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WILD RICE

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HISTORY

Wild rice (*Zizania sp.*) is a native North American plant which grows in the eastern and east-central parts of the North American continent (Figure 1). A study by McAndrews, 1969, of Rice Lake in Becker County Minnesota using radiocarbon dating of wild rice pollen indicated the extensive stand of wild rice in this lake predates by 1000 years the prehistoric cultures that were known to have used wild rice in Minnesota. Historically, stands of wild rice were found in shallow lakes and rivers throughout this area. The great extent of wild rice areas in some places, such as along the Wisconsin River, was recorded by Marquette, in 1673, who told how difficult travel was through the areas of "wild oats" and how guides were necessary to prevent getting lost (Vennum, 1988). However, today, there are considerably fewer natural stands than were present in the late 1600's. In some of the areas, only a few isolated plants can be found. One species, *Z. texana*, Hitchcock, is on the endangered species list and can only be found in a small area on the San Marcos River in Texas.

The grain from the large-seeded species, *Z. palustris* Hitchcock, has been used as food by Native American tribes, especially the Ojibway, Menomini and Cree tribes in the North Central region of the continent (Vennum, 1988). In the Great Lakes Region where *Z. palustris* grew, the Chippewa and Menomini tribes predominated; they gathered, processed and stored wild rice and used it as their carbohydrate source for the long-cold winters. Wild rice was considered as a divine gift and used ceremonially as they do today. The Chippewa and Sioux contended for many years over the possession of the best wild rice country, the Chippewa eventually gaining control. The legal status of wild rice harvesting continues to be an issue today, especially in Minnesota and Wisconsin. Stands of wild rice on reservations are under control for harvesting by Native Americans but the Departments of Natural Resources control other stands. Based on original treaty rights, Native Americans are contesting the harvesting rights of wild rice stands controlled by the Departments of Natural Resources.

Early American explorers traded with Native Americans to obtain wild rice for food, without which they could not have survived the long-cold winters. In 1766, Carver (Jenks, 1901) wrote that in the future periods it (wild rice) will be of great service to infant colonies as it will afford them a present support until in the course of cultivation other supplies may be produced. In 1775, Alexander Henry, as written in his Travels, believed that without the large quantity of wild rice he obtained in the Lake of the Woods area, his voyage northwestward beyond the Saskatchewan River could not have been completed. Thus, wild rice had an important role in the settlement of the North American Continent.

The names used for wild rice have been many. The Ojibway name for wild rice is manoomin. The popular interpretation of the word is "good berry" or "good seed", however there is disagreement over the exact definition (Vennum, Jr. 1988). Other names used for wild rice include Indian rice, Canadian rice, squaw rice, oats, water oats, blackbird oats, march oats, water rice and tuscarora. The early French explorers called the plant folle avoine (literally, fool oats or wild oats) because of its resemblance to "tares", a bane to French wheat farmers. The French also used avoine sauvage also meaning wild oats. Eventually, as the French lost territory to English speakers, the term "wild rice" predominated and continues to be used in the trade and publications.

The two-word and uncapitalized name wild rice, however, causes confusion especially where rice, (*Oryza sativa* L.) is grown because weedy strains of *Oryza* are termed wild rice. Some authors have proposed using the hyphenated "wild-rice", the single word "wildrice" or "zizania" for wild rice. In this article since the trade uses wild rice we will use the two word, wild rice, as the common name for the genus *Zizania* for this native North American cereal even though the wild type of rice (*Oryza*) is also called wild rice.

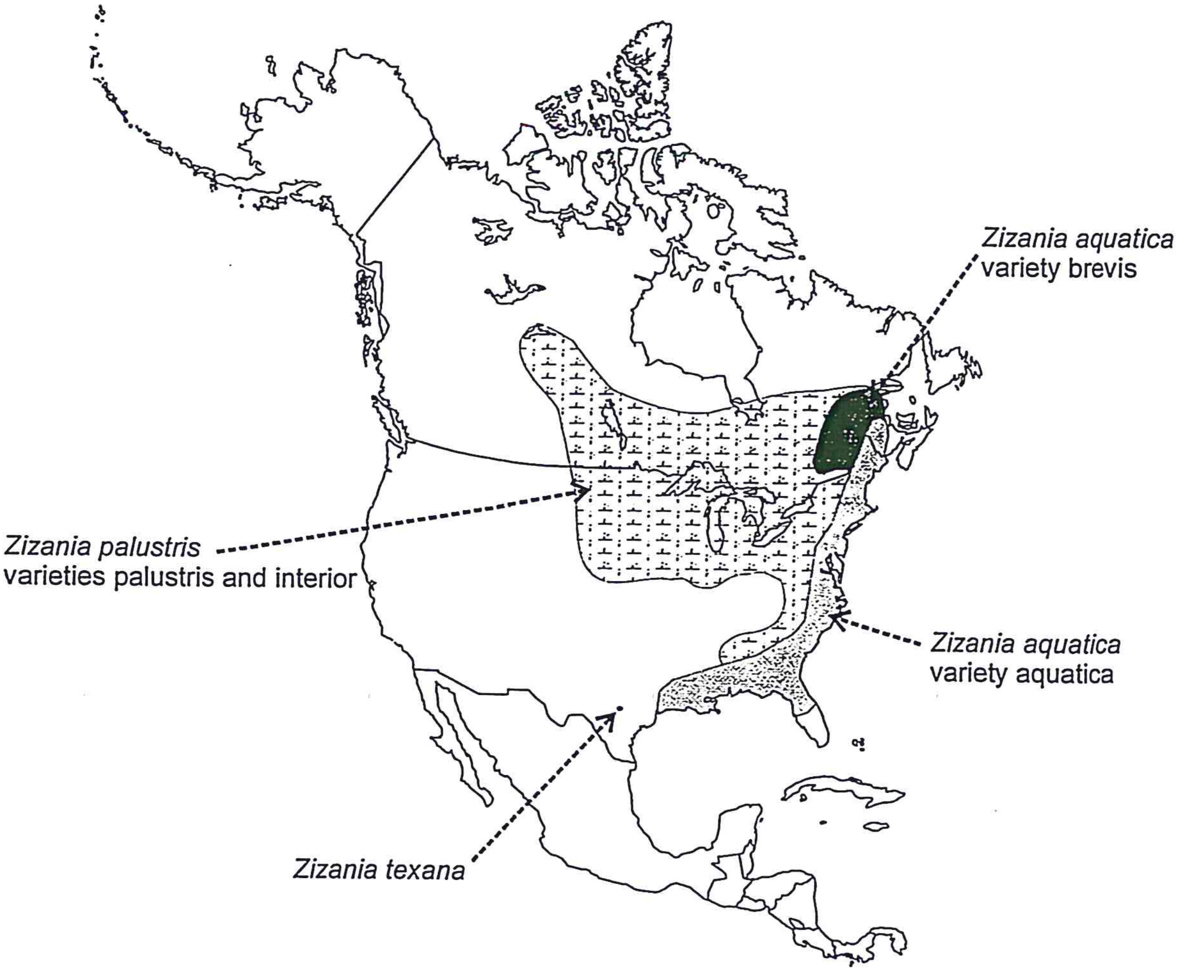

Figure 1. Distribution of wild rice in North America. Adapted from USDA, Technical Bulletin 634.

BOTANICAL DESCRIPTION AND TAXONOMY

Wild rice was first classified by Linnaeus in 1753 using a plant specimen sent to J. F. Gronovius in Leyden, Holland, by John Clayton which he collected in Virginia in 1739. Based on the description of Gronovius, C. Linnaeus designated the binomial *Zizania aquatica* for Clayton's herbarium sample (Clayton No. 574). The original specimen is preserved in the Gronovian Herbarium in the British Museum of Natural History in London, England (Dore, 1969). *Zizania* is a small genus of aquatic grasses in the tribe *Zizanieae* which immediately follows the tribe *Oryzeae* to which rice belongs.

Originally there was some confusion about the number of species of *Zizania* based on subsequent specimens sent to Linnaeus which were not clearly marked. However, the consensus today is that there are four species of *Zizania*. Linnaeus (1753), Dore (1969), Dore and McNeill (1980), and Duvall et al. (1993) recognized two species that are broken out of the *Z. aquatica* binomial: *Z. aquatica* and *Z. palustris*. The subspecies of *Z. aquatica* are vars. *aquatica* and *brevis* and for *Z. palustris* they are vars. *palustris* and *interior* (Warwick and Aiken, 1986). Dore and McNeill (1980) and Aiken et al. (1988) defined the species' differences based on differences in the lemma and palea of the pistillate spikelets and number of spikelets per branch. Isozyme work of Warwick and Aiken (1986) and Counts (1993), and Terrell and Wergin's (1981) scanning electron microscope studies agree with the previous distinction of *Z. aquatica* and *Z. palustris*. *Z. palustris* is the large-seeded type that grows throughout the upper Midwest and Southern Canada, and is cultivated in Minnesota, Wisconsin, Canada, and California. *Z. aquatica* grows from the St. Lawrence Seaway down the Eastern Seaboard to Florida and Louisiana (Warwick and Aiken, 1986; Duvall and Biesboer, 1989). In addition to *Z. aquatica* and *Z. palustris*, there are two other species, *Z. texana* Hitchc., a perennial type localized in the San Marcos River in Texas (Oelke, 1993), and *Z. latifolia* (Fassett, 1924), an Asian species. The distribution of the three North American species are shown in Figure 1. The categories recognized by Dore (1969) and names suggested for them by other workers are summarized in Table 1 and their descriptions are given in Table 2. In the early literature *Zizania aquatica* L. was used as the binomial for all of the annual species of wild rice.

The North American *Zizania* species are all 2n=2x=30 (Bolkhovskikh et al., 1969; Oelke et al., 1982). Fifteen bivalents (eight rods and seven rings) are present at meiosis (Grombacher et al., 1993). *Z. latifolia*, the Asian species, is 2n=2x=34 (Fassett, 1924). In interspecific crossing experiments, Duvall and Biesboer (1988) noted a crossing incompatibility in that *Z. aquatica* was required as the female parent in crosses with *Z. palustris* in order to obtain seed set.

TABLE 1

Classifications of Wild Rice Species and Races Within the Genus *Zizania*[a]

Classes used by Dore (1969)	Classes used by Fassett (1924), Fernald (1950), and Gleason and Cronquist (1963)
Annuals Found in the United States and Canada	
1*a*. *Z. aquatica* var. *aquatica* L. **southern wild rice**	*Z. aquatica* L. *Z. palustris* L.
1*b*. *Z. aquatica* var. *brevis* Fassett **estuarine wild rice**	*Z. aquatica* var. *brevis* Fassett
2*a*. *Z. palustris* var. *palustris* L. **northern wild rice**	*Z. aquatica* var. *angustifolia* A. S. Hitchc.
2*b*. *Z. palustris* var. *interior* (Fassett) Dore **interior wild rice**	*Z. aquatica* var. *interior* Fassett
Perennials Found Elsewhere	
3. *Z. texana* A. S. Hitchc. **Texas wild rice**	
4. *Z. latifolia* Turcz. **Manchurian water-rice**	

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[a]Adapted from Aiken et al. (1988). Used by permission.

TABLE 2
Description and Distribution of *Zizania* Species.

Zizania aquatica var. *aquatica* L. southern wild rice	Annual plants 180 to 240 cm tall; stalk often 2.5 cm thick at base; leaf blades 2.5 to 5.0 cm wide, pale green, usually drooping outwards at top; panicles large, usually 50 cm long, many branched with numerous florets; pistillate florets with an awn usually 2.5 to 7.5 cm long. Hull of grain thin papery, dull and minutely roughened on the surface. Found on muddy shores of streams in southern Ontario and Quebec, southward to Florida and Louisiana.
Zizania aquatica var. *brevis* Fasset estuarine wild rice	Annual plants 30 to 90 cm tall, with slender flexible stalks; leaf blades usually less than 1.5 cm wide, dull green. Panicles usually 10 to 25 cm long, few branched and with few florets. Pistillate florets with awns less than 1.2 cm long. Hull of grain thin, paper, dull and minutely roughened on the surface. Found on tidal flats of St. Lawrence River estuary.
Zizania palustris var. *palustris* L. northern wild rice	Annual plants 90 to 240 cm tall; stems usually extending 60 to 120 cm above the water surface, rather slender; leaf blades 1 to 2 cm wide; panicle slender and few flowered, the staminate florets usually numbering less than 15 on a branch, the pistillate usually only 2 to 6 on a branch. Hull of the grain firm and leathery, shiny and smooth on the surface but scabrous in the furrows. Found in water up to 120 cm deep; widespread in southern Canada from New Brunswick to Manitoba and in the northern states of the United States.
Zizania palustris var. *interior* (Fassett) Dore interior wild rice	Annual plants 120 to 240 cm tall; leaf blades 1.2 to 3.6 cm wide; panicles ample, branches generally divergent and many flowered, the staminate florets numbering over 30 on a branch, the pistillate 10 to 30 on a branch. Hull of the grain firm and leathery, shiny and smooth on the surface but scabrous in the furrows. Found on muddy shores and in water up to 30 cm deep along rivers in southeastern Manitoba and adjoining Ontario and abundant in the North Central States.
Zizania texana A. S. Hitchc. Texas wild rice	Perennial plants with 50 or more decumbant stems that can be over 360 cm long. Roots develop at the nodes of decumbant stems; basel area of clone ranges from a few to over 300 square cm; leaves are bright green ribbon like, 2.5 cm wide and can exceed 180 cm in length; panicles 20 to 30 cm long; panicle characteristics similar to *Z. aquatica* var. aquatica, but seeds much shorter. Found in localized areas in San Marcos River in Texas.
Zizania latifolia Turcz. Manchurian water-rice	Perennial plants, spreading by coarse subterranean runners; staminate and pistillate florets borne on stems having hairs at tips, a corresponding crown of hairs present on the base of the hull of the floret; hull of the grain thin, papery, dull and rough. A native grass of Manchuria, Korea, Japan, Burma and northeaster India. Base of plant often becomes infected with fungus which is used as a food delicacy.

Growth and Development of *Z. palustris* - The Large-Seeded Species Harvested for Food

Wild rice (*Z. palustris*) is an annual, cross-pollinated species that grows in flooded soils. In Minnesota it matures in about 120 days, and requires about 2,600 growing degree days (40 F base) (Oelke et al., 1982). The growth cycle begins when germination occurs usually when soil/water temperatures reach 6 C. Germination is evident when the coleoptile breaks through the pericarp. Next the primary root extrudes through the pericarp 7-10 days after emergence of the coleoptile. The seedlings have three submerged leaves after 3 weeks (Figure 2). The next 2-3 leaves float on the water surface ("floating leaf stage"). Additional leaves are aerial varying in width from 1-3 cm and up to 75 cm long. Ligules are present at the leaf blade and sheath junction. Growth stages have been classified by Grava and Raisanen (1978) and Percich et al. (1988). Figure 3 illustrates the growth cycle as illustrated by Aiken et al. (1988). Mature plants are 60 to 70 cm tall and can produce up to 50 tillers per plants. In cultivated fields plants usually have three to six tillers (Figure 4). Stems are hollow except at nodes where leaves, tillers, roots, and flowers appear. Internodes are separated by thin parchment-like partitions. The shallow root system has a spread of 20 to 30 cm and mature roots are straight, spongy and have very few roots hairs and are often orange (rusty) in color due to oxidized iron on their surfaces. Ribbon-like leaf blades vary in width from 0.6 to 3.2 cm. Mature plants have five or six leaves above the water per stem or tiller.

Flowers are in a branching panicle with female (pistillate) flowers at the top oppressed to the rachis and male (staminate) flowers on branches usually spread to a near horizontal position on the lower portion. Variations of this panicle form include the "bottlebrush" characteristic (often associated with male sterility), in which male branches also remain oppressed, giving the panicle the compact appearance of a bottle brush. The "crowsfoot" panicle is another type in which the pistillate branches spread in the same manner as in *Z. aquatica* panicles. The "pistillate" trait has panicles in which male florets are

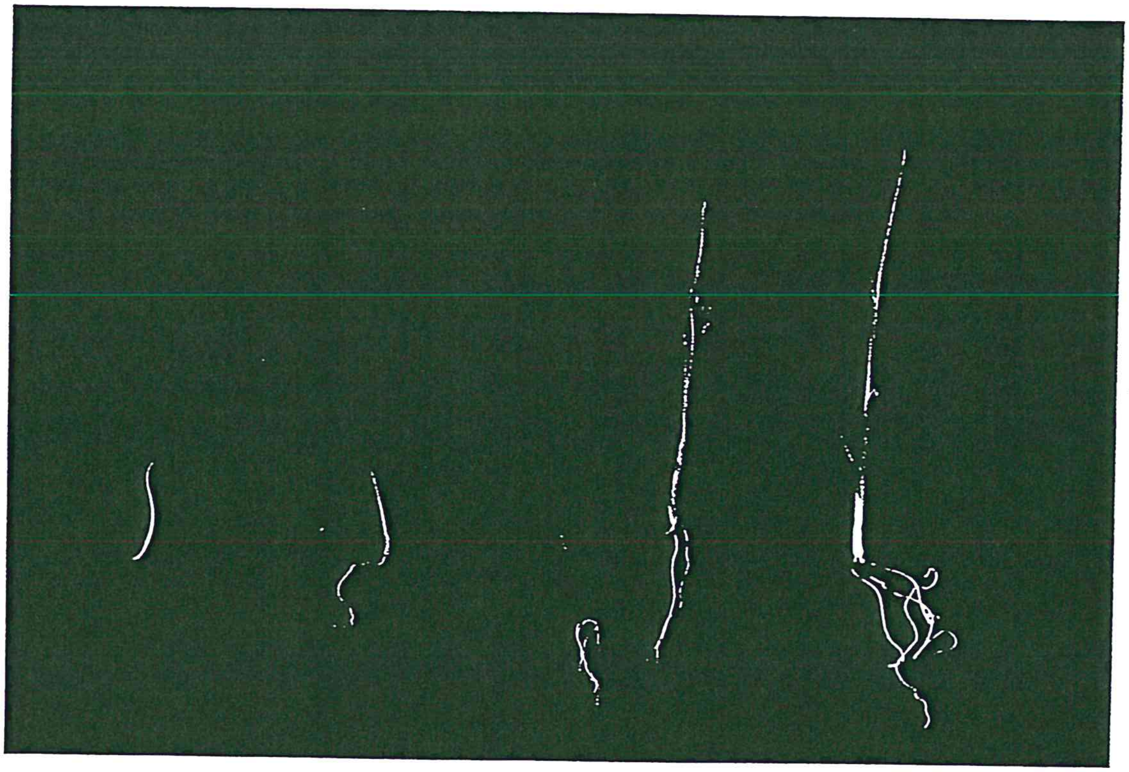

Figure 2. Submerged wild rice seedlings 6, 10, 14, and 18 days old from left to right. Height of right seedling is 6 cm.

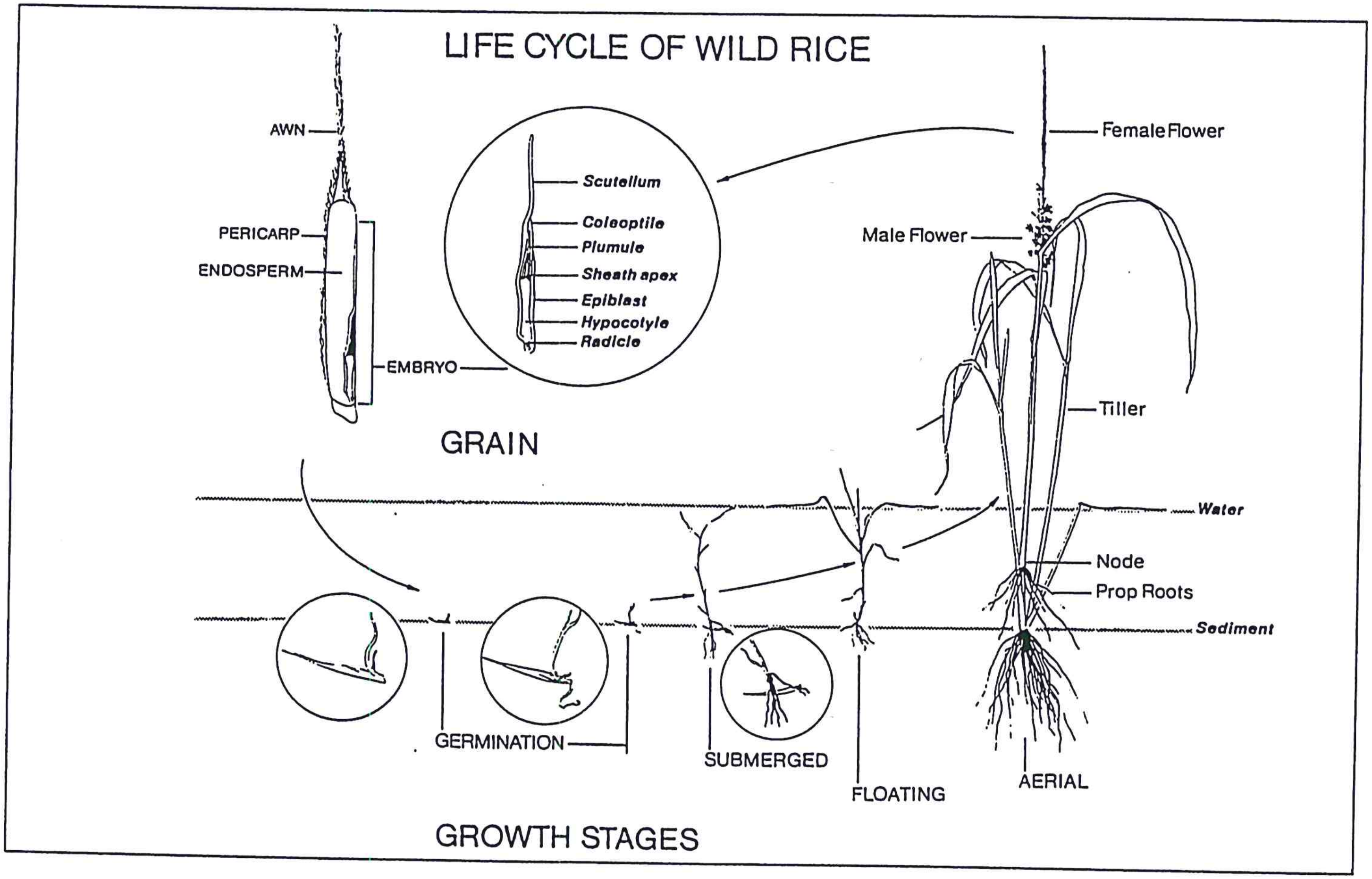

Figure 3. The life cycle of Z. *palustris*. Adapted from Aiken et al., (1988). Used by permission.

Figure 4. A mature plant of *Z. palustris*, cultivar 'K2' with some seed shattering resistance. Plant height is 170 cm.

replaced with female florets, resulting in a gynoecious, or all-female, panicle. Schumer (unpublished data) found that the average number of female florets was 137 for a normal panicle, and 382 for a pistillate panicle. Figure 5 shows the various panicle types of *Z. palustris*.

Cross pollination usually occurs since female flowers emerge first and become receptive and are pollinated before male flowers on the same panicle shed pollen (Figure 6). Sometimes the transition florets, which are located between the pistillate and staminate florets on the panicle, have both stigmas and anthers (pollen), and can therefore be self-pollinated. When viable pollen grains land on the stigma, they germinate within 1 hour and reach the embryo sac within 2 hours (Weir and Dale, 1960) Two weeks after fertilization the seeds are visible, and after 4 to 5 weeks, it is ready for harvest. The seed is a caryopsis that is similar to the grain of cereals. The caryopsis has an impermeable pericarp, large endosperm, and small embryo. Grains with the palea and lemma (hulls) removed, range from 8 to 16 mm in length, and from 1.5 to 4.5 mm in diameter (Figure 7). Immature seeds have a green, aleurone layer which turns a purple-black color as seeds reach physiological maturity. Seeds on a given tiller will mature at different times, and on secondary tillers they mature later than on main tillers.

The flowering time of *Z. palustris* plants is very responsive to daylength and temperature. When the value for the 'Johnson' and 'Canadian' cultivars were averaged, they flowered 20 days earlier in a daylength of 9 hr vs. a simulated (9 hr full light and 6 hr low light) 15 hr daylength (Oelke et al., 1982). They also had 4 times fewer florets (20 vs. 80) per panicle in short vs. long day photoperiods. These differences in flowering time and daylength were negated by growing the plants in a temperature regime

Figure 5. Various panicle types of Z. *palustris*. Left to right: 1 - Pistillate, 2 - Crowsfoot, 3 through 5 - Bottlebrush, 6 through 8 -Normal nonshattering, 9 through 11 - Shattering (male flowers dehisce immediately after pollen shed).

Figure 6. Plant development stages of *Z. palustris*, cultivar 'K2'. Left to right, 1 - Boot stage, 2 - Female flower emergence and, 3 - Panicle emergence complete with male flowers (branched part) emerged.

of 22 C vs. 19 C during the day but both with a 10 hr, 16 C night temperature. Subsequent studies (Oelke et al., 1993) confirmed these results using a constant day/night temperature of 18 C with 4 hr night interruptions with low light to simulate an 18 hr photoperiod. This was compared to an 8 hr full light and 16 hr dark photoperiod. The long day again resulted in later flowering and more floret numbers per plant compared to the short day for the 'K2' and 'Canadian' cultivars. A third study by Oelke and Jin (1994) compared flowering response of *Z. palustris*, *Z. aquatica* and *Z. texana*. They simulated 12, 15 and 18 hr photoperiods by night interruption at a constant 21 C temperature and as in previous research, *Z. palustris* and *Z. aquatica* flowered earlier when subjected to short days compared to longer days. Plant size and floret number were reduced when grown under short days compared to longer days (Figure 8). *Z. texana*, however, did not respond as much to daylength as the other two species (Figure 9).

Seeds of *Z. palustris* will not germinate for at least 3 months after reaching maturity, even if environmental conditions are satisfactory for growth. An after-ripening period is required in water at freezing or near-freezing temperatures (3 C) before the embryo releases dormancy and germination can occur (Muenschen, 1936; Simpson, 1966). This seed dormancy is caused by the impermeable pericarp that is covered by a layer of wax, and by an imbalance of endogenous chemical growth promotors and inhibitors (Albrecht et al., 1979; Oelke and Albrecht, 1980). In the spring, seeds will start to germinate when the water temperature reaches about 6 C (Oelke et al., 1982). Freshly harvested seeds can be made to germinate by carefully scraping off the pericarp directly above the embryo (Woods and Gutek,

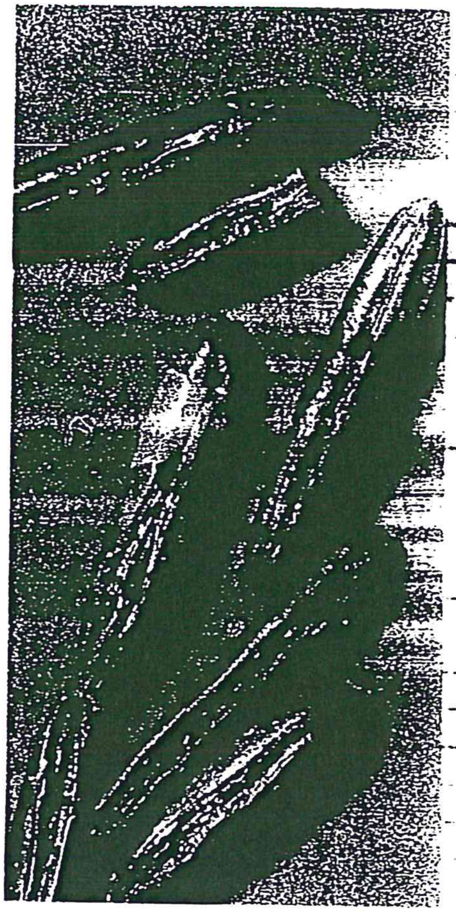

Figure 7. Processed grains of Z. *palustris*, cultivar 'K2'. Scarification has removed some of the dark aleurone layer on 2 of the kernels. Shrunken area is vascular strand which collapses at physiological maturity.

1977; Cardwell et al., 1978). The viability of seeds of Z. *palustris* is difficult to maintain for more than 1 year or even during the 3 months of cold water storage. Recent research has shown however, that seed can be stored over a longer period when fully hydrated, and can tolerate drying and freezing under some conditions (Kovach and Bradford, 1992a, 1992b; Oelke and Stanwood, 1988; Oelke et al., 1990; Oelke and McClellan, 1992; Vertucci et al., 1994).

Figure 8. Plant growth comparison of Z. *aquatica* when grown in growth chambers with simulated or 18-hour photoperiod with a constant 21 C temperature.

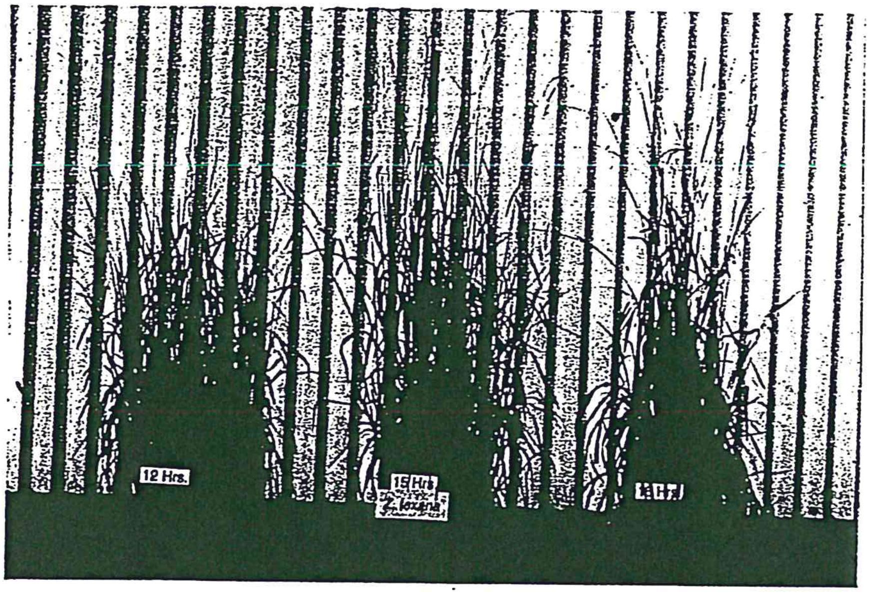

Figure 9. Plant growth comparison of Z. *texana* when grown in growth chambers with simulated 12-, 15- or 18-hour photoperiod with a constant 21 C temperature.

COMPOSITION AND PHYSICAL PROPERTIES

The wild rice kernel is similar in structure to other cereals, consisting of a pericarp, aleurone layer, endosperm and embryo. The pericarp and embryo each represent about 5% of the caryopsis weight, with the endosperm and the aleurone layer making up the remaining 90% (Albrecht et al., 1979).

The nutritional quality of wild rice appears to be equal to or better than that of other cereals (Candlish et al., 1984; Anderson. 1986). Protein content is relatively high and lysine and methionine comprise a higher percentage of the protein than in most other cereals (Tables 3 and 4). The SLTM value (the sum of lysine, threonine, and methionine contents), often used as a measure of nutritional quality of cereals, is slightly higher for wild rice than for oat groats, which is considered one of the better cereals for humans (Oelke, 1976). The similarity in amino acid composition of processed and unprocessed wild rice indicates little reduction in nutritional quality through processing (Lund et al., 1977; Candlish et al., 1984).

Researchers at the University of Wisconsin at Madison analyzed the different parts of the wild rice kernel for amino acids (Lund et al., 1977). They found that removal of the pericarp produced a slight reduction in the levels of histidine and arginine (Table 5). However, total removal of the pericarp had little influence on either amino acid distribution or protein content of the kernel. Lysine concentration is highest in the embryo, and lysine content is reduced if the embryo is lost during processing or cooking.

TABLE 3
Composition of Wild Rice, Cultivated Brown Rice, and Wheat

Nutrient	Wild rice values		Cultivated brown rice	Wheat
	Early[a]	1993[b]		
		%		
Protein	13.8 (12.8-14.8)[c]	12.7	8.1	14.3
Ash	1.7 (1.4-1.9)	1.5	1.4	2.0
Fat	0.6 (0.5-0.8)	1.5	1.9	1.8
Fiber	1.2 (1.0-1.7)	4.5	1.0	2.9
Carbohydrates	---[d]	76.6	---	—
Ether extract	0.5 (0.3-1.0)	---	2.1	1.9
Nitrogen (free % extract)	82.4	---	87.4	78.9
Phosphorus	.28	.37	.22	.41
Potassium	.30	---	.22	.58
Magnesium	.11	---	.12	.18
		PPM		
Calcium	20	76.6	32	46
Iron	17	13.2	10-17	60
Manganese	14	---	30-39	55
Zinc	5	34.8	24	—
Copper	13	---	4-7	8
Sodium	---	30.1	---	—
		Per 100 gm		
Total kilocalories	---	372	---	—
Kilocalories from fat	---	14	---	—

[a] Anderson, 1976.
[b] Minnesota Cultivated Wild Rice Council, 1993.
[c] Numbers in parentheses indicate ranges in values.
[d] Values not reported.

TABLE 4
Amino Acid Composition of Processed and Unprocessed Wild Rice, Two Cultivars of Unprocessed Cultivated Rice, and Wheat[a]

Amino	Unprocessed wild rice	Processed wild rice	Cultivated rice (C.V. Bray)	Cultivated rice (C.V. Lebonnet)	Wheat
	- - - - - - - - - - - - grams amino acid per 100 grams protein - - - - - - - - - - - -				
Lysine	5.2	4.1	3.8	4.28	2.8
Histidine	2.8	2.7	2.5	2.64	2.4
Ammonia	2.4	2.4	2.4	2.29	4.0
Arginine	8.2	7.3	8.9	8.77	4.7
Aspartic	10.4	10.3	9.6	9.81	5.4
Threonine	3.6	3.6	3.7	3.79	2.9
Serine	5.5	5.2	5.2	5.01	4.8
Glutamic	18.7	18.2	19.4	18.34	35.4
Proline	4.1	4.1	5.0	4.63	11.8
Glycine	4.8	4.8	5.0	5.16	4.3
Alanine	5.8	5.8	5.8	5.94	3.6
Cystine	2.8	---[b]	3.9	3.60	3.3
Valine	5.8	5.7	5.8	5.85	4.4
Methionine	2.8	3.0	2.2	2.06	1.4
Isoleucine	4.4	4.3	4.0	4.06	3.6
Leucine	7.4	7.3	8.3	8.30	7.2
Tyrosine	3.8	3.5	4.5	4.34	2.9
Phenylalanine	5.1	5.0	5.0	4.88	5.3
Tryptophan	1.8	1.6	1.8	1.72	1.6

[a] Wild rice = *Zizania palustris*, cultivated rice = *Oryza sativa*; Oelke and Strait (1982).
[b] Not determined.

The fatty acid composition of wild rice and several other cereal grains is given in Table 6. Lund et al. (1977) found that although wild rice contains less than 1% fat, linolenic acid comprises a much higher proportion of the fat than in rice, wheat, or oats. Linoleic and linolenic acids, which make up about 68% of the total fatty acids, are easily oxidized and make wild rice quite susceptible to the development of rancid odors. However, high levels of linoleic acid also make wild rice highly nutritious.

The mineral composition of wild rice compared favorably with oats, wheat, and corn (Anderson, 1976). Wild rice, with the exception of calcium, has a higher mineral content than brown rice (Table 3). Removing the pericarp (polishing) from rice reduces mineral content considerably (Anderson, 1976). With wild rice, however, scarifying causes no such reduction, according to Wisconsin researchers (Lund et al., 1977). Wild rice contains 0.28% phosphorus (Table 3), much of it in the form of phytate (myoinositol hexaphosphate). This has a number of important ramifications as related to antioxidants. Processed wild rice grain contains no vitamin A, but is an excellent source of the B vitamins -- thiamine, riboflavin, and niacin (Table 7; Anderson, 1976).

Antioxidants are currently under intense investigation as possible preventive agents in human heart disease (Addis and Hassel, 1992). However, there has been an increasing concern for potential toxic and carcinogenic effects of synthetic antioxidants like butylated hydroxy anisole (BHA) and butylated hydroxy toluene (BHT), as documented by Johnson (1971), Branen (1975) and Ito et al. (1985). This

TABLE 5
Amino Acid Distribution in Kernel Fractions of Parched Wild Rice[a]

Amino acid	Whole kernel	Endosperm plus embryo	Endosperm plus pericarp	Embryo alone
	- - - - - - - grams/100 grams recovered amino acids - - - - - -			
Alanine	5.7	5.9	6.0	7.8
(Ammonia)	2.3	2.1	2.3	1.7
Arginine	8.1	7.3	6.7	6.1
Aspartic acid	10.0	10.3	10.6	10.6
Cysteine	1.4	1.3	--[b]	--
Glutamic acid	19.9	20.5	20.8	13.6
Glycine	4.9	4.9	5.1	6.6
Histidine	3.5	2.7	--	--
Isoleucine	4.1	4.3	4.5	4.9
Leucine	7.3	7.5	7.7	8.8
Lysine	4.7	4.2	4.5	7.7
Methionine	2.2	2.4	2.8	1.9
Phenylalanine	5.0	5.2	5.4	5.2
Proline	3.6	4.5	3.5[c]	2.4[c]
Serine	5.5	5.7	5.8	5.4
Threonine	3.4	3.4	3.4	5.8
Tyrosine	2.7	2.5	3.7	3.8
Valine	5.6	5.5	6.1	6.7
SLTM	10.3	10.0	10.7	15.4
% Protein	13.3	13.6	--	--

[a] Lund et al. (1977).
[b] Not determined.
[c] Estimated from the 570 nm curve.

has increased the demand for natural antioxidants. Uses of antioxidants include increasing the resistance of foods and foodstuffs to rancidity, nutrients (vitamins C and E, and the vitamin A precursor, ß carotene), and possible medical agents to help prevent diseases such as coronary heart disease and certain types of cancer. Antioxidants come in two main varieties, Type I and Type II. The former are phenolic compounds that interrupt and stabilize the free radical reactions that are responsible for rancidity. The latter are generally chelators of transition metals such as iron and copper, the primary initiators of free radical reactions of lipids (Miller et al., 1990).

Minerich et al. (1991) clearly demonstrated that hydrated wild rice, if mixed with ground beef, had significant antioxidant activity. Frozen ground beef mixed with wild rice displayed lower thiobarbituric acid reactive substances (TBARS) values, a commonly used measure of rancidity, than did control ground beef. Minerich et al. (1991) also demonstrated that taste panelists actually preferred the wild rice patties to controls and furthermore preferred low-fat patties (with wild rice) to regular fat (26%) patties (without wild rice). Subsequent research isolated and identified by ^{31}P and ^{13}C nuclear magnetic resonance that phytate was a key antioxidant in wild rice (Wu et al., 1994). Current research at the University of Minnesota has identified several phenolic antioxidants in the hulls of wild rice.

TABLE 6
Fatty Acid Composition of Hexane Extracts of Wild Rice, Rice, Oats and Wheat

Fatty Acid	Wild Rice Early[a]	Wild Rice 1993[b]	Brown Rice	Polished Rice	Oat groats[c]	Wheat[c]
	% of total					
Palmitic (16.0)	14.5[d]	18.6	20.4	33.8	16.2	24.5
Stearic (18.0)	1.1	4.7	1.6	2.7	1.8	1.0
Oleic (18.1)	15.9	22.2	41.3	43.3	41.2	11.5
Linoleic (18.2)	37.7	29.1	34.5	18.0	38.8	56.3
Linolenic (18.3)	30.0	25.4	1.0	0.6	1.9	3.7
Saturated fat	--[e]	0.36	--	--	--	--
Unsaturated fat	--	1.17	--	--	--	--

[a] Lund et al. (1977).
[b] Minnesota Cultivated Wild Rice Council, 1993.
[c] Anderson (1976).
[d] Number in parentheses indicates number of carbon atoms in molecule, with number of unsaturated carbons after decimal.
[e] Values not determined.

TABLE 7
Vitamin Content of Wild Rice and Other Cereals

Vitamin	Wild Rice Values Early[a]	Wild Rice Values 1993[b]	Brown rice	Polished rice	Oats	Hard red winter wheat	Corn
Thiamin (mg/100 g)	0.45	<.02	0.34	0.07	0.60	0.52	0.37
Riboflavin (mg/100 g)	0.63	.26	0.05	0.03	0.14	0.12	0.12
Niacin (mg/100 g)	6.2	6.5	4.7	1.6	1.0	4.3	2.2
Vitamin C (mg/100 g)	0	<1.0	0	0	0	0	0
Vitamin A (IU)	0	<35.0	0	0	0	0	490
Vitamin B6	--[c]	.46	---	---	---	---	---

[a] Anderson, 1976.
[b] Minnesota Cultivated Wild Rice Council, 1993.
[c] Values not determined.

AGRONOMIC PRODUCTION AND GENETIC IMPROVEMENT

Domestication/Commercialization

Perhaps the first individuals to attempt to increase availability of wild rice for food were Native Americans (Steeves, 1952). Often suitable lakes or rivers were seeded to wild rice by mixing seed into clay, rolling it into a ball and dropping the clay ball into the water. This resulted in some increase in natural stands.

Businessmen and botanists have thought about cultivating this plant for over 100 years (Steeves, 1952). Early European explorers collected seed for planting in Europe, but these failed probably because the seed was not handled properly to remain viable. In 1828 Timothy Flint in "Geography and History" wondered why so little attention has been paid to wild rice. In 1852 Joseph Bowron suggested wild rice be seeded for agricultural purposes. In 1853 Oliver Kelly, founder of the National Grange, made the same proposal. Mechanical harvesting of private lands in Canada started in 1917 by H.B. Williams and Z. Durand.

Since about 1950, wild rice has been in the process of becoming a domesticated crop in the United States and is now being grown commercially in both the United States and Canada (Oelke et al., 1982; Stevenson, 1988). Prior to that time, natural stands were the only source of the grain, and supplies were limited and varied greatly from year to year. With the advent of commercial production, supplies of wild rice have increased tremendously over the last 30 years. Natural stands continue to be harvested, but the proportion of total supplies derived from natural stands has steadily declined. In some areas, including the entire state of Minnesota, natural stands of wild rice, by law, must be harvested only by traditional "canoe-and-flail" method, whereas in some parts of Canada, mechanized harvest is permitted. Included in Table 8 are annual harvest estimates from natural stands in Minnesota since 1963. Of all the wild rice harvested by hand, Minnesota is likely to account for more than half in any given year.

In Canada, commercial production of wild rice takes place predominantly in lakes leased from the various provincial governments (Winchell and Dahl, 1984). Lease provisions vary by province, but generally lease holders are permitted to seed the lakes and, in some cases, control water levels, and are granted exclusive harvesting rights. Much of the wild rice acreage in these leased lakes is harvested by airboats (Stevenson, 1988). Shown in Table 8 are annual harvest estimates from lakes and rivers in four Canadian provinces since 1963.

In the United States, wild rice is being produced commercially as a "domesticated" field crop in diked, flooded fields. Minnesota and California account for most of the acreage (6800 and 3200 hectares, respectively, in 1994) with smaller amounts in Idaho, Wisconsin and Oregon. Table 9 gives production totals from cultivated fields in Minnesota and California since 1968.

Growing wild rice as a field crop was first attempted near Merrifield, Minnesota in 1950-1952 (Oelke et al., 1982). James and Gerald Godward diked a 0.5 ha area, planted it with seed collected from a nearby lake, and flooded the field. The field was drained before harvest and the crop was harvested by hand. An additional 16 ha were planted by them in 1953 and harvested with a small pull-type combine. They had good crops the first few years, but leaf blight (*Bipolaris oryzae* B. de Haan) caused serious losses thereafter. However, they continued their pioneering efforts, and today one of their sons has nearly 400 hectares in wild rice production.

Initially, the only seed available for planting in fields was of shattering types found in natural stands. These early fields were harvested several times over a 2- to 3-week grain-ripening period with specially designed, multiple-pass harvesters (Figure 10). In 1963, Dr. Paul Yagyu and Mr. Erwin Brooks with the University of Minnesota, Department of Agronomy and Plant Genetics, discovered plants in a grower's field that retained their seed longer than the rest of the plants (Oelke et al., 1982). From these few plants, they and other breeders developed cultivars with more resistance to shattering than types growing in lakes and rivers. Today, most of the wild rice being grown in fields is of the more shattering resistant cultivars. Yields of unprocessed grain from shattering types ranged from 168 to 224 kg/ha, whereas shattering resistant cultivars have yielded as high as 1680 kg/ha in Minnesota and twice that amount in California.

The development of more shattering resistant cultivars of wild rice resulted in a tremendous expansion in field production in the late 1960s and early 1970s. Practically all the expansion at that time was occurring in Minnesota where acreage increased from 354 ha in 1968 to 7090 ha in 1973 (Oelke et al., 1982) The finding of improved shattering resistance also made possible the shift to more efficient harvest with grain combines (Figure 11). The improved harvest efficiency from the use of combines, together with greater harvested yields from shattering resistant varieties, were major contributing factors to expanded field production.

Other factors that were important in the development of wild rice as a field crop were the contracting of production by Uncle Bens, Inc., and the formation of Manomin Development Corporation in 1967 to

TABLE 8
Wild Rice Harvest Quantities from Lakes and Rivers in Canada and Minnesota, 1963-1994

Years	Minnesota	Manitoba	Saskatchewan	Ontario	Alberta	Canada Total	Grand Total
	1,000 Processed Pounds[a]						
1963	1,286	--[b]	0	22	0	22	1,308
1964	514	---	0	23	0	23	537
1965	435	---	0	12	0	12	447
1966	429	---	0	18	0	18	447
1967	1,051	---	0	226	0	226	1,277
1968	524	---	0	126	0	126	650
1969	392	---	0	63	0	63	455
1970	489	60[c]	1	26	0	87	576
1971	487	200	9	121	0	330	817
1972	414	273	22	436	0	731	1,145
1973	406	250	5	519	0	774	1,180
1974	400	55	9	4	0	68	468
1975	200	57	17	37	0	111	311
1976	800	140	39	450	0	629	1,429
1977	437	462	34	344	0	840	1,277
1978	220	190	25	62	0	277	497
1979	304	240	64	120	0	424	728
1980	1,000	560	128	388	0	1,076	2,076
1981	400	182	200	272	0	654	1,054
1982	440	166	208	75	0	449	889
1983	480	134	243	76	0	453	933
1984	540	249	450	160	0	859	1,399
1985	161	258	117	14	4	393	554
1986	179	342	304	40	7	693	872
1987	500	661	515	576	8	1,760	2,260
1988	300	---	---	---	---	1,220	1,520
1989	100	---	---	---	---	1,400	1,500
1990	300	---	---	---	---	2,500	2,800
1991	100	---	---	---	---	2,000	2,100
1992	100	---	---	---	---	1,000	1,100
1993	40	---	---	---	---	600	640
1994	75	---	---	---	---	2,000	2,075

[a] Estimated, using 40 percent yield of processed from unprocessed wild rice.
[b] Values not available.
[c] Value x 453.6 = kg.

develop seed and markets for wild rice. The formation of a Wild Rice Growers' Association, the initiation of a research program in 1970 on wild rice processing at the University of Wisconsin-Madison, and the initiation of a research program in 1972 at the University of Minnesota on breeding, production, diseases, insects, soil fertility, machinery, and processing also contributed to the expansion of wild rice production. In 1974 a Minnesota Paddy and Wild Rice Research and Promotion Council was formed and growers voted to contribute a specified fee for each pound of processed grain produced for promotion and research of the crop. In the early 1970's wild rice cultivation began in California and by

TABLE 9
Wild Rice Harvest Quantities and Price from Cultivated Fields
in Minnesota and California, 1968-1994

Year	Minnesota	California	Wholesale Prices
	--- 1,000 Processed Pounds ---		$/processed lb.
1968	36[a]	0	3.27
1969	160	0	2.66
1970	364	0	2.88
1971	608	0	2.71
1972	1,496	0	2.34
1973	1,200	0	2.11
1974	1,036	0	2.37
1975	1,233	0	2.51
1976	1,809	0	2.68
1977	1,031	0	4.25
1978	1,761	100	5.15
1979	2,155	200	5.01
1980	2,320	400	4.47
1981	2,274	500	3.79
1982	2,697	880	3.40
1983	3,200	2,500	3.35
1984	3,600	3,800	3.30
1985	4,200	7,900	3.25
1986	5,100	9,000	2.75
1987	4,200	4,200	1.50
1988	4,000	3,500	1.65
1989	3,978	4,000	1.65
1990	4,800	4,200	1.70
1991	5,500	5,500	1.70
1992	6,100	7,500	1.70
1993	5,300	7,500	1.65
1994[b]	5,300	5,000	1.65

[a] Value x 453.6 = kg.
[b] Estimated.

1987 the added production had a significant impact on supply and price. In 1982 an International Wild Rice Association was formed to include all producers, processors and marketers in the U.S. and Canada.

Marketing and processing of wild rice was significantly aided by the formation of two cooperatives in Minnesota (Winchell and Dahl, 1984). In 1971 the first successful cooperative was United Wild Rice, Inc. They constructed facilities and hired a professional manager and sales force. A second cooperative, Minnesota Wild Rice Growers (MRG) was formed in 1974 and a third cooperative was organized in 1983 under the name of the Independent Wild Rice Producers Association. Later in 1987 a marketing and product development company, New Frontier Foods, Inc. was formed by some growers. In 1986 Busch Agricultural Resources purchased processing and marketing operations from United Wild Rice thus involving another large marketer in the industry. The marketing of the cultivated crop was significantly aided by the long-time harvest and marketing of the grain from natural stands. The name of the product was already established in the gourmet markets, thus the cultivated crop could exploit the gourmet nature of the grain.

Even though wild rice is now grown on acreage in several states it still possesses several traits of a wild species such as some seed shattering, seed dormancy, tiller asynchrony, and variable seed size (Hayes et al., 1989). However since these traits are under genetic control and given the heritability of these traits, deliberate selection should accelerate the domestication process.

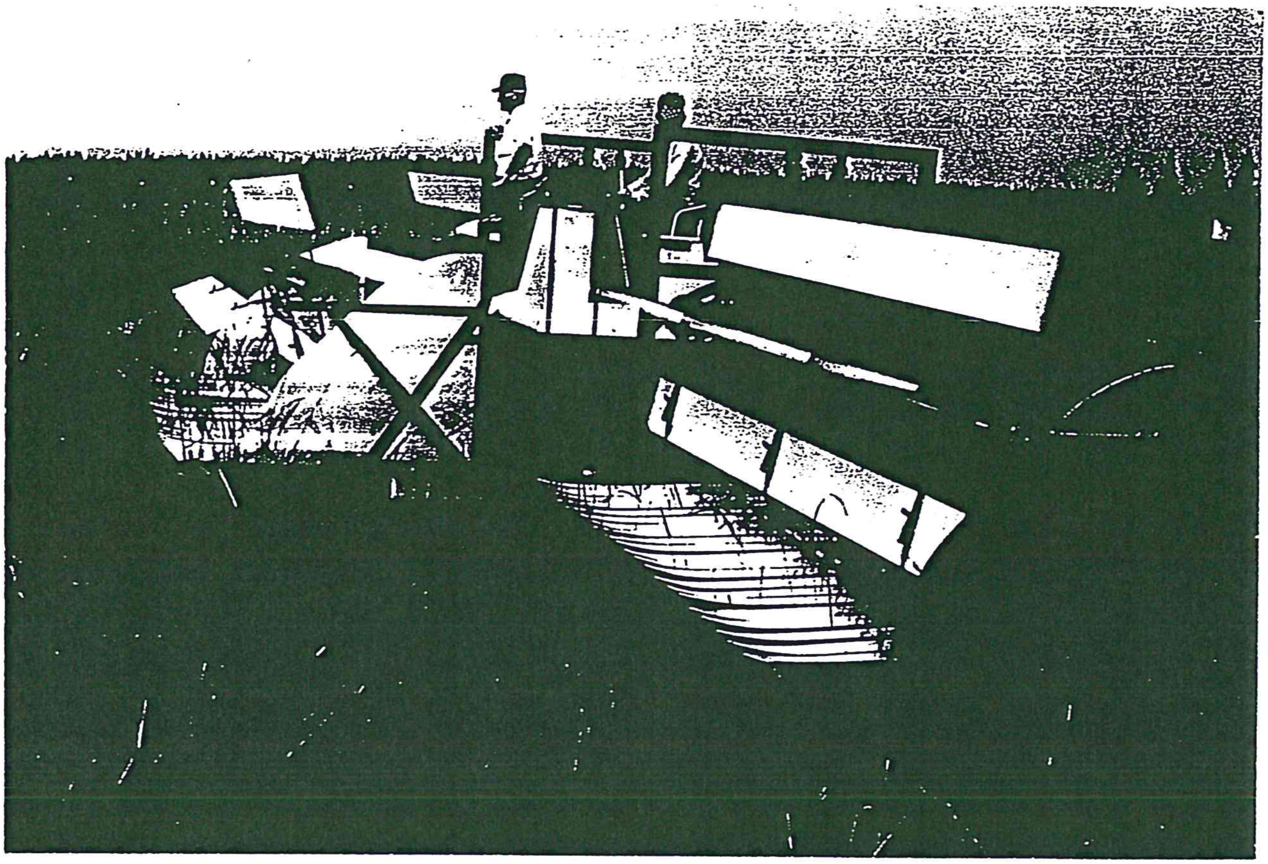

Figure 10. Harvesting early shattering types of *Z. palustris* with a picker-harvestor.

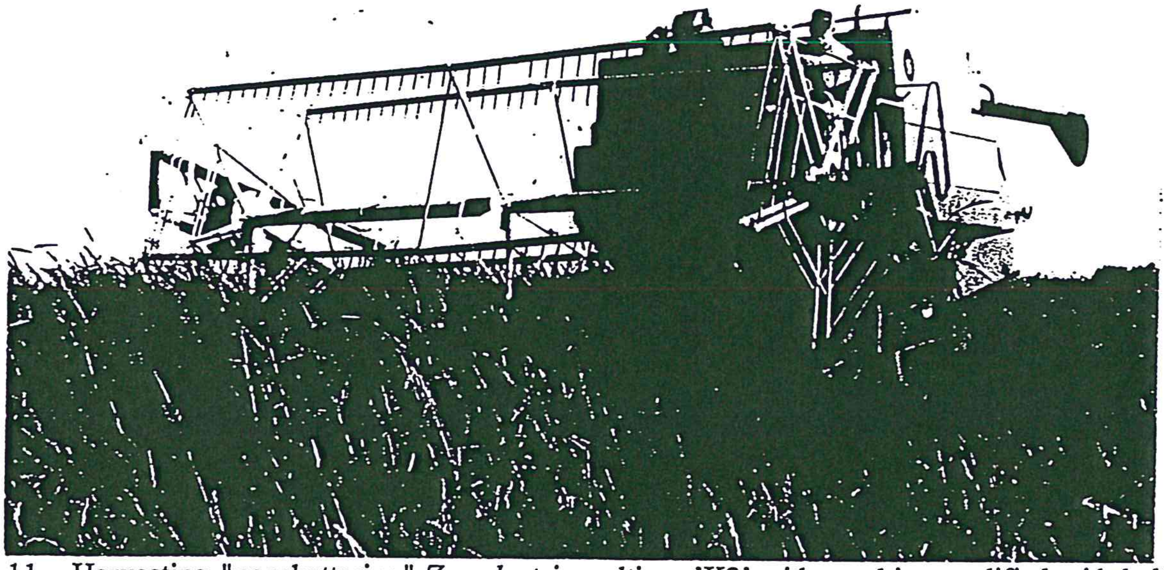

Figure 11. Harvesting "nonshattering" *Z. palustris*, cultivar 'K2' with combine modified with half-tracks and enlarged reel.

Agronomics

Adaptation

Wild rice is well adapted to northern latitudes. It is not very productive in the southern United States where warm temperatures accelerate plant development, and as a result, plant heights are shorter with an accompanying lower number of florets and tillers (Oelke et al., 1982). High humidity may result in severe leaf diseases (brown spot, *Bipolaris* sp.). Wild rice grows well in the warmer climate of northern California and cultivars have been developed for that area where the humidity is very low, and leaf diseases are not prevalent. No resistance to brown spot has been found, however variability in the germplasm for many of the other characteristics and with some breeding effort, the genus could be adapted to other areas in the future.

The crop is grown like rice (*Oryza*), thus relatively flat areas are needed where a water depth of 30 cm can be maintained for most of the season. Wild rice grows well on organic or inorganic soils if the proper nutrients are applied but its nitrogen requirements are lower than for rice since that plants are tall and can lodge. Wild rice grows well in cooler and deeper water than rice, thus water depth can be used more for weed control in wild rice compared to rice.

Wild rice seed needs to be stored for 90 days in cold (3 C) water before dormancy is released. Seed storage is an added cost in the Sacramento Valley of California but not in Minnesota. Wild rice seed loses viability after dormancy release if it is allowed to dry below 25% moisture content. Dormant seed can withstand drying below 25% moisture and stored without submerging the seed into water but it must still be stored in cold (3 C) water for 90 days to release dormancy (Oelke and McClellan, 1992). Wild rice seed when planted 5 to 8 cm into the soil before flooding can still grow when covered for more than a few days by both soil and water. In Minnesota new fields are seeded with 45 kg ha^{-1} of seed (35% moisture) but in California a seeding rate of 112 kg ha^{-1} is common. This higher seeding rate is used in California because plants don't tiller as well and a higher plant population can be utilized since leaf diseases are not a problem.

Minnesota and Wisconsin fields are prepared, fertilized and seeded in the fall and flooded to a depth of about 30 cm in the spring. In California these operations are done in the spring except in some of the higher elevations where production practices are similar to those in Minnesota.

In Minnesota, once a field is planted to wild rice it will reseed itself due to shattering even when planted to cultivars with some shattering resistance. Thus, fields are generally kept in production for 3 to 4 years. It is also difficult to change to a new cultivar because seed dormancy results in volunteers the following year. Cultivars without seed dormancy are needed to allow more rapid adoption of new, improved cultivars. The plant density following the first year is too high making it necessary to reduce the plant population using airboats equipped with a series of V-shaped knives set 15 to 20 cm apart on a toolbar at the rear of the boat (Oelke et al. 1982). The boat travels at a speed of 55 km h^{-1} with the knives riding on the soil surface removing about 70% of the plants to give a desired plant density of 40 plants m^{-2}.

In Minnesota and California, fields are drained about 3 weeks before harvest. Combines are often adapted with half or full tracks to allow harvesting in moist soils (Figure 11). The grain is harvested at 30% moisture since shattering occurs if seed is allowed to dry more on the plant. Moist grain is immediately transported to processing plants. At the processing plant the grain is cured, parched, hulled and graded.

Diseases

Diseases in natural stands of wild rice are not usually too destructive, but in field-grown wild rice they can cause serious losses (Percich, 1982). In the early years of commercial production, severe epidemics of brown spot destroyed entire crops in some locations. Almost every disease pathogen of wild rice has been observed previously on rice (*Oryza*).

Brown spot (formerly called *Helminthosporium* brown spot) is the most serious disease affecting wild rice that is grown in Minnesota but is not a problem in California (Percich, 1982). This disease is caused by *Bipolaris oryzae* Luttrell (*Helminthosporium oryzae* B. de Haan) and *B. sorokiniana* Luttrell (*H. sativum* P.K. and B.). Every cultivar of wild rice is susceptible to brown spot (Johnson, 1991). This disease is most severe when day temperatures range from 25 to 35 C and nights are 20 C or warmer. High relative humidity (greater than 89 percent), and the continuous presence of free water on leaf surfaces also favors infection (Percich et al., 1994). All parts of the plant are susceptible to infection. The brown, oval leaf spots usually have yellow margins and are about the size of sesame seeds. These uniform spots are evenly distributed over the leaf surface. Severe infections result in weakened and broken stems, damaged florets, and a reduced quantity and quality of grain. Yield reductions can vary from none to 100 percent. Incorporating residue and a fungicide are needed for control.

Stem rot is the second most common disease in field-grown wild rice. Two fungi, a *Sclerotium sp.* and *Helminthosporium sigmoidium* Cav., may cause this disease (Percich, 1982). These fungi produce dark structures called sclerotia in culms, leaf sheaths, and stems. Small, oval, purple lesions develop initially on stems or leaves at the water surface. Extensive lodging may result after the fields are drained because the infected stems have become dry and brittle. Control of stem rot is achieved most effectively by appropriate sanitation and cultural practices. Plant residue must be removed or tilled into the soil, only clean seed should be used, and resistant crops or fallow should be in the rotation. No fungicide is available for effective control.

Stem smut is caused by the fungus *Entyloma lineatum* (Cke.) Davis. Economic losses from this disease have not been a problem in cultivated fields (Percich, 1982).

Ergot is rarely found in cultivated fields, but it can be a serious problem in natural stands (Percich, 1982). This disease is caused by the fungus *Claviceps zizaniae* Fyles, a different species than the one causing ergot in cereal grains. Wind-borne ascospores infect flowers and hard, dark sclerotia eventually develop in place of the grain. No specific control is recommended, but poisonous ergot bodies should be removed from harvested grain by flotation, or by screening.

Bacterial leaf streak and wheat-streak mosaic virus have been found in cultivated wild rice in Minnesota (Percich, 1982; Berger et al., 1981). Bacterial leaf streak is caused by *Pseudomonas syringae*. The wheat streak mosaic virus-wild rice is the only one known to infect wild rice. Economic losses for grain yield, if any by these diseases, have not been determined. No control measures are known.

Scab has recently been identified as a disease in wild rice (Nyvall et al., 1994). The most common fungus isolated from wild rice seed was *Fusarium graminearum*. The severity of this disease in wild rice has not been determined at this time.

Crown and root rot has recently been identified in California wild rice fields by Webster and Gunnell (1989). They showed the causal organism to be *Phytophthora erythoseptica*. The effect of this disease on yield is undetermined at this time.

Insects and Other Animals

The rice worm (*Apamea apamiformis* Guenee), which is the larval stage of the noctuid moth, is the most serious insect pest of wild rice in the Upper Midwest but not a problem in California (Noetzel, 1982; Peterson et al., 1981). Significant yield losses have been caused by this insect. Its life cycle is coordinated closely with the growth and development of wild rice. Adult moths begin to emerge at about the same time as flowering begins in wild rice during late June or early July. Nectar from milkweed flowers serves as the primary food source for adult moths through August. Eggs are deposited in wild rice flowers over a period of 4 to 6 weeks. Larvae hatch and develop through several instars or stages, and feed during grain fill as they grow. Yield potential is reduced by the initial feeding activity on the glumes of the spikelet and subsequent feeding on kernels. Rice worms bore into stems of wild rice or migrate to plants that border the production area as their growth and development nears completion. Rice worms overwinter inside the stems in the seventh instar. After a final molt and some additional feeding in the spring, the larvae usually pupate in early June, and develop into the adult moth. Research in Minnesota found that one larva per plant reduces yield by 10 percent. Control of the rice worm has been proven effective with several insecticides. Only malathion, at one pound of active ingredient per acre, is approved for use in wild rice.

A number of midges use the flooded paddies for larval development. Eggs are laid in the moist soil and hatch when the fields are flooded (Noetzel, 1982). One of the midges, *Cricotopus spp.*, has caused severe damage to first-year fields in Minnesota and California. The mosquito-like adults are so small that most growers will not see them. Algal growth is associated with paddies showing high midge numbers. A slow emergence of seedlings due to algal growth results in greater damage by midges since it allows more time for feeding activity. The larvae feed on leaf edges and cause frayed leaf edges with subsequent curling of leaves. The leaf curling and webbing that midges produce will interfere with seedling emergence above the water. As a result, the damaged seedlings fail to reach the floating-leaf stage and the stand is thinned severely. Midge control with malathion is often necessary in first-year fields. In the following years control is not usually necessary since there is no economic loss. This is not the result of a lack of midges, which actually increase in number, but due to higher plant numbers so the damage goes unnoticed.

Rice stalk borers (*Chilo plejadellus* Zincken), rice water weevils (*Lissorhoptrus spp.*), rice leafminer (*Hydrellia spp.*), rice stem maggot (*Eribolus longulus* Loew), and other insects will feed on wild rice plants. Research in Minnesota has not revealed any economic injury from these insects (Peterson et al., 1981).

Crayfish (*Orconectes virilis* Hagen) are carried into paddies by flood waters where they forage and may reduce the number of seedlings (McDonald et al., 1993). Once crayfish are established in a field, they persist. They survive by burrowing into moist soil between periods of paddy flooding. Severe stand reductions have occurred in some fields in Minnesota. No chemicals are cleared for their control.

Red-winged blackbirds (*Agelaius phoeniceus*) are a major pest in both Minnesota and California. These birds use the dikes as nesting sites and are present in large numbers in the growing areas. Birds begin feeding on wild rice when the kernels are in the milk stage. Control measures should start when blackbirds are first observed.

Wild rice fields are also ideal sites for resting, foraging, nesting, and raising broods of migratory and resident water birds (Svedarsky, 1994). Four species of ducks (mallard, pintail, blue-wing teal, and green-wing teal) and more than 35 species of shorebirds and wading birds inhabit wild rice fields. Economic damage from waterfowl is rarely observed. Wild rice fields are excellent for duck production.

Raccoon, mink, and skunk search for food on the dikes and in ditches (Svedarsky, 1994). Deer and moose occasionally cause some damage in the fields, but it usually has no economic importance. Muskrats can cause problems by feeding on seedlings and mature plants and by burrowing holes in the sides of dikes. However, since muskrats are not permanent inhabitants due to the annual drainage of the paddies for the harvest, they do not pose a threat to the dikes.

Weeds

The common broadleaf water weeds of the Upper Midwest are a more serious problem than aquatic grassy weeds in Minnesota and at the higher elevations in California (Oelke et al., 1982). Common waterplantain (*Alisma trivale* Pursh) is the most troublesome weed in wild rice fields. Early control of this weed is critical since competition with wild rice is greatest after 8 weeks of growth (Ransom and Oelke, 1982). First-year seedlings of common waterplantain are usually too small to compete with wild rice. Water management is the major control measure (Ransom and Oelke, 1983). Aquatic grassy weeds in Minnesota and California are also controlled by water management. No chemicals are presently cleared for grassy weed control in wild rice.

Genetics

Cultivar Development

Wild rice germplasm available for a breeding program is limited to seed which has been harvested within the past 1-2 years because of the current limitations of seed storage. This mandates yearly seed increases of germplasm populations and cultivars, and prohibits maintenance of large germplasm collections. In Minnesota and other Great Lakes states and provinces (center of origin for *Z. palustris*), seed is still occasionally collected from wild populations of *Z. palustris* var. *interior* for immediate use in breeding and other research. The variability within this genus, even within populations collected from a single lake can be quite high. Cultivars have been developed primarily by population improvement of wild populations, as opposed to inbred lines or other methods which reduce genetic variability. Plant-to-plant heterogeneity is still characteristic of cultivars. For most traits, genetic variability within cultivars is more than sufficient to allow selection progress (Foster and Rutger, 1980).

All of the cultivars and most breeding populations are *Z. palustris* var. *interior*. Populations were first introduced from Minnesota lakes into paddies in 1950 (Oelke et al., 1982). Plants had the same shattering tendency of the wild populations until plants with some shattering resistance were discovered and developed into the first "nonshattering" cultivar, 'Johnson', which was first put into production in 1968 (Stucker. 1982). Minnesota cultivars, both those developed by growers and those released by breeders, are summarized in Table 10. Although Hayes et al. (1989) believe that this initial collection of nonshattering plants was the germplasm base from which all current cultivars are descended, some growers who developed subsequent cultivars indicate they were developed from other independent lake collections. The exact pedigrees of many of these cultivars remains unclear. Johnson was late-maturing with high yields but yields were greatly reduced by frost in some years. Once earlier cultivars were developed, cultivation of Johnson was abandoned in Minnesota; however, California growers continue to grow various reselected versions of Johnson. Currently, the most widely grown cultivars in Minnesota

TABLE 10
Summary of Wild Rice Cultivars Released in Minnesota[a]

Cultivar	Description
Johnson	Tall, late, some non-purple panicles. Released 1968.
MI	Medium to late maturity. Developed by Manomin Dev. Co. in 1970.
K2	Early to medium maturity, medium to high yield. Developed by Kosbau Bros. in 1972.
M3	Medium to late maturity, having a mixture of gynoecious and monoecious panicles, high yield. Developed by Manomin Dev. Co. in 1974.
Netum	Early maturity, low to medium yield. Developed by Minnesota Agricultural Experiment Station and released in 1978.
Voyager	Short to medium height, early maturity, and medium to high yield. Released by Minnesota Agricultural Experiment Station in 1983.
Meter	Short height, very early maturity and reduced foliage in the canopy. Large seed size and low to medium yield. Released by Minnesota Agricultural Experiment Station in 1985.
Petrowske bottlebrush	Medium to late maturity, high yield. Up to 50% of plants can have bottlebrush panicle type. Developed by K & D Wild Rice.
Franklin	Medium to early maturity, more shattering resistant than other varieties. Released by the Minnesota Agric. Exp. Station in 1992.

[a] Adapted from Stucker (1982); Hayes et al. (1989); Porter et al. (1995).

are K2, Petrowske bottlebrush, Voyager, and Franklin.

Other North American species of *Zizania* can be used as sources of genetic material for breeding programs. Duvall and Biesboer (1986 and 1988) found that nonreciprocal crosses between the different botanical types of *Z. palustris* and *Z. aquatica* could produce viable seed from which fertile plants grew. These results opened up additional gene pools from which to introgress new traits. For example, a *Z. aquatica* population collected in northern Florida shows greatly reduced or absent seed dormancy, robust stature, and more female florets per panicle (Porter et al., 1995). Another possible source of traits could be *Z. aquatica* var. *brevis*, characterized by short awns, short seeds, short height, and adaptation to higher salinity of a tidal habitat (Aiken et al. 1988). Some populations of *Z. palustris* (var. *palustris* and var. *interior*) and *Z. aquatica* var. *aquatica*, as well as *Z. texana*, have been obtained and used by breeders to make wide crosses with *Z. palustris*. The potential for incorporated useful genes from *Z. latifolia* into *Z. palustris* has not been explored.

Currently, the University of Minnesota and Lakehead University in Thunder Bay, Ontario, have wild rice breeding programs which are developing cultivars for Minnesota and Canada, respectively, while one private breeding company (NorCal Wild Rice) develops cultivars for California's Sacramento valley. Minnesota growers continue to practice mass selection to improve their own seed.

Molecular Genetics

At the University of Minnesota, a molecular genetics project was initiated in 1993 as an adjunct to the breeding program (Grombacher and Phillips, 1994). The goals of the project are to develop an RFLP linkage map in wild rice and to identify RFLP markers for important agronomic traits.

A wild rice genomic library was constructed using DNA from Franklin, a K2 derived cultivar (Grombacher et al., 1993). The library was designated pAWG (Plasmid Aquatica Wildrice Genomic). Whole genomic DNA was digested with PstI and fractionated on a sucrose gradient. The DNA was inserted into PUC18, and the recombinant plasmids transformed into E. coli strain DH10B. The average insert size in 3.25 Kb with an insert range of 0.5 to 6.0 Kb.

DNA samples from wild rice populations have shown it to be polymorphic. Seventy percent of the pAWG library (4,365 clones) are single or low copy, with the potential of 3,000 probes available to map the genome. Mapping populations are being developed, and mapping techniques are being adapted to wild rice.

PROCESSING

Separation Of Immature Kernels

An optional first step in processing wild rice performed at some Minnesota plants is separation of immature kernels. Much of the wild rice harvested by grain combine in Minnesota has a relatively high concentration of very immature kernels. Processors find it advantageous to separate out this fraction before proceeding with subsequent processing steps. Most large processing plants in Minnesota that process cultivated wild rice have an air-stream separator to remove immature grain (Oelke and Boedicker, 1991). Wild rice harvested from fields planted to shattering types or from natural stands by multiple-pass (hand or machine) methods or wild rice harvested by combine in California typically have low concentrations of very immature kernels; hence, this separation step in unnecessary for grain from these sources.

The air-stream separator was built by the Agricultural Engineering Department of the University of Minnesota (Oelke and Strait, 1982). It is designed to separate freshly harvested wild rice into three fractions designated as heavy, medium and light. The heavy fraction consists mostly of plump, mature kernels; the medium fraction, kernels of intermediate stages of maturity; and the light fraction, predominantly small immature kernels and empty hulls and chaff. Separating out and discarding the light fraction effectively increases plant capacity by a percentage at least equal to the percent reduction in volume that results from this separation. Some processors parch the heavy, mature fraction directly, thus bypassing fermentation which typically is the next step in processing.

Fermentation Or Curing

Fermentation or curing of wild rice is a complex process involving respiration and numerous microorganisms (Lund et al., 1977; Goel et al., 1972). In the typical fermentation process, grain is formed into windrows on a impervious surface outdoors and periodically stirred and watered for several days (Figure 12). Windrows range from 1 to 2 m wide and 0.2 to 0.3 m deep. Watering keeps moisture content high (desired for next processing step) and, along with stirring, helps maintain aerobic conditions while limiting heat build-up to minimize dry matter loss and the development of undesirable molds. During normal weather conditions, windrows are stirred and watered once or twice daily. Fermentation periods normally range from 4 to 7 days. Over 20 percent of usable wild rice can be lost in 10 days through respiration and microbial action (Table 11; Lund et al., 1977). In California, some processors ferment wild rice in 3.1 x 3.1 x 3.1 m metal containers. But the grain still requires watering and aeration to maintain its condition (Oelke and Boedicker, 1991).

Although fermentation of wild rice is not completely understood, at least three changes occur to the grain in the process: (1) less mature kernels change color from green to brown, (2) hulls partially degrade permitting easier hulling and (3) some of the characteristic flavor is imparted to the grain. Wisconsin researchers (Lund et al., 1977) measured changes in color over 5 weeks of fermentation and found a significant color change after one week. Goel et al. (1972) also identified microorganisms present on fermenting and parched wild rice (Table 12). They concluded that hull removal and final cooking virtually eliminate all viable microorganisms.

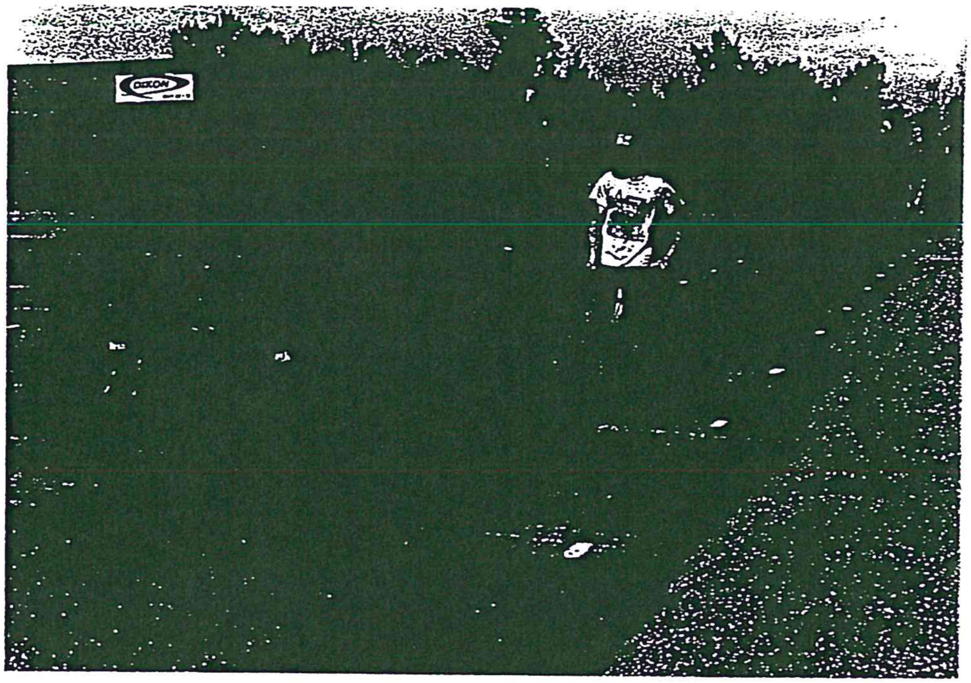

Figure 12. Unloading combined grain into windrows onto a hard surface fermentation field.

TABLE 11

The Percentage of Processed Grain Recovered from Grain as Influenced by Storage Time at Ambient Temperature[a]

Length of Storage and Turning[b]	Percent of Processed Grain Recovered[c]
Days	%
0	100
1	100
2	97
3	98
4	93
5	92
6	93
7	89
8	89
10	79

[a] Lund et al. (1977).

[b] Wet wild-rice (ca. 50% moisture) stored in 18 to 24-in. deep bins with daily watering and turning.

[c] 0 days storage used as base (100%).

Drying or Parching

After fermentation, the grain is moved from the fermentation field to driers. The most commonly used drying procedure is referred to as parching. Parching at most plants is performed in batch type, rotary drum parchers, Figure 13, which typically are loaded by hand. During parching, the 40 to 45 percent moisture content of the fermented grain is reduced to approximately 7 percent and a slightly toasted flavor is imparted to the grain. In the process starch in the kernels is gelatinized, giving a glassy, translucent appearance to the inside of the kernel.

Parching drums are typically about 1.2 m in diameter and 1.8 to 2.4 m in length and are supported by rollers at the front and rear to permit rotation. The forward (open) end has vanes set at an angle to aid both in retaining the grain during parching and in grain removal (Figure 13). Most parchers are fired with propane burners located below the drum and typical parchers can dry from 114 to 182 kg/hour.

During parching, the drum is rotated continuously causing the grain to tumble. Individual kernels intermittently come into contact with the hot surface. Some parchers have small bars extending longitudinally through the parcher drum to provide better mixing as the grain tumbles. Some processors prefer to cover the front opening of the parcher during parching to help retain steam for quicker or more efficient drying with less temperature fluctuation within the drum. As parching of each batch nears completion, the grain is periodically sampled or grain temperature measured to monitor progress of the gelatinization process.

Parching is complete when kernels reach a hard, flinty condition and the starch in the kernels is gelatinized. When parching is completed, the rear of the drum is raised slightly and the direction of rotation reversed, discharging the grain. Parching time per batch is about two hours. During parching, temperature in the drum is controlled not to exceed about 135 C. Boedicker et al. (1993) found that grain temperature and moisture were closely correlated, thus processors now use laser thermometers to determine grain temperature. Once the grain temperature reaches the desired temperature, it is removed from the drier.

TABLE 12
Kinds of Microorganisms and Frequency of Isolation of Specific Organisms From Fermenting and Parched Wild Rice Samples[a]

Source and kind of microorganism	Fermenting wild rice[a]	Parched wild rice
	No. specific kind/total isolates	
From place count agar (30 C)		
Gram-positive rods	5/27	17/25
Gram-negative rods	14/27	6/25
Gram-positive cocci	8/27	2/25
Bacillus species	0/27	15/25
Corynebacterium species	0/27	2/25
Lactobacillus species	2/27	0/27
Leuconostoc species	3/27	0/27
From plate count agar (7 C)		
Pseudomonas species	23[b]	3[b]
Pigmented Pseudomonas species	8/23	0/3
From violet red bile agar		
Escherichia coli	2/44	1/6
Enterobacter aerogenes	5/44	1/6
Intermediates	37/44	4/6
From KF agar		
Streptococcus faecium	14/35	7/11
Streptococcus faecalis	6/35	1/11
Other streptococci	15/35	3/11
From acidified potato dextrose agar		
Aspergillus species	5/16	2/10
Penicillium species	2/16	3/10
Mucor species	8/16	5/10
Rhizopus species	1/16	0/16

[a] Goel et al. (1972).

[b] A total of 70 colonies was isolated from fermenting and parched wild rice.

Some continuous flow parchers are in use and consist of four long drums, each about 9 m long, placed side by side (Oelke and Boedicker, 1991). As the drums rotate, the grain is moved successively from one drum to the next, the process being controlled such that parching is complete upon discharge of the grain from the fourth drum.

As an alternative to the rotary drum parcher, the University of Minnesota Agricultural Engineering Department built and tested a large prototype continuous-flow dryer utilizing superheated steam as the drying medium (Oelke and Boedicker, 1991). Components of this drying included a feeding mechanism to meter fermented grain into the top of the dryer, a three-tiered woven wire conveyor system to move it though the dryer and several stirrers to mix the grain on its travel on the conveyors. The dryer also has a fan and ductwork to recirculate steam up through the tiers of grain and a propane fired furnace and heat exchanger to add heat to the recirculated steam. The source of steam in the dryer was moisture given off by the grain itself, excess steam being allowed to continuously escape to the atmosphere

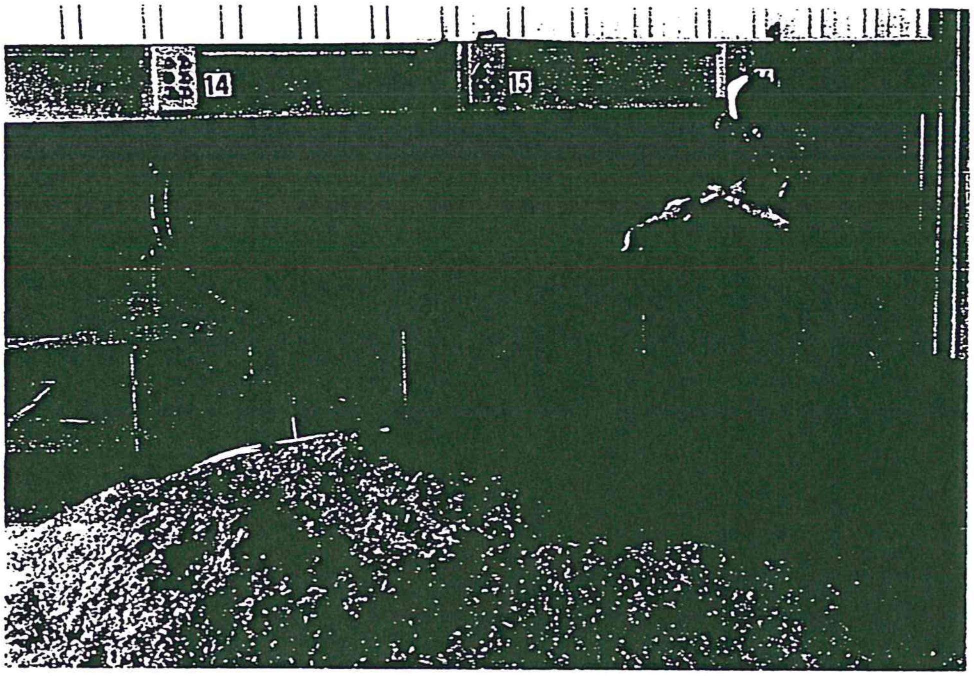

Figure 13. Loading fermented grain into a parcher.

through a duct from the top of the dryer. Best overall dryer performance was achieved with a steam supply temperature of 146 C return temperature. Capacity of the dryer was about 454 kg/hr of fermented grain. Grain residence time in the dryer was approximately 40 minutes. Advantages of the system included more mechanized grain handling and less than half the fuel requirement of rotary drum parchers per quantity of water removed. One possible disadvantage was that grain dried in the unit lacked the toasted, nutlike flavor characteristic of parched wild rice that many consumer prefer.

A commercial continuous-flow dryer, modeled after the prototype and rated at 1364 kg/hr, was built and presently is being used in California for drying wild rice. It performs satisfactorily although kernel breakage tends to exceed that from a well-operated rotary drum parcher. In the future, as production expands and energy costs increase, it is conceivable that continuous-flow driers will find their place in the processing industry, particularly for wild rice destined for the blend market for which a toasted flavor is less important.

A minor step following parching or drying is separation of any large pieces of stalk and fragments of ferrous metal from the grain. Stalk pieces are separated out by screening. Ferrous metal fragments are captured by permanent magnets positioned closely over conveyors transferring the dried, screened grain to hullers.

Hulling

Hulls remain intact during drying or parching and must be detached from the edible portion of the kernel. Although some barrel-type hullers are still used, the most common type of huller is the roller huller consisting of two closely spaced, counter-rotating hullers with rubber-like outer surfaces (Figure 14). The grain is fed to pass between the rollers and as it does, a rubbing action created by the rollers being operated at different peripheral speeds causes the hulls to become detached. The roller surface material found to give the best compromise between levels of kernel breakage and unhulled kernels is neoprene of 66 durometer hardness (Strait et al., 1984). To maintain good huller

Figure 14. Hot parched grain passed between the two rubber coated rollers which travel at different speeds to remove hulls (lemma and palea) from grain.

performance, processors must pay close attention to roller clearance and condition. Effective feeder and roller conditioning systems along with sensitive means for adjusting roller clearance are important features of any roller huller system.

Scarification

Scarification is the process of removing part of the outer impermeable layer of the kernel. Wild rice used in mixes with rice (*Oryza sativa* L.) must be scarified sufficiently to reduce its cooking time to that of rice (Oelke and Boedicker, 1991). The typical scarifier consists of a long, inclined tube with rubber paddles inside mounted to a rotation shaft. The degree of scarification that occurs is dependent upon inclination of the scarifier, speed of the shaft and clearance of the rubber paddles. In some operations, grain is scarified after being size-graded for even better control of cooking time.

Cleaning, Grading and Packaging

In addition to screening and separation of ferrous particles as described above, grain is subjected to several other cleaning operations as it progresses through the plant. Aspirating devices are employed after hulling and scarifying operations to separate out hulls and chaff (Oelke and Boedicker, 1991). Aspirated material is conveyed outside the plant. Gravity tables are used to separate out unhulled grain as well as small pebbles and other debris. Unhulled grain is either recycled directly to hullers or stored and rerun later.

Wild rice is graded principally on the basis of kernel size. Various types of length and width graders are used for the grading process. No uniform grading standards for wild rice are yet in place across the industry, and plants sort processed wild rice differently, often depending on specifications of particular

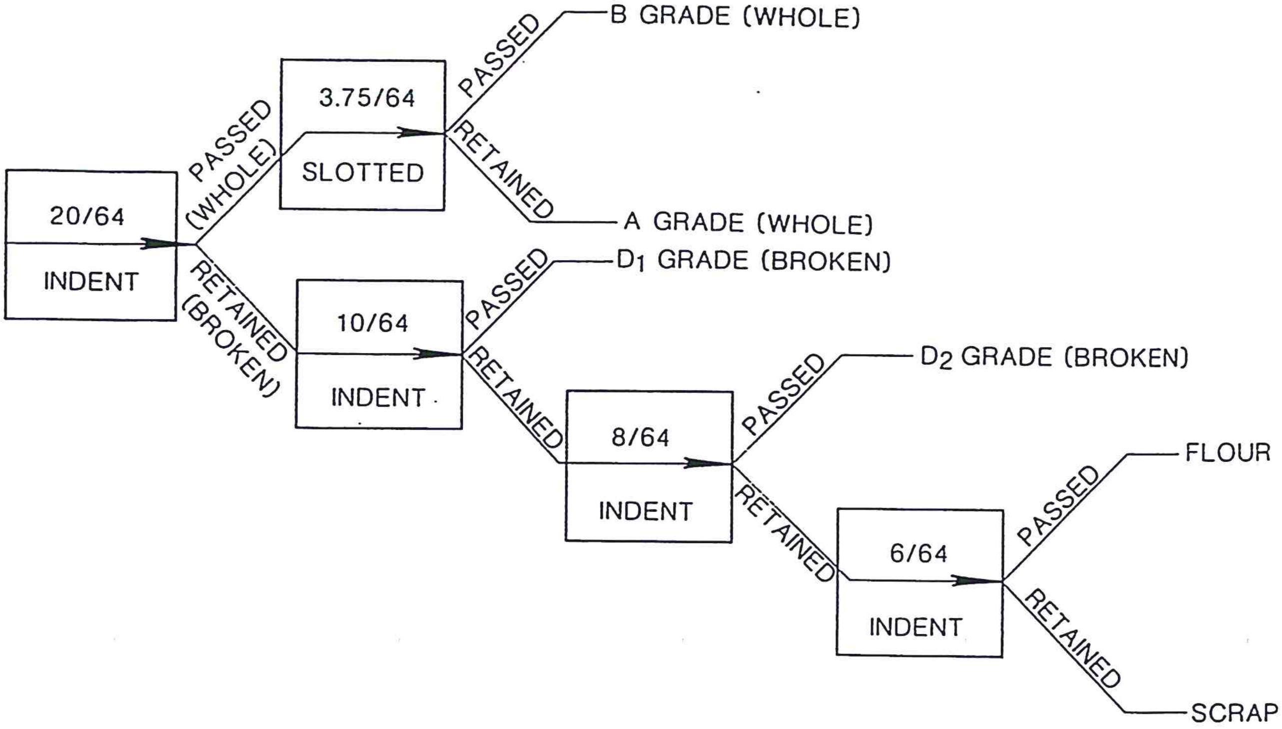

Figure 15. Grades based on size, of processed wild rice used by some processors. Numbers are in fractions of an inch.

buyers. Figure 15 illustrates grading steps used by some processors. In this grading system, kernels are defined as being either whole or broken solely on the basis of length, regardless of whether the kernels are actually broken or not. Whole grain (≥ 20/64 inch in length) is divided in A and B grades according to diameter. Grain classified as broken is further graded on the basis of length only. In 1984, the International Wild Rice Association proposed a somewhat different grading standard (Table 13) that some plants are now following to a limited extent. Some processing plants have developed their own grain specifications as shown by the example in Table 14. These specifications differ from those depicted in Figure 15 and Table 13, and buyers need to be aware of actual grain specifications for the various grading systems in use. To-date the industry has not agreed to a standard grading system for wild rice.

Most plants bag processed wild rice into 45 kg sacks, which are stored in clean, dry warehouses. Many plants are equipped to package wild rice in small packages and some will blend and package wild rice and rice, according to customers' specifications.

Quality

Even though industry-wide quality standards have not been developed, several factors relating to quality are recognized by most marketers (Oelke and Boedicker, 1991). Broken grain is undesirable because it detracts from appearance of the final product. Also undesirable is the presence of stress cracks which can develop during parching due to excessive temperature and moisture gradients produced by drying the grain too rapidly. Stress cracks make kernels more susceptible to breaking in subsequent handling and processing operations. A white center in the kernel is another undesirable appearance-related characteristics that is quite evident in grain containing broken kernels. White centers are thought to result from gases becoming trapped in the center of the kernel during parching. Percentages of cracked, broken and white centered kernels vary considerably from plant to plant and even among

TABLE 13

Wild Rice Grades - Length and Diameter Quality of Grades and Definition of Grades

GRADES[a] - LENGTH & DIAMETER

Screens	Diameter measure[b]	Letter grade	Grades						
425	425 & above	T	T1	T2	T3	T4	T5		
400	400	0	01	02	03	04	05		
375	375	P	P1	P2	P3	P4	P5		
350	350	I	I1	I2	I3	I4	I5		
325	325	N	N1	N2	N3	N4	N5		
300	300	G	G1	G2	G3	G4	G5		
	Below 300	S	---	S2	S3	S4	S5		
	Number Grade:		1	2	3	4	5	6	7
			(Long Grain)		(Med Grain)	(Short Grain)		(Small Broken)	
	Length Measures:[c]		30	26	20	12	10	8	6
	Riddle:[d]				#1	000			

[a] Although there is a potential of 49 grades, the smaller lengths cannot be used.

[b] Measurements expressed in 64th of an inch (ex. 425 = 4 1/4/64ths).

[c] Measurements expressed in 64th of an inch (ex. 32 = 32/64ths).

[d] Measurement of Riddle: #1=20/64ths; #000=12/64ths.

QUALITY OF GRADES

	Foreign Material						
Description	Solids	Dust & chaff	Other[a]	Chalky kernels	Damaged kernels[b]	Percent moisture	Other
Premium	<.0001	<.002	<.01	<.1	<.1	3-10	All FDA standards
Choice	<.0002	<.005	<.025	<.5	<.2	3-11	All FDA standards
Good	<.0005	<.01	<.05	<2.0	<1.0	3-12	All FDA standards
Standard	<.001	<.02	<.10	<5.0	<3.0	3-13	All FDA standards

[a] Other--unhulled, weed seed, other grain, etc.

[b] Damaged kernels--heat, frost, etc.

DEFINITION OF GRADES

Description	Percent long grains	Percent medium grains	Percent short grains	Percent brokens
Long Grain	85 min.	10 max.	7 max.	3 max.
Medium Grain	10 max.	80 min.	10 max.	7 max.
Short Grain	5 max.	10 max.	80 min.	10 max.
Broken	1 max.	5 max.	20 max.	80 min.
Mill Run	70 min.	20 max.	10 max.	5 min.

[a] Adopted by Processors Committee of the International Wild Rice Association on May 22, 1984.

TABLE 14

Standard Specifications for Wild Rice for a Wild Rice Processing Plant in Minnesota[a]

PHYSICAL FORM:

Variable	Specifications
Form:	Kernels
Color:	Greenish brown to dark brown to charcoal black
Flavor/Odor:	Nutty flavor - faintly roasted odor

ANALYTICAL SPECIFICATIONS:

Variable	Specifications
Moisture:	Less than 10% by A.O.A.C.
Length:	Greater than 20/64" = Long Grain Less than 20/64" - greater than 10/64" = Medium Grain Less than 10/64" - greater than 8/64"[b] = Short Grain
Width:	2.5/64" - 5.5/64"
Water Absorption:	Upon rehydration (cooking) product will typically increase in weight by 250% to 375%
Microbiological Standards:	Provided by an outside, reputable analytical laboratory and consulting service, 55 years in service.
Total Aerobic Plate Count	3,000,000/grams **maximum**
E. Coli	Less than 3/10 grams
Staphylococcus	Negative/25 grams
Salmonella	Negative/100 grams
Aflatoxin	Less than 2 P.P.B.

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[a] Deer River Wild Rice, Inc., Deer River, Minnesota.

[b] Product less than 8/64" (chits and fines) discarded.

batches processed at the same plant.

Two additional quality factors of importance are color and taste. Any green coloration, characteristic of inadequately fermented immature kernels, is generally undesirable (Lund et al., 1977). The preferred color is blackish-brown. Scarification, which results in removal of some of the seed coat, detracts from the desired dark color, however, for grain that must be scarified to reduce its cooking time, some of the color is removed during scarification. As for taste, many consumers prefer a slightly toasted flavor as mentioned above. Any off flavor, which can result from improper handling and fermentation, is highly undesirable (Lund et al., 1977).

Some in the industry claim that wild rice harvested from lakes and rivers is of better quality than cultivated wild rice. However, quality differences are due primarily to variations in how wild rice is handled and processed and not to any inherent differences related to how or where it is grown (Lund et al., 1977). The industry is continually striving to improve the quality and uniformity of processed wild rice, regardless of its source.

MARKETING, DISTRIBUTION AND UTILIZATION

Since 1968 the per-pound wholesale price of processed wild rice has ranged from a low of $2.10 in 1987 to a high of $5.15 in 1978 (Table 9; Oelke et al., 1994). Price variations between 1968 and 1977 reflected limited and erratic supplies due to variations in lake and early cultivated harvests. The high prices of 1978 through 1980 reflected attempts by marketers to withhold supply, but these attempts were short-lived because the high prices simply encouraged increased production. Expansion in Minnesota was modest during 1978 through 1980, but California doubled production annually through 1981 (Table 9). By 1981, high inventory storage costs were forcing the sale of stocks and prices returned to market determined levels. Production increased 26% per year between 1982 and 1984, but markets were able to absorb this increase with only a slight drop in price. In 1985, California production more than doubled over 1984 and prices declined sharply in 1987. The price increased slightly in 1988 and has remained similar for the last few years.

Wild rice markets have expanded at a vigorous rate during the 1982-84 period when demand increased 52% (Nelson and Dahl, 1985). Most of this growth was in the blend market, where sales increased an average of 15% per year from 1961-84 when Uncle Ben's Inc., first introduced its packaged blend of wild rice, long grain rice and herbs (Nelson and Dahl, 1985). Presently, other types of blends containing wild rice are also available such as soups, vegetable-based side dishes, and convenience foods such as dehydrated mixes and frozen entrees. Wild rice blends have helped to increase consumer awareness of wild rice in the U.S. from 8% to 30% in recent years (Nelson and Dahl, 1985).

Figure 16 shows the percent of wild rice sales by market outlet for the 1982 crop year (Nelson and Dahl, 1985). About one-third of the wild rice sold that year was in the pure form. However, a large portion of these sales eventually reaches the consumer in the form of blends prepared by restaurants and other users. Long grain wild rice is preferred for the pure market; however, a considerable amount of short or broken grain is also sold in pure form for use in soups and stuffings. An emerging market is the mixing of cooked wild rice with meat to utilize wild rice's antioxidant characteristic (Minerich et al., 1991). In time, this could develop into a significant market. Presently in Minnesota several meat products are sold with cooked (hydrated) wild rice. These include ground beef, pork breakfast sausage patties, and link-sausages. Consumer acceptance has been good.

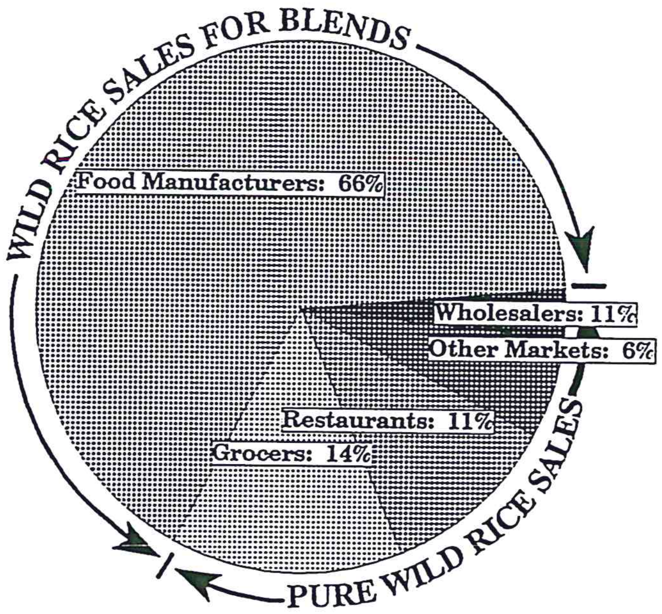

Figure 16. The percentage of wild rice sales to various market outlets for the 1982 crop.

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