Rice is one of the leading food crops and sustains two-third of the world's population, providing 20 per cent of the world's dietary energy supply. Despite being a primary food, rice is low in protein and high in starch. The low protein levels in rice cause deficiencies of protein and some essential amino acids in people who take it as their primary diet. For example, lysine, which is responsible for proper growth of the human body, is the essential amino acid found in the lowest quantity in rice.

One approach to overcome these difficulties is to prepare rice analogues by extrusion, in which the vitamins are embedded and consequently do not separate from the rice grains. This will utilise mainly the broken rice which is either discarded or sold at lower prices. The fortification of rice analogues will allow consumers to benefit without making major changes in their dietary habits. Broken rice can also be ground into rice flour and used to produce value added products. Extrusion processing gives the option of reforming the rice flour into a precooked product that can be shaped, and have a texture similar to a cooked rice kernel. In this process, we can add different vitamins, minerals, beta-carotenes and other potential functional ingredients inside the rice.
body. The rice then can be sold to consumers who are looking for health benefits from eating foods. The rice does not need to be soaked in water for a long time prior to cooking, so therefore, all the added ingredients will stay within the rice.

**Principles of extrusion**
Extrusion cooking has been defined as the process by which moistened, expandable, starchy and/or proteinaceous materials are plasticised in a tube by a combination of moisture, pressure, heat and mechanical shear. This results in elevated product temperatures within the tube, the gelatinisation of starchy components, the denaturisation of proteins, the stretching or restructuring of tractile components and the exothermic expansion of the extrudate.

The extrusion system must accomplish a number of phenomena in a very short time under controlled, continuous, steady state conditions. These phenomena include tempering, feeding, mixing, cooking and shaping.

**Feeding / tempering**
The raw materials are fed uniformly into a preconditioner where they are mixed and tempered with water and steam. This results in moistened-uniform mixture entering the extruder and is critical for producing a high quality final product.

**Cooking**
Through the addition of moisture, energy and time, the starch portion of the recipe is cooked or gelatinised and the proteins are denatured.

**Mixing**
The extrusion system provides a homogeneous, irreversible, bonded dispersion of all ingredients. This not only insures uniformity of all ingredients such as dyes throughout the product, but also provides a means whereby minor ingredients can be intimately associated with potential reaction sites promoting desirable chemical and physical modifications of the starch and protein fractions of the raw ingredients.

**Shaping and sizing of the final extruded product**
Extruded rice must be properly shaped and sized during extrusion. This allows it to be placed in convenient and transportable sized portions prior to packaging for the retail and institutional marketplace. The rice exiting the extruder die mimics the size, shape and texture of real rice. Selection of the proper raw materials and system configuration are essential for producing an acceptable final product.

**Raw materials**
The raw materials used for the production of extruded rice are both the most expensive and the most important consideration of the process. There are several important raw material characteristics that require attention. These include the protein, starch, oil, fibre and particle size of each ingredient.

In any extrusion process, the particle size of the raw material is important. Large particles are difficult to hydrate and may require additional preconditioning or additional mechanical energy input in order to plasticise and disperse the entire particle. In some cases, very fine, floury particles are also detrimental because they tend to agglomerate in the preconditioner and then these agglomerates are difficult to re-disperse in the extruder barrel.

A wide variety of rice flours can be used as a base for the recipe. However, each flour imparts its own textural and flavour characteristics to the final product.

**Extruded rice production system**
A typical process flow diagram for the production of extruded rice is shown in
EXTRUSION

Figure 1. Raw materials are supplied either in bulk as shown or in bags. After mixing, the raw materials are conveyed to the live bin of the extrusion portion of the system. Flavours, colouring agents and other liquid additives may be introduced at this phase of the process insuring thorough and continuous mixing of all the foodstuffs entering the extruder barrel.

Extruder

The preconditioner discharges directly in to the extruder assembly consisting of the barrel and screw configuration. The extruder conveys the rice in an environment that controls the energy inputs to enhance the conditions required for final product texture.

Extruders used for the manufacture of extruded rice are twin screw in design. The impact on final product characteristics such as texture, rehydration, density, etc. is produced by screw and barrel profile, screw speed, processing conditions (temperature, moisture, retention time), raw material characteristics and die selection.

The initial section of the extruder barrel is designed to act as a feeding or metering zone to simply convey the preconditioned rice away from the inlet zone of the barrel and into the extruder. The material then enters a processing zone where the amorphous, free flowing rice flour is worked into a colloidal dough. The compression ratio of the screw profile is increased in this stage to assist in blending water or steam with the raw material. The temperature of the moist dough is increased slightly though the addition of mechanical energy via the extruder screws. The temperature rise in the extruder barrel is from mechanical energy dissipated through the rotating screw.

The extrusion portion of the system includes a live bin/feeder, preconditioner, extrusion cooker, and die/knife assembly as shown in Figure 2. The design of each of these components is engineered to accomplish a specific function in the process of extruded rice. Within the design features, the operating conditions are adjusted to vary the properties of the finished product. The effects of each processing step on the product are specifically addressed.

Live-bottom holding bin/feeder

The live bin/feeder provides a means of uniformly metering the raw materials (typically floury in nature) into the preconditioner and subsequently into the extruder. This flow of raw material must be uninterrupted and rate controllable. The live bin/feeder controls the product rate or throughput of the entire system. The live bin/feeder system can be controlled in a volumetric or gravimetric manner. In a volumetric setup, the feeder delivers a constant volume of feed to the preconditioner. When operating under gravimetric, or loss-in-weight (LIW), conditions the feeder delivers a set mass flow rate of raw material to the preconditioner.

Preconditioner

Preconditioning is required to provide uniform and complete moisture penetration of raw ingredients. This significantly improves the stability of the extruder and final product quality. In addition, by completely plasticising the raw material particles prior to their introduction into the extruder barrel, extruder wear caused by the abrasive raw material particles is greatly reduced.

In the atmospheric preconditioner, moisture is uniformly applied in the form of water and steam to achieve a uniformly moistened mass. The time and mixing of the mass in the preconditioner is accomplished via mixing and conveying elements consisting of rotating shafts with radially attached pitched paddles.
Die
The extrusion chamber must be capped with a die apparatus. The die offers restriction to product flow and shapes the extrudate. Dies for extruded rice are typically face dies. The die is fitted with a variable speed cutting device to size the kernel.

Drying
As with most extruded products, extruded rice must be subjected to drying, primarily to make the product shelf stable.

Since extruded rice is an extremely dense product, it must be carefully dried to prevent case hardening or cracking. To accomplish this, drying rate is artificially reduced by injecting live steam, which raises the humidity in the dryer, throughout the drying process. After drying, the rice is cooled prior to storage. After cooling, fines are removed and the product is segregated into the appropriate size ranges and then sent to holding bins prior to packaging.

Final product specifications
After the processing steps are completed, the next step is rehydrating or reconstituting the rice product. This step can be performed either by the consumer or the rice may be rehydrated and added to a convenience food product.

Extruded rice produced on a Wenger system requires approximately 10 minutes of preparation time as opposed to the 20 minutes necessary to completely cook and hydrate an unprocessed rice kernel. This extruded rice has a very similar texture to a cooked rice kernel. Figure 3 shows an example of dry extruded rice and Figure 4 shows a sample of a prepared dish of extruded rice.

The texture of the prepared rice will be affected by the preparation procedure. The preparation methods are typically very flexible.

The rice simply requires rehydration to 58 to 60 per cent moisture, in order to be edible. The following procedures have shown to give good results:
1) Add equal volumes of rice and cold water to a container. Then cover and allow to set for two hours for complete rehydration
2) Put equal volumes of rice and water in a microwave safe container. Microwave on high until the water begins to boil. Cover the container and wait for 10 minutes for complete rehydration
3) Boil the rice for three to five minutes in excess water. The water should be boiling before the rice is added. Then remove the heat and allow to set for an additional six to eight minutes before draining off the excess water (the entire time needs to be 10 to 12 minutes)
4) One part rice can be added to 1.25 parts boiling water (by volume). The rice should be boiled for three minutes, then covered and allowed to sit for an additional seven to 10 minutes.

The final rice texture can be adjusted by using modifying the ratio of water and rice and altering the rehydration times. For example using additional water and longer rehydration times will result in the rice having a softer texture.

**FIGURE 3** Extruded rice

The rice simply requires rehydration to 58 to 60 per cent moisture, in order to be edible. The following procedures have shown to give good results:
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**FIGURE 4** A sample of a prepared dish of extruded rice

The rice simply requires rehydration to 58 to 60 per cent moisture, in order to be edible. The following procedures have shown to give good results:
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**BIOGRAPHY**

Dr. Mian N. Riaz is Director for the Food Protein R&D Center, Head of the Extrusion Program and Graduate Faculty in the Food Science and Technology Program at Texas A&M University, College Station, Texas. Dr. Riaz has published five books and three of them are in the area of extrusion technology (Extruder in Food Application, Extruders and Expanders in Pet Food, Aquatic and Livestock Feeds and Extrusion Problem Solved) and one in the area of soybeans (Soy Application in Food). He also published 17 chapters in different books including some chapters in the area of extrusion. He offers four short courses in the area of extrusion annually, two courses are in feed extrusion and two courses are in food extrusion.