at two levels of temperature, 185° and 212°F, for three periods of elapsed time—5, 10, and 15 minutes); (3) drying (convective air drying at two air flow rates, 88 and 120 cfm, and two air temperatures, 180° and 200°F, and partial freeze-drying followed by convective air drying at 120 cfm and 200°F); (4) rehydration; and (5) organoleptic evaluations.

The data indicated that chemical treatment and freeze-drying were critical steps for the preservation of nutrients during processing.

Chemically treated raw rice soaked at 122°F for 15 minutes, and cooked in an autoclave at 250°F for 3 minutes, followed by freeze-drying and convective air drying, exhibited maximum retention of thiamin, niacin and iron.

When the rehydrated rice was evaluated organoleptically, the color, flavor, cohesiveness and texture were shown to be highly acceptable.

This superior instant rice with these desirable chemical, physical and organoleptic characteristics can be produced industrially by simple process equipment changes.
INTRODUCTION

New convenience food items are now in great demand, since they have become widely accepted by the American public. Instant rice, also called quick-cooking rice, is one such product. In contrast to parboiled rice, which is more dense and requires a longer cooking time than raw milled rice, quick-cooking rices are light, porous, take up water readily, and can be prepared for the table in about 5 or 6 minutes. There are many approaches to rendering raw, milled rice into a quick-cooking product. Essentially the process consists of soaking premium grades of the selected rice varieties in water to attain a moisture content of approximately 35%. The rice is cooked, sometimes under pressure, and subsequently dried under controlled conditions of temperature and humidity in an air stream. Frequently, prior to reconstituting in water, a hot air blast is employed to effect fissuring of the rice kernel. This promotes porosity and aids in speeding of water absorption. Other methods employ pressure cooking followed by release into a vacuum to effect increased porosity of the kernel. More recent approaches to effecting quick-cooking properties employ soaking and cooking of the rice, then freezing, thawing, and dehydrating, or drying. The final dehydrated product can be prepared for consumption in approximately five minutes—or less with the addition of the recommended quantity of hot, boiling water. Several other processes, employing the puffing-gun and pressure-vacuum methods, are responsible for
quick-cooking products.

One of the principal physical modifications of rice produced by most of these methods is that of gelatinizing the starch by the application of heat, with a gradual increase in moisture content to about 70%. Hot water, steam, dielectric, infrared, or microwave energy have been applied as the source of heat. Certain chemical treatments have also been tried to gelatinize starches. However, chemical treatments also employ hot water, steam or both, in gelatinization processes.

Heat treatment of the rice is effected in the presence of the aqueous chemical or chemical solution. An aqueous solution can be used which is initially either cold or hot. Such a chemical may be an alkali metal phosphate, i.e., phosphate of sodium or potassium including orthophosphates, metaphosphates or pyrophosphates. Specific examples are monosodium phosphate, \( \text{NaH}_2\text{PO}_4 \), disodium phosphate, \( \text{Na}_2\text{HPO}_4 \), sodium trimetaphosphate, \( (\text{NaPO}_3)_5 \), disodium dihydrogen pyrophosphate, \( \text{Na}_2\text{H}_2\text{P}_2\text{O}_7 \), and tetrasodium pyrophosphate, \( \text{Na}_4\text{P}_2\text{O}_7 \). The alkali metal phosphates act principally to modify the starch of the rice for increasing its hydrophilic character, but may also modify the protein of the rice to reduce its protection of the starch from water absorption. Trisodium phosphate, \( \text{Na}_3\text{PO}_4 \), is undesirable because of its adverse cross linking characteristics which may actually deter absorption of water by the rice and prevent its gelatinization.

Chemicals believed to act principally to modify the protein structure by attenuation, disruption and/or disintegration are citrates, including magnesium citrate, sodium citrate, \( \text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \), and calcium citrate, \( \text{Ca}_3(\text{C}_6\text{H}_5\text{O}_7)\cdot 4\text{H}_2\text{O} \). Such citrates are not sufficiently effective alone to produce a desirable quick-cooking rice product in conjunction
with heat treatment. Such a citrate should be used either with alkali metal phosphate or calcium chloride, CaCl₂.

Auxiliary chemicals reported as having beneficial effects are fatty acid glycerides, which deter adhesion, and primary or secondary calcium phosphates which facilitate absorption of water by the starch and enhance the whiteness of the rice product. However, use of these chemicals has been shown to result in higher percent of broken rice and to adversely affect the storage life.

Milling, soaking and steaming methods that are presently used for the production of quick-cooking rice remove much or all of the vitamins and minerals occurring naturally in the rice grain. Boiling rice destroys a part of the total thiamin. Soaking, per se, does not lead to loss, but much thiamin is leached out if rice grains split during soaking. Steaming partially destroys the thiamin. However, when rice grains are enriched with vitamins such as riboflavin, a yellow-orange color is imparted to the rice particles which distinguishes the riboflavin enriched material from the conventional product of commerce, making it unacceptable to consumers. In a product in which the enriched material is incorporated in the form of a premix, the colored grains might be individually removed from the mixture and thus the benefits of the vitamin and mineral enrichment are lost to the user. Coatings which are conventionally applied to fortify rice fail to mask the color.

Of the dozens of quick-cooking and enrichment processes and their respective combinations which have been reported over the past thirty years, only a very few have been proven partially satisfactory. There is still active interest among instant rice manufacturers in developing new and improved quick-cooking rice products with the view toward
increasing yields, retaining higher percent nutrients, shortening process time, and improving appearance and other organoleptic qualities—all of which should ultimately increase the total consumption of rice in the United States and elsewhere.

This investigation was designed to develop industrially applicable methods for the production of a quick-cooking rice with pre-selected properties. The end product should have the normal appearance of presently available commercial rice, and the grains should not be appreciably different in size from unmodified rice. Such rice should have substantially the same characteristics of swelling as natural rice, and when finally cooked will have flavor, texture, taste and appearance very similar to ideally cooked conventional milled rice. The processing methods used for the preparation of such quick-cooking rice must have whole grains which are strong and not fractured or mutilated. Avoidance of mutilation of the rice grains minimizes losses of starch and nutrients in the process of preparing the quick-cooking rice.

The modified processes proposed in this research include chemical treatment of raw rice followed by convective air and freeze drying. Raw rice was chemically treated to modify the protein component of the rice so that more water would be available to the starch component by imbibition, and to modify the starch component of the rice to increase its hydrophilic characteristics. These chemical treatments include those which fortify the rice product with calcium, sodium, citrate, etc. Relatively low temperatures used in convective air and freeze drying for drying the product should keep the nutritional losses to a minimum.
Although the results of many investigations on rice research have been available in scientific and technical publications and in trade journals for many decades, pertinent information on processing improvements and the preparation of instant rice is relatively recent and covers a period of approximately twenty-five years between 1950 and 1975. Selected references on these topics have been abstracted, and brief summaries of their important findings are presented below.

Standard milled rice, depending on variety and grain size (long, medium or short), requires from 20 to 35 minutes to cook to a satisfactory culinary acceptability when boiled according to usual recipe directions. In some instances the rice is soaked and boiled, then washed and steamed, which requires a total attention time of about an hour. The relatively long preparation time in the home--plus an occasional pot of sticky, pasty cooked rice--has restricted rice consumption in the United States for many years. Thus, considerable efforts have been directed to the development of quick-cooking rice products with the view toward increasing consumption of rice and developing profitable new products.

The preparation of quick-cooking rice from raw rice generally involves the operations of soaking, cooking and gelatinization followed by drying of the product. Certain pretreatments are necessary to facilitate hydration and gelatinization (15). Although the general procedure for producing most instant rice products involves the above steps, variations in the procedure have a significant effect on the time of cooking and the
characteristics of the final product.

Soaking

Much of the instant rice produced today utilizes soaking by a spray hydration process patented by Ozai-Durrani in 1960 (49). Washing and rinsing for long periods of time prior to cooking removes up to 25% of the original weight of the rice and eliminates substantially all of the vitamins and minerals as well as most of the taste and flavor. Such losses are reduced by using the Ozai-Durrani process (49) whereby the moisture content of hulled rice is increased by moving the rice through successive sprays of water, thus limiting the amount of water used for initial hydration. The amount of water emerging from the sprays is varied according to the coefficient of absorption of the rice. This coefficient varies somewhat with different types of rice and with the temperature of the rice and of the water. The extent of milling, parboiling, and other conditions also have an effect on this coefficient. Preferably no more water should be used than the rice grains can absorb (15).

Spraying permits the rice pores to absorb water more quickly and transmit it to the inner segments and interior of the grain more rapidly than does submerging the grain in a volume of water. The time necessary for rice to reach the saturation point depends upon the degree to which the grains have been milled and the temperature of the hydrating sprays (15).

At the saturation point the rice has a total moisture content of about 30%, feels dry to the touch and is free flowing. During the initial steps of hydration the rice grain is observed to absorb moisture
through 5 to 8 or more channels running crosswise of the grain and distributing moisture to other parts of the grain. The end from which the embryo has been removed allows very rapid water penetration. As the moisture content increases, the rice grains become opaque after the moisture is equally distributed throughout the grain. This rice is easily friable to a granular moist flour-like state.

When the grain is viewed under magnification it is seen to have water droplets encircling the entire surface of the grain. A longitudinal or lateral cross-section of the grain viewed under high power shows enlarged starch granules suspended in water. The grain is nearly impervious to light transmission and appears to be a compressed, snow-like, white mass. The grain is thus changed during hydration from a translucent state to an opaque state.

It is not essential to completely saturate the grains with moisture prior to the cooking or gelatinization step.

Cooking and Gelatinization

The cooking of rice results essentially in the gelatinization and swelling of the starch granules in the rice endosperm, with absorption of water. Rice varieties, because of their various physical and chemical structures, differ significantly in their cooking and processing qualities. Well-cooked milled kernels of short- and medium-grain varieties are usually relatively firm and sticky, whereas long-grain varieties are flaky and maintain grain integrity.

Numerous attempts have been made to relate the chemical and physical properties of rice kernels and rice starch with the hydration and processing characteristics of commercial milled rice. Several
investigators have reported a close association between amylose content of rice and its swelling characteristics. Long-grain varieties are the highest in amylose content (23, 54, 79). The temperature of gelatinization seems to be an index of the ease of cooking polished rice (72). High amylose rice absorbs more water and increases more in size during cooking than does low amylose rice.

Primo and co-workers (52) demonstrated that the protein content of the outer layer of cooked polished rice grains differed among varieties and had a highly significant negative correlation to cohesiveness. Cooking time increases with protein content. The protein matrix around starch granules is a physical barrier to water absorption (8). Low protein rice is more tender, more cohesive and of a sweeter flavor than rice with higher protein levels (33).

Many investigators report that the thickness of the cell walls of the rice endosperm could be an important consideration in cooking quality since disintegration of rice grains while being cooked was localized and marked by thin cell walls and protein matrices. Water absorption during cooking may thus be a function of the surface area of the kernel aside from other physiochemical considerations (31).

The characteristics of the starch are of the greatest importance when considering the cooking qualities of rice. Each type of starch, i.e., rice, corn, wheat, potato, has starch granules of a characteristic shape and size. These granules are organized in distinct spherules within parenchyma cells. According to Trubell (75), the rice starch granules are the smallest of the starches of commerce; their sizes range from 3 to 8 microns. Only certain, rare, noncommercial starches have smaller granules than rice starch (64). The large rice granules are
about the same size as, but more angular and smaller than, those of corn. They are polygonal in shape and are sometimes found in honey-combed clusters or in compound granules, the outline of the whole being either round or polygonal. Starch granules are deposited in layers in the plant storage area. This process is known as apposition or the depositing of the most recent starch on the outside of the granule. The granule increases in size with maturity and undergoes a proportionate increase in linear content (76). Because of the small size of the rice granule, the characteristic features such as the hilum, striations and birefringence are not very distinct. The polygonal shape of rice may be due to close packing and compression of the starch granules during grain development (30).

Rice starch is composed of glucose in polymers of two types. This was first shown by Maquenne and Roux in 1904 (10). Haworth and Meyer later elucidated the structure of these compounds (16). One is a simple linear chain with alpha 1,4-anhydroglucosidic linkages known as amylose. In the other fraction, known as amylopectin, the regularities of the chain are interrupted with frequent alpha 1,6-anhydroglucosidic branching. The synthesis of this starch fraction involves a transferase regulating the progressive condensation of the glucose units (62, 65).

Molecular size and shape give high polymers of which the properties are very different from the basic units. This is evidenced by the ability of linear chains to associate in strong intermolecular bonds and form insoluble precipitates, whereas the highly branched molecule is less prone to associate. Its presence in a mixture of starch has a modifying influence on precipitation of the starch amylose (65).

Starches are often divided into two groups, according to the
proportions of the branched and unbranched molecules. Those high in amylose are termed non-waxy, while those with a minute amount are termed waxy. Waxy (or glutinous) rice contains only miniscule amounts (0.8 to 1.3%) of amylose which is probably located in the center of the granule (30).

The texture and appearance of cooked rice reflect the ratio of the two starch fractions. Increasing the amylose content improves the capacity of the starch granule to absorb water and expand without collapsing. This effect is due to the greater capacity of amylose to form hydrogen bonds.

Gelatinization is the process by which the application of heat and water result in hydration and irreversible swelling of the starch granule. The swelling may be attributed to the chemical hydrophilic affinity of the hydroxyl groups of the starch molecules for the solvent (40). The degree of association and the molecular arrangement within the crystalline micelle, which is largely the linear fraction, is responsible for maintaining granule integrity during swelling (63).

When starch granules are placed in cold water only the amorphous region will take up water. This is by loose associative bonding which causes a swelling of about 10% to 15% (63).

The relative concentration of amylose and amylopectin are of paramount importance in determining the physiochemical properties of rice. The amylose content of non-waxy, milled rice may constitute 7% to 33%, but waxy rice has an amylose content of only 0.8% to 1.3% of its dry weight (30).

Starch molecules within a granule are not deposited in a uniform manner, but rather unevenly with the bonding forces differing in
different areas of the starch granules. This can be shown by the unequal resistance to attack during digestion with either acid or enzymes. Certain parts of the starch molecule are thus believed to be in a compact, highly ordered crystalline state. The crystallinity of the starch has been ascribed to the amylose fraction by many investigators (85); however, the crystallinity has also been reported to be due mainly to the amylopectin moiety since glutinous rice also has an X-ray diffraction pattern identical to that of non-glutinous rice.

Starch granules are composed of starch molecules associated by hydrogen bonding either directly or through water hydrate bridges which produce a three-dimensional network controlling the behavior of starch in water. Treatment of an aqueous suspension of starch with heat or appropriate chemicals weakens the network within the granules by disruption of the hydrogen bondings, thus permitting easier penetration of water into the granules and an irreversible granule swelling, a process termed gelatinization (40, 53).

The gelatinization of starch by heating in water occurs in three distinct phases. In the first phase water is slowly taken up, accompanied by a limited swelling. This phase is reversible, allowing the starch to be dried to the initial state with no obvious changes in appearance or birefringence (polarization crosses when viewed under a microscope in plane, polarized light) of the starch granules. The second stage is characterized by a sudden many-fold swelling of the granule, taking up a great deal of moisture and a rapid loss of birefringence (loss of birefringence is the preferred criterion of gelatinization temperature). This second stage occurs in a relatively narrow temperature range. During the third phase, which occurs with increasing
temperature, the granules become almost formless sacs with the more soluble part of the starch being leached out.

With increasing crystallinity an increase in gelatinization temperature is observed. This depressed ability of the starch molecules to swell results from a higher degree of hydrogen bonding with its associative forces increasing the crystallinity and the temperature required for gelatinization (31).

Meyer in 1942 (45) proposed molecular radially oriented bundles or "micelles" within the layers of the granule, with intermingled and branched molecules radially oriented toward the hilum (the botanical eccentric origin of the granule) and the aldehydic terminals pointed inward. The micelles are formed whenever linear segments of the branched fraction or the linear fractions parallel each other and associate by hydrogen bonding between the hydroxyl groups on neighboring chains. A chain is not restricted to one bundle but may participate in several micelles, thus forming three-dimensional lattices of micelles. Between the loosely organized regions of the micelles are regions of more amorphous and loose character where the chains criss-cross randomly. These intermicellar regions impart a degree of elasticity to the granule as is reflected by the reversible swelling or absorption of water (83). This arrangement of micellar and intermicellar regions with their differing degrees of organization give rise to the polarization cross and beta X-ray diffraction spectrum of the granule (45).

Gelatinization, pasting characteristics and cooking behavior of the many varieties of rice can be largely explained by two factors: (1) the formation of amyllopectin and amylose into micelles within the crystalline granule, and (2) the presence and properties of the two
starch fractions in their particular special conformation.

The degree of branching in each of the starch polymers accounts for the difference in physical properties between amylose and amylopectin. Although amylose is generally considered to be a straight-chain polymer, it does branch on occasion. Because of its greater branching, amylopectin is a larger molecule than amylose. Experimenters using light scattering (passing monochromatic light through a solution of starch and measuring turbidity by the angle of refraction) have determined the average molecular weight of potato starch amylose to be $1.9 \times 10^6$ while the average molecular weight for amylopectin was $36 \times 10^6$ (45). Both starch polymers show considerable variation in molecular weight.

The degree of branching varies considerably in starch. Amylose branching commonly varies in degree from 200 to 2000 glucose units depending upon the plant source, while amylopectin has degrees of polymerization ranging over 200,000 glucose units (83). The average length of the individual branches ranges from 25 to 30 glucose units (65).

Amylopectin forms stable solutions in water but amylose is only slightly soluble and will not dissolve directly in water. Amylose must first be subjected to dilute alkali treatment (0.1N to 1N sodium or potassium hydroxide) and then neutralized before it will dissolve in water. Even after such treatment turbidity sets in and the amylose precipitates (20). The dilute alkaline treatment probably ionizes some of the mildly acidic hydroxyl groups on the polymer (pK approximately 12), thus enhancing the solubility of the polymer. Such alkaline treatment is, however, often detrimental since both amylose and amylopectin are prone to oxidative degradation under such conditions (20).
Unbranched amylose has a greater capacity to form hydrogen bonds than amylopectin (30). It is thus more capable of absorbing water and forming water bridges.

When reacted with iodine amylose gives a strong blue color, while amylopectin gives a much weaker red color. This shows the tightness with which iodine is bound (20). These results indicate that although both polymers are helical, amylose is a stiff coil while amylopectin is a random coil. The tightness of the coil accounts for amylose's poor solubility in water because fewer sites are available than on the more flexible random coil of amylopectin. It has been postulated that the tight amylose coil is held by hydrogen bonding between the oxygen atoms of the carbons of a glucose or a glucose residue and between oxygens on carbons six and two of glucose units in neighboring turns of the helix (20).

The appearance does not change until sufficient heat and water are supplied to overcome the cohesive forces of the intermolecular bonds of the highly hydroxylated glucose polymers. When this energy is supplied the granules swell and begin to lose their polarization cross, with both actions beginning at the hilum and progressing toward the granule periphery. This point is termed gelatinization temperature (83).

Gelatinization is believed to start in the more accessible loosely bonded intermicellar regions (40), and to be facilitated by the dissociation caused by heat-imparted motion (76). The intermicellar regions differ in their degree of association in each granule of a starch, therefore a starch will gelatinize over a range of temperature rather than at one point (usually a range within 10°C). Swelling of the granule after initial gelatinization results in the eventual collapse or rupture of
some of the granules, causing dispersion of molecules, granular fragments, and associated molecules.

The amylose content has a substantial effect on the swelling behavior and gelatinization because of its heavy hydroxylation and the linear arrangement which allows amylose chains to approach one another and strongly form hydrogen bonds. The temperature of gelatinization is elevated since considerable energy is necessary to overcome these forces. In starch chemistry it is generally agreed that the higher the linear content, the stronger the intermolecular association within the granule (65); in rice, however, the linear content appears to have no influence on gelatinization temperature (32).

Starches may be gelatinized by solvents other than water. There are considerable differences in the possible extent of gelatinization and the concentration of solvent necessary for gelatinization. Only low concentrations of sodium hydroxide are required in the gelatinization of starch. The critical concentration for gelatinization with each solvent varies with the species of starch (40).

Starch derivatives are defined as chemically modified substances in which the chemical structures of glucose units have been altered (57), but which retain the intact starch molecule to an appreciable extent.

Starch in its native state cannot be widely used in the food industry. Small changes in the starch molecule are required to extend the usefulness of starch for different purposes. Industrial techniques used to modify the characteristics of starches in the past 35 years have given rise to a number of derivatives to improve textural qualities, thickening and stabilizing properties (83).

Various types of starch derivatives such as starch esters, ethers,
oxidized starches, and cross-bonded starches have been prepared in order to modify different characteristics of starch. These derivatives are characterized by the nature of their chemical modification and their degree of substitution, which is the average number of substituents per D-glucose unit. Each of these glucose units along the starch chain has unsubstituted hydroxyl groups on carbon atoms 2, 3, and 6. The maximum possible degree of substitution is thus 3.0 for each glucose unit. The starch derivatives can then be characterized as having either a high (over 2.0 substitutions per glucose), or a low (less than 2.0) degree of substitution.

Substitution of the hydroxyl groups in starch with either organic or inorganic radicals will yield starch esters. It is necessary to pretreat the starch in order to overcome the poor reactivity of starch molecules. The nature and conformation of the starch granule has a profound effect upon the chemical reactivity of the starch. The crystallinity resulting from inter- and intramolecular hydrogen bonding in starch granules represents associative forces that strongly resist the penetration of reagents of low polarity. Many methods have been developed for disrupting the natural compactness of the starch granules in order to bring the starch into a readily esterifiable condition. The best methods use a swelling or disorganization of the starch granules by reagents which produce little or no degradation of the starch molecule. Complete destruction of the granule is not required for improved reactivity.

Numerous reagents such as water, alcohol, aqueous pyridine, sodium peroxide, hot glycerol, alcoholic hydrochloric acid, 85% phosphoric acid, formic acid, and other acids have been employed for
activation of starch, but with a few exceptions most of these reagents cause some degradation in the starch, making them unsuitable for this use (81).

The majority of starch derivatives are formed by relatively low levels of substituent groups reacting with the hydroxyl groups of the unswollen starch to prevent side-by-side alignment of linear molecules. Levels of from two to ten substitutions per hundred glucose units have been suggested as optimal (40, 63). With the use of mild reagents, such as epichlorohydrin or phosphorous oxychloride, ether or ester bridges are formed. Because of the low degree of substitution on these molecules, the starch remains relatively unchanged but the effect upon its physical properties is profound. Cross-linking strengthens the granule by reinforcing the hydrogen bonding of the molecules during cooking.

A common method of preparation of derivatives of a low degree of substitution is to add a limited quantity of the derivatizing agent to uncooked starch slurried in water containing a strong alkaline solution and an inorganic salt, and to hold the slurry at some temperature below the gelatinization point until the reaction is completed. In this technique, a strong base is used as a catalyst and activating agent. Although starch granules can be completely gelatinized in aqueous alkali, the degree of granule swelling depends upon the nature of the starch, the relative amounts of starch, alkali, and water, the nature of the alkali, and the presence or absence of neutral salts which inhibit granule swelling (84).

In aqueous alkaline slurries, most of the alkali is absorbed by the starch granules. This sufficiently enhances the reactivity of the resulting alkali-starch complex to enable it to compete successfully
with water in reactions with compounds subject to nucleophilic attack.

Reactivity of the starch in aqueous alkali is further increased by the addition of neutral salts. These salts shift the starch alkali absorption equilibrium such that alkaline absorption is increased, probably by decreasing the effective water concentration through solvation (56).

Different organic and inorganic starch esters have been extensively investigated, both as to manner of preparation and to properties of the starch esters. Of these, the starch acetates have received the most attention because of their ease of preparation and their useful properties in the food and textile industries (57). Pyridine is the most commonly used catalyst for the preparation of starch acetates with a high degree of substitution. The aqueous alkali method is the most convenient way to prepare starch acetates with a low degree of substitution. In both of these methods acetic anhydride is the preferred acetylated agent. Starch may also be acetylated by heating with relatively small amounts of glacial acetic acid, but because direct esterification leads to some degradation of starch it is not a suitable way to produce starch acetates (57, 82).

This same basic procedure can be used to produce low degrees of substituted derivatives of diabasic acids such as succinic, which is capable of yielding a half-ester with a free carboxyl group.

Caldwell (10) reported that starch granules acetylated in alkaline systems with acetic anhydride yield a product which readily absorbs water. Roberts (57) similarly reported that the introduction of carboxyl substituted ester groups increased the hydrophilic character of starch esters, especially in alkaline systems.
Rutledge et al. (61) proposed a technique of strengthening starch granules by cross-linking or reinforcing the hydrogen bonding of the molecules. This technique involves the use of epichlorohydrin to strengthen the inter- and intramolecular bonds within the rice kernel in canned rice. Such treatment improved canning stability of rice by reducing distortion of grains, increasing resistance to overcooking and producing 78% lower solids losses.

The use of succinate as a stabilizing group in deriving starch fractions was patented in 1946 (34). The application of succinates in improving instant rice was investigated by Yaghoubian (84), who used succinic anhydride.

Roberts et al. (60) found that citric acid caused rice to be tough or rubbery when boiled in 0.01% to 0.1% citric acid solutions. Citric acid is widely used in breakfast foods as a chelating agent to inactivate the catalytic effects on oxidation by trace metals such as iron and copper (6).

Rice Processing

During the cooking step the rice may be processed by any of several methods to raise the temperature above the gelatinization point. In many processes the quantity of water is limited so as not to significantly exceed the amount which the rice can absorb. After gelatinization the entire grain should be tender throughout and easily crushed. It should appear and taste like cooked rice and be increased in volume two or three times over that of nonhydrated rice.
Drying

The rice, after having been cooked and gelatinized and moisturized to an extent compatible with retaining the starch cell walls and the intact identity of the rice grain, may then be treated in any suitable manner to reduce the moisture content. Drying is most commonly accomplished by subjecting the grains to air drying until a stable moisture content of between 10 and 14% total moisture is reached. The drying temperature is not critical. Alternately, the rice grains may be chilled and then subjected to a hot air blast. It is preferred that the air blast be forced through the spaces between the grains of the rice so that the moisture of each grain is reduced simultaneously. This allows for uniform dehydration throughout the grains of rice without collapsing the cell walls (15).

Generally the dehydration following the cooking and rinsing steps is not critical if the pretreatment (the fissuring and/or initial hydration) and cooking of the grains has been carried out to achieve maximum gelatinization of the rice. Usually rice is dried on belt driers where the cooked rice is loaded to a depth of about one inch. Humidity and temperature are controlled at different levels for different sections of the drier. The object of effective drying is to remove the particle water from the surface of the grain at a rate which will minimize case-hardening and will also permit water to diffuse rapidly from the interior surfaces while keeping shrinkage to a minimum. Several procedures are used in the industry to insure uniform drying throughout the bed (15). Other drying techniques are used which impart a porous structure to the grains and thus permit rapid diffusion of water to the surface. This is accomplished by puffing and other expansion processes.
Minute Rice, marketed by General Foods, was the first convenience rice on the market. It utilized the Ozai-Durrani patent (46) whereby raw milled white rice was soaked in water at room temperature to increase the moisture content. Water absorption in rice is maximal at elevated temperatures, thus modern processes soak at 65° to 75°C for 25 to 27 minutes. The rice is then cooked at 95° to 100°C for 12 to 14 minutes to increase the moisture content to 65 to 70%. The rice is drained, cooled and washed with cold water for one to 2 minutes. Drying conditions are critical with moisture being removed more rapidly from the surface than the rate of diffusion from the interior to the surface. A forced air drier is utilized with an inlet temperature of 140°C and an air velocity of 200 feet per minute to dry the rice to a final moisture content of 8 to 14%. The initial high temperature causes a fast moisture removal from the surface, preventing shrinkage and promoting a porous structure in the kernels. The residual moisture is removed with gradually decreasing temperatures. Some hard ungelatinized parts remained at the center of the kernel of the early Minute Rice, which after adding boiling water required 10 to 15 minutes to be completely cooked and ready to serve.

Numerous improvements on this procedure have been instituted by different investigators, thus reducing the preparation time and improving the quality of the finished product. The 1956 Durrani Basic Process (47) utilizes a pregelatinized rice with a moisture content of from 30 to 70%. This pregelatinized rice is then pressed and dried to a 10 to 14% moisture content. Seltzer also has patents for the preparation of a quick-cooking rice by pressing pregelatinized rice (66, 67). The rice prepared by these methods is dried to a glassy texture rather than a
porous one. This type of rice is most commonly used in dry soup mixes with the process being modified to give the rice the characteristics of hydration necessary for the particular product usage.

Attempts have been made by numerous investigators to facilitate and decrease the soaking and cooking operations by producing small cracks throughout the kernels prior to soaking or cooking (68).

The General Foods Fissured Rice Process was patented by Hollis et al. (24) in 1958. In this process the raw milled rice was subjected to heating in dry air at 93°C for 15 minutes to produce numerous small cracks or fissures extending inward from the surfaces of the grain. The grains were then partially cooked in water at 92°C for 11 minutes to provide a layer of gelatinized starch. This layer of gelatinized starch retains the integrity of the grain during the subsequent steam-cooking. Also by discontinuing water cooking at a point short of surface overcooking the usual losses due to excessive swelling and bursting of the starch granules on the surface of the grain are prevented. The grain is subsequently steamed at atmospheric pressure for 10 minutes. This supplies the heat required to complete gelatinization of the starch throughout the grain while controlling the amount of water available to the starch, thus controlling the bursting of starch granules. The cooked-steamed rice is washed with cold water, drained and dried by passing it through a forced air drier at 121°C and a velocity of 175 feet per minute. Because of its greater size, uniform and complete gelatinization, and greater porosity, this rice product is superior upon rehydration to any such product produced at an earlier time.

The General Foods Stepwise Hydration and Cooking Process patented by Flynn and Hollis (17) was another attempt to produce a porous dry
product. The principal steps in this process comprise heating partially hydrated rice in the absence of water to cause partial gelatinization of the starch; then further hydrating of the rice to increase its moisture content and cause partial enlargement of the grains, while heating to complete gelatinization. The rice is then dried to a stable moisture content under conditions such as to retain at least a substantial part of the enlargement of the wet grains and to produce a dry porous structure.

Several investigators have attempted to produce a suitable x-expanded volume pregelatinized rice as a quick-cooking rice (18, 59, 78). The main procedure in all cases utilizes a hot medium (150° to 260°C, or higher) such as air or oil to puff the pregelatinized dry starchy kernel of rice (53). Products prepared by this procedure are usually very light and crisp, and when hydrated in water yield a mushy and slightly off-color rice with an atypical flavor. They are used as breakfast cereals or in the preparation of flavored rice dishes, or casserole-type products.

An effective heat expansion method was developed by Wayne (78). In this process moist, gelatinized grains are injected into a fluidizing gas stream which is maintained at a sufficient temperature to vaporize and cause escape of moisture from grains and thus expand them. The gas stream has sufficient velocity to carry the expanded grains to the terminus of the gas stream and thus to separate the expanded grains from the unexpanded grains. The degree of expansion of rice is due to the formation of steam from the moisture within the rice kernel, and may be controlled by adjusting the temperature of the fluidizing gas stream.

Gun-puffing (18) can be used to produce a quick-cooking rice
product provided that the degree of enlargement is no more than that ef-
affected by the normal cooking procedure (2 to 3 times its original size). Gun-puffing is dependent upon the terminal temperature and moisture con-
ditions (those conditions just prior to release of pressure) at which point the vapor pressure of the kernel corresponds to that of saturated steam. The grain puffs when the pressure is released allowing this vapor to expand.

Roberts (59) patented an expanded rice produced by hydrating the rice to an equilibrium moisture level in warm water (up to 65°C), fol-
lowed by pressure cooking the rice in steam until completely gelatinized. This cooked rice is then dried at a low temperature (35° to 100°C) to a moisture content of from 8 to 14% before it is subjected to a blast of hot air (200° to 260°C) causing rapid expulsion of residual moisture and the resultant puffing of grains to about four times that of the original white rice.

Carman and Allison (12,13) described vacuum chambers to expand the rice volume and produce a porous structure for a quick-cooking rice. Raw white rice is conditioned to a moisture content of from 20 to 22% and steamed in a reduced pressure chamber (1.5 inches of Hg), until the rice is completely cooked. The pressure is then quickly released, throw-
ing the rice into an expansion chamber which has a reduced pressure of about 0.1 inches of Hg. This causes the expansion of the rice. The vacuum is then released and the product is discharged. The puffed pro-
duct is then dried to below 15% moisture content. The finished product can be cooked and served in about five minutes, but is not commercially successful in the United States.

Dry-heat treatment has been used by different companies to
produce a quick-cooking rice which can be prepared and served in 10 to 15 minutes. In this method raw white or brown rice is exposed to either circulating air at 57° to 82°C yielding a product that can be cooked in 10 minutes, or to circulating air at about 270°C which produces a chalky and probably dextrinized rice endosperm with some degree of swelling. This can be prepared for serving in 15 minutes (58).

An effective development in commercial quick-cooking rice production involved the extra step of freeze-thawing, which resulted in a successful product in the United States. In this method rice is steeped, cooked, and may be steamed to bring the rice starch to complete gelatinization, washed with an excess amount of cold water to cool it and prevent self-cooking, drained and frozen. Freezing must be slow in order to insure the formation of large ice crystals which break down the colloidal starch structure and produce a porous kernel. Before drying, thawing at room temperature prevents the grains from adhering together, and thus yields a high quality product. The thawed rice is then dried to a moisture content of 8%. This process was described by Keneaster and Newlin in their patent of November 19, 1957 (34).

A similar method was patented by Ozai-Durrani on June 15, 1965 (48). In this process the rice is cooked until completely gelatinized and then rapidly frozen. An expansion occurs in the individual starch cells which causes the cell walls to rupture somewhat and be more amenable to subsequent rehydration. The frozen rice is then subjected to a controlled thawing treatment such that the water in the rice is slowly thawed and allowed to reabsorb in the grains but not be separated from the grains.

This controlled rate of thawing is the essential feature of the
process. If the rate of thawing is not controlled and is permitted to proceed at a rate more rapid than the rice grains will absorb the melted ice, the grains will shrink, thereby losing volume and collapsing into flat grains. If the controlled thawing treatment is successful, the expanded condition of the rice grains is retained on thawing. After the water is completely thawed and reabsorbed by the grains, the rice is dried by ordinary air drying.

A very high quality instant rice can be produced by freeze-drying. In this process, patented by Wayne in 1963 (13, 77), gelatinized rice is subjected to a freezing operation at a temperature sufficiently low and for a period sufficient to freeze the interstitial water and the gel-bound water as ice. The frozen gelatinized rice is subjected to a sublimation operation under the dynamic conditions of a vacuum, or while subjected to the drying action of air or other low humidity gases between the freezing point of gelatinized rice (26° to 28°F) and 32°F, until one-third to one-half of the ice as ice vapor is removed leaving voids or pores in the rice. In terms of time and expense it is not economical to remove all of the bound water by sublimation. After partial removal of the interstitial water and the gel-bound water by sublimation, the resulting rice product is sufficiently dry and free-flowing to permit its handling by a drying operation. The residual moisture is removed in hot air currents (300° to 600°F) with controlled humidity to avoid browning. This produces almost instant flashing and expansion of the moisture within the product, some of which escapes as superheated water vapor and leaves further voids or pores within the product.

Gorozpe (27) patented a method of producing a rice product by controlling the rate and degree of gelatinization at every step of
manufacture. Rice grains are hydrated in water below the gelatinization temperature (approximately 55°C) until the rice is saturated with moisture. Hydration is continued intermittently while maintaining the temperature of each layer of the rice grain above the gelatinization point until that layer of the rice grain is gelatinized. This eliminates over-gelatinization of the portions already gelatinized.

**Chemical Treatments:** One of the principal physical modifications of rice produced by most of the methods thus far developed is that of gelatinizing the starch by the application of heat, with a gradual increase in moisture content to about 70%. Hot water, steam, dielectric, infrared, or microwave treatments have been applied as the thermal source. Certain chemical treatments can also be used to gelatinize starches. In various investigations of the application of chemical treatment to producing quick-cooking rice, few processes have been patented.

Lewis et al. (41) used a saturated sodium chloride solution at 80°C which partially gelatinizes the rice. This treatment reduces the cooking time of the dry product and increases its resistance to vermin and microbial attack.

Tanaka and Yukami (73) soaked rice in a solution containing 0.05 to 0.5% phosphates or polyphosphates, 0.3 to 10% saccharide (lactose), and a 0.25% surfactant (glycerol monostearate) until the rice was about 70% gelatinized with a moisture content of from 50 to 70%, then steamed to complete gelatinization and rapidly dried. The finished product is said to recook in five minutes.
Nutrients in Rice and Enrichment

Milling, steaming and drying of cereal grains such as rice remove much or all of the naturally occurring nutrients. Therefore, the commercial rice sold in the supermarket is commonly enriched with vitamins and minerals.

Data on the composition of rice and rice products were published by Watt and Merril (76) and McCall et al. (42). A comprehensive tabulation of compositional data for rice was compiled by Juliano (29), together with an extensive bibliography of articles from which the data were taken.

Summaries of vitamin content of rices were compiled by the Food and Agriculture Organization (19), McCall and co-workers (43), Julian o (29), Kik (35), and Kik and Williams (38).

The protein content and amino acid profile of rice and rice products were reviewed by Houston and Kohler (25).

Studies by Juliano and co-workers (31) revealed that the protein content of rough, brown and milled rice varied significantly among varieties. The Asian varieties were generally of lower protein content than those varieties planted in the United States, with one exception in the first crop and one exception in the second crop. They also pointed out a difference of some 4% in protein content of the same variety of rice planted in different seasons.

McCall et al. (43) investigated the influence of variety and environment of growth on the physical and chemical composition of different rice varieties. They reported that both variety and environment had a highly significant influence on yields of milling and anatomical fractions of rough rice and the composition of true bran. Variety was
reported to have a highly significant influence on the lipid content of white rice and a highly significant influence on the nitrogen content of white rice and the ash content of hulls. Environment had a highly significant influence on the ash content of hull and on the lipid, nitrogen, ash and starch content of the white rice.

Borasio and Gariboldi (5) made a comparative study of the protein content of Avorio and Cristallo Processed rice. They reported a protein content of 6.30% for Avorio rice, 6.95% for Cristallo rice, and 6.10% for normal milled rice. It was pointed out that the improved chemical composition of milled parboiled rice is due to the decrease in removal of material during milling. This decrease is attributed to the increased hardness of the kernels.

Cagampang et al. (11) reported results of studies on the soluble fraction of the protein of milled rice, bran and polished rice of high and low protein samples. He showed glutelin to be the predominant fraction in the whole grain, the milled product and in the rice polish. Albumin and globulin are the major proteins of the bran and are concentrated there during polishing. Prolamine is rather evenly distributed in all three fractions. The differences in the total protein content of the whole grain are mainly due to differences in the glutelin content.

The influence of parboiling on the protein fractions was studied at the International Rice Research Institute (25). Parboiling was shown to have no effect on protein content but reduced the extractability of protein by an average of 45%. The globulin fraction exhibited the largest reduction--65%.

Tamura and co-workers (74) reported the amino acid composition of the four main protein fractions of milled rice, pointing out the high
concentration of lysine in albumin, cystine in globulin, and of leucine and proline in prolamine.

Significant negative correlations between crude protein content and percentages of lysine, methionine, and threonine in a series of 16 rices were observed by Juliano and co-workers (31). Positive correlation was found for tyrosine, arginine and leucine.

Hunter, Ferrel and Houston (26) reported the free amino acids of fresh and aged parboiled rice. Greatest initial concentrations were observed for alanine, aspartic acid, and glutamic acid. Those in intermediate concentrations were arginine, asparagine, glycine, leucine, lysine, proline, serine, valine and one unidentified ninhydrin-reacting compound. Those in the lowest concentration were cystine, histidine, methionine, phenylalanine, threonine, tryptophan and tyrosine. A significant loss of amino acids during accelerated storage was indicated by the intensity of the amino acid spots.

Aykroyd, Krishnan and Sundararajan (2) pointed out that machine milled rice from raw rough rice contained 1.0 ng/gm of vitamin B₁. Machine milled rice from parboiled rice contained 2.20 ng/gm. Similarly, milled rice from raw rice had 16 ng/mg nicotinic acid, while milled rice from parboiled rice had 38 ng/gm.

According to Kik et al. (35) rough rice or paddy had 3.0 ng/gm of B₁, polished rice 0.6 ng/gm, while rice bran had 21 to 31 ng/gm of vitamin B₁. Later, Kik (36) reported that the Conversion and Malekised processes yielded products that showed greater retention of vitamins than did untreated rice.

The distribution of thiamin in rice was discussed by Simpson (70). He confirmed that the thiamin was largely centered in the scutellum but
that the riboflavin was more uniformly distributed throughout the embryo.

Investigations on the losses of vitamins during parboiling and mechanical drying were made by Mitra and Chandhuri (44). Using Rupsal, Patna and Sitosal varieties grown in West Bengal, the losses of vitamins were reported to be negligible. About 17 to 20% of the thiamin was lost along with the bran during milling.

Bhattacharya and Rao (4) studied the effect of parboiling conditions on thiamin contents of rice. Their findings indicate that parboiling destroys part of the total thiamin content of the paddy. Soaking per se did not lead to losses, but much thiamin was leached out if rough rice split during soaking. Soaking at high pH may also reduce thiamin. The thiamin has been shown to be protected during milling by high temperature soaking or by soaking and steaming.

There has been a continued interest in vitamin enrichment of rice since the discovery by Ejkman in 1927 that beriberi was caused by the lack of a nutritonal factor, later shown to be thiamin, in milled-rice diets. Direct addition of synthetic thaimin and niacin is required by law in South Carolina, Puerto Rico, and parts of the Philippines. Standards of identity of enriched rice have been issued by the U.S. Food and Drug Administration (1957) (Table I).

<table>
<thead>
<tr>
<th>TABLE I. Levels of Nutrients in Enriched Rice</th>
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<tbody>
<tr>
<td>Thiamin, mg/lb</td>
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<tr>
<td>Riboflavin, mg/lb*</td>
</tr>
<tr>
<td>Niacin, mg/lb</td>
</tr>
<tr>
<td>Iron, mg/lb</td>
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<tr>
<td>Calcium, mg/lb</td>
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<td>Vitamin D, USP units/lb</td>
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*The requirement for riboflavin is stayed until final action to dispose of objections to yellow color imparted to rice (7).
The rinsing and decantation of cooking water which is common in many countries depletes the nutrients of rice to such a great extent that the mode of cooking becomes a prime concern governing the feasibility of effective nutrient improvement of milled, white rice (30). In the late 1940's the Hoffman-LaRoche Process (21, 22) solved the problem of providing an enriched rice to the consumer with the first rinse-resistant premix. In this process a water-resistant zein coating is applied at a rate of one-half pound per 99.5 pounds of white rice. A similar process was developed by the Merck Company. This process coats the rice with a white shellac (39). In both of these processes talc is dusted onto the enriched cereal grain while the coating material is still tacky. Minerals such as iron may also be added to the cereal grain in the dusting powder. Titanium oxide has been used in some instances to cover up the yellow color imparted by riboflavin enrichment.

The vitamins and minerals may be added to all of the grain kernels or a highly fortified premix may be prepared. Preferably such a mix is formed by fortifying a portion of the cereal grain with a highly concentrated amount of vitamins and minerals in the manner described. The premix is then mixed with unenriched rice in a proportion of one part enriched grain to 199 parts of unenriched grain to produce a total mixture fortified with the desired proportions of vitamins and minerals.

Packaged rice, as distributed through retail outlets in the United States, is enriched by adding a powdered premix at the rate of 0.5 to 1 ounce per 100 pounds of finished white rice. The powdered premix adheres sufficiently to the rice to provide good distribution of enrichment during customary handling. Since this enrichment would be removed by rinsing the rice before and after cooking, retail packages of rice enriched
with the powdered premix are labeled with the caution that the rice should not be rinsed before or after cooking (69).

Cooking and Processing Quality

Until recent years, the quality of rice in the United States was judged solely on the basis of its milling quality, those factors affecting milling yields, and on cleanliness and purity of the rice. However, in 1951 a long-grain variety was released for commercial production which proved to be unacceptable to the consumer. This pointed out the need for developing tests for cooking and processing quality to insure that new varieties possessed the inherent cooking and processing characteristics required by the ultimate consumer before being released for production.

Several methods of measuring important quality characteristics of rice have been reported in the literature. Most of these tests are related in some manner to palatability tests of the rice. In the United States the average consumer desires a rice which will cook to a creamy-white color, with tender, well-separated grains possessing a bland flavor.

Qualitative differences among varieties were observed by Jodon and Jenkins (28) by cooking 25 to 30 grams of rice in aluminum coffee balls in an excess of water for 18 to 20 minutes. Rao et al. (55) reported on water absorption as a "swelling number" or the weight of water imbibed by 100 grams of rice when cooked at 98°C under standard conditions. This "swelling number" was then used as an index of cooking quality. Parthasarathi and Nath (50) also examined the water absorption of 2 grams of rice when cooked in a wire cage in excess water at certain temperatures. The time taken to cook the rice to different degrees of doneness was determined by evaluating the time needed for the rice to absorb different
amounts of water. Rice was said to be cooked when 2 grams had absorbed 4.5 grams of water during cooking at 100°C. Doneness was tested by pressing a rice grain between the thumb and forefinger.

Roberts et al. (60) judged quality by "expanded volume," or the bulk volume of an expanded sample of parboiled rice divided by its initial volume. Expanded volume was determined by heating portions of dry parboiled rice in an air blast oven at 250°C for 16 to 18 seconds and measuring the increase in volume.

Sreensivasan (71) also devised a test for expansion which he measured by water displacement of the grains before and after cooking.

Methods of determining the soluble starch content of ground parboiled rice have been described by Roberts et al. (60).

Batcher et al. (3) measured quality of rice by determining the water absorbed by a specified quantity of rice in a given length of time (designated as water uptake ratio), the volume of a given weight of rice when cooked, total solids and estimated starch in the residual cooking liquid.

Other quality tests include: amylose content; alkali spreading value, or the extent of disintegration of whole-kernel milled rice in contact with dilute alkali—an indicator of gelatinization temperature; and birefringence end point temperature, or the temperature at which the starch birefringence changes indicating gelatinization.

Prescott and Haas measured gelatinization and water uptake by staining individual grains and examining them microscopically (51).

Cooked instant rice is most commonly judged for flavor, texture, color, cohesiveness of the grains, and the ability to rehydrate.
MATERIALS AND METHODS

In planning appropriate research for the successful manufacture of an improved instant rice, the selection of raw materials of a known history, and the development of process equipment which can be applied to industry, are critical factors which must be considered.

Raw, white, long-grain Bluebonnet variety rice of known history, obtained from the Louisiana Rice Experiment Station in Crowley, Louisiana, was used in this investigation. Both non-enriched and enriched rice were studied. The enriched rice was prepared by thoroughly mixing 99.5% of non-enriched rice with 0.5% premix, which was enriched, rinse-proof rice with 400 mg of thiamin, 3200 mg of niacin, and 2600 mg of iron per pound, an adhesive, and talc. The premix was furnished by Mr. S. L. Wright of Crowley, Louisiana, who processes and distributes this material to commercial rice packers. Adding 0.5 pounds of premix to 99.5 pounds of non-enriched rice brings the nutritional level of the rice-premix mixture to the level set forth in the Standard of Identity for Enriched Rice which requires that enriched rice have 2-4 mg thiamin, 16-32 mg of niacin, and 13-26 mg of iron per pound of rice.

Representative samples of the milled, unenriched rice and the enriched rice (99.5% unenriched rice + 0.5% premix) used in these experiments were analyzed for thiamin, niacin, and iron content using the official methods recommended by the Association of Official Analytical Chemists (1).
The five major steps—soaking, cooking, drying, rehydration, and organoleptic evaluation—in the laboratory operations for the preparation of optimal quality quick-cooking rice are outlined below.

Step 1. The Soaking Process

The effects of four aqueous soaking media—distilled water, and water containing 1%, 3.5%, and 7% of a 50-50 mixture of sodium citrate and calcium chloride, together with two levels of water temperature (70° and 122°F) during soaking and two periods of elapsed time (one and 15 minutes) during soaking—were chosen for study in these experiments. The four levels of soaking media, and two levels each of temperature and periods of time yielded a total of 32 groups of soaked rice, that is, 16 groups each for unenriched rice and enriched rice. The percent moisture uptake and volume increase were determined for each of the 32 groups of soaked rice. These data indicated that, without exception, the 15-minute period of soaking yielded better products than the one-minute period of soaking. The 16 groups of one-minute soaked rice were not investigated further.

Step 2. The Cooking Methods

Aliquots of the 16 groups of rice that had been soaked for a period of 15 minutes were subjected to two methods of cooking: (1) heating in an autoclave at 250°F, 15 psig, for two periods of elapsed time—2 and 3 minutes; and (2) heating in water at two levels of temperature—185° and 212°F—for three periods of elapsed time—5, 10 and 15 minutes. These cooking operations yielded a total of 128 groups of cooked rice, of which 32 groups had been heated in an autoclave and
96 groups had been cooked in hot water. The percent moisture uptake, volume increase, and gelatinization were determined for each of the 128 groups. The data indicated that those groups which had been soaked in the 3.5% and 7% solutions of sodium citrate-calcium chloride were of inferior quality; consequently, these 64 groups of cooked rice were not investigated further. The data for the three attributes of cooked, enriched rice groups were virtually identical with the data for the corresponding cooked unenriched rice groups. This finding indicated that the 0.5% content of premix had no significant effect on the cooking qualities of the various rice groups.

From the remaining 64 groups of cooked rice, a total of 16 groups were selected for drying on the basis of optimal percent moisture uptake, volume increase, and gelatinization; these 16 groups also represented matched groups with respect to: (a) enriched and unenriched rice; (b) soaking media—distilled water and 1% solution of sodium citrate-calcium chloride; (c) soaking conditions—70° or 122°F for 15 minutes; and (d) cooking methods—heating the soaked rice in an autoclave at 250°F for either 2 or 3 minutes and in hot water at 212°F for 10 minutes.

Step 3. The Drying Methods

The moisture content of the above selected 16 cooked rice groups was reduced to 12-14% by procedures employing convective air drying. Five different sets of drying conditions yielded a total of 80 different groups of dried cooked rice. Two rates of air flow, 88 and 120 cfm, and two levels of air temperature, 180° and 200°F, yielded 64 groups, while a procedure involving partial freeze drying followed by convective
air drying at 120 cfm and 200°F yielded 16 additional groups of dried cooked rice. The weight, volume, and quality attributes such as clumpiness and breakage were determined for each of the 80 groups. From these 80 groups, based on the presence of a volume ratio (volume of dried cooked rice/volume of raw rice) of 1.5 or above, and the absence of clumpiness and breakage of the rice grains in the dried cooked products, a total of 28 groups were selected for rehydration; of these, 20 were from the 64 groups obtained by the procedure involving convective air drying alone, and 8 were from the 16 groups obtained by the procedure involving freeze drying. These 28 groups also represented matched groups with respect to (a) enriched and unenriched rice, and (b) soaking media—distilled water and 1% solution of sodium citrate-calcium chloride.

Step 4. The Rehydration Process

Each of the above selected 28 groups of dried, cooked rice was rehydrated by heating in hot water at 212°F for a period of 5 minutes. The rehydration ratio and the percent increase in volume were determined for each of the 28 rehydrated products.

Step 5. Organoleptic Evaluations

Each of the rehydrated products was evaluated organoleptically with respect to color, cohesiveness, flavor, and doneness by a panel of five judges. The four rehydrated products that received the highest overall organoleptic scores were then analyzed for thiamin by Thiochrome fluorescence, niacin content by colorimetry, and iron content by colorimetry.
Details of Laboratory Procedures

**Soaking:** A total of 32 samples of rice, each weighing 100 grams, were prepared. Each 100-gram sample was placed in a 2-liter beaker to which was added 800 ml of the appropriate aqueous soaking medium. The mixture was stirred manually while soaking at the appropriate temperature (70° or 122°F) for the proper length of time (1 or 15 minutes). At the end of the soaking period, the solution was decanted and the excess moisture was removed by spreading the samples over filter paper. The samples were then placed in a tared 300-ml evaporating dish and weighed. The sample was transferred to a 500-ml graduate cylinder to determine the volume.

**Cooking:** All samples were cooked by simple methods which simulate batch-type processing operations used in industry, and which could easily be incorporated into existing rice parboiling operations in many underdeveloped countries.

Samples from each presoaking treatment were cooked under controlled conditions of time, temperature, pressure and cooking medium. Experimentally, the 100-gram samples of soaked rice were cooked in 1000 ml of water at 185° or 212°F under atmospheric conditions for time periods of 5, 10 and 15 minutes respectively, and pressure cooking at 15 psig and 250°F for 2 and 3 minutes, respectively. A sample of each 15-minute soaked rice was subjected to each of the cooking treatments.

After being heated for the appropriate period of time, the cooking solution was decanted and the cooked rice was rinsed and chilled with cold water (32° to 35°F). The excess moisture was removed by spreading the cooked rice over filter paper. The sample was then weighed.
in a tared evaporating dish, the percent moisture, the water uptake ratio (weight of cooked rice divided by the weight of raw rice), the volume (measured in a one-liter graduate cylinder) and the percent gelatinization were determined.

**Drying:** The samples were dried in the convective drying equipment (Fig. 1), specially designed by the Louisiana State University Agricultural Engineering Department, and modified for use in the present experiments. It consisted of an eleven-inch fan which forced air through an insulated sheet metal duct containing electric heaters, baffles, and a test section to introduce a wire mesh tray holding the rice sample. Heat was supplied to the drier by four banks of electric finstrip type heaters controlled by variable voltage regulators (rheostats) which allowed for varying heat inputs.

The sheet metal duct was fabricated with a cross-sectional area of 81 square inches (9" by 9") at the test section. Four baffles were provided just prior to the test section to obtain a fairly uniform air flow through the test section of the duct. The fan was equipped with a manifold to allow variation of the flow rates of air.

The following steps were performed during the actual drying of rice samples. The sample was spread evenly on the tray. Heat input to the drier was controlled to give the desired air temperatures (200° and 180°F). The air flow rate was controlled at 120 or 88 cfm. The drying rate was monitored by regular weighings, and a final moisture content of 12 to 14% was determined by using the Motomco moisture meter. The percentage of adhering and broken grains was visually observed and scored.
Figure 1. Convective Drying Equipment
Freeze-Drying with Convective Air Drying: The equipment used for freeze-drying was a USM-15 model Virtis freeze-dryer (Fig. 2) consisting of two fixed black anodized aluminum shelves for rapid freezing of the product below the eutectic temperature of water. The shelves were mounted inside the stainless steel vacuum chamber with two accessory platens. The heating platens were surrounded by shelf coils which were connected to the main heating element. The main heating element and the coils were heated by circulating hot silicone fluid, the temperature of which was controlled by an adjustable thermostat, between the temperatures of 60° and 250°F. This arrangement serves as a control device to increase the input necessary for the sublimation of ice. Vacuum up to 30 microns of Hg can be obtained in the stainless steel vacuum chamber. A pressure gauge attached to the chamber indicated the inside pressure from 0 to 5000 microns of Hg. A condenser capable of cooling to -50°C was located inside the lateral wall of the chamber and surrounded the chamber, where the water due to sublimation of ice was collected and deposited as frozen water on the interior wall of the chamber. The shelf and condenser temperatures were continuously monitored by a thermometer type electronic indicator.

In the freeze-drying method, the cooked and cooled rice samples were spread in foil compartments within stainless steel freeze-dry trays, covered with aluminum foil, and frozen in a -10°C freezer. These frozen samples were then partially dried in the Virtis model USM-15 freeze-drier to a moisture content of from 25 to 30%. Operating conditions for the freeze-drier were an atmosphere reduced to 60 μ, and a shelf temperature under 40°F. The sublimation step was followed by treatment in the convective air dryer at 200°F and an air velocity of 120 cfm. The use of a
Figure 2. The Virtis Co. Freeze Drier
combination of methods was an attempt to simulate an economically feasible procedure for industrial application because drying totally by freeze-drying methods requires considerable time and energy and is thus impractical.

**Organoleptic Evaluations:** For the organoleptic tests, 10 grams of each of the rice samples to be evaluated were rehydrated in the manner usually prescribed for commercially available instant rices (adding an equal volume of boiling water to the rice and allowing it to steep for five minutes with occasional stirring). The rice was fluffed lightly with a fork and transferred to a petri dish before serving. Four samples were presented to the panel in randomized order at each evaluation session, with each sample representing a different treatment. The panel of five experienced tasters rated the samples on color, cohesiveness, off flavor, and doneness, using the hedonic scale shown in Figure 3.

**Analyses:** Physical and chemical analyses were performed on the rice at various stages of processing. Chemical analyses were done according to the official methods prescribed by the Association of Official Analytical Chemists (1) for the determination of thiamin, niacin, and iron at the beginning of the experimentation and also on selected cooked products at the end of the experimentation.

Before processing, and after each step of processing, the moisture content of the rice was determined by using a Motomco moisture meter. The accuracy of this instrument was periodically checked by the official air-oven method of moisture determination as described in the USDA Announcement No. 147.
**ORGANOLEPTIC SCORE SHEET**

<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COLOR</strong></td>
<td></td>
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</tr>
<tr>
<td>9. White</td>
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<tr>
<td>7. Cream</td>
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<tr>
<td>5. Grey-yellow</td>
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<tr>
<td>3. Tan</td>
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<tr>
<td>1. Brown</td>
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<tr>
<td><strong>COHESIVENESS</strong></td>
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<td>9. Well separated grains</td>
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<td>7. Partially separated</td>
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<td>5. Sticky</td>
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<tr>
<td>3. Very sticky</td>
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</tr>
<tr>
<td>1. Pasty</td>
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<tr>
<td><strong>OFF FLAVOR</strong></td>
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<tr>
<td>9. None</td>
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<td>7. Perceptible</td>
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<tr>
<td>5. Slightly strong</td>
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<td>3. Moderately strong</td>
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<tr>
<td>1. Very strong</td>
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<tr>
<td><strong>DONENESS</strong></td>
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<tr>
<td>9. Underdone</td>
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<tr>
<td>7. Slightly underdone</td>
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<tr>
<td>5. Done</td>
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<td></td>
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<tr>
<td>3. Slightly overdone</td>
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<td></td>
</tr>
<tr>
<td>1. Overdone</td>
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</table>

Figure 3. Hedonic scale for instant rice
The volume of the rice sample was determined before and after each processing and cooking step by placing an aliquot in a graduate cylinder of known diameter. The height of the rice in the column was then measured in millimeters and the volume was calculated using the formula: \[ V = \pi r^2 h \]

where:  
- \( V \) = volume  
- \( \pi = 3.1416 \)  
- \( r \) = radius  
- \( h \) = height.

Percent volume increase was determined by dividing the increased volume of the rice by the original volume of the rice and multiplying by 100.

**Percent Gelatinization:** The percent gelatinization was measured microscopically by slicing thin sections of the cooked rice with a razor blade and staining these sections with a 0.5% solution of Congo Red dye which differentiates gelatinized (red) granules from ungelatinized (uncolored) granules.

**Rehydration Ratio:** Duplicate 10-gram samples of the quick-cooking rice were weighed on a torsion balance, placed in individual 600-ml pyrex beakers, to each of which was added water. The beakers were covered with watch glasses, placed on electric heaters and allowed to boil for 5 minutes at 212°F. The contents of the beakers were then transferred into corresponding 75-ml Buchner funnels fitted with coarse, porous filter paper and gentle suction was carefully applied for one-half to one minute, or until the drip from the funnel had almost ceased. The solids from the funnel were removed and weighed. The rehydration ratio was calculated by dividing the weight of the initial sample of dry quick-cooking rice.
RESULTS AND DISCUSSION

The major objectives in producing a superior instant rice by processing modifications have been attained during the performance and completion of this project. The results presented here offer conclusive evidence that the final product is superior to instant rice presently available in the market place, when evaluated from the standpoint of its chemical, physical and nutritional properties.

This investigation was designed to make process modifications for preparing a dehydrated, viz. precooked, porous, quick-cooking rice which may be regenerated into a highly satisfactory and superior product. Such a product when cooked in the average kitchen by a simple, standard cooking procedure should yield a fluffy, tender, table-ready rice in which the grains stand apart instead of being cooked into a sticky, gummy material consisting largely of conglomerates and broken grains.

The experimental data consisted of percent moisture uptake, percent volume increase, percent gelatinization, percent nutrient retention (thiamin, niacin and iron) and rehydration ratios of the non-enriched and enriched rice groups resulting from the various effects of processing conditions. These processing variations included: soaking in four different aqueous media (distilled water and water containing 1, 3.5, and 7% of a 50-50 mixture of sodium citrate and calcium chloride), two different levels of water temperature during soaking (70° and 122°F), and two periods of elapsed time during soaking (1 and 15 minutes) followed by two methods of cooking and two methods of drying. The two methods of
cooking were: (1) heating the soaked rice in an autoclave at 250°F, 15 psig, for two periods of elapsed time (2 and 3 minutes); and (2) heating in hot water at two levels of temperature (185° and 212°F) for 3 periods of elapsed time (5, 10 and 15 minutes). The two methods of drying employed were: (1) convective air drying at two rates of air flow (88 and 120 cfm) and two levels of air temperature (180° and 200°F), and (2) partial freeze-drying followed by convective air drying at 120 cfm and 200°F.

The non-enriched rice consisted of white, long-grain Bluebonnet variety of known history obtained from the Louisiana Rice Experiment Station in Crowley, Louisiana. Enriched rice was prepared by mixing thoroughly 99.5% of the non-enriched rice with 0.5% premix, which included enriched, rinse-proof rice with 400 mg of thiamin, 3200 mg of niacin, and 2600 mg of iron per pound, an adhesive and talc. Adding 0.5 pounds of premix to 99.5 pounds of non-enriched rice brought the mixture to the level set forth in the Standard of Identity for Enriched Rice.

The results of the study furnished some relevant information regarding the effects of soaking, cooking, and drying methods on the overall quality of quick-cooking rice.

Soaking: Soaking increases the depth and uniformity of the migration of the cooking water into the rice grain. The rate of migration of soak water into the rice grain depends upon the soaking period and temperature of the soak water. Such penetration reduces the tendency of the rice grain to disintegrate or be mutilated from the action of internal osmotic pressure acting to burst the rice grains during subsequent boiling, which results in starch being lost to the cooking water.
Addition of calcium chloride to the soak water deters adhesion between the grains which would cause mutilation if the grains were forced apart. Sodium citrate in the soak water acts principally to modify the protein structure of the rice by disruption and disintegration.

The differences in percent moisture uptake and percent volume increase which result from each variable, viz. soaking temperature and time, chemical treatment of the non-enriched (16 samples) and enriched (16 samples) are shown in Table II and Figures 4 and 5.

The data indicated a maximum percent moisture uptake of 28% for both the non-enriched and enriched groups at a soaking temperature of 122°F and a 15-minute soaking time. Under the same soaking conditions, the minimum percent volume increase for these two groups was 5.0. The maximum percent moisture uptake (33%), and percent volume increase (4.8%) for the chemically treated groups were at 1.0% chemical treatment, 122°F soaking temperature and 15 minutes soaking time. An analysis of these data shows that enrichment of the rice samples did not affect the degree of moisture uptake or volume increase; however, samples which were chemically treated had almost 50% more moisture uptake than the controls soaked under identical conditions in distilled water. Enrichment or chemical treatment did not appear to appreciably affect the percent volume increase.

Increasing the concentration of chemicals in the soak water from 1% to 3.5% and 7% did not improve either the moisture uptake or the volume increase. A 1% chemical solution did at least as good a job of altering the percent moisture uptake and percent volume increase of the soaked rice as did the 3.5% or 7% solution of sodium citrate-calcium chloride.
TABLE II. The Effect of Soaking on Percent Moisture Uptake and Percent Volume Increase of Raw Rice  
(total samples, non-enriched and enriched = 32)

<table>
<thead>
<tr>
<th>Soaking Temp. (°F)</th>
<th>Control</th>
<th>1% Chemical Treatment</th>
<th>3.5% Chemical Treatment</th>
<th>7% Chemical Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soaking Time (min)</td>
<td>70 15</td>
<td>1 15</td>
<td>70 15</td>
<td>70 15</td>
</tr>
</tbody>
</table>

Non-Enriched  
Samples, Total 16

| % Moisture uptake | 9.2 14.0 13.4 28.0 | 12.0 16.5 14.0 34.0 | 11.9 15.6 14.0 33.0 | 11.0 13.0 11.5 33.0 |
| % Volume increase | 3.8 4.8 3.8 5.0     | 3.7 4.7 3.7 4.9     | 3.5 4.6 3.7 4.8     | 3.7 4.5 3.6 4.7     |

Enriched Samples,  
Total 16

| % Moisture uptake | 9.1 14.0 13.4 28.0 | 11.9 16.4 14.1 34.0 | 11.9 15.6 13.9 33.0 | 11.0 13.0 11.5 33.0 |
| % Volume increase | 3.8 4.8 3.8 5.0     | 3.9 4.6 3.7 4.9     | 3.5 4.6 3.7 4.7     | 3.7 4.5 3.6 4.6     |

Selection: High percent moisture uptake preferred.  
High percent volume increase preferred.  
Discard all one-minute samples.  
Samples taken for cooking, 8 + 8 = 16.
Figure 4. The Effect of Temperature, Chemical Treatment and Time on the Percent Moisture Uptake During Soaking of Enriched Rice
Figure 5. The Effect of Temperature, Time and Chemical Treatment on Percent Volume Increase of Enriched Rice
Cooking: The cooking of rice results essentially in the gelatinization and swelling of the starch granules within the rice endosperm. It is believed that the internal structure of a rice grain may include an integumental web formed by the protein components which sequester the starch to deter imbibition of water by the starch for gelatinization. This protein shielding of the starch is believed to be responsible for the long time ordinarily required to cook rice in boiling water (14). Cooking can be effected by the rice being processed in hot or boiling water at atmospheric pressure or by the rice being steamed in an autoclave. Steaming the rice under pressure in an autoclave increases the rate of gelatinization and thus reduces the heating time.

The differences in percent moisture uptake, percent volume increase and percent gelatinization in non-enriched and enriched controls and non-enriched and enriched chemically treated groups due to each cooking variable, viz., cooking time, cooking temperature, and cooking methods, are shown in Tables III through VI, and Figures 6 through 17. The data indicate that those groups which had been soaked in the 3.5 and 7% solutions of sodium citrate-calcium chloride were of inferior quality; consequently these groups of cooked rice were not investigated further and will not be included in the discussion. The non-enriched and enriched control groups which were soaked at 122°F for 15 minutes were 100% gelatinized when cooked under 15 psig of pressure and 250°F for 3 minutes.

A comparison of percent gelatinizations of both the enriched and non-enriched groups when soaked and cooked under different conditions indicated that cooking the soaked rice in an autoclave at 250°F and 15 psig for 3 minutes results in maximum gelatinization. Similar
TABLE III. The Effect of Cooking on Percent Moisture Uptake, Volume Increase Ratio and Percent Gelatinization of Control Group. Soaking time: 15 minutes, in water. Soaking temperature: 70° and 122°F. Method of Cooking: boiling water; constant temperature water bath, 185°F; autoclave, 250°F and 15 psig.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Soaking temperature, 70°F; time, 15 minutes</th>
<th>Soaking temperature, 122°F; time, 15 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (min)</td>
<td>185°F 10 15</td>
<td>212°F 5 10 15</td>
</tr>
<tr>
<td>Non-Enriched Rice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Moisture uptake</td>
<td>44.7 53.3 64.0</td>
<td>59.3 63.4 75.0</td>
</tr>
<tr>
<td>Volume increase ratio</td>
<td>1.8 2.0 2.4</td>
<td>2.2 2.4 2.7</td>
</tr>
<tr>
<td>% Gelatinization</td>
<td>65.0 71.0 79.0</td>
<td>81.0 79.0 88.0</td>
</tr>
<tr>
<td>Enriched Rice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Moisture uptake</td>
<td>44.5 53.0 63.9</td>
<td>59.2 63.9 75.1</td>
</tr>
<tr>
<td>Volume increase ratio</td>
<td>1.8 1.9 2.4</td>
<td>2.2 2.4 2.7</td>
</tr>
<tr>
<td>% Gelatinization</td>
<td>65.0 70.0 79.0</td>
<td>80.0 80.0 88.0</td>
</tr>
</tbody>
</table>

Criteria for Selection: (1) High % gelatinization, (2) Moderate moisture uptake, (3) moderate to high volume increase.

Order of Critical Samples: Cooked at 250°F for 3 minutes - Soaked at 122°F for 15 minutes
Cooked at 250°F for 2 minutes - Soaked at 122°F for 15 minutes
Cooked at 250°F for 3 minutes - Soaked at 70°F for 15 minutes
Cooked at 212°F for 10 minutes - Soaked at 122°F for 15 minutes

Total Samples Selected: The four above samples from both the enriched and non-enriched groups = 8.
TABLE IV. The Effect of Cooking on Percent Moisture Uptake, Volume Increase Ratio and Percent Gelatinization of 1% Chemically Treated Rice. Soaking time: 15 minutes in 1% chemical solution. Soaking temperature: 70° and 122°F. Method of Cooking: boiling water; constant temperature water bath, 185°F; autoclave, 250°F and 15 psig.

<table>
<thead>
<tr>
<th>Temperature Time (min)</th>
<th>Soaking temperature, 70°F; time, 15 minutes</th>
<th>Soaking temperature, 122°F; time, 15 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>185°F 212°F 250°F 185°F 212°F 250°F</td>
<td>185°F 212°F 250°F 185°F 212°F 250°F</td>
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<tr>
<td></td>
<td>5 10 15 5 10 15 2 3</td>
<td>5 10 15 5 10 15 2 3</td>
</tr>
<tr>
<td>Non-Enriched Rice</td>
<td>% Moisture uptake</td>
<td>% Moisture uptake</td>
</tr>
<tr>
<td></td>
<td>47.1 55.4 66.0 61.5 65.5 79.2 60.5 64.0</td>
<td>51.0 59.6 69.4 65.0 69.2 70.4 65.2 67.1</td>
</tr>
<tr>
<td></td>
<td>Volume increase ratio</td>
<td>Volume increase ratio</td>
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<tr>
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<td>1.8 2.1 2.4 2.3 2.4 2.6 2.1 2.4</td>
<td>2.0 2.2 2.3 2.3 2.5 2.9 2.4 2.7</td>
</tr>
<tr>
<td></td>
<td>% Gelatinization</td>
<td>% Gelatinization</td>
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<tr>
<td></td>
<td>68.0 74.0 83.0 79.0 83.0 92.0 85.0 88.0</td>
<td>73.0 78.0 87.0 80.0 87.0 95.0 91.0 100.0</td>
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<tr>
<td>Enriched Rice</td>
<td>% Moisture uptake</td>
<td>% Moisture uptake</td>
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<tr>
<td></td>
<td>47.2 55.4 59.9 61.4 65.6 79.3 60.4 64.0</td>
<td>51.3 59.4 69.2 65.0 69.3 79.5 65.1 67.2</td>
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<td>1.8 1.9 2.5 2.3 2.4 2.7 2.1 2.4</td>
<td>2.0 2.1 2.5 2.3 2.5 2.9 2.4 2.7</td>
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<tr>
<td></td>
<td>% Gelatinization</td>
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<tr>
<td></td>
<td>68.0 75.0 83.0 80.0 83.0 92.0 85.0 88.0</td>
<td>74.0 77.0 78.0 80.0 87.0 96.0 91.0 100.0</td>
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</tbody>
</table>

Criteria for Selection: (1) High % gelatinization, (2) Moderate moisture uptake, (3) Moderate to high volume increase.

Order of Critical Samples: Cooked at 250°F for 3 minutes - Soaked at 122°F for 15 minutes
Cooked at 250°F for 2 minutes - Soaked at 122°F for 15 minutes
Cooked at 250°F for 3 minutes - Soaked at 70°F for 15 minutes
Cooked at 212°F for 3 minutes - Soaked at 122°F for 15 minutes

Total Samples Selected: (The same four critical samples from each of the enriched and non-enriched groups were selected according to the criteria for selection) = 8.
TABLE V. The Effect of Cooking on Percent Moisture Uptake, Volume Increase Ratio and Percent Gelatinization of 3.5% Chemically Treated Rice. Soaking time: 15 minutes in 3.5% chemical solution. Soaking temperature: 70° and 122°F. Method of Cooking: boiling water; constant temperature water bath, 185°F; autoclave, 250°F and 15 psig.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>185°F</th>
<th>212°F</th>
<th>250°F</th>
<th>185°F</th>
<th>212°F</th>
<th>250°F</th>
<th>185°F</th>
<th>212°F</th>
<th>250°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (min)</td>
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<td>10</td>
<td>15</td>
<td>5</td>
<td>10</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>% Moisture uptake</td>
<td>43.1</td>
<td>51.1</td>
<td>52.1</td>
<td>53.1</td>
<td>63.0</td>
<td>71.3</td>
<td>55.9</td>
<td>60.8</td>
<td>44.2</td>
</tr>
<tr>
<td>Volume increase ratio</td>
<td>1.6</td>
<td>1.9</td>
<td>2.0</td>
<td>2.0</td>
<td>2.3</td>
<td>2.7</td>
<td>1.9</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>% Gelatinization</td>
<td>63.0</td>
<td>69.0</td>
<td>70.0</td>
<td>71.0</td>
<td>77.0</td>
<td>88.0</td>
<td>73.0</td>
<td>83.0</td>
<td>65.0</td>
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<tr>
<td>% Moisture uptake</td>
<td>43.1</td>
<td>50.9</td>
<td>52.1</td>
<td>53.0</td>
<td>63.1</td>
<td>71.1</td>
<td>55.7</td>
<td>61.0</td>
<td>44.2</td>
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<tr>
<td>Volume increase ratio</td>
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<td>1.9</td>
<td>2.0</td>
<td>2.0</td>
<td>2.3</td>
<td>2.6</td>
<td>1.9</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>% Gelatinization</td>
<td>63.0</td>
<td>69.0</td>
<td>70.0</td>
<td>71.0</td>
<td>77.0</td>
<td>87.0</td>
<td>72.0</td>
<td>84.0</td>
<td>65.0</td>
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</table>

Criteria for Selection: (1) High % gelatinization, (2) Moderate moisture uptake, (3) Moderate to high volume increase.

No samples from this group were acceptable for further processing. The samples were tough, poorly gelatinized, and had poor moisture uptake percentages; probable cause, high percentage of calcium in the treatment solution.
TABLE VI. The Effect of Cooking on Percent Moisture Uptake, Volume Increase Ratio and Percent Gelatinization of 7% Chemically Treated Rice. Soaking time: 15 minutes in 7% chemical solution. Soaking temperature: 70° and 122°F. Method of Cooking: boiling water; constant temperature water bath, 185°F; autoclave, 250°F and 15 psig.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>% Moisture uptake</th>
<th>% Gelatinization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soaking temperature, 70°F; time, 15 minutes</td>
<td>41.6 43.8 44.1 52.1 62.0 63.5 50.9 59.0</td>
<td>60.0 63.0 64.0 70.0 75.0 77.0 68.0 80.0</td>
</tr>
<tr>
<td>Soaking temperature, 122°F; time, 15 minutes</td>
<td>42.3 44.0 45.1 54.0 62.8 63.8 51.2 59.7</td>
<td>60.0 63.0 64.0 52.3 62.1 63.4 50.8 59.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
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<td>Non-Enriched Rice</td>
<td>1.4</td>
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<td>1.6</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Volume increase ratio</td>
<td>1.6</td>
<td>1.8</td>
<td>1.9</td>
<td>1.8</td>
<td>2.3</td>
</tr>
<tr>
<td>% Gelatinization</td>
<td>60.0</td>
<td>63.0</td>
<td>64.0</td>
<td>70.0</td>
<td>75.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enriched Rice</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Volume increase ratio</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
<td>1.8</td>
<td>2.3</td>
</tr>
<tr>
<td>% Gelatinization</td>
<td>60.0</td>
<td>63.0</td>
<td>64.0</td>
<td>70.0</td>
<td>75.0</td>
</tr>
</tbody>
</table>

Criteria for Selection: (1) High % gelatinization, (2) Moderate moisture uptake, (3) Moderate to high volume increase.

No samples from this group were acceptable for further processing. The samples were tough, poorly gelatinized, and had poor moisture uptake percentages; probable cause, high percentage of calcium.
Figure 6. Effect of Time and Temperature on Moisture Uptake in Cooking Enriched, Water-Soaked Control

- Soaked at 70°F
- Soaked at 122°F
- a = Cooked at 185°F
- b = Cooked at 212°F
- c = Cooked at 250°F
Figure 7. Effect of Time and Temperature on Moisture Uptake in Cooking 1% Chemically Treated, Enriched Rice

-—— soaked at 70°F
--- --- soaked at 122°F
a = cooked at 185°F
b = cooked at 212°F
c = cooked at 250°F
60

soaked at 70°F
----- soaked at 122°F
a = cooked at 185°F
b = cooked at 212°F
c = cooked at 250°F

Figure 8. Effect of Time and Temperature on Moisture Uptake in Cooking 3.5% Chemically Treated, Enriched Rice
Figure 9. Effect of Time and Temperature on Moisture Uptake in Cooking 7% Chemically Treated, Enriched Rice
Figure 10. Effect of Time and Temperature on Volume Increase in Cooking Enriched, Water-Soaked Control
Figure 11. Effect of Time and Temperature on Volume Increase in Cooking 1% Chemically Treated, Enriched Rice
Figure 12. Effect of Time and Temperature on Volume Increase in Cooking 3.5% Chemically Treated, Enriched Rice
Figure 13. Effect of Time and Temperature on Volume Increase in Cooking 7% Chemically Treated, Enriched Rice
Figure 14. Effect of Time and Temperature on Gelatinization in Cooking Enriched, Water-Soaked Control
Figure 15. Effect of Time and Temperature on Gelatinization in Cooking 1% Chemically Treated, Enriched Rice
Figure 16. Effect of Time and Temperature on Gelatinization in Cooking 3.5% Chemically Treated, Enriched Rice
Figure 17. Effect of Time and Temperature on Gelatinization in Cooking 7% Chemically Treated, Enriched Rice
observations were made with respect to chemically treated groups. However, the percent moisture uptake and percent volume increase (67.1 and 100%, respectively) of these chemically treated groups were found to be slightly higher than the untreated control groups which were soaked and cooked under identical conditions. Apparently the groups which were soaked in aqueous solutions of sodium citrate and calcium chloride had a modified protein and/or starch component as a result of the chemical treatment which facilitated penetration of the water into the interior of the rice grains and expedited the imbibition of such water by the starch during gelatinization. For optimal drying and superior quick-cooking rice, it is desirable to have a high percent gelatinization, moderate moisture uptake and moderate to high percent volume increase in the cooked product.

Drying: The conditions under which a food product should be dried (drying time, temperature, amount of heat to be supplied, amount of water to be removed, etc.) vary greatly because the products to be dried are very different from each other in nature, and in properties such as shape and dimensions, water content and temperature sensitivity. Even when the drying conditions are fixed, there are still many possible variations in the technical execution of the process. Economic considerations play an important role in the final choice of design and construction of the drier. When designing a drier to dry a particular food product, it is very important to insure that the drying of the given food is very uniform, the heat consumption and the drying temperature are very low, the construction is simple and the operation is easy. Use of very high temperatures destroys temperature-sensitive nutrients and causes case hardening.
In preparing quick-cooking rice, generally the drying operation which follows the cooking and rinsing steps is not critical provided that pretreatments of the grains and the cooking are carried out to achieve optimal gelatinization of the rice. Commercially, rice is dried on belt driers where the cooked rice is loaded to a depth of about one inch. Temperature and humidity are controlled at different levels in different sections of the drier. The object of effective drying is to remove the particle water from the surface of the grain at a rate which will minimize case hardening and will also permit water to diffuse rapidly from the interior surface of the grain. Shrinkage must be kept at a minimum. However, belt driers with their relatively high drying temperatures have the disadvantage of imparting cooked flavors and destroying the thermolabile nutrients.

The preparation of quick-cooking rice by freeze-drying has been explored for many years but has traditionally been considered too expensive. In addition, it is very difficult to freeze-dry rice because of its unfavorable physical properties and gel-bound water. Therefore, a combination of freeze-drying followed by the convective air drying approach was used in this study.

The variations in volume ratio, clumpiness and breakage in the non-enriched and enriched control groups and the chemically treated (7%), enriched and non-enriched groups due to each variable (convective air drying--air flow 88 and 120 cfm, air temperature 180° and 200°F; and freeze-drying followed by convective air drying) are presented in Tables VII and VIII. Highest volume ratio (1.5-1.6), minimum clumpiness and breakage (<5%) were observed in the non-enriched and enriched control groups when they were dried by convective air drying at 120 cfm air
TABLE VII. The Effect of Convective Air Drying Variables on Volume Ratio, Clumpiness and Breakage in Cooked Rice

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td>180</td>
<td>200</td>
<td>180</td>
<td>200</td>
<td>180</td>
</tr>
<tr>
<td>Air Temp.</td>
<td>(°F)</td>
<td>180</td>
<td>200</td>
<td>180</td>
<td>200</td>
<td>180</td>
<td>200</td>
<td>180</td>
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<tr>
<td>Water Soaked</td>
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<td>Volume ratio</td>
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<td>1.5</td>
<td>1.4</td>
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<td>1.5</td>
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<td>+++</td>
<td>+</td>
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<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
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<td>Volume ratio</td>
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<td>1.6</td>
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</tr>
</tbody>
</table>
| Criteria for selection for further processing: high volume ratio, low clumpiness and breakage. Number of samples selected for further processing: 10 + 10 = 20 (underlined samples).

Clumpiness and breakage rating: <5% = +; 5-25% = ++; 25-75% = +++; 75-100% = +++.
TABLE VIII. The Effect of Freeze-Drying and Convective Air Drying on Volume Ratio, Clumpiness and Breakage in Cooked Rice. 
Freeze-dry conditions: pressure, 60 microns; temperature, 40°F. Cooked samples were freeze-dried to 20% moisture followed by convective air drying at 200°F and an air flow velocity of 120 cfm until the moisture reached 12%.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>2.0</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
</tr>
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<td>&lt;5</td>
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<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
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</tbody>
</table>

Number of samples selected for further processing: 4 + 4 = 8 (underlined samples).
flow and 180° and 200°F drying temperatures. However, under the same drying methods and conditions, the chemically treated groups showed higher volume ratios than the respective controls. From these data it appears that enriching the rice did not affect the volume ratios. Chemical treatment (1%) of the rice did result in an increased volume ratio.

The highest volume ratio (2.0) for the non-enriched and enriched control groups and (2.2) for chemically treated enriched and non-enriched groups were observed when the cooked samples were freeze-dried followed by convective air drying. Clumpiness and breakage were maintained at the same level (<5%). These data indicate that a combination of freeze-drying followed by convective air drying of the cooked rice results in an increased volume ratio (2.2 to 2.0), which is a desirable attribute in quick-cooking rice. The cooked rice which is frozen prior to freeze-drying is somewhat less sticky and has better dry flow characteristics than the conventionally dried rice product. The freezing process appears to toughen the gel structures to a considerable extent, thus reducing the extreme stickiness of some of the starch-glutelin gel complexes which result from the pre-cooking process; in addition there is a coagulation and shrinking of the starch gel and the glutelins. These glutelins become hydrated to a considerable degree under the freezing conditions. The coagulation releases free water into the voids which are opened by coagulation and shrinkage, and the liberated water migrates and increases the size of any ice crystal nuclei which are present. The freezing process thus liberates water from these gels while partially denaturing the protein lattice. This sufficiently reduces the tendency of the individual grains to stick together, and to mash and break at the slightest pressure. During freeze-drying all the
liberated water formed into ice crystals is removed in the vapor state without passing through the liquid state. This thus avoids rehydration of the starch during thawing and the resultant collapsing of the granules, starch granule breakage and the production of a more sticky and pasty final product.

Rehydration: The rehydration of a dehydrated food product is too often taken for granted; not infrequently it turns out to be difficult and the resultant product quite unsatisfactory. One could probably assert that no animal or vegetable tissue has ever been dried completely without irreversibly losing some of its original properties. Practical considerations of drying are to a large extent governed by the necessity for minimizing this damage. Indeed the reason freeze-drying was such an important new development was that freeze-dried products rehydrate quickly and assume moisture contents and physical properties somewhat similar to the original properties.

High drying temperature can be detrimental. It has been reported (34) that some food products such as carrot slices dried at 200°F showed a reduction in rate and maximum degree of rehydration. The longer the high temperature was continued, the lower was the rehydration ratio. In addition, drying the food product under unfavorable conditions destroys the cell walls and the swelling power of the starch, both of which are important for good rehydration. A carefully planned procedure is thus necessary both for drying and rehydration if the food is to be successfully reconstituted.

The rehydration ratios of non-enriched and enriched control groups and chemically treated non-enriched and enriched groups dried by
convective air drying are presented in Table IX. Chemically treated freeze-dried groups showed a maximum rehydration ratio of 2.2, whereas chemically treated convective air dried groups reached a maximum rehydration ratio of 2.0. A rehydration ratio range of 1.7 to 1.9 was obtained in controlled non-enriched and enriched groups which were not chemically treated. From these data it appeared that enrichment did not significantly affect the rehydration ratios. However, chemical treatment and partial freeze-drying improved the rehydration ratios of the quick-cooking rice.

**Organoleptic Evaluation:** The organoleptic evaluation for color, cohesiveness, off flavor and doneness was performed on a total of 28 groups of rehydrated, cooked rice. The test groups consisted of 20 rice samples selected from convective air drying (10 non-enriched and enriched control groups and 10 chemically treated non-enriched and enriched groups) and 8 samples from partial freeze-drying. The selection of these test groups was based upon their superior quality with respect to maximal percent volume increase, percent moisture uptake and moisture uptake characteristics, maximal percent gelatinization and minimum clumpiness and breakage. The taste panel consisted of 5 individuals, all of whom were males between 20 and 30 years old. The panelists were presented with four test groups and one control (commercially available A & P instant rice) at a time (7 sessions for 28 samples) for evaluation based on a hedonic scale for color, cohesiveness, off flavor and doneness (see Table X for scale and judges' ratings). During the test period, oral and visual communication were restricted.
TABLE IX. The Effect of Processing Variables on Rehydration Ratios of Instant Rice

<table>
<thead>
<tr>
<th>Samples</th>
<th>Non-enriched</th>
<th>Enriched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convective Air Dried Samples</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water soaked</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>1% Chemical soaked</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Freeze-Dried + Convective Air Drying:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Chemical treatment (1,2,5,6); Water soaked (3,4,7,8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>2.0</td>
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<tr>
<td></td>
<td>2.0</td>
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<tr>
<td></td>
<td>2.0</td>
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</tr>
</tbody>
</table>
TABLE X. Organoleptic Score Sheet for Cooked Instant Rice. Scores are averages of ratings by five judges.

<table>
<thead>
<tr>
<th></th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
<th>Sample 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COLOR</strong></td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>9. White</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Cream</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Grey-yellow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Tan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Brown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COHESIVENESS</strong></td>
<td>9</td>
<td>9</td>
<td>7.5</td>
<td>7.5</td>
<td>8</td>
</tr>
<tr>
<td>9. Well-separated grains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Partially separated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Sticky</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Very sticky</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Pasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OFF FLAVOR</strong></td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9. None</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Perceptible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Slightly strong</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Moderately strong</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Very strong</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DONENESS</strong></td>
<td>5</td>
<td>5</td>
<td>6.5</td>
<td>6.5</td>
<td>4.5</td>
</tr>
<tr>
<td>9. Underdone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Slightly underdone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Done</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Slightly overdone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Overdone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample #1--Chemically treated raw rice, soaked at 122°F for 15 minutes and cooked by autoclave at 250°F for 3 minutes before freeze-drying and convective air drying.

Sample #2--Same as Sample #1, except no chemical treatment.

Sample #3--Same as Sample #1, except convective air dried only.

Sample #4--Same as sample #3, except no chemical treatment.

Sample #5--Commercially available enriched instant rice.
After analyses and comparison of the raw data obtained from the seven taste-testing sessions, the four test groups of rice which had received the highest organoleptic scores were set aside for nutrient analyses. The four test groups which were rated superior in all attributes in the descending order were: (1) chemically treated raw rice, soaked at 122°F for 15 minutes and cooked by autoclaving at 250°F for 3 minutes followed by partial freeze-drying and convective air drying; (2) same as Group 1 but with no chemical treatment; (3) same as Group 1 except the cooked rice was dehydrated in a convective air drier; (4) same as Group 3 except with no chemical treatment. Group 5 represented commercially available A & P brand enriched instant rice.

An inspection of organoleptic scores received by the four test groups and one control group indicated that there was little or no difference in terms of color. All samples were white to the same extent and received the highest organoleptic score. However, in terms of cohesiveness, off flavor and doneness, the taste panelists rated Groups 1 and 2 as superior to Groups 3, 4, and 5. These scores indicate that Groups 1 and 2 were well separated with no off flavor and were cooked to perfect doneness. The organoleptic results indicate that chemically treated raw rice, soaked at 122°F for 15 minutes, cooked in an autoclave at 250°F for 3 minutes and followed by a combination of freeze-drying and convective air drying produces a superior quick-cooking rice. When compared to Group 1, Groups 2, 3, 4 and 5 were second, third, fourth, and fifth best products.
Nutrient Analyses: In the preparation and production of quick-cooking rice the methods and conditions of soaking, cooking and drying have a considerable effect on the percent retention of nutrients in the finished product. Kik and Williams (38) in their discussion of rice cookery, point out that rinsing, soaking, cooking and drying methods so profoundly deplete the nutrient content of rice that the mode of manufacturing becomes one of the prime considerations regarding the feasibility of effective nutritonal improvement of quick-cooking rice. Cooking the rice grains destroys a high percentage of the total thiamin. Soaking per se does not lead to losses, but much thiamin may be lost if the soak water volume ratio and temperature are not properly adjusted.

The nutrient analyses for thiamin, niacin and iron were performed on a total of six groups of instant rice. The test groups consisted of 4 quick-cooking rice samples which received the highest organoleptic scores, and one each of enriched and non-enriched samples. The enriched and non-enriched groups were analyzed to determine the variations, if any, in the values of thiamin, niacin and iron from the theoretical data obtained by mixing 0.5 pounds of premix to 99.5 pounds of raw rice. The other four groups were analyzed to determine the effect of different soaking, cooking and drying conditions on the percent nutrient retention and availability in these quick-cooked rice samples which ultimately reach the consumer's table. The results of the analyses are presented in Table XI.

An examination of these data indicated Group 1 (chemically treated raw rice, soaked at 122°F for 15 minutes and cooked in an autoclave at 250°F for 3 minutes followed by a combination of freeze-drying and convective air drying) contained the maximum amounts of thiamin
TABLE XI. The Effect of Processing on the Nutritive Value of Instant Rice

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>Enriched</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiamin, µg/g</td>
<td>0.72</td>
<td>2.1</td>
<td>2.00</td>
<td>1.90</td>
<td>1.40</td>
<td>1.25</td>
</tr>
<tr>
<td>Niacin, µg/g</td>
<td>14.0</td>
<td>31.0</td>
<td>27.4</td>
<td>23.1</td>
<td>16.5</td>
<td>14.8</td>
</tr>
<tr>
<td>Iron, µg/g</td>
<td>1.6</td>
<td>27.0</td>
<td>25.1</td>
<td>25.0</td>
<td>24.9</td>
<td>24.9</td>
</tr>
</tbody>
</table>

Group 1--Chemically treated raw rice, soaked at 122°F for 15 minutes and cooked by autoclave at 250°F for 3 minutes before freeze-drying and convective air drying.

Group 2--Same as Group 1, except no chemical treatment.

Group 3--Same as Group 1, except convective air dried only.

Group 4--Same as Group 3, except no chemical treatment.
(2.0 µg/g), niacin (27.4 µg/g), and iron (25.1 µg/g). However, Groups 3 and 4, which were dried by convective air drying alone, showed considerably lower values of thiamin (1.25 to 1.40 µg/g), niacin (14.8 to 16.5 µg/g) and iron (24.9 µg/g). These results indicate that partially freeze-drying the cooked rice reduced the nutrient losses during the preparation of quick-cooking rice.
SUMMARY

This investigation was designed to develop industrially applicable methods for the production of a quick-cooking rice with preselected properties. The end product should have the normal appearance of presently available commercial rice, with grains not appreciably different in size from unmodified rice. Such rice should have substantially the same characteristics of swelling as natural rice, and when finally cooked should have flavor, texture, taste and appearance very similar to ideally cooked conventional milled rice. The processing methods used for the preparation of such quick-cooking rice must have a minimum of detrimental effects on the nutrients.

The modified process which has resulted from this research incorporated chemical treatment of raw rice followed by convective air and freeze-drying.

Raw, white, long-grain Bluebonnet rice of known history obtained from the Louisiana Rice Experiment Station in Crowley, Louisiana, was used in this investigation. Both non-enriched and enriched rice were studied. The enriched rice was prepared by thoroughly mixing 99.5% of the non-enriched rice with 0.5% premix, an enriched, rinse-proof rice with 400 mg of thiamin, 3200 mg of niacin and 2600 mg of iron per pound, plus an adhesive and talc.

Representative samples of the milled, unenriched rice, the enriched rice and four selected groups of finished quick-cooking rice were analyzed for thiamin, niacin and iron content.
The laboratory operations for the preparation of optimal quality quick-cooking rice included five major steps--soaking, cooking, drying, rehydration and organoleptic evaluations.

The effects of four aqueous soaking media--distilled water, and water containing 1, 3.5 and 7% of a 50-50 mixture of sodium citrate and calcium chloride--together with two levels of water temperature during soaking (70° and 122°F) and two periods of elapsed time during soaking (one minute and 15 minutes) were chosen for study in these experiments. The data indicated that, without exception, the 15-minute period of soaking yielded better products in terms of percent water uptake and percent volume increase than the one-minute period of soaking.

Aliquots of the 16 groups of rice that had been soaked for a period of 15 minutes were subjected to two methods of cooking: (1) heating in an autoclave at 250°F at 15 psig for two elapsed time periods, 2 and 3 minutes; and (2) heating in water at two levels of temperature (185° and 212°F) for three periods of elapsed time, 5, 10, and 15 minutes. It was found that in terms of percent moisture uptake, percent volume increase and percent gelatinization, cooking the soaked rice in an autoclave at 250°F for 3 minutes was optimum. The findings also indicate that the 0.5% content of premix had no significant effect on the cooking qualities of the various rice groups.

The moisture content of the selected 16 cooked rice groups was reduced to 12-14% by employing (1) convective air drying (two rates of air flow, 88 and 120 cfm, and two air temperatures, 180° and 212°F) and (2) partial freeze-drying followed by convective air drying at 120 cfm and 200°F. The data indicated that the partial freeze-drying of the cooked rice resulted in maximal percent moisture uptake, and percent
volume increase with minimal clumpiness and breakage in the dry product. The chemical treatment appeared to enhance these desirable attributes.

Each of the 28 groups of dried rice obtained by convective air and freeze-drying was rehydrated by heating in hot water at 212°F for a period of 5 minutes. The results obtained indicated that enrichment did not significantly affect the rehydration ratios. However, chemical treatment and partial freeze-drying improved the rehydration ratios.

The rehydrated products (28 groups) were evaluated organoleptically with respect to color, cohesiveness, off-flavor and doneness by a panel of five judges. The product that was chemically treated, soaked at 122°F for 15 minutes and cooked in an autoclave at 250°F for 3 minutes followed by a combination of freeze-drying and convective air drying received the highest score in all of the organoleptic attributes. Groups 2, 3, and 4 received lower scores (Group 2--same as Group 1 but not chemically treated; Group 3--same as Group 1 except the cooked rice was dehydrated in the convective air drier; Group 4--same as Group 3 except with no chemical treatment).

The effect of processing and cooking on the nutritional levels of the quick-cooking rice was investigated by performing analyses for thiamin, niacin and iron on six groups of rice. These test groups consisted of the four quick-cooking rice groups receiving the highest organoleptic scores, and one each of enriched and non-enriched raw rice. The raw samples were used to evaluate the nearness of the actual values of thiamin, niacin and iron to the theoretical values expected after mixing 0.5 pounds of premix to 99.5 pounds of raw rice, and served as reference points for comparing the effects of varying the soaking,
cooking and drying conditions on the percent nutrient retention in the four quick-cooking rice groups. Group 1 (the chemically treated raw rice soaked at 122°F for 15 minutes and cooked in an autoclave at 250°F for 3 minutes followed by a combination of freeze-drying and convective air drying) contained the maximum amounts of the tested nutrients. The data from the other samples indicated that chemical treatment and freeze-drying were critical process modifications in the maintenance of nutrients during processing.

A superior instant rice with characteristics of perfectly cooked rice, and a high retention of original nutrients, can be produced by process modifications.
CONCLUSIONS

1. A process including chemical treatment of raw rice followed by pressure cooking, freeze-drying and convective air drying has been developed for producing an improved quick-cooking rice with preselected chemical, physical and nutritional properties.

2. Laboratory operations for the preparation of optimal quality quick-cooking rice included five major steps: (1) soaking, (2) cooking, (3) drying, (4) rehydration, and (5) organoleptic evaluations.

3. The moisture content of cooked rice was reduced to 12%, and results showed that chemical treatment and freeze-drying were critical steps for the preservation of nutrients during processing.

4. Chemically treated raw rice soaked at 122°F for 15 minutes, and cooked in an autoclave at 250°F for 3 minutes, followed by freeze-drying and convective air drying exhibited maximum retention of thiamin, niacin and iron.

5. When the rehydrated rice was evaluated organoleptically, the color, flavor, cohesiveness and texture (degree of cooking) were shown to be highly acceptable.

6. This superior instant rice with these desirable chemical, physical and organoleptic characteristics can be produced industrially by simple process equipment changes.
BIBLIOGRAPHY


VITA

Durward A. Smith was born in Raymond, Washington.

He received his primary and secondary education in the Willapa Valley School System, Menlo, Washington. He then attended Grays Harbor College in Aberdeen, Washington, where he received an Associate in Arts degree in 1967. A Bachelor of Arts in Zoology was received from the University of Washington in 1970, and a Bachelor of Science in Agriculture from the University of Idaho in 1972. In September, 1972, the author began graduate work at Louisiana State University where he earned a Master of Science in Food Science. He is currently a candidate for the Doctor of Philosophy degree in Food Science with a minor in Dairy Science.
EXAMINATION AND THESIS REPORT

Candidate: Durward A. Smith

Major Field: Food Science

Title of Thesis: Process Modifications for Producing a Superior Instant Rice

Approved:

[Signatures]

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

July 9, 1976