Characteristics of Red Rice in Louisiana.

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CHARACTERISTICS OF RED RICE IN LOUISIANA

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Agronomy

by

Milton James Constantin
M.S., Louisiana State University, 1958
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ABSTRACT

During August, 1958, a study of red rice, a weed in rice fields, was made in the southwestern Louisiana rice area. A total of 1,084 panicles of red rice was collected for laboratory studies of variation in grain characteristics. During November, 1959, several rice mill operators were interviewed individually to determine the problem that red rice presents to the milling industry.

The survey showed that red rice plants were present in all fields, although their frequency varied greatly among fields. Two major hull color types, straw and black, were easily recognizable. Some fields had both straw colored and black hull plants in about equal frequencies, while either of these two types predominated in other fields.

Most mill operators reported that red rice is a serious problem to the industry because it lowers the quality and price of rice, necessitates more severe milling, subsequently decreasing milling quality. Red rice is more objectionable in long grain rice, but is reportedly more common in medium grain rice. Although there is equipment capable of removing most red rice from long grain rice, it is impractical for mills to do so. The foreign markets show less discrimination towards red rice than the American market. A lot of rice is never discarded because it contains excessive red rice.

It was found in the laboratory that all plants had
shattering spikelets with red seed coats and pubescent hulls. Red rice plants differed genetically in hull color, awned condition, awn color, awn pubescence, awn length, grain length, grain width, percentage of kernel breakage, and intensity of seed coat color. There was a wide degree of variation among plants in most of these characteristics. No variation could be detected among plants in grain shattering and hull pubescence.

Three hull color types were recognized, straw, gray, and black, and these were used in the discussion of other characteristics of red rice. The gray hull type was an intermediate type, and possessed certain characteristics in common with each of the two major hull color types. The black and gray hull types were mostly awned, while the straw colored hull type was predominantly awnless. Awns of the straw colored and gray hull types were straw colored, while practically all those of the black hull type were black. The straw colored hull type included the shortest grains, while the gray hull type included the longest grains. There was appreciable difference among hull color types in percentage of kernel breakage, which was in all cases greater than that of cultivated varieties. Hull color types differed genetically in awned condition, awn color, awn length, grain length, and percentage of kernel breakage. They did not seem to differ in grain shattering, hull pubescence, seed coat color intensity, awn pubescence and grain width.

Red rice is probably an introduced type or form of...
O. sativa var. fatua Prain, which has become established in Louisiana and has subsequently been modified greatly by natural hybridization with cultivated rice. Southeast Asia may be the probable center of origin, from which red rice spread to other countries as mixtures in seed rice. The wide variation in most characters is assumed to be due mostly to natural hybridization with cultivated rice, and partly to introductions of various types, and mutations. The two main factors involved in the survival and spread of red rice are grain shattering, and the ability of the grains to remain viable in the soil during long adverse periods.
INTRODUCTION

Cultivated rice, *Oryza sativa* L., is a complex species which is grown in all countries of the world that have tropical or subtropical climates. This species includes numerous cultivated varieties of rice, and also some wild rice as well. According to Copeland (1924), wild rice that resembles cultivated rice is found in many parts of the world where rice has been grown for a long time. Wild rice that grows in association with cultivated rice as weeds creates a problem for many farmers in rice producing countries. Prain (1903) classified the annual wild rice of south and southeast Asia as *Oryza sativa* var. *fatua*. This wild rice is considered by some authorities as having given rise to cultivated rice, while other authorities consider that it arose from cultivated rice. It is distinguished from cultivated-rice by means of grain shattering plus other distinctive characteristics.

In Louisiana and other rice growing areas of the United States, rice farmers are faced with a serious problem created by a type of wild rice referred to as "red rice". The term "red rice" is applied to this type of annual wild rice because the grains possess a red colored seed coat. Red rice is a type or form of wild rice which was presumably introduced into the United States as a mixture in seed rice obtained from foreign countries.

Red rice resembles very closely cultivated rice in...
respect to many morphological characters. It is identified as a wild rice type by the fact that the plants produce grains that shatter, possess red seed coats, and possess the ability to remain viable in the soil through periods of adverse conditions. These characteristics of red rice are in direct contrast to cultivated rice.

Although red rice has been a problem to the Louisiana rice farmers for many years, very few detailed studies of red rice have been conducted. The few detailed studies of red rice that were conducted during the nineteenth-century and the beginning of this century are not sufficient. They are not sufficient because, 1. other red rice types may have been introduced, 2. the red rice of that time may have changed, 3. details were mostly comparisons of red rice with cultivated rice which has definitely been altered. Therefore, statements made at that time have become out-dated and are no longer applicable.

Studies of red rice have been conducted since the time of these early studies. Some of the later studies were conducted within the last decade. These studies are inadequate because they were not designed to study variability in red rice. There is no available information concerning red rice and the rice milling industry.

Thus, the amount of detailed information concerning red rice is very limited, and some that is available is obsolete while some were not designed to study variability. Much
more detailed information concerning red rice is needed for both research and practical applications.

Red rice is generally found growing in close association as a weed with cultivated rice. In Louisiana, it is found mainly in fields of cultivated rice and abandoned rice fields. Red rice is not a homogenous group of plants. Although all red rice plants apparently have some characters in common, there is wide variation for most characters among plants within the group.

Red rice is a problem to the rice industry because 1. plants of red rice compete with plants of cultivated rice for space, light and nutrition, 2. total yield per acre is reduced due to grain shattering of the red rice types prior to harvesting, 3. the presence of red rice lowers the grade and price of cultivated rice, 4. the presence of red rice in a sample usually necessitates the use of more severe milling which reduces the total milling yield and the yield of head rice.

When it is considered that most Louisiana rice fields are infested to some extent with red rice, it is easy to understand the wide scope and the seriousness of the red rice problem. Estimates are not available regarding the total monetary value that is lost due to lowered production in the field, lowered milling yields, lowered quality and price, plus added expenses that are directly attributable to red rice. However, the problem is such that it surely merits
additional research work and attention.

This study was designed to determine 1. the extent of variation present in several grain characteristics of red rice, 2. the extent of variation in field infestations of red rice, 3. the reasons for and the extent of the red rice problem in respect to the Louisiana rice milling industry. In order to determine the extent of variation in grain characteristics, a collection of red rice plants (1,084) was made in August, 1958, and analysed in the laboratory. The determination of the extent of variation in field infestations of red rice was limited to estimates of the number of plants per acre, and the relative frequency of the major hull color types of red rice in relation to the total red rice population. This was done in the fields by means of visual observations. The viewpoint of the Louisiana rice milling industry towards red rice was obtained from the mill operators by means of a prepared list of questions presented to each operator during a personal interview.
It was apparent from the very beginning that publications concerning red rice specifically were very limited. Information concerning red rice was obtained from publications containing general information about rice and rice culture.

United States Department of Agriculture workers reported (DeBow's Review, 1850) that they considered red rice as being rice approaching more nearly its natural state. They based their opinion on the fact that red rice plants usually appear to be the most hardy, thrifty and luxuriant of the crop. Knapp (1899) described red rice plants as being practically wild, and exhibiting stronger and hardier growth than cultivated rice plants. Vincenheller (1906) described plants of red rice as being vigorous, persistent and possessing other true weed characteristics. The red rice plants were described by Kennedy (1923) as being more vigorous and aggressive than white rice plants.

Chambliss (1920) reported that red rice plants can be easily distinguished from cultivated rice plants after heading time. Grist (1955) claimed that red rice plants are very difficult to identify in the field prior to flowering. Jones, et al (1952) and Grist (1955) reported that some red rice plants are seemingly identical to plants of cultivated varieties except for the red seed coat of the kernels. They also stated that it is not possible to identify such plants in the
fields except by means of kernel examination.

Dodson (1900) reported that red rice plants are shorter than plants of cultivated varieties, and grow in stools or clumps. Quereau (1920) and Jones, et al (1950) described the growth habit of red rice plants as spreading. Nelson (1908) reported that red rice plants tiller profusely producing from ten to sixty tillers per plant, and thereby forming stools or clumps.

Dodson (1900) and Kennedy (1923) reported that the stems of red rice stool at an angle (approximately 65° angle) rather than perpendicular such as those of cultivated rice. Nelson (1907) stated that the red rice stems tend to weaken at the first or second internode below the panicles, and usually bend over at either of those two points. Quereau (1920) reported that red rice possesses weak straw that tends to bend and break before the rice is fully mature.

The red rice panicle was described by Dodson (1898, 1900), Knapp (1899), Nelson (1907), Chambliss (1920), and Jones, et al (1950) as being long, openly branched, light weight and erect, bearing comparatively few spikelets that shattered upon reaching maturity. Knapp (1899) referred to panicles of red rice as being similar to those of Johnson Grass.

In addition to the general description of panicles given in the previous paragraph, Dodson (1898) reported that main branches of the panicles are bent in a series of curves. The spikelets are borne by very short pedicels which causes the branch continuing above each spikelet to curve rather than
continue straight. Nelson (1907) reported that main branches of the panicle are arranged in whorls and also mentioned that the grains are borne by short pedicels. All workers reported that spikelets shattered upon reaching maturity.

The grains of red rice are colored red in direct contrast to those of cultivated white rice. According to Dodson (1898), Knapp (1899) and Grist (1955) some red rice grains possess red color throughout the entire substance, while other grains possess red color only in the seed coat. However, Chambliss (1920), Quereau (1920) and Kennedy (1923) claimed that the red pigment was confined to the seed coat. Kato and Isikawa (1921) reported that the red pigment was contained chiefly in the large cells of the seed coat. Dodson (1898), Knapp (1899), Nelson (1907), Kennedy (1923) and Williams (1956) reported that the kernel color intensity ranged all the way from pink to dark-red. Variation in the intensity of the red color was explained as being the result of hybridization between red rice and white rice (Dodson, 1898 and Nelson, 1907).

Allston (1846) described three types of red rice, one type resembled cultivated gold hull rice but had longer awns, the other two types resembled cultivated white hull rice but one type was awned and the other awnless. United States Department of Agriculture workers (DeBow's Review, 1850) reported that there were some red rice with white chaff and other with yellow chaff. Quereau (1920) described the outer husk of red rice spikelets as being rough. Goss and Brown (1939)
classified red rice into two types and referred to one type as Southern Black Hull Red Rice and the other type as Southern Red Rice. Williams (1956) classified red rice into two groups. One group he described as having dark colored hulls and long awns. He did not indicate hull color nor awn condition of the spikelets of the other group.

Grains of red rice were described as varying in size and shape. According to Dodson (1898) typical red rice grains are small and short, and the light colored grains are intermediate in length between typical red and cultivated rice. He assumed that the atypical characters resulted from hybridization. Grist (1955) reported that the red rice grains are not sufficiently dissimilar from grains of cultivated varieties in which they are found to allow for mechanical separation. According to Jones, *et al* (1952) and Grist (1955) the various sizes and shapes of red rice grains are due directly to hybridization of red rice with the various cultivated varieties.

Dodson (1898, 1900), Kennedy (1923), Grist (1955), Williams (1956) and Hodges (1957) reported that once the red rice grain falls to the ground and becomes embedded in the soil it can remain viable for years. Quereau (1920) reported proven germination of red rice grains even after 12 years of exposure in the soil. Goss and Brown (1939) conducted experiments at Beaumont, Texas; Stuttgart, Arkansas; and Biggs, California in order to determine the viability of red rice grains as compared to that of cultivated rice grains. Both
types of grains were exposed to similar conditions and tested for germination at regular intervals. Under dry storage conditions at soil temperature level all red rice grains showed good viability after 7 years, while grains of cultivated rice lost their viability after 3 years. When buried in the soil at ordinary plow depth the cultivated rice grains lost viability during the first year of exposure, while red rice grains showed good viability after 3 years, and some germination even after 7 years of exposure. Red rice grains retained their viability better when buried under irrigated conditions than under non-irrigated conditions.

According to Dodson (1900), Vincenheller (1906) and Kennedy (1923), red rice is just as nutritious as cultivated white rice. Austin (1893), Dodson (1898, 1900), Chambliss (1920), Kennedy (1923), Grist (1955), Hodges (1957) reported that the public demands white rice, therefore, the presence of red grains in cultivated rice lowers the quality of the product. Vincenheller (1906) reported that the red rice kernels were soft, brittle, and broke during the milling process, and that this also helped to lower the quality of the product.

Red rice has been classified as a separate species from cultivated rice by some authorities, and as a botanical variety or a complex of botanical varieties of Oryza sativa L. by others. Stubbs, et al (1904), and Kennedy (1923) referred to red rice as a species under the name O. rufipogon as classified by Griffith in 1851. Quereau (1920) also mentioned the classification of red rice as a species under the
name *O. rufipogon* Griffith. However, he believed red rice to be a botanical variety of *O. sativa* L. rather than a separate species. Knapp (1899) accepted Watt's classification of wild rice in India, 1891, and reported that American red rice belongs to *O. sativa* L. var. *rufipogon*. This classification was accepted by Nelson (1907) and Bellue (1932). Dodson (1898, 1900) and Vincenheller (1906) claimed that red rice presented ample evidence to justify its classification as a botanical variety of *O. sativa* L. if not a distinct species. Austin (1893) referred to red rice as *O. sativa* L. var. *praecox*. Copeland (1924), Jones, *et al* (1950), Grist (1955), Williams (1956) and Hodges (1957) referred to red rice either as a botanical variety or a mixture of varieties of *O. sativa* L. but did not specify any varietal name.

According to Chatterjee (1947), Koenig assigned the name *O. fatua* to the wild rice of India in 1840. According to Watt (1891), Griffith classified the possible progenitor of all red rices as *O. rufipogon* in 1851. Watt (1891) in his treatise on rice in India recognized the following four botanical varieties of *O. sativa* L.: 1. *rufipogon*, 2. *coarctata*, 3. *bengalensis*, and 4. *abuensis*. He accepted Griffith's idea about *rufipogon* being the probable progenitor of all red rices, however, he assigned it the status of a botanical variety rather than a species.

Prain (1903) classified the annual wild rice of India as *O. sativa* L. var. *fatua*. He described *O. sativa* var. *fatua* as being an annual plant bearing spikelets with long
awns. Graham (1913) stated that wild rices are common in marshy places and cultivated fields of rice in India. He described them as weedy plants bearing deciduous spikelets with stout awns and dark red grains. He reported that these wild rices were very similar to *O. sativa* L. var. *fatua* Prain.

Roy (1921) also referred to the group of wild rices in India by the name *O. sativa* L. var. *fatua* Prain. He mentioned shedding of the spikelets and the ability of the grains to remain dormant in the soil through periods of adverse conditions. The great degree of variation in the group was brought out by the fact that he distinguished twenty-four types.

Roschevicz (1931) stated that wild rice occurs all over central Africa, in the greater part of India and Indo-China, and northern Australia. He claimed that wild rice taken in its complex is the progenitor of the majority of cultivated varieties of rice in India and Indo-China. Roschevicz (1931) assigned to it the name *O. sativa* L. f. *spontanea*. He claimed that it represents a complex of species, and it closely approaches cultivated rice in all respects except shattering of the spikelets.

Mitra and Ganguli (1932) reported that wild rice grows in ditches and low lying areas. They described the panicles as being erect and loosely branched bearing deciduous, awned spikelets with black inner glumes (lemma and palea). They described the grains as being slender and red.
Ramiáh (1937) discussed the degree of variation and complexity within the group of wild rice associated with cultivated rice in India. He considered natural intercrossing as a prime factor contributing to variation. One character which was present in all of wild rice types was the shattering nature of the spikelets.

Backer (1946) described plants of the species, *O. fatua* Koen., as being aquatic, having spreading or drooping panicle branches, and long awned spikelets. He stated that plants of this species resemble closely plants of some forms of the highly variable cultivated rice, except for shedding of the mature spikelets. He described the plants as perennial which does not coincide with other descriptions.

Chatterjee (1947) considered that cultivated rices arose by means of domestication of the wild rices. He mentioned deciduous nature of the spikelets and presence of awns ranging in length from 3-10cm. Chatterjee (1948) rejected the species status, *O. fatua* Koen., for this wild rice because it was not validly published. He provisionally accepted the classification by Prain in 1903, whereby the name *O. sativa* var. *fatua* was assigned to this wild rice of India.

Coyaud (1950) reported that poor people harvest this bearded red rice which he referred to as *O. sativa* L. var. *spontanea* Rosch. He also claimed that it is found in fields of cultivated rice where it forms a host of hybrids with plants of the cultivated varieties. He reported the possible
extent of intercrossing between the wild and cultivated rice plants as being 10 to 15%.

Chatterjee (1951) accepted the botanical classification of *O. sativa* L. var. *fatua* Prain, but he mentioned that in his opinion it deserves a species name. He listed *O. sativa* L. f. *spontanea* Rosch. as a synonym for *O. sativa* L. var. *fatua* Prain. He also mentioned the great amount of variation that exists within the group, and traced its antiquity to the time of classical Sanskrit.

Ramiah and Ghose (1951) reported that varietal diversity of rice is greatest in India, and that *O. sativa* L. var. *fatua* Prain occurs there in abundance. They claimed that the distribution of *O. sativa* L. var. *fatua* Prain coincides with areas of most ancient rice cultivation. *O. sativa* L. var. *fatua* Prain was described by them as being procumbent, which does not coincide with other descriptions. They reported that *O. sativa* L. var. *fatua* Prain crossed readily with cultivated rices and produced fertile hybrids with varying degrees of *fatua* characters. They also considered *O. sativa* L. var. *fatua* Prain as the progenitor of cultivated rice, and that characters such as erect plant habit, white kernels and non-shattering spikelets developed by means of mutations.

Sampath and Rao (1951) considered *O. sativa* L. var. *fatua* Prain as representing *spontanea* varieties of *O. sativa* L. and recommended that the term *fatua* be dropped in the literature. The authors considered *O. perennis* Moench. as the progenitor of cultivated rice, because of its crossability
with cultivated rice. They reported that selfing hybrids of *O. sativa* L. and *O. perennis* Moench. produced segregates very similar to the *spontanea* rices, therefore, they considered the *spontanea* rices to be of such hybrid origin. They considered the *spontanea* group as being too complex and artificial to be accepted as the progenitor of cultivated rice. They also assumed that natural crossing between *spontanea* and cultivated rice occurs, and results in the production of natural hybrids and segregates to further complicate the picture.

According to Grist (1955), Burkill reported that *O. fatua* Koen. was found growing in fields of southwestern and western India, and that it was very similar to cultivated rice in all respects except shattering of spikelets. Grist (1955) also mentioned *O. sativa* L. f. *spontanea* in connection with the origin of cultivated rice. He apparently accepted *O. fatua* Koen. as a species and the *spontanea* rices as a variety of *O. sativa* L.

Sampath and Govindaswami (1958) classified the wild rice of India into two classes, *O. perennis* and *O. sativa* var. *spontanea*. Thus, they preferred the term "spontanea" instead of "fatua." The *spontanea* rices were described as annuals propagated by seed. They are different from *O. perennis* in that they lack subterranean stems and floating habit. According to them *spontanea* rices have red colored pericarp, dark colored husk and spikelets that shatter. They reported that individual *spontanea* plants usually show
segregation of characters, and varying degrees of self-sterility, indicating hybridization.

Sampath and Govindaswami (1958) classified *spontanea* rices into three general groups. The groups are: 1. plants that resemble *O. perennis*, 2. plants that resemble *O. sativa*, 3. plants that are intermediate between the first two groups. Their idea was that *O. sativa* and *O. perennis* hybridize under field conditions, subsequently producing *spontanea* rices. However, they did not completely ignore the possibility that some *spontanea* types may have evolved directly from *O. perennis* without hybridization with *O. sativa*.

The planters were among the first to offer an explanation for the occurrence of red rice in fields of cultivated rice. Allston (1846), Austin (1893) and Dodson (1898) gave similar accounts of planters' opinions concerning the yearly occurrence of red rice. According to these authors, planters believed that grains of cultivated rice that remained in the fields over-winter deteriorated as a result of exposure to adverse environmental conditions. The following year these deteriorated grains germinated and produced red rice plants. These red rice plants would in turn continue producing red rice grains that became more fixed in their characteristics.

Dodson (1898) conducted experiments to determine the validity of the planters' opinions. His results convinced him that the planters were wrong. In his experiments red rice grains produced red rice plants, and white rice grains
produced white rice plants. He reported few grains of white rice germinated after exposure, but no changes from white to red rice were noticed. No reversions of red to white rice were observed either. His conclusion was that they were two distinct types and the grains of one type could not produce plants of the other type. Knapp (1899), Chambliss (1915) and Quereau (1920) reported essentially the same conclusions.

Nelson (1908), Chambliss (1915), Quereau (1920), Goss and Brown (1939), Grist (1955) and Hodges (1957) agreed that red rice is introduced in a field by planting seed rice infested with red rice grains. Goss and Brown (1939) reported the results of a survey conducted on seed rice being planted in Louisiana, Texas, and Arkansas. Out of 337 lots of seed rice sampled, 54% contained an average of twenty-eight grains of red rice per pound of sample. One sample contained 585 grains of red rice per pound of sample. At the planting rate of eighty pounds per acre, they calculated that over half the farmers were planting an average of 2,300 red rice grains per acre. Dodson (1896), Vincenheller (1906), Kennedy (1923), Williams (1956) and Hodges (1957) reported that once red rice is introduced in a field and allowed to mature seed, it becomes very difficult to eradicate.

The increase in population density of red rice in fields of cultivated rice has been explained by Nelson (1907), and Jones, et al (1952) on the basis of cross fertilization between red rice and cultivated rice. Their explanation is that red rice characteristics are dominant in the hybrids,
and that red rice plants in the fields not only mature their grains but also fertilize cultivated rice, giving rise to hybrids producing red grains the following season. Nelson (1908) offered another explanation based on the number of tillers per plant and the number of grains per panicle. He considered that one red rice grain would germinate and produce from ten to sixty tillers. Each tiller produces a panicle with an average of 100 grains, of which fifty to seventy-five per cent fall to the ground before harvest where they may remain viable for several years. He also mentioned his original idea concerning the increase of red rice plants in the fields by hybridization with cultivated rice. Chambliss (1920), Quereau (1920), Kennedy (1923), Grist (1955), Williams (1956) and Hodges (1957) attributed the persistency of red rice in fields of cultivated rice to the shattering nature of the red rice spikelets, and their ability to remain viable in the soil for several years.

Dodson (1900) considered it quite probable that red rice was brought into the United States with the Honduras and Japanese varieties. McCrady (1901) mentioned that DuBois, treasurer of the East India Company, sent seed rice to Charleston, South Carolina at an early date. Both red rice and white rice were supposedly brought into the United States at that time. Stubbs, et al (1904) reported that red rice was probably brought into the United States in both the Japanese and Honduras Varieties. Vincenheller (1906) surmised that red rice is probably native to India, where it still
grows. According to his interpretation, red rice spread from the fields of India to those of China, Japan and other rice countries of the world including the United States. Efferson (1952) considered that the original introductions of Carolina Gold were fairly pure, and that no forms of wild rice existed in the southeast United States where these were grown, therefore, a uniform high quality rice resulted.

Dodson (1898, 1900) claimed that the red rice found growing in parts of Louisiana where the Honduras variety was exclusively grown was very similar to that found in areas of the state where Japanese varieties were grown. Knapp (1899), Nelson (1907) and Grist (1955) mentioned variability existing in red rice, but they did not elaborate on the various types.

Allston (1846) listed three types of red rice common at that time. Red rice with grains having gold colored husk like those of Carolina Gold, but possessing longer awns was one type. A second type of red rice produced awnless grains with white husk such as those of Carolina White. The third type produced grains with white husk such as those of Carolina White, but possessed long awns.

United States Department of Agriculture workers (DeBow's Review, 1850) listed four different types of red rice. Type one had white husk and was awnless. The second and most common type had a white husk with a black point and was awned. The third type had yellow husk and was awned. The fourth type had yellow husk, the spikelets did not shatter, and it
was impossible to distinguish this type from cultivated rice except by means of the red seed coat color.

In the course of their survey Goss and Brown (1939) divided red rices into two groups. One group they referred to as Southern Red Rice, and the other group they referred to as Southern Black Hull Red Rice. In the viability phase of their work, the two groups reacted differently.

Williams (1956) considered that there were several varieties of red rice, and he distinguished two general classes. Common Red Rice he described as having light colored foliage, and erect panicles above the level of the field. His second class was Vermilion Red Rice which he described as having pale green foliage, appearing nearly white in fields of cultivated rice, with erect panicles above the level of the field bearing spikelets with dark colored husk and long awns.

Dodson (1898, 1900), Nelson (1907, 1908), Jones, et al (1952), Grist (1955) and Jodon (1959) discussed the occurrence of cross fertilization in the fields between red rice and cultivated rice. Available evidence indicated that red rice characteristics were dominant. Some of them also mentioned that the variation existing among varieties of cultivated rice was in part responsible for some of the variation existing in red rice.

Beachell, et al (1938) conducted an experiment to determine the extent of natural crossing under Arkansas, California, Louisiana and Texas conditions. The average percentage of natural hybridization was 0.45 over a four to six year period.
Louisiana had an average percentage of 0.51, which was slightly greater than average for the experiment. There was annual variation, variation among locations and also among varieties in the experiment.

Jodon (1959) reported that cross pollination occurs under Louisiana conditions, and that red rice undoubtedly crosses with cultivated rice in the fields. He claimed that the reason red rice types are not more numerous than they are, is that the red rice hybrids are late maturing and often do not set seed under our cultivation system.

The occurrence of cross fertilization between cultivated and wild rices was also discussed by Roy (1921), Goyaud (1950), Ramiah and Ghose (1951), Sampath and Rao (1951), and Sampath and Govindaswami (1953). They brought out the fact that in India and other countries, intercrossing occurs between cultivated rice and wild rice. According to them the occurrence of natural cross-fertilization between wild and cultivated rices is much higher than among cultivated rice varieties.
MATERIALS AND METHODS

Studies were conducted in Louisiana which took under consideration the red rice problem in relation to the Louisiana rice industry, and the extent of variability that exists in grain characteristics of red rice.

Red Rice and the Louisiana Rice Industry

During the latter part of August, 1958, a study was conducted in the rice growing region of southwest Louisiana. The material used in this study was what is commonly known as red rice as it was found growing in fields of cultivated rice in southwest Louisiana. Fields of mature rice in which the study was conducted were chosen at random while driving along the highways and side-roads of the rice area.

Red rice is so called because the grains possess a red seed coat in direct contrast with those of the white grained cultivated varieties. In addition to this off-type grain characteristics, red rice plants generally have other off-type characteristics that set them aside from plants of cultivated varieties. In practice, red rice plants were located in fields of cultivated rice as off-type plants, which differed in several traits from the cultivated rice plants. The following off-type characteristics were used in locating red rice plants in fields of cultivated rice: 1. plant height above that of the level of the field, 2. plant color that was lighter than that of cultivated rice plants in the field, 3. lax or open panicles, 4. panicles
with spikelets showing evidence of shattering, 5. spikelets with black hulls, 6. spikelets with awns. Any one or a combination of these various off-type characteristics was used to locate the red rice plants in the fields of cultivated rice. A sufficient number of these off-type plants were examined to verify that they did have a red seed coat.

The first phase of the study was devoted to making general observations of red rice plants in rice fields in the vicinity of Crowley, Louisiana. These observations indicated that red rice plants could be identified readily when the plants were mature, that an appreciable number of these plants were present in most rice fields, and that the plants could be divided easily into two major distinct types. In one of these types the hulls (lemma and palea) were straw colored like ordinary cultivated varieties, while in the second type the hulls were black.

Studies were made in fields of cultivated rice in Acadia, Allen, Evangeline, Jefferson-Davis, and St. Landry parishes. These studies involved determination of the approximate number of red rice plants per acre, and the relative frequency of the two major types of red rice plants (straw colored hulls and black hulls) in relation to the total red rice plant population per field. Investigations were conducted in twenty-one fields, which were chosen at random in the parishes listed above.

In order to make a reliable estimate of the number of red rice plants per acre, a rope was tied to four stakes in
such a manner that it would enclose an area 14.8 feet square when stretched out. A spot was randomly selected in a field, the rope was staked out, and the red rice plants within the roped area were counted and recorded. One such area was sampled per field. To calculate the estimated number of red rice plants per acre, the number of red rice plants within the roped area was multiplied by 200.

The relative frequency of straw colored hull to black hull types of red rice was estimated in the same twenty-one fields. While walking through the individual fields, the red rice population was observed and visual estimates were made regarding the approximate percentage of each of the two major types of red rice plants comprising the total red rice population of the respective fields. In the twenty-one fields checked, the area which was used to determine the approximate number of red rice plants per acre was not considered in making the estimates of the relative frequency of the two types of red rice plants. Later, during the course of the study, estimates of relative frequency of the two types of red rice plants were made in forty-four additional fields located in Acadia, Calcasieu, Jefferson-Davis, Lafayette, and Vermilion parishes. Thus, estimates were made of the relative frequency of plants of each hull color type red rice in a total of sixty-five individual fields.

During the latter part of November, 1959, managers or operators of twenty Louisiana rice mills were interviewed concerning red rice. Information was obtained from the
following mills:

Louisiana State Rice Milling Co., Inc.
Abbeville, Louisiana

The Dore Rice Mill
Crowley, Louisiana

Eagle Rice and Feed Mills, Inc.
Crowley, Louisiana

Hope Rice Mill
Crowley, Louisiana

Independent Rice Mill, Inc.
Crowley, Louisiana

Louisiana Rice Growers, Inc.
Crowley, Louisiana

Robert's Rice Mill
Crowley, Louisiana

Supreme Rice Mill
Crowley, Louisiana

Estherwood Rice Mills, Inc.
Estherwood, Louisiana

Republic Rice Mill, Inc.
Gueydan, Louisiana

Kaplan Rice Mills, Inc.
Kaplan, Louisiana

Liberty Rice Mill, Inc.
Kaplan, Louisiana

Farmers' Rice Mill, Inc.
Lake Charles, Louisiana

Louisiana State Rice Milling Co., Inc.
Lake Charles, Louisiana

Imperial Rice Mills, Inc.
Mermentau, Louisiana

Mermentau Rice Mill Co., Inc.
Mermentau, Louisiana

Edmundson-Duhe Rice Mill
Rayne, Louisiana
Information was obtained by use of a questionnaire that contained nineteen questions pertaining to red rice in relation to the milling industry. In obtaining answers to the questions, each manager was encouraged to add any additional pertinent information which he felt would contribute to the study. The following questions were included in the questionnaire:

1. What is the approximate percentage of the lots of rice bought by the mill that contain sufficient red rice to be objectionable?

2. What percentage of red rice must a lot of rice contain for it to be considered objectionable?

3. Are any lots of rice refused by the mill because of their excessive red rice content?

4. If answer to number 3 is yes, what percentage of red rice must be present in a lot of rice to cause the mill to refuse it?

5. If answer to number 3 is yes, what is done with the rice which contains excessive red rice?

6. What are the specific reasons why millers object to red rice?

7. Can part of the red rice be removed from a lot of rice before the milling process?

8. If answer to number 7 is yes, how is it removed?

9. If answer to number 7 is yes, what proportion can be removed?

10. What is done with the red rice that is removed?

11. Have you noticed much variation in the amount of red rice from different localities?
12. Do you feel that there is more red rice in some varieties than in others?

13. Do you feel that red rice is more serious in one grain length class (short, medium and long) than another?

14. If answer to number 13 is yes, discuss to learn which class is more serious.

15. Do you feel that the red rice problem varies in seriousness from year to year?

16. Do you feel that the red rice problem is: improving, getting worse, or not changing?

17. Which one of the two types of red rice (straw colored hull or black hull) is more serious in the rice brought to your mill?

18. Does the amount of red rice present affect the price paid for rice by the mill?

19. Other remarks.

Additional information was obtained from the Federal-State Rice Inspection Service Laboratory at Crowley, Louisiana. The two main questions asked there were:

1. What is the approximate percentage of the total lots of rice graded by the laboratory that contain red rice?

2. What is the average percentage of red rice contained by the lots of rice graded by the laboratory?

All answers for each question were recorded and analyzed. Arbitrary classes were established for data which required such classification.

Variability in the Grain Characteristics of Red Rice in Louisiana

The other phase of the study was devoted to making a collection of individual red rice panicles from the red rice population of various fields to measure the extent of variation in grain characteristics. The collection of
individual red rice panicles was obtained from forty-four fields located in Acadia, Calcasieu, Jefferson-Davis, Lafayette and Vermilion parishes. These were the same fields in which observations were made concerning the relative frequency of plants of the straw colored hull and black hull types of red rice.

Red rice panicles were collected individually from the population of red rice that was found growing among the plants of the cultivated variety in the fields. With the aid of a pocket knife the peduncle or central axis of the red rice panicle was cut below the lowermost branches of the panicle. Only one panicle was usually collected from each red rice plant, and the number of red rice panicles collected per field averaged 25, with a range of from ten to thirty-two. Each panicle was placed in an individual brown office type envelope immediately after having been cut. Each envelope was numbered consecutively as collected in the field, and the bundle of envelopes from each field was designated according to its approximate location within the respective parish. Altogether, panicles from 1,034 plants of red rice were collected for the variability study.

When the collecting phase of the study was ended, the entire collection of red rice panicles was spread out to dry in their respective envelopes. The drying was done in a laboratory room of the Agronomy-Horticulture building on the Louisiana State University campus at Baton Rouge, Louisiana. The collection was also stored in that same
laboratory room.

The laboratory analyses were designed to determine the amount of variation that exist among plants in various grain characteristics. The spikelets of red rice were analysed for variation in hull color, hull pubescence, awn condition, awn length, awn color, awn pubescence, grain length, grain width, grain shattering, percentage of kernel breakage by mechanical dehulling, and intensity of seed coat color.

In the analysis of red rice panicles for spikelet hull color, three classes were established. The classes were: 1. straw colored hulls, 2. gray hulls, and 3. black hulls. Each panicle of red rice was visually examined and assigned to one of the three classes depending upon the hull color of the spikelets.

Spikelets of red rice were examined and classified according to the presence or absence of pubescence on the hulls. Only two classes were established, and these were: 1. spikelets with smooth hulls, and 2. spikelets with pubescent hulls. Spikelets were examined visually and assigned to their respective class.

From initial field observations of red rice populations, it was evident that red rice spikelets varied in awn condition. In the laboratory analysis phase of the study three general classes were established. These classes were as follows: 1. awned, 2. partially awned, and 3. awnless. The limitations of each class were as follows: the awned class included those panicles having all or practically all
spikelets bearing awns, the partially awned class included those panicles having some spikelets with awns, while the majority of the spikelets were awnless, the awnless class included those panicles having all spikelets without awns. Classification was done by visual examination of the spikelets of each red rice panicle in the collection.

All panicles that were classified as having awned spikelets were analysed for awn length, awn color and awn pubescence.

Awn length was determined by using a small metric ruler to measure the distance between the base and the tip of the awn. Ten spikelets were randomly chosen from each panicle, and their awns were measured and recorded. Spikelets having awns that were obviously broken were discarded, and replaced with other spikelets. The awn length of the sample was the average length of the ten awns expressed in centimeter values.

Awn color was determined by means of visual examination of the awns. The awns were classified as being either straw colored or black.

Awn pubescence was expressed in terms of the presence or absence, and the distribution of pubescence on the awns. Three arbitrary classes were recognized as follows: 1. entirely smooth, 2. smooth towards the base and pubescent towards the tip, 3. entirely pubescent.

In order to facilitate the determination of grain length and grain width a simple measuring board was co-
constructed. Two small, smooth boards were nailed together lengthwise at right angles to each other. Then, the front edge of the horizontal board was elevated in order to tilt upward the right angle formed by the two boards. A small plastic metric ruler was then fastened flat upon the horizontal board with the edge of the ruler having the millimeter calibrations placed flush against the surface of the vertical board. The angle formed by the two boards served as a trough in which to align the grains upon the ruler.

Grain length was determined prior to removal of the lemma and palea, and was expressed in terms of millimeter values. Awns were removed before the grains were measured. Ten grains were chosen at random from each panicle and these were aligned end to end on the plastic ruler. A pair of laboratory blunt end forceps were used to align the grains on the ruler. Care was taken to make sure that the grains were touching but not overlapping before the measurement was taken. The total length of the ten grains was used to obtain the average, and this value was recorded as the grain length of the respective panicle.

The same ten grains that were used in the grain length determination were also used in the grain width determination. Grain width was expressed in terms of millimeter values. Grain width was determined by placing the ten grains side by side on the ruler. Care was taken to make sure that all grains were lying flat and barely touching one another. The total width of the ten grains was used
to obtain the average, and this value was recorded as the grain width of the respective panicle.

Spikelets of all panicles were analysed for grain shattering, and two classes were established. The two classes were: 1. mature spikelets shattered upon handling the panicle, and 2. mature spikelets did not shatter upon handling the panicle. The latter was comparable to spikelets of the commonly cultivated rice varieties, which do not ordinarily shatter upon handling the panicle.

Later during the study, all of the sound, mature kernels were removed from each panicle of red rice and were counted. After having been counted they were placed in separate small coin envelopes. Each envelope was identified as to field number, plant number, and the number of grains that it contained. All samples having less than forty sound mature grains were kept separate from those samples having forty or more grains. These sound red rice grains were used in determining the percentage of kernel breakage by mechanical dehulling, and it was felt that less than forty grains would not provide reliable results. Therefore, all samples having less than forty grains were not used.

A laboratory model of the McGill Rice Sheller was used to remove mechanically the lemma and palea from the red rice grains. The manufacturer's instructions concerning the setting of the space between the rollers were based upon grain length with three classes recognized.
Therefore, all red rice samples were classified as being short grain (less than 8mm.), medium grain (8 thru 9mm.) and long grain (greater than 9mm.). Each sample of red rice in each grain length class, along with samples of representative cultivated rice varieties, were run through the sheller which was set according to instructions. When all samples of one class were dehulled, the setting of the sheller was changed to accommodate the samples of the next class. The samples of cultivated rice varieties were used as a check with which the red rice samples could be compared.

The percentage of kernel breakage by mechanical dehulling was based on numerical values. A known number of grains were run through the sheller, and the dehulled grains were collected and returned to their respective envelopes to be counted at a later date. When the entire collection had been dehulled, the whole kernels were separated by hand from the broken kernels. The whole kernels were then counted and the number was recorded. Percentage of kernel breakage by mechanical dehulling was then calculated by dividing the number of whole kernels per sample after dehulling by the original number of kernels, and subtracting that value from a hundred.

Seed coat color intensity was determined by a visual examination of the kernels after the lemma and palea were removed. Samples that had not been mechanically dehulled because of too few kernels, were classified after removing by hand the lemma and palea from several kernels. The
darkest grains of each sample were used in making the determinations. Three classes of seed coat color intensity were arbitrarily established in order to facilitate classification. These classes were as follows: 1. light red, 2. medium red, 3. dark red.

All data were recorded appropriately in an analysis pad, and the distribution of panicles per class was calculated for each character analysed. Awn length, grain length, grain width and percentage of kernel breakage involved quantitative measurements. In order to facilitate analysis of data for quantitative characters, arbitrary classes were established as follows: nine classes at 1.0 cm. intervals for awn length, fourteen classes at 0.3 mm. intervals for grain length, nine classes at 0.2 mm. intervals for grain width, and seventeen classes at 6.0% intervals for percentage of kernel breakage. Hull color types of red rice were conveniently used in the discussion of all characters analysed.
RESULTS

Red Rice and the Louisiana Rice Industry

General observations made in rice fields of the Crowley, Louisiana area indicated that red rice plants were present in varying numbers in practically all rice fields. These observations also indicated that red rice could be separated into two easily identified types. The grains of one of these types had straw colored hulls, while the grains of the other type had black hulls.

The number of red rice plants per acre was estimated in twenty-one fields of cultivated rice located in Acadia, Allen, Evangeline, Jefferson-Davis, and St. Landry parishes. Estimates ranged from a few plants to approximately 25,000 red rice plants per acre. The results are presented in Table 1.

Of the twenty-one fields that were checked, nine appeared to have fewer than 200 red rice plants per acre (no plants found in the test area of 14.8 feet square), eight had at least 200 but less than 1,000 red rice plants per acre, and four had 1,000 or more red rice plants per acre. Although nine fields had no red rice plants within the test area, all of these had a few red rice plants outside the test area. No fields entirely free of red rice were found.

Less variation in the number of red rice plants per acre was found in the fields located in Allen, Evangeline, the northern part of Jefferson-Davis, and St. Landry parishes.
Table 1. The number of red rice plants per acre found in fields of cultivated rice in Louisiana.

<table>
<thead>
<tr>
<th>Field No.</th>
<th>Parish</th>
<th>No. of Plants per 14.8 ft. sq.</th>
<th>Approximate No. of Plants per Acre(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acadia</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>17</td>
<td>3,000</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>125</td>
<td>25,000</td>
</tr>
<tr>
<td>6</td>
<td>Allen</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>7</td>
<td>&quot;</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>8</td>
<td>&quot;</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>9</td>
<td>&quot;</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>6</td>
<td>1,200</td>
</tr>
<tr>
<td>11</td>
<td>Evangeline</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>12</td>
<td>&quot;</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>13</td>
<td>&quot;</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>14</td>
<td>&quot;</td>
<td>5</td>
<td>1,000</td>
</tr>
<tr>
<td>15</td>
<td>Jeff-Davis</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>16</td>
<td>&quot;</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>17</td>
<td>&quot;</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>18</td>
<td>&quot;</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>19</td>
<td>&quot;</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>20</td>
<td>St. Landry</td>
<td>0</td>
<td>0(2)</td>
</tr>
<tr>
<td>21</td>
<td>&quot;</td>
<td>1</td>
<td>200</td>
</tr>
</tbody>
</table>

1. To convert the number of plants per 14.8 feet square to plants per acre, multiply by 200.

2. Some red rice plants were seen in all of these fields.
This area comprises what may be referred to as the northern fringe area of the southwestern Louisiana rice region. The red rice problem in the fields of this area appeared to be less serious than in the fields located in areas of more extensive rice production. The number of red rice plants per acre ranged from very few to approximately 1,200 in the fields located in the northern fringe area, while the range was from very few to approximately 25,000 in fields of Acadia Parish.

Any field in which 200 or more red rice plants were found per acre was considered to be infested with red rice. Fields in which 1,000 or more red rice plants were found per acre were considered to be heavily infested with red rice. Of the twenty-one fields checked, four were considered to be heavily infested and eight were considered to be infested with red rice. However, these results are probably not representative of the red rice problem in the principal rice growing areas of Louisiana, because some of the fields checked were located in fringe areas where the red rice problem seems to be less serious.

Estimates of the relative frequency of plants of the straw colored hull and black hull types of red rice in relation to the total red rice population of each field were made in sixty-five rice fields. Twenty-one of these sixty-five fields were the same fields in which estimates were made concerning the total number of red rice plants per acre. The fields were located in Acadia, Allen, Calcasieu,
Jefferson-Davis, Evangeline, Lafayette, St. Landry and Vermilion parishes. The results are presented in Table 2.

Both types of red rice plants were found in all fields in each locality, however, their relative frequency varied among fields. The relative frequency of plants of the straw colored hull type ranged from less than 1% to more than 99% among the sixty-five fields that were checked. Relative frequency of plants of the two different types of red rice was not affected by the severity of the red rice infestation in the fields, nor by the cultivated variety grown in the fields.

There were twenty-one fields of cultivated rice in which plants of both types of red rice were present in approximately equal numbers, nineteen fields had predominantly black hull type plants, while twenty-five fields had predominantly straw colored hull type plants. There were two fields that had less than 1% straw colored hull type plants and more than 99% black hull type plants, while five fields had more than 99% straw colored hull type plants and less than 1% black hull type plants. These results indicated that both types of red rice were about equally common in the rice fields that were checked, with some indications that the straw colored hull type may have been more common.

The red rice problem was also studied from the standpoint of the Louisiana rice milling industry. This was accomplished by using a questionnaire consisting of nineteen different questions in interviewing the managers or
Table 2. Classification of sixty-five rice fields according to the relative frequency of straw colored hull type red rice plants expressed in percentages of the total red rice population in the respective fields.

<table>
<thead>
<tr>
<th>Total Fields</th>
<th>Relative frequency classes in percentage values</th>
<th>More than</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than (2)</td>
<td>1-10</td>
</tr>
<tr>
<td>65</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

1. The relative frequency of the black hull type plants equals the difference between the value recorded for the straw colored hull type plants and 100%.

2. The class "less than 1%" was set up to accommodate fields in which only a few plants of the straw colored hull type could be found in a population of predominantly black hull type plants.

3. The class "more than 99%" was set up to accommodate fields in which only a few plants of the black hull type could be found in a population of predominantly straw colored hull type plants.
operators of Louisiana rice mills. Remarks other than those necessary to answer the questions, yet pertinent to establishing the seriousness of the red rice problem to the milling industry, were also obtained. The information is presented either in table form or discussion form following each question of the questionnaire. Question number 1. What is the approximate percentage of the lots of rice bought by the mill that contain sufficient red rice to be objectionable?

The answers to question 1 are summarised in Table 3. These answers represent a wide range in the percentage of rice having objectionable red rice that is handled by the mills. Two main reasons account for this range in the answers provided by the mills. These reasons are: 1. the proportion of the mills' trade that is exported, 2. individual mill policies, which vary in the amount of red rice necessary to be considered objectionable. A mill which exports a large part of its rice will find red rice to be less serious than one that buys rice only for the domestic market. This is due to the fact that the export trade accepts more grade U. S. No. 4, U. S. No. 5, and U. S. No. 6 rice, which may contain greater quantities of red rice than grade U. S. No. 1 and U. S. No. 2 rice, than does the domestic or American trade.

Two mills did not buy any rice with objectionable amounts of red rice, but the reasons for this are quite different. One of these mills dealt exclusively in rice for
Table 3. The approximate percentage of rice having objectionable amounts of red rice handled by Louisiana rice mills.

<table>
<thead>
<tr>
<th>Total No. of Mills</th>
<th>Number of mills handling the following percentage of rice with objectionable amounts of red rice:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>2</td>
</tr>
</tbody>
</table>
export trade, in which case all rice regardless of the amount of red rice present could be disposed of. The other mill refused to buy rice that was considered to have objectionable amounts of red rice. Thus, it is seen that one mill did not consider any amounts of red rice as objectionable, while the other did not buy any rice that had more red rice than the amount considered acceptable.

Eleven mills reported that 5 to 20% of the rice handled had objectionable amounts of red rice. Four mills reported that 25 to 40% of the rice handled had objectionable amounts of red rice. Two mills reported that 45 to 50% of the rice handled had objectionable amounts of red rice. Both of the latter mills placed more emphasis on rice for domestic market, in which case the presence of even small quantities of red rice is considered objectionable. However, both mills did not refuse to buy rice that contained objectionable amounts of red rice providing that a lower price was accepted for the rice. One mill reported that approximately 75% of the rice handled had some red rice in it, but did not specify what percentage had sufficient red rice to be considered objectionable.

These answers indicate a wide range in the amounts of red rice that is tolerated in cultivated rice by various mill. At least seventeen mills recognized the fact that objectionable amounts of red rice were present in some Louisiana rice, and have devised means by which this rice may be purchased and disposed of.
Question number 2. What percentage of red rice must a lot of rice contain for it to be considered objectionable?

Thirteen of the millers answered that they considered as objectionable the presence of enough red rice to lower the grade of the sample, and they followed the U.S.D.A. grade standards in that respect. The U.S.D.A. grade standards for rough rice are as follows as far as red rice is concerned: U.S. No. 1, 0.5%; U.S. No. 2, 1.5%; U.S. No. 3, 2.0%; U.S. No. 4, 3.0%; U.S. No. 5, 6.0%; U.S. No. 6, 15.0%. These values represent maximum percentage of red rice and damaged kernels (singly or combined) tolerated in each grade of rough rice. The ones answering in terms of per cent values were as follows: two answered, 5% or more; two answered, 10% or more; two answered, 20% or more; and one answered, 25% or more. Variation depends upon individual mill policy, and the proportion of trade that is export.

Question number 3. Are any lots of rice refused by the mill because of excessive red rice content?

Nine of the managers answered no, providing a lower price was accepted for the rice. One of these answered that he would refuse a small lot of rice with excessive red rice, if it meant tying up one of his bins during the milling season without occupying the bin's total capacity. Eleven managers answered that they occasionally refuse to buy rice because of excessive red rice. One of these reported that approximately 20% of the rice offered to the
mill was refused because of excessive red rice.

Question number 4. If answer to number 3 is yes, what percentage of red rice must be present in a lot of rice to cause the mills to refuse it?

The eleven managers who answered that they do refuse to buy rice with excessive red rice listed the following percentages of red rice as excessive: one answered, 8% or more; four answered, 10% or more; three answered 30%, 35%, and 50% or more, respectively. This represents quite a range of tolerance to red rice, and reflects mill policy as well as the proportion of the trade that is export.

Question number 5. If answer to number 3 is yes, what is done with the rice which contains excessive red rice?

The rice with excessive red rice that is refused by some mills is bought by other mills providing a cut in price is accepted. They mill such rice and blend it with better rice in order to meet specifications for export trade. Such rice is never discarded.

Question number 6. What are the specific reasons why millers object to red rice?

All managers listed some or all of the following reasons: 1. Consumers prefer white rice, therefore, red rice leads to discrimination and thus lowers grade and price of the product. 2. Presence of red rice in a sample makes more severe milling necessary, and this results in lowered milling quality. Milling quality is lowered, because the red rice grains and grains of cultivated rice vary in size and
length, thereby necessitating more severe milling which increases kernel breakage. 3. The red bran from red rice grains cause some degree of smearing on the white grains. 4. Rice with red rice in it requires more polishing.

Question number 7. Can part of the red rice be removed from a lot of rice before the milling process?

Most mills answered that red rice can be removed from long grain rice, but that only a small portion can be removed from medium grain rice. They also answered that in practice very little if any red rice is removed by the mills before or during the milling process. The reason is that the equipment used to remove red rice has low capacity, and would decrease the mill output, and increase cost of processing. Also taken into consideration is the fact that the red rice removed from the rough rice would finally be blended into the finished product, often times the same rice from which it had been initially removed.

Question number 8. If answer to number 7 is yes, how is it removed?

Three different machines capable of removing red rice from cultivated rice were mentioned. The Carter Disc Separator and the Dockins Seed Grader are capable of removing red rice and other seeds from rough rice prior to milling. Both of these machines remove from cultivated rice any off-type grains providing that they vary in size from those of the cultivated variety. The Paddy Separator removes from brown rice (after dehulling) those grains that
still possess hulls. In most cases such grains are red rice grains. In practice the Paddy Separator actually removes only a small portion of the red rice from cultivated rice during the milling process. Both the Garter Disc Separator and Dockins Seed Grader are more extensively used in the seed rice processing business than in the rice milling industry.

Question number 9. If answer to number 7 is yes, what proportion can be removed.

Nine mills answered that over 95% of the red rice can be removed from long grain rice by use of the Dockins Seed Grader. Two of these answered that all short and medium length grains of red rice can be removed from long grain rice. However, they all reported that very little red rice can be removed from medium grain varieties. All mills reported that such removal of red rice by mills is impractical, and is not done at the present time.

Question number 10. What is done with the red rice that is removed?

The small amount that is removed is milled separately and blended with other rice which is usually exported. The broken red rice kernels are granulated along with the broken white rice kernels and this is sold to brewers.

Question number 11. Have you noticed much variation in the amount of red rice from different localities?

All mills except two answered that variation in the amount of red rice existed among the various localities.
Question number 12. Do you feel that there is more red rice in some varieties, than in others?

Ten mills answered that there is a tendency to find more red rice in the medium grain varieties which are usually earlier maturing varieties, than in the long grain varieties. The others reported that no difference was noticed. All mills reported that the greatest amount of variation was from field to field.

Question number 13. Do you feel that red rice is more serious in one grain length class (short, medium and long) than another?

All managers answered that red rice is more serious to mills in the long grain varieties.

Question number 14. If answer to number 13 is yes, discuss to learn which class is more serious, and why?

The managers answered that red rice is more serious in the long grain varieties. They gave the following reasons: 1. Long grain rice is grown and processed for premium grade, therefore, red rice is more discriminated against in it than in the medium length grain varieties. 2. Unequal grain size of the red rice and long grain varieties presents a more serious problem to the mills. 3. The presence of red rice in long grain rice lowers the milling quality more than it does in medium grain varieties.

Question number 15. Do you feel that the red rice problem varies in seriousness from year to year?

All managers except one answered that the amount of
red rice varies from year to year. It seems as though the amount of red rice varies with the climatic conditions prevailing during the planting season. It was the opinion of most managers that red rice is more prevalent in years with wet springs in which farmers are unable to fallow plow prior to planting.

Question number 16. Do you feel that the red rice problem is: improving, getting worse, not changing?

All managers except two answered that they felt the red rice problem was improving since the war years. The two managers who disagreed answered that the red rice problem was not changing. The reasons listed for the improving condition were: 1. farmers have become more conscious of red rice, 2. better seed rice is now available, 3. better farming practices are followed, 4. better farming equipment is used, and 5. better land selection and use because of acreage allotment program. Those who felt that the problem was not changing did so because of annual variation in the amount of red rice.

Question number 17. Which one of the two types of red rice (straw colored hulls or black hulls) is more serious in the rice brought to your mill?

All managers except one answered that the black hull type red rice is more serious to the mills. The reasons given were that black hull type red rice grains are more difficult to dehull, the red bran layer is more difficult to remove, and the spikelets have awns. The one who
disagreed answered that the straw colored hull type red rice is more serious, because of less breakage. This results in more red rice in the finished product.

Question number 18. Does the amount of red rice present affect the price paid for rice by the mill?

All managers answered that it lowers the price paid for rice by the mills.

Question number 19. Any other remarks?

The following remarks were made by the various managers:

1. The straw colored hull type red rice is more common than the black hull type red rice.
2. Heaviest concentration of black hull type red rice is in Vermilion Parish, but it is on the increase as far as other areas are concerned.
3. There is less variation in the black hull type red rice than in the straw colored hull type red rice.
4. The black hull type red rice has greater tendency to shatter when mature.
5. In some grains of red rice the red color is limited to the bran layer, while in others the entire grain is colored.
6. Some long grain red rice is found occasionally, and seems to be increasing because of elimination of short grain types from processed long grain seed rice.
7. All red rice identification is done after the hulls have been removed from the grain.
8. When *Sesbania* seed is present in rice it creates as serious
a problem to mills as does red rice.

The Federal-State Rice Inspection Service Laboratory at Crowley, Louisiana reported that at least 80% of the rice that they grade has some red rice in it. As an average of all samples having red rice, the per cent of red rice present is approximately 2%. This value represents the amount of red rice present in head rice only. The actual amount of red rice in rough rice as taken from the fields is usually much higher.

Variability in Grain Characteristics of Red Rice

A collection of individual "red rice" panicles was obtained in 1958 from forty-four randomly selected fields of mature rice in southwest Louisiana. The fields were located in Acadia, Calcasieu, Jefferson-Davis, Lafayette, and Vermilion parishes. An average of twenty-five panicles were collected from as many individual "red rice" plants in each field. "Red rice" plants from which panicles were obtained were identified while walking through the fields by means of off-type plant characteristics. Color of seed coat was not determined in making the collection.

An examination of 1,084 panicles, collected from plants which possessed off-type plant characteristics, revealed that all of the panicles bore grains that had red seed coats. The red seed coat color varied in intensity among the individuals, but the red pigment was recognizable in all cases. Red seed coat color and the off-type plant characteristics are genetic in nature and the results
indicate that these traits are in some way associated. It appears from these results that virtually all wild type rice plants found growing in fields of cultivated rice in Louisiana have red seed coats and can be properly designated "red rice".

**Hull Color.** This character was used as the basis for classification of red rice into types, and in the discussion of other traits, because it was the most stable characteristic of red rice. The spikelets of one type had straw colored hulls, while spikelets of the other types had dark colored hulls. The latter types appeared to have the same pigment in the hulls, and distinction was based on the concentration of the pigment. One of these types had spikelets with grayish-brown to gray hulls, and the other type had black hulls. Thus, three hull color types of red rice were recognized as follows: straw, gray, and black. The straw colored hull type was distinctly different from the other two hull color types. The black and gray hull types, however, were not distinctly different, and the difference may have been due partially or entirely to environment. It was assumed that red rice differed genetically in hull color among plants. Results are presented in Table 4.

Of the total panicles of red rice in the collection, 60.8% had spikelets with straw colored hulls, 24.6% had spikelets with black hulls, and 14.6% had spikelets with gray hulls. However, no efforts were made to collect the panicles of each hull color type at random or according
Table 4. Classification of the panicles of red rice in respect to color of hulls and awned condition.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Panicles having spikelets that were:</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Awned</td>
<td>Partially Awned</td>
<td>Awnless</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>252</td>
<td>15</td>
<td>---</td>
<td>267</td>
<td></td>
</tr>
<tr>
<td>Gray</td>
<td>117</td>
<td>38</td>
<td>3</td>
<td>158</td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>60</td>
<td>219</td>
<td>380</td>
<td>659</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>429</td>
<td>272</td>
<td>383</td>
<td>1,084</td>
<td></td>
</tr>
</tbody>
</table>
to the frequency distribution of plants of each type in the fields. Therefore, the frequency of each hull color type in the collection is not necessarily indicative of the frequency of plants of each hull color type in the fields.

During the process of making the collection, it was noted that the frequency of plants of each hull color type varied among fields. The relative frequency of plants of the different hull color types also varied from one locality to another. However, the straw colored hull type appeared to be the most common type in the rice area. The black hull type appeared to be most prevalent in certain localities, and the gray hull type was the least common.

**Awned Condition.** Some panicles in the collection had all or practically all spikelets with awns, some panicles had most spikelets without awns, but also had a few spikelets with awns, and some panicles had all spikelets without awns. The following classes were established in reference to awned condition: 1. awned, 2. partially awned, and 3. awnless. Results are presented in Table 4.

Approximately 40% of the collection of panicles was classified as awned, approximately 25% was classified as partially awned, and approximately 35% was classified as awnless. Thus, approximately 65% of the collection had spikelets with awns (either fully awned or partially awned), while approximately 35% of the collection was classified as awnless.

The difference in awned condition in plants of red rice
appeared to be due to genetic differences among the plants. Partially awned types were more of an intermediate form, but were assumed to differ genetically from the awnless and fully awned types. This assumption was made because all three types of plants were found in close proximity in the same fields.

The awned condition in relation to hull color is also shown in Table 4. All of the black hull type panicles had spikelets with awns (either fully awned or partially awned). Ninety-five per cent of the black hull type panicles were classified as awned, and 5% were classified as partially awned. None of the black hull type panicles were classified as awnless. This was sufficient, however, to indicate the presence of genetic variation.

Seventy-four per cent of the gray hull type panicles were classified as awned, 24% were classified as partially awned, and 2% were classified as awnless. Thus, 98% of the gray hull type panicles had spikelets with awns (either fully awned or partially awned), while 2% of the panicles were classified as awnless. These differences in awned condition appeared to be due to genetic differences among plants. The gray hull and straw colored hull types of red rice showed more variation in awned condition than did the black hull type. All three classes of awned condition were represented in these hull color types, whereas, there were no black hull type panicles classified as awnless.

Nine per cent of the straw colored hull type panicles
were classified as awned, 33% were classified as partially awned, and 58% were classified as awnless. These differences appeared to be due to genetic differences among the straw colored hull type plants. Thus, 42% of the straw colored hull type panicles had spikelets with awns (either fully awned or partially awned), while 58% of the panicles were classified as awnless. The straw colored hull type was unique in the fact that it was predominantly awnless, while the other two types were mostly awned.

The results presented in Table 4 indicate that separation of the red rice panicles into primary classes based on hull color was justified. The black and straw colored hull types were distinctly different in respect to awned condition. As pointed out earlier, the black hull type was mostly awned while the straw colored hull type included both awned and awnless plants but was predominantly awnless. It is apparent that the black and straw colored hull types represent types which differ genetically from each other in other traits also. The position of the gray hull type is more uncertain. Gray hull type plants resembled more closely plants of the black hull type in awned condition, however, they were not identical.

**Color of Awns.** Awn color was either black or straw and all awned panicles were classified accordingly. The variation in awn color was apparently due to genetic differences among plants. Results are presented in Table 5.

Of all panicles in the collection classified as fully
Table 5. Classification of the panicles of red rice in respect to hull color, awn color and awn pubescence.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Awn Color</th>
<th>Awn Pubescence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Straw</td>
<td>Black</td>
</tr>
<tr>
<td>Black</td>
<td>7</td>
<td>245</td>
</tr>
<tr>
<td>Gray</td>
<td>117</td>
<td>---</td>
</tr>
<tr>
<td>Straw</td>
<td>60</td>
<td>---</td>
</tr>
<tr>
<td>Total</td>
<td>184</td>
<td>245</td>
</tr>
</tbody>
</table>
awned, 59.5% had black awns, while 40.5% had straw colored awns. The apparent predominance of black awns was somewhat misleading due to the fact that most of the awned panicles were in the black hull type and practically all of these had black awns.

Ninety-seven per cent of the black hull type panicles had spikelets with black awns, while only 3% had spikelets with straw colored awns. This was sufficient to show slight variation in awn color among plants of the black hull type. This variation in awn color within the black hull type red rice was in all probabilities due to causes other than genetic. No variation in awn color was evident in the gray hull and the straw colored hull types of red rice. All awned spikelets of these types of red rice had straw colored awns.

**Pubescence of Awns.** Awns varied in the presence and absence of pubescence, and in the distribution of pubescence along the awns. The three following classes were established in reference to awn pubescence: 1. entirely smooth, 2. smooth towards the base and pubescent towards the tip, and 3. entirely pubescent. The results are presented in Table 5.

Of all panicles classified as fully awned, 77% were classified as having entirely pubescent awns, and 19% were classified as having awns with smooth bases and pubescent tips, while 4% were classified as having entirely smooth awns. Thus, the great majority of red rice panicles classified as fully awned had entirely pubescent awns. The next
most common class was that in which the awns were smooth
towards the base and pubescent towards the tip, while the
least common class was the entirely smooth awns. However,
it is of considerable interest to note that eighteen of
the 429 awned panicles lacked pubescence on the awns.

One per cent of the panicles of the black hull type
red rice had spikelets with entirely smooth awns, 12% had
spikelets with awns that were smooth towards the base and
pubescent towards the tip, and 87% had spikelets with en-
tirely pubescent awns. Three per cent of the panicles of
the gray hull type red rice had spikelets with entirely
smooth awns, 29% had spikelets with awns that were smooth
towards the base and pubescent towards the tip, and 68%
had spikelets with entirely pubescent awns. Twenty per
cent of the panicles of the straw colored hull type red
rice had spikelets with entirely smooth awns, 32% had spike-
lets with awns that were smooth towards the base and pubes-
cent towards the tip, and 48% had spikelets with entirely
pubescent awns.

It appeared that awn pubescence was a genetic trait,
because not all plants subjected to the same or highly sim-
ilar environmental conditions in restricted areas were
similar in respect to awn pubescence. Although genetic
variation existed among red rice plants, it was assumed that
there were no genetic differences in awn pubescence among
the three hull color types of red rice, because the distri-
bution of plants within each color type followed a similar
pattern.

Awn Length. Awn length was determined by measuring ten randomly selected awns from each panicle classified as awned. Awn length was not determined for panicles classified as partially awned. Since awn length was quantitative in nature, arbitrary classes were established at 1 cm. intervals in order to facilitate presentation. Results are presented in Table 6.

Awn length varied from 1.5 to 8.5 cm., however, there were relatively few panicles classified in the two extreme classes. The greater majority of panicles were classified in the 3.5 to 6.5 cm. classes. The wide range in awn length indicated that the variation among plants was probably due to genetic differences rather than environmental variation.

The mean awn length of the black hull, gray hull, and straw colored hull types of red rice was 5.8 cm., 5.3 cm., and 4.1 cm., respectively. A comparison of the means of the three hull color types showed sufficient variation to indicate genetic differences. Thus, there seem to be genetic differences among hull color types as well as among individual plants.

Both the black hull and the gray hull types had more panicles with spikelets having awns 6.5 cm. or longer, than panicles with spikelets having awns 3.5 cm. or shorter. This was not true in the case of the straw colored hull type of red rice. The mean awn length of the straw colored hull type red rice was also distinctly less than that of
Table 6. Frequency distribution of panicles of each hull color type according to awn length classes established arbitrarily at 1 cm. intervals.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Number of panicles in following awn length classes:</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5</td>
<td>2.5</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
<td>6.5</td>
<td>7.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Black</td>
<td>2</td>
<td>3</td>
<td>12</td>
<td>28</td>
<td>88</td>
<td>96</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Gray</td>
<td>-</td>
<td>3</td>
<td>16</td>
<td>33</td>
<td>25</td>
<td>29</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Straw</td>
<td>2</td>
<td>19</td>
<td>15</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>25</td>
<td>43</td>
<td>67</td>
<td>119</td>
<td>133</td>
<td>34</td>
<td>4</td>
</tr>
</tbody>
</table>
the black hull and gray hull types. The latter two hull
color types resembled one another in respect to awn length.

**Grain Length.** Grain length was determined by measuring the
grains without removing the lemma and palea. The average
length of ten randomly selected grains was recorded as the
grain length of the respective panicles. Because grain
length was quantitative in nature, arbitrary classes were
established at 0.3mm. intervals to facilitate presentation.
Results are presented in Table 7.

Grain length varied from 6.1 to 10.0mm, however, the
extreme classes were due to only two out of 1,084 plants.
The majority of plants varied in grain length only from
7.0 to 8.8mm. and the mean of all plants was 8.0mm. It
is possible that environment could have affected grain
length, but not enough to produce the great degree of varia­
tion found among individuals in the collection. Hence,
it may be assumed that there were genetic differences in
grain length among plants of red rice.

The black hull type red rice panicles had grains that
varied in length from 7.0 to 9.4mm. with a mean of 8.1mm.
The gray hull type red rice panicles had grains that varied
in length from 7.0 to 10.0mm. with a mean of 8.2mm. The
straw colored hull type red rice panicles had grains that
varied in length from 6.1 to 9.1mm. with a mean of 7.9mm.

Thus, there was very little variation among the means
of the three hull color types of red rice in respect to
grain length. The greatest mean grain length was 8.2mm,
Table 7. Frequency distribution of panicles of each hull color type according to grain length classes arbitrarily established at 0.3mm. intervals.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Number of panicles in following grain length classes:</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.1 6.4 6.7 7.0 7.3 7.6 7.9 8.2 8.5 8.8 9.1 9.4 9.7 10.0</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>-- -- -- 1 10 11 74 113 44 9 4 1 -- --</td>
<td>8.1</td>
</tr>
<tr>
<td>Gray</td>
<td>-- -- -- 1 3 13 24 57 47 12 -- -- --</td>
<td>1</td>
</tr>
<tr>
<td>Straw</td>
<td>1 5 17 41 78 122 143 127 85 35 5 -- --</td>
<td>7.9</td>
</tr>
<tr>
<td>Total</td>
<td>1 5 17 43 91 146 241 297 176 56 9 1 0 1</td>
<td>8.0</td>
</tr>
</tbody>
</table>
while the least was 7.9mm. The black hull type had a mean grain length of 8.1mm., which resembled more closely that of the gray hull type (8.2mm.) than that of the straw colored hull type (7.9mm.). However, this degree of variation was not sufficient to suggest the presence of genetic differences among the three hull color types. Nor was it sufficient to distinctly separate the black hull and gray hull types from the straw colored hull type of red rice.

However, while both black hull and gray hull types did not have any panicles with grains shorter than 6.9mm., twenty-three panicles of the straw colored hull type had grains shorter than 6.9mm. This indicates that within the straw colored hull type, there were some plants that differed genetically in grain length from plants of the black hull and gray hull types.

Grain Width. Grain width was determined prior to removal of the hulls. The average width of ten grains was recorded as the grain width of the respective panicle. Because grain width was quantitative in nature, classes were arbitrarily established at 0.2mm. intervals to facilitate presentation. Classes ranged from 2.25mm. to 3.85mm. Results are presented in Table 8.

Grain width of all individuals ranged from 2.3 to 3.9mm. However, the extreme grain width classes were due to only two plants out of 1,084 individuals. There were sixteen plants that had grain widths of 2.7mm. or less, while there were seventeen individuals that had grain widths of 3.6mm.
Table 8. Frequency distribution of panicles according to grain width classes arbitrarily established at 0.2mm. intervals.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Number of panicles in following grain width classes:</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.25 2.45 2.65 2.85 3.05 3.25 3.45 3.65 3.85</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>-- -- 2 15 125 114 10 1 -- 3.14</td>
<td></td>
</tr>
<tr>
<td>Gray</td>
<td>-- -- 4 24 54 50 21 5 -- 3.14</td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>1 -- 9 98 210 228 102 10 13.16</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1 0 15 137 389 392 133 16 13.15</td>
<td></td>
</tr>
</tbody>
</table>
or greater. Of the 1,084 individuals, the majority had grain widths of 3.0 to 3.3mm. The mean grain width of all panicles in the collection was 3.15mm.

As in the case of some other characteristics, environmental affect cannot be totally ignored. However, in view of the great degree of variation present, it was assumed that genetic differences accounted for a major portion of the variation in grain width among plants of red rice.

Both the black hull and gray hull types of red rice varied in grain width from 2.7 to 3.6mm, and in both types the mean grain width was 3.14mm. The straw colored hull type red rice varied in grain width from 2.3 to 3.9mm, and the mean grain width was 3.16mm. Although there was some variation within hull color types of red rice, there was essentially no difference among the hull color types of red rice. Therefore, the three hull color types of red rice were considered as not being genetically different as far as grain width was concerned.

**Intensity of Red Seed Coat Color.** Although all of the panicles had grains with red seed coats, the material showed a continuous gradation in the intensity of the seed coat color from light red to dark red. Three seed coat color intensity classes were arbitrarily established as follows: 1. light red, 2. intermediate red, and 3. dark red. The results are presented in Table 9.

Seven per cent of the collection had grains with light red seed coats, 62.5% had grains with intermediate red seed coat.
Table 9. Classification of the panicles of red rice in respect to intensity of red color in the seed coat.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Number of panicles in following seed coat color intensity classes:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light Red</td>
<td>Intermediate Red</td>
<td>Dark Red</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>9</td>
<td>222</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Gray</td>
<td>17</td>
<td>91</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>49</td>
<td>357</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td>670</td>
<td>327</td>
<td></td>
</tr>
</tbody>
</table>
coats, and 30.5% had grains with dark red seed coats. Thus, a majority of panicles had grains with intermediate red seed coats, while only a relatively few panicles had grains possessing light red seed coats.

The intensity of red seed coat color could possibly vary in accordance with the stage of maturity when collected. This was indicated by the presence of some variation in respect to red seed coat color intensity among grains of the same panicle. However, the red seed coat itself is a genetic trait, and it appeared that variation in the intensity of the red color was governed to some extent by genetic factors.

Although some variation existed among individuals within each hull color type of red rice, there was essentially no variation existing among the three hull color types. Thus, the hull color types of red rice did not appear to be genetically different in respect to intensity of red seed coat color.

**Percentage of Kernel Breakage by Mechanical Dehulling.**

There were 920 panicles dehulled mechanically and analysed for percentage of kernel breakage. Results are presented in Table 10. Percentage of kernel breakage by mechanical dehulling varied from 0 to 100%, and the mean was 25.6%. Sixty-six per cent of the panicles that were dehulled mechanically had less than 30% kernel breakage, and 34% of the panicles had over 30% kernel breakage. There were 158 panicles of red rice in the 0 to 5% kernel breakage class,
Table 10. The classification of red rice panicles according to hull color types in respect to percentage of kernel breakage by mechanical dehulling.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>No. of Indiv.</th>
<th>0</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
<th>30</th>
<th>36</th>
<th>42</th>
<th>48</th>
<th>54</th>
<th>60</th>
<th>66</th>
<th>72</th>
<th>78</th>
<th>84</th>
<th>90</th>
<th>96</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>221</td>
<td>16</td>
<td>24</td>
<td>30</td>
<td>35</td>
<td>18</td>
<td>17</td>
<td>12</td>
<td>17</td>
<td>10</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>5</td>
<td>--</td>
<td>33.1</td>
</tr>
<tr>
<td>Gray</td>
<td>127</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>12</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>41.1</td>
</tr>
<tr>
<td>Straw</td>
<td>572</td>
<td>133</td>
<td>116</td>
<td>93</td>
<td>52</td>
<td>40</td>
<td>35</td>
<td>33</td>
<td>23</td>
<td>15</td>
<td>13</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>19.3</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>920</td>
<td>158</td>
<td>149</td>
<td>131</td>
<td>98</td>
<td>69</td>
<td>63</td>
<td>56</td>
<td>48</td>
<td>37</td>
<td>25</td>
<td>18</td>
<td>19</td>
<td>16</td>
<td>8</td>
<td>14</td>
<td>8</td>
<td>3</td>
<td>25.6</td>
</tr>
<tr>
<td>Cultivated(1)</td>
<td>10</td>
<td>-</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.8</td>
</tr>
</tbody>
</table>

1. Each entry represents a different cultivated variety.
while there were only three panicles in the 96 to 100% kernel breakage class.

Ten cultivated varieties of rice were tested to determine percentage of kernel breakage. Nine of the ten varieties had from 6 to 35%, and one variety had 56% kernel breakage. The cultivated varieties had a mean kernel breakage percentage of 20.8, which was about 5% less than that of red rice.

Although the mean percentage of kernel breakage of red rice and cultivated rice did not vary greatly, there were many samples of red rice with percentage of kernel breakage much above that of the cultivated varieties. Apparently red rice kernels were slightly more apt to break during dehulling than were kernels of the cultivated varieties.

The black hull type red rice varied in percentage of kernel breakage by mechanical dehulling from 0 to 95%, and had a mean of 33.1%. The gray hull type red rice varied in percentage of kernel breakage by mechanical dehulling from 0 to 100%, and had a mean of 41.1%. The straw colored hull type red rice varied in percentage of kernel breakage by mechanical dehulling from 0 to 100%, and had a mean of 19.3%.

Percentage of kernel breakage varied widely among plants of red rice, and this possibly could have been due to variation in grain length. Although the above may be true, there were sufficient differences among the means of the hull color types to indicate genetic differences.

The tendency of kernels to break during the dehulling
process is generally associated with grain length; i.e. the longer the kernels, the greater the tendency to break. Red rice panicles within each hull color type were separated into three grain length classes and percentage of kernel breakage was calculated for each. However, there were too few individuals of each hull color type in the long grain class to provide reliable information. The results are presented in Table 11.

Panicles of the black hull type that were classified as short grain varied in kernel breakage from 0 to 71%, and had a mean of 19.5%. The medium grain class varied from 0 to 95%, and had a mean of 36.2%. Panicles of the gray hull type that were classified as short grain varied in kernel breakage from 0 to 53%, and had a mean of 19.5%. The medium grain class varied from 0 to 100%, and had a mean of 46.4%. Panicles of the straw colored hull type that were classified as short grain varied in kernel breakage from 0 to 100%, and had a mean of 10.5%. The medium grain class varied from 0 to 89%, and had a mean of 28.6%. The ten cultivated varieties had the following mean percentage of kernel breakage according to grain length classes: short grain, 13.3%; medium grain, 14.0%; long grain, 33.3%.

In each hull color type of red rice, and also in the cultivated varieties, the medium grain kernels had a greater tendency to break during dehulling than did the short grain kernels. Indications were that kernel breakage was associated with length of grain. However, there also appeared to
Table 11. The classification of panicles of each hull color type according to grain length classes and percentage kernel breakage by mechanical dehulling.

<table>
<thead>
<tr>
<th>Hull Color Type</th>
<th>Grain Length Class</th>
<th>No. of Indiv.</th>
<th>Number of panicles in the following percentage kernel breakage classes:</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0  6 12 18 24 30 36 42 48 54 60 66 72 78 84 90 96 100</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>Short</td>
<td>44</td>
<td>11  7  8  4  2  3  4  1  2  -  1  1  -  -  -  -  -  -  -</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>175</td>
<td>5  17  22  31  15  13  8  16  8  7  3  5  8  4  8  5  -</td>
<td>36.2</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>2</td>
<td>-  -  -  -  1  1  -  -  -  -  -  -  -  -  -  -  -  -  -</td>
<td>30.5</td>
</tr>
<tr>
<td>Gray</td>
<td>Short</td>
<td>26</td>
<td>6  7  3  1  1  -  4  3  1  -  -  -  -  -  -  -  -  -  -</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>100</td>
<td>3  2  5  10  10  10  7  5  11  5  7  7  5  4  5  3  1</td>
<td>46.4</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>1</td>
<td>-  -  -  -  -  -  1  -  -  -  -  -  -  -  -  -  -  -  -</td>
<td>32.0</td>
</tr>
<tr>
<td>Straw</td>
<td>Short</td>
<td>308</td>
<td>117  84  58  21  8  10  5  1  -  2  1  -  -  -  -  -  -  -</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>262</td>
<td>16  32  35  31  32  25  28  22  15  11  6  6  2  -  1  -  -  -</td>
<td>28.6</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>2</td>
<td>-  -  -  -  -  -  -  -  -  -  -  1  -  -  -  -  -  -  -</td>
<td>86.5</td>
</tr>
<tr>
<td>Cultivated(1)</td>
<td>Short</td>
<td>3</td>
<td>-  1  2  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>3</td>
<td>-  1  1  1  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>4</td>
<td>-  -  -  1  1  1  -  -  -  -  -  1  -  -  -  -  -  -  -</td>
<td>33.3</td>
</tr>
</tbody>
</table>

1. Each entry represents a different cultivated variety.
be genetic differences among the hull color types within grain length classes. This was based on the fact that within classes of restricted grain lengths, there was variation among the means of the hull color types. In all cases, the straw colored hull type red rice had the least percentage of kernel breakage, while the gray hull type had the greatest percentage of kernel breakage. Both the gray hull and black hull types, however, had equal kernel breakage in the short grain class.

Hull Pubescence. All panicles were analysed for hull pubescence. All spikelets of red rice were found to have pubescent hulls. No variation in hull pubescence was detected among plants.

Grain Shattering. All panicles were analysed for grain shattering. No red rice panicles were found that had non-shattering spikelets characteristic of cultivated rice. All had shattering spikelets and no variation among plants was detected.
DISCUSSION

Red rice is a common, serious weed of the Louisiana rice fields. The red rice plants resemble plants of cultivated rice in many morphological characteristics. However, red rice plants produce grains that shatter and have red seed coats in contrast to plants of cultivated rice.

Origin of Red Rice in Louisiana. Published reports indicate that red rice was present in fields of cultivated rice in the Carolinas as early as 1346. Allston (1346) referred to at least three types of red rices, which were distinguished according to hull color and the presence or absence of awns. United States Department of Agriculture workers (DeBow's Review, 1850) listed four different kinds of red rice, which they identified by use of hull color, presence or absence of awns, and grain shattering. McCrady (1901) reported that the East India Company sent seed rice to Charleston, South Carolina, at an early date. He surmised that some red rice was introduced as a mixture in that seed rice. Therefore, it appears from the literature that red rice was present in the rice growing region of the southeastern United States before rice cultivation was begun on a commercial scale in Louisiana.

Dodson (1900) concluded that red rice possibly was introduced as a mixture in seed rice of Japanese and Honduras varieties. He based his conclusion on his finding that the red rice found in Louisiana areas where either of these
varieties were grown appeared to be identical. Stubbs, et al (1904) reached a similar conclusion. Vincenheller (1906) concluded that red rice was a native of India, and had spread from there to fields of other rice growing countries including the United States.

There appears to be two possible sources of red rice as far as Louisiana is concerned. Evidently red rice was introduced into Louisiana as a mixture in imported seed rice. The most logical place from which seed rice was probably originally obtained was the rice growing region of the southeastern United States where red rice was present. The second place is foreign countries from which Louisiana farmers obtained seed rice that probably included red rice as a mixture.

Wild rices, which normally produce grains that shatter and possess red seed coats, including types which would be referred to in Louisiana as red rice, reportedly have been a serious problem to farmers in south and southeast Asia. According to publications, wild rices grow as weeds in rice fields, irrigation channels and road-side ditches in rice growing areas of that part of the world. This wild rice is reportedly not a problem in Japan and Formosa, because of the intensive type rice production which includes transplanting and frequent hand weeding even until just prior to harvesting. Thus, it appears highly improbable that the latter countries served as a source of red rice, while it is quite possible that countries of southeast Asia served
as a source of red rice.

There is an unconfirmed report that the black hull type red rice was brought into Vermilion Parish as a potential cultivated variety, and that it was abandoned as soon as it was found to shatter prior to harvesting. From this original foothold it seems to have spread to most areas of southwest Louisiana, although it still appears to be more heavily concentrated in parts of Vermilion Parish.

The black hull red rice type appears to be a relatively recent introduction. Early publications in which various hull color types of red rice were described, do not mention it. In fact, this black hull type red rice was not mentioned by Dodson (1898, 1900), Knapp (1900), Nelson (1907) and Chambliss (1920), although some of these published fairly detailed descriptions of red rice including grain characteristics. Older farmers and rice buyers seem to remember that it was not present in Louisiana fields prior to 1900, whereas regular straw colored hull type red rice was present. This evidence indicates that it is a more recent introduction than the straw colored hull type red rice.

Another possibility of origin of red rice is by mutations in cultivated varieties, which give rise to red rice types spontaneously in the fields. However, the various plants of red rice have several distinctive characteristics in common that differentiate them as a group from cultivated rice. The presence of these several distinct plant and
grain characteristics would require a series of mutations occurring simultaneously, which is highly improbable. Also, if that were true, such mutations would be occurring at present and such mutants have not been found in populations of cultivated rice.

Therefore, all evidence indicates that the origin of red rice in Louisiana may be explained in the following manner. Red rice was probably introduced into the rice producing area of the southeastern United States as a mixture in seed rice. When rice production moved to Louisiana, this early rice producing area served as a source of seed rice, which probably included red rice as a mixture. In addition, new varieties were later introduced from foreign countries in which red rice is common and was probably present in the seed rice as a mixture. Apparently southeast Asia served as the original source of red rice.

Factors Involved in Survival and Spread of Red Rice. Red rice was probably introduced originally in only a limited number of rice fields and in a limited amount per field. Today red rice plants are present in almost all Louisiana rice fields, and some fields have very severe infestations of red rice plants. Evidently red rice had the ability to become established, to increase in number, and to spread to surrounding areas.

The weed-like nature of the red rice plant allows it to grow and reproduce under conditions prevailing in fields of cultivated rice. Red rice plants are fertile, and
usually produce seed under field conditions. Like other weed plants, the red rice plant produces seed that shatters upon maturity, and have the ability to remain viable in the soil even for several years.

The tendency of grains to shatter upon reaching maturity is a definite advantage or asset to the red rice plant. Once the grains shatter, they fall to the ground where they are capable of being moved by wind, water, animals, and cultivation implements. Thus, the immediate surrounding area is infested with red rice grains. If grain shattering were absent, red rice grains would be harvested along with the cultivated rice, and red rice would not be such a problem to farmers.

Besides shattering, the red rice grains have the ability to remain viable in the soil until conditions suitable for germination occur. Once the grains are buried in the soil, they appear to have the ability to remain viable for several years. This also is a definite asset to the plant's ability to survive, because the grains in the soil are capable of producing plants even if unfavorable conditions should prevent seed production for one season.

All plants collected had grains that shattered and possessed red seed coats. As previously mentioned, grain shattering plays a very important role in the perpetuation of red rice plants. There are three possible explanations for the presence of red seed coat types in combination with grain shattering in all of the red rice plants in the
collection. They are: 1. the two characters are very closely linked, 2. one gene governs the expression of both characters, and 3. the presence of the red pigment in the seed coat has some significance in the ability of the grains to remain viable for several years in the soil. The nature of this study was such that the answer to this question could not be ascertained.

Significance of Wide Genetic Variation in Most Characters. The writer found a wide degree of genetic variation in most of the characters of red rice that were analyzed. The most probable causes of this variation include 1. introduction of genetically different types of red rice as mixtures in seed rice, 2. mutations occurring in red rice, and 3. natural hybridization between red rice and cultivated rices.

Various types of red rice were probably introduced as mixtures in imported seed rice. Seed rice was imported from different foreign countries, in which more than one type of red rice may have been present. Therefore, it is possible that seed rice obtained from one country may have included as a mixture more than one type of red rice. It is also possible that different red rice types were present in each country, and seed rice obtained from different countries included different red rice types. These various types undoubtedly had some characters in common while they also differed in respect to one or more other characters.

However, it appears that the introduction of various red rice types as mixtures in lots of seed rice is not
sufficient to account for more than a minor portion of the wide genetic variation found in most characters. This is due to the fact that whoever was responsible for the importation of seed rice probably did not accept samples which were severely infested with red rice. Thus, it is assumed that only a limited quantity of red rice was introduced as a mixture per lot of seed rice, and that only a relatively few lots of seed rice were imported for commercial production. Therefore, it appears highly improbable that enough red rice types were introduced as mixtures in seed rice to account for the extreme genetic variation that was found in the present study for most characters.

Mutations occurring in red rice probably account for part of the genetic variation found in most characters of red rice. Whenever mutations occur, they give rise to new types which contribute to genetic variation providing that they become established. However, it is assumed that the amount of genetic variation in red rice contributed by mutations is very small. Mutations do not occur and become established in high enough frequency to account for very much of the wide genetic variation found in most characters of red rice.

The occurrence of natural hybridization between red rice and cultivated rices would produce genetic variation in many characters by means of segregation. There are several lines of evidence that point to natural hybridization between red rice and cultivated rice as the major
source of genetic variation in red rice. They are as follows: 1. various rice workers report in the literature that natural crossing occurs between red rice and cultivated rice under field conditions, 2. natural crossing is known to occur in cultivated rice under field conditions, 3. there is evidence to show that red rice and cultivated rice will hybridize, and 4. it appears that only a limited portion of the wide genetic variation may be attributed to the introduction of various red rice types as mixtures in imported seed rice, and the occurrence of mutations in red rice.

Dodson (1898, 1900), Nelson (1907, 1908), Jones, et al. (1952), Grist (1955), and Jodon (1959) reported that natural hybridization of red rice and cultivated rice occurred in the fields. Dodson (1898) and Nelson (1907) explained the presence of variation in the intensity of seed coat color as the result of natural hybridization. Jones, et al. (1952) and Grist (1955) reported that natural hybridization caused variation in the size and shape of red rice grains. Jodon (1959) reported that red rice undoubtedly cross-pollinates readily with cultivated varieties. He also reported that the possibility of releasing a new variety developed from a natural cross of red rice and the cultivated rice, Rexoro, was being considered.

Roy (1921), Goyaud (1950), Ramiah and Ghose (1951), Sampath and Rao (1951), and Sampath and Govindaswami (1958) reported natural hybridization between wild rice and
cultivated rice in India. Ramiah and Ghose (1951) reported that in a collection of wild rice in India, only one plant bred true while all the others were of hybrid origin. It has been said that the wild rices are more subject to cross-fertilization than the cultivated rices.

Although cultivated rice is a highly self-fertilized plant, it is recognized that some cross-fertilization occurs. The extent of natural crossing appears to vary according to immediate environmental conditions. Beachell, et al. (1938) conducted studies in Arkansas, Louisiana, Texas and California in which it was found that natural crossing averaged 0.45% in all areas studied, and 0.51% in Louisiana. One pair of varieties showed 1.63% natural crossing under Louisiana conditions and 1.32% under Texas conditions, which indicates varietal as well as environmental differences. Results from other countries indicate from 0.5 to 2.0% of natural crossing normally occurring in the fields. Some reports mention, however, that natural crossing may be as frequent as 4.0%, 8.0% and even over 20.0%. These no doubt represent abnormal conditions.

Although this study was not designed to determine the amount of natural crossing between red rice and cultivated rice, the material analyzed was highly suggestive of natural hybridization. Extreme variation was present in most of the characters analyzed. In view of this fact, plus the evidence previously cited, it was assumed that most of the wide genetic variation found in red rice can be attributed
to natural hybridization.

Beachell, et al (1938) reported that natural crossing in cultivated rice averaged approximately 0.51% under Louisiana conditions. All plants in the field, including red rice plants, are exposed to equal opportunities for natural crossing. Naturally there will be less crossing involving cultivated rice and red rice than crosses involving only cultivated rice, because the number of red rice plants is far less than the number of cultivated rice plants. Normally reciprocal crossing is expected. However, in order that natural crossing may contribute new red rice segregants, it is probable that red rice plants serve as seed parents. The reason for this is the fact that the hybrid seeds present on cultivated rice plants are usually removed from the field during harvesting. This is not so in the case of hybrid seed on red rice plants, because they will very likely shatter prior to harvesting.

There is evidence to show that hybrid vigor is expressed in rice hybrids. Therefore, hybrid plants of red rice and cultivated rice should possess as much or more plant vigor than either of the parents. This would enable hybrid plants to successfully compete with plants of cultivated rice and pure red rice under field conditions. Controlled crosses between red rice and cultivated rice have shown that hybrid plants are normally partially to fully fertile. Therefore, red rice hybrid types would appear to be able to become established by virtue of the fact that the plants
are vigorous and usually set seeds under field conditions. 

**Comparison of Red Rice with Cultivated Rice in Respect to Length of Grain.** The present day extensive production of long grain varieties of rice has enabled the seed establishments to remove red rice grains from cultivated rice. This is accomplished by the use of equipment which separates the two on the basis of differential grain length and size. Thus, the shorter red rice grains are removed from the long grain cultivated rice. Medium grain cultivated varieties cannot thus be cleaned, because there is not sufficient differences between the two grain types to allow for the separation and removal of red rice grains.

However, some long grain red rice types were found in the collection. There were eleven plants of red rice included in the collection that had grains of 9.0mm. or longer. The average grain length of these was 9.2mm. The grain length of long grain varieties such as Fortuna, Rexoro, Texas Patna, and Bluebonnet ranges from approximately 9.0 to 9.8mm. The average grain length of these long grain varieties is approximately 9.4mm. Thus, in grain length, the long grain red rice resembled the long grain cultivated varieties. Grain width was similar, but there were some red rice grains that were broader than regular long grain cultivated types.

At present only a minor portion of the red rice population consists of plants that produce long grains. However, these long grain type red rice plants do occur, and with
the continued increase in the production of long grain rice varieties there is a possibility that these may become more common. Should these long grain red rice types become more numerous, the red rice problem will become correspondingly more difficult to control. The differences in grain length and grain width would no longer be present, and it would be impossible to separate and remove mechanically red rice from cultivated rice.

Although no important consequences could be associated with an increase in short grain types of red rice, it should be mentioned that short grain types of red rice were found. There were twenty-three plants in the collection that had grains measuring 6.8mm. or shorter. This is shorter than any cultivated variety grown in Louisiana at present, and possibly shorter than the cultivated short grain varieties that were previously grown here. These short grain red rice plants all had grains with straw colored hulls, while all hull color types recognized in this study were present in the long grain red rice types.

Classification of Red Rice. The wild rices of south and southeast Asia have been described in the literature as a complex group, in which there are some types that resemble very closely cultivated rice in all respects except grain shattering. The presence of deciduous spikelets is the only means by which Chatterjee (1948) distinguished the group of wild rice designated as O. sativa var. fatua Prain from cultivated rice. Grain shattering and similarity to
cultivated rice are consistently mentioned in descriptions of fatua or spontanea type rices.

Other workers have further described the fatua or spontanea type rices as annuals, that lack rhizomes and floating plant habit. Spikelets are generally described as awned, and grains are generally described as having red seed coats and the ability to remain viable in the soil through periods of adverse conditions. Plants are generally described as showing various degrees of semi-sterility and segregation for characters, indicative of hybridization. Plants within the group reportedly differ in both plant and grain characteristics. This fatua or spontanea rice is usually associated with cultivated rice, either in the fields or in irrigation channels and field border areas.

Published descriptions of fatua or spontanea type rices usually are very general in all respects except grain shattering, and apparently include types such as those which are referred to as red rice in Louisiana. The wild rice known as red rice, which is found in rice fields of Louisiana, is in all probabilities a type or form of O. sativa var. fatua Prain, because: 1. red rice plants resemble morphologically plants of cultivated rice, 2. red rice plants are annuals which reproduce by seeds, 3. red rice plants produce grains that shatter upon reaching maturity, 4. red rice grains have red seed coats and possess the ability to remain viable in the soil through periods of adverse conditions, 5. there is wide genetic variation within the
red rice group in respect to most grain characteristics,
and 6. red rice was evidently introduced originally into the
southeastern United States and later into Louisiana from
foreign countries in which fatua type rices is a problem.
On the basis of these factors, it is assumed that red rice
is an introduced type or form of O. sativa var. fatua Prain
which has become established in rice producing areas of Lou­
isiana and other parts of the United States. It is assumed
further that this form has been modified greatly since its
introduction by natural hybridization with cultivated rice.
SUMMARY

During August, 1959, a study was conducted in the rice growing area of southwestern Louisiana, which included making estimates of the number of red rice plants per acre, and the distribution of red rice types in relation to the total red rice population in the fields, and making a collection of red rice panicles in order to analyze grain characteristics in the laboratory.

During November, 1959, the mill operators were interviewed in order to obtain information concerning the red rice problem in relation to the Louisiana rice milling industry.

The number of red rice plants per acre varied greatly among fields throughout the rice area, and ranged from a very few plants to as many as 25,000 plants per acre in the fields that were checked. No fields were found in which there were no red rice plants.

It was found that red rice could be separated readily into types or classes in the field by means of the color of the hulls (lemma and palea). Black hull and straw colored hull types of red rice are very easily distinguishable in the fields. Both of these major types were found in all fields that were checked, however, the relative frequency of each varied greatly among fields. Of sixty-five fields checked, there were twenty-one fields in which plants of both types were present in approximately equal frequencies, twenty-five fields had a predominance of straw colored hull
type plants, while nineteen fields had a predominance of black hull type plants. The straw colored hull type red rice appeared to be more common throughout the rice area, while the black hull type appeared to be more heavily concentrated in parts of Vermilion Parish.

Most mill operators recognize the fact that some Louisiana rice has objectionable amounts of red rice, and they have devised means of disposing of such rice. The foreign market generally accepts rice with more red rice in it than does the American market. Therefore, rice which contains too much red rice for the American market is generally disposed of on the foreign market.

The primary objections to red rice are that its presence lowers the quality and the price of the rice, and necessitates more severe milling subsequently increasing kernel breakage and lowering milling quality of cultivated rice.

The Carter Disc Separator, the Dockins Seed Grader, and the Paddy Separator are capable of removing red rice from cultivated rice, especially from the long grain cultivated varieties. However, except for the small amount of red rice removed by the Paddy Separator from brown rice, the rice mills do not attempt to remove red rice from cultivated rice because it is impractical to do so.

A majority of the mills reported variation in the amount of red rice present in rice from different localities, and of different seasons. They also claim that red rice is
more objectionable in long grain varieties, because long grain rice is grown and processed for premium grade. The presence of red rice makes it more difficult to mill and usually decreases the milling quality.

The black hull type red rice is considered more of a problem than the straw colored hull type red rice. The reasons given were that it is more difficult to dehull, the bran layer is more difficult to remove, and the spikelets have awns. However, it was the opinion of the mill operators that the straw colored hull type red rice is more commonly found in cultivated rice than is the black hull type red rice.

Three hull color types of red rice were recognized in the laboratory analysis. In addition to the two major hull color types, black hull and straw colored hull, an intermediate type referred to as gray hull was recognized. The collection of red rice panicles consisted of 60.8% straw colored hull, 24.6% black hull, and 14.6% gray hull type panicles.

Approximately 65% of the collection had spikelets with awns (either fully or partially awned), while approximately 35% had spikelets without awns. All panicles of the black hull type and 98% of the panicles of the gray hull type had spikelets with awns (either fully or partially awned), while the straw colored hull type had 42% of the panicles with awned spikelets (either fully or partially awned). Thus, the black hull and the gray hull types of red rice
were predominantly awned types, while the straw colored hull type red rice was predominantly awnless.

Awn color was either black or straw, and 59.5% of the awns were black, while 40.5% were straw colored. Approximately 97% of the awned black hull type red rice had black awns, while all of the awned gray hull and straw colored hull types of red rice had straw colored awns.

A great majority of the awned red rice had entirely pubescent awns, however, there were 19% that had awns that were smooth towards the base and pubescent towards the tip, while 4% had entirely smooth awns. Plants of each hull color type that had spikelets with entirely pubescent awns were most numerous, followed by those with awns that were smooth towards the base and pubescent towards the tip, while those with entirely smooth awns were least numerous.

The material in the collection varied in awn length from 1.5 to 8.5 cm. The majority of panicles were in the 3.5 to 6.5 cm. classes. Mean awn length of the black hull type was 5.8 cm., that of the gray hull type was 5.3 cm., while that of the straw colored hull type was 4.1 cm.

Grain length varied from 6.1 to 10.0 mm., however, the majority of red rice plants had grains varying in length from 7.0 to 8.8 mm. Mean grain length of the black hull type was 8.1 mm., that of the gray hull type was 8.2 mm., while that of the straw colored hull type was 7.9 mm. There were eleven plants with grains that were almost as long as grains of the long grain cultivated varieties, while there
were twenty-three plants with grains shorter than the commonly cultivated short grain varieties.

Grain width varied from 2.3 to 3.9mm., and there was essentially no variation among the red rice hull color types. Both the black hull and the gray hull types had mean grain width of 3.14mm., while the straw colored hull type had a mean grain width of 3.16mm.

All panicles in the collection had grains with red seed coats, but the intensity of the red pigment varied from light red to dark red. Seven per cent of the collection had light red seed coats, 62.5% had intermediate red seed coats, and 30.5% had dark red seed coats.

Percentage of kernel breakage by mechanical dehulling in red rice varied from 0 to 100%, and the mean kernel breakage was 25.6% compared to a mean of 20.8% for ten cultivated varieties. Sixty-seven per cent of the collection had less than 30% kernel breakage by mechanical dehulling. Mean kernel breakage was 33.1%, 41.1% and 19.3% for the black hull, gray hull and straw colored hull types of red rice, respectively.

Kernel breakage was also calculated for various grain length classes of red rice within each hull color type. The short grains (less than 8mm.) of black hull, gray hull, and straw colored hull types had mean kernel breakage of 19.5%, 19.5% and 10.5%, respectively. The medium grains (8 thru 9mm.) of black hull, gray hull, and straw colored hull types had mean kernel breakage of 36.2%, 46.4% and
28.6%, respectively. There were too few long grain (greater than 9.0mm.) plants to provide reliable data. Percentage of kernel breakage was considerably less in the short grain class than in the medium grain, indicating that length of grain affected kernel breakage. However, kernel breakage varied among hull color types within short and medium grain classes, indicating genetic differences.

There was no detectable variation among red rice plants in respect to grain shattering and pubescence of the hulls.

Red rice plants in the collection appeared to differ genetically in hull color, awned condition, awn pubescence, awn length, awn color, grain length, grain width, intensity of seed coat color, and percentage of kernel breakage by mechanical dehulling.

The hull color types of red rice appeared to differ genetically in awned condition, awn color, awn length, grain length and percentage of kernel breakage by mechanical dehulling. They did not differ in respect to grain shattering, hull pubescence, awn pubescence, grain width and intensity of seed coat color.
SELECTED BIBLIOGRAPHY


Milton James Constantin was born March 25, 1934, in Lafayette Parish near Duson, Louisiana.

He received his primary and secondary education at Indian Bayou High School, where he graduated in May, 1952.

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