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Review

Wild rice – a potential new crop for Finland

Pirjo Mäkelä
Department of Plant Production, University of Helsinki, current address: Division of Genetics, Department of Biosciences, PO Box 56, FIN-00014 University of Helsinki, Finland, e-mail: pirjo.makela@helsinki.fi
O.William Archibold
Department of Geography, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W0, Canada.
Pirjo Peltonen-Sainio
Department of Plant Production, PO Box 27, FIN-00014 University of Helsinki, Finland.

Wild rice (*Zizania palustris* L.), an aquatic grass that grows naturally in lakes and slowly flowing rivers in North America, has been used as a food for thousands of years by some aboriginal tribes. In natural stands, the seeds mature in the autumn and overwinter on the lake bed. They germinate in May, with growth to maturity requiring approximately 100 days. The similarity of growing conditions between North America and Finland suggests that wild rice might succeed in northern Europe. The wild rice plant and the production of both organically grown Canadian wild rice and paddy-grown wild rice in the USA are briefly described in this review article together with the results of preliminary growth trials and an assessment of its agricultural role in Finland.

Key words: crop management, ecology, phenology, *Zizania* spp.

Introduction

Wild rice (Fig. 1) is the common name given to monoecious aquatic grasses of the genus *Zizania* (Poaceae). There are four different wild rice species: *Z. palustris* L. (var. *palustris* 'northern wild rice' and *interior* 'interior wild rice'), *Z. aquatica* L. (var. *aquatica* and *brevis*), *Z. texana* Hitchcock and *Z. latifolia* (Griseb.) Turcz. ex. Stapf., also known as *Z. caduciflora* Turcz. The commercial species, originally native to the Great Lakes region of NorthAmerica, is Z. *palustris*, an annual that produces comparatively large seeds. *Z. palustris* var *palustris* is a smaller plant (0.7–1.5 m tall) with fewer, but longer, grains than *Z. palustris* var. *interior* (0.9–3 m), and is also the parental of paddy grown wild rice (S. Aiken, pers. comm.). In Finland, the height of *Z. palustris* var. *palustris* has ranged from 0.80 m to 1.60 m. *Z. aquatica*, another annual, grows in the St. Lawrence River region and in coastal

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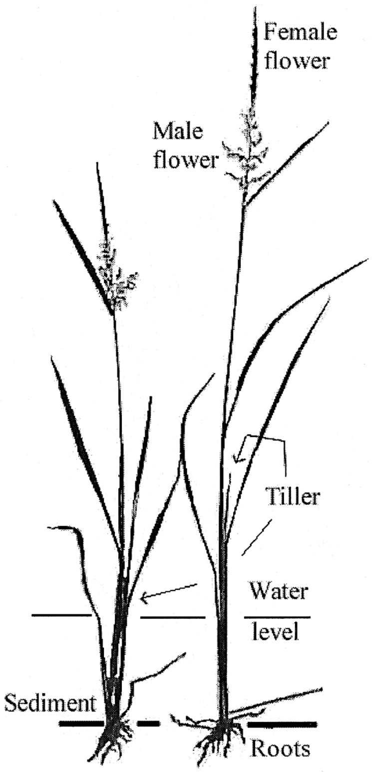

Fig. 1. Finnish grown wild rice (P. Mäkelä).

areas of the eastern and south eastern USA. Being slender in seed type, it is not, however, used commercially. The small-seeded perennial species Z. *texana* grows in a small area in Texas and is considered endangered due to its limited distribution (Terrell and Wergin 1981, Oelke 1982a, Duvall and Biesboer 1988). Another perennial, Z. *latifolia*, which is native to Asia, does not set seed very often because of infection within the rhizome caused by the systemic mycelium of smut fungus (*Ustilago esculenta* P. Henn.). This fungal infection results in hyperplastic growth of the flowering culm. The swollen part of the culm, *gau sun*, is cultivated and consumed as a vegetable in Asia (Chan and Thrower 1980). In the following we deal with *Z. palustris* unless stated otherwise.

Z. palustris phenotypes, especially their reproductive schedule, differ from one region to another in Canada and the USA, apparently reflecting intense competitive pressure within the canopy (Counts 1993). For example, in Saskatchewan plants reach maturity earlier in the east of the province but are more robust, tiller more vigorously and develop more florets in their panicle in the west. There intense competitive pressure is mainly due to differences in the water depth and pH of the lakes (Archibold and Weichel 1986). In general, large seeded plants tend to be early, short, and low-tillering (Foster and Rutger 1980).

The similarity in physiography and climate between Canada and northern Europe suggests that wild rice might have potential as a crop in Finland. The first attempts to grow wild rice (*Z. aquatica* L.) in Finland were made in the 1930s and 1950s (Inkilä 1958). The experiments in the 1930s were not encouraging, but those conducted in the 1950s indicated that it might be possible to cultivate wild rice in Finland as it reproduced during several years (Inkilä 1958). However, at that time little was known about growing wild rice, and the experimental areas were inadequately established. Moreover, *Z. aquatica* L. was probably not best choice for cultivation in Finland as it originates in warmer parts of the USA. Our preliminary experiments indicate that wild rice (*Z. palustris* var. *palustris*) grows and reproduces in southern Finland, but that it requires a longer period to reach maturity (Figure 1, Table 1). Wild rice is grown in Saskatchewan (Canada) between latitudes 54° and 58°N, where average growing degree days (GDD, 5°C as base temperature) between May and September ranged from 900 to 1300 dd °C in 1984–1987. In Finland, the experiments were established at latitude 60°N. In southern Finland, the average GDD for the growing season is 1200–1300 dd °C (Kolkki 1969).

Commercial demand for wild rice, which is grown without fertilisers or herbicides, is growing with popularity of organically grown foods. Prospects for an expanding market are therefore good. Other benefits might also derive from cultivation of wild rice in Finland. Due to its high nutrient demands, for instance, it could help to

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Table 1. Calendar of phenology of the wild rice crop in Minnesota (Oelke 1982b), Saskatchewan (Archibold 1995) and Finland (unpublished). Preliminary experimental data from Finland were collected from two ponds where wild rice (*Z. palustris* var *palustris*) stands were established in late autumn 1995 (latitude 60°N). Figures shown are averages over whole plant stands during 3 years (1996-1998).

	Stages of Development	Days (MN, USA)	Date (MN, USA)	Days (Canada)	Date (Canada)	Days (Finland)	Date (Finland)
Vegetative growth phase	Germination & seedling emergence	0	May	0	May 15	0	May 5
	Floating leaf	29	May	26	June 10	34	June 8
	Aerial leaf	39	June	36	June 20	41	June 15
	Early tillering	49	June	61	July 15	75	July 19
Reproductive growth phase	Early flowering	83	July	66	July 20	90	August 3
	Mid flowering	91	July	76	July 30	97	August 10
	Grain formation	105	August	82	August 5	104	August 17
	Maturity	121	August	102	August 25	131	September 13

scavenge the excess agricultural fertilisers leaching into rivers, main drainages and eutrophicated lakes. It could also be grown in damp places currently not cultivated. Thus, rather than interfering with lake ecosystems, wild rice could be used to remove nutrients from water systems. Moreover, wild rice stands would provide habitats for birds and mammals. The potential of wild rice to reproduce and grow wild in Finland needs, however, to be carefully investigated if proper management strategies are to be developed for potential habitats. We here describe the production of wild rice in North America, with special reference to crop prospects in Finland.

Phenology of wild rice

Wild rice seeds require a dormancy period of 3 to 4 months in cold water to promote germination as the water temperature rises to about 5°C (Oelke 1982b, Aiken et al. 1988, Archibold 1995). Seed dormancy is caused mechanically by the tough, impermeable and waxy pericarp and by biochemical growth inhibitors, such as abscisic acid (ABA). The dormancy of freshly harvested seeds can be broken by scraping and tumbling, although germination remains low (Oelke and Albrecht 1978). The period of dormancy can be shortened by chemical treatment with a combination of ethanol, gibberellic acid and a synthetic cytokinin, 6-benzyl adenine (Oelke and Albrecht 1980).

Being heavy, wild rice seeds sink to the bottom of water after shattering or seeding, usually with the embryo end pointing downwards (S. Aiken, pers. comm.). During germination, the coleoptile emerges before the first root (Hawthorn and Stewart 1970). The young wild rice seedlings are submerged (floating leaf stage, Table 1) until internode elongation begins, after emergence of the third leaf (Archibold 1995). The submerged leaves grow rapidly, are thin, pale and ribbon-like, and have no epicuticular wax on their surfaces (Hawthorn and Stewart 1970). The floating leaf stage begins when the long, ribbon-like floating leaves, the upper epidermis of which is coated with wax, emerge at the water surface. At this stage, air reaches all parts of the plant through internal tissue differentiation. Later, aerial leaves coated with wax are established above the water surface (Aiken et al. 1988). Tillers arise from the basal nodes of the main stem and may result in as many as 50 stems per plant. Adventitious roots form at the first internode but are shallow, straight and spongy, and lack root hairs. Flowering begins in mid-July, forming a branching panicle up to 50 cm long with as many as 200 female florets (Oelke 1982b). Wild rice flowers are protogynous with the female florets (Fig. 1) developing before the male ones. The floral sex ratios favour males, although the biomass of the female florets exceeds that of the males (Willson and Ruppel 1984).

Wild rice is cross-pollinated, and 2 weeks after fertilisation the caryopsis is visible. Four to 6 weeks after pollination it becomes firm and greenish-black and is ready for harvest (Oelke 1982b, Archibold 1995). Wild rice requires approximately 100 days from germination to reach maturity at northern latitudes (Table 1). High temperatures accelerate its development and may sometimes lead to lower hectare yields in warmer areas (Oelke 1982b). For this reason we felt justified in looking again at the feasibility of growing wild rice commercially in the relatively cool climate of Finland.

Cultivation technique

Pre-seeding steps

Before wild rice stands are seeded for commercial purposes, the suitability of the cultivation area should be checked by analysing water and sediment samples and by conducting pre-seeding trials on small plots (Archibold 1995). The environmental factors that affect wild rice productivity in Canada are listed in Table 2. As any of these can lead to crop losses, it is important to identify regional limitations beforehand and to ensure that all the factors listed in Table 2 are at least within the 'manageable' range (Weichel and Archibold 1989). Habitat evaluation is thus an important preliminary step in the establishment of wild rice in Finland. The most important factors affecting seeding success are water depth, sediment texture and available phosphorus levels, followed by water pH and transparency, and iron and zinc concentrations in the sediment (Lee and Stewart 1984). Our observations suggest that extensive algae growth and muddy coloured waters effectively destroy emerging plants. Due to the high redox potentials of sediments (optimum is around –114 mV), crop establishment has, however, been poor even when sediment nutrient levels have been appropriate. Highly reduced sediments may interfere with root respiration and nutrient uptake; moreover, microbial respiration gases may be toxic and germination low in poorly oxygenated sediments (Painchaud and Archibold 1990).

Wild rice is a poor competitor, especially with tall emergent perennials. However, some of these 'weeds' can be used as indicators in efforts to select suitable areas for wild rice production. In Canada, for example, the presence of a few yellow pond lilies (*Nuphar variegetum*), water milfoil (*Myriophyllum sibiricum*), and pond weed (*Potamogeton* spp.) often indicates that a site is suitable for wild rice production, whereas bladderwort (*Utricularia vulgaris*) and white water lilies (*Nymphaea odorata*) indicate nutrient-poor, acidic water bodies, which are not favoured by wild rice (Archibold 1995). These species, which are also common in Finnish waters (Retkeilykasvio 1986), could serve as preliminary indicators of potential wild rice habitats in Finland.

Seeding and fertiliser use

Germination of the larger wild rice seeds is delayed because they remain dormant longer than smaller seeds (Counts and Lee 1991). Testing the seeds for germinability before seeding can be complex not least due to the long period of dormancy. Autumn seeding is preferred as germination occurs very rapidly after dormancy is broken. Also, improper storage of seed can reduce viability; seeds must not be allowed to dry at a moisture content of under 28% and they must be stored at low temperatures (Archibold 1995).

Wild rice can be seeded in lakes by spread-

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Table 2. Habitat suitability for wild rice after Archibold (1995).

Criteria	Ideal Waterbody	Manageable Range
Water depth	75–105 cm	45–75 cm or 105–135 cm
Fluctuations in water depth	Slight & gradual change during growing season	Moderate or gradual change during growing season
Water clarity	Bottom sediment visible through tea coloured water	Visibility good at least to 45 cm
Water movement	Water body with continuously flowing inlet & outlet	Water body with some flow during growing season
Water quality	pH 7–8, conductivity 100–250 mS cm^{-2}	pH 6–7 or 8.5, conductivity 60–100 or 250–300 mS cm^{-2}
Type of sediment	Dark organic sediment mixed with silts & clays	Most types of sediment except sandy, gravelly, rocky or very light coloured clay
Sediment firmness	Soft, but forms a ball when squeezed	Soft & at least half of the material forms a ball when squeezed
Sediment thickness	Over 45 cm	15–45 cm
Sediment redox potential	Eh reading higher than -150 mV	Eh between -150 and -200 mV
Weeds (emergent, floating and submerged)	Cover less than 10% of site	Cover 10–30% of site
Shelter	Bays protected from wind, tall trees around the shore or small lakes	Sufficient shelter to minimise uprooting of young plants
Accessibility	Good access for truck & boat launching	Area reachable by truck or boat

ing the seeds on the ice when the lake is frozen. After the spring thaw they will sink and become embedded in the mud (S. Aiken, pers. comm.). The seeds can be broadcast either by hand from a boat or mechanically with a cyclone seeder, especially in the autumn before ice formation. The recommended seeding rate is typically 25–35 kg ha^{-1}, which results in about 30 plants m^{-2} (Archibold 1995). Our small-scale plots were seeded by hand and developed into well-stocked stands of uniform density.

Some fertiliser can be added to augment yields because wild rice has a relatively high requirement for plant nutrients (Grava and Raisanen 1978). According to Grava and Raisanen (1978), a single wild rice plant accumulated 300 mg of nitrogen and 109 mg of phosphorus. At maturity, the grain contained 37% nitrogen and 22% phosphorus of the whole plant. The dry matter produced (11 800 kg ha^{-1}) was calculated to contain 120 kg ha^{-1} nitrogen and 40 kg ha^{-1} phosphorus (Grava and Raisanen 1978).Trials conducted in wild rice paddies have, however, indicated that excessive nitrogen, applied as ammonium phosphate 7.5–10 cm below the soil surface, can cause lodging. Nitrogen can also be applied by topdressing once leaves have emerged on the wild rice canopy. The University of Minnesota has published series of tables giving the recommended rates of fertiliser application for field-grown wild rice (Grava 1982). However, fertiliser use is forbidden in Canadian lakes (Aiken et al. 1988, Archibold 1995). In Finland, too, our primary focus is on the improvement in water quality that would accrue through the ability of wild rice to remove nutrients leached from adjacent agricultural land.

Canopy management

After seeding, Canadian lake-grown wild rice requires little care, and the grower usually only needs to inspect the lakes a couple of times between seeding and harvest. To reduce the risk of seedlings being killed in the following growing season, some sites may, however, need thinning during the growing season or straw removal after harvest (Archibold 1995). Straw removal can increase yields significantly. In the long run, however, it may have an adverse effect on lake fertility as most of the nutrients tend to be concentrated in the easily removed upper parts of the plant and thus also in the seeds to be harvested (Archibold 1991). Keenan and Lee (1988) have observed that the decrease in the yield of lake-grown wild rice that recurs in established stands every 5 years or so is most likely due to the decrease in sediment nitrogen levels caused by the slow decomposition of straw at cool, northern latitudes. Other limiting factors may be the phosphorus and potassium concentrations in and the composition of the sediment (Keenan and Lee 1988, Day and Lee 1990). According to our preliminary observations, plants grown in a pond with water running mostly from a fountain were more robust and darker green in 1996 than in 1997 and 1998. This was probably due to the limited availability of nutrients, especially as there was no change from one year to another in the size of the plants grown in a pond with water running from fields and forest. Moreover, the plants are more robust when grown on organic than on mineral soils, again suggesting the important role that wild rice could play in attempts to ameliorate the problem of eutrophication in Finland. In sites where it might be desirable to retain the straw in the lake, the adverse effects of straw build-up could be minimised by mulching (Archibold 1990, 1991).

Lake-grown wild rice stands have a tendency to increase in density following initial establishment because the seeds shatter readily and so reseed the stands (Archibold 1990). However, as wild rice is a self-thinning plant, the canopies tend to be quite uniform (Weiner and Whigham 1988). Mechanical thinning has not been advantageous in lake grown wild rice (Archibold 1990), although it is a common practice during the floating leaf stage in paddy grown wild rice stands (Lee and Stewart 1981).

Water depth can be successfully managed in wild rice stands to suit the requirements of the growth stages. In paddies some of the field and crop management procedures (e.g. seeding and fertiliser application) are best carried out in unflooded fields. Paddy-grown wild rice (*Z. palustris* var. *interior*) does not, however, become well established without field flooding. Thus, Oelke (1982c) recommends that a minimum water level of 15 cm should be maintained in the shallowest part of a wild rice paddy, and a maximum level of 36 cm in the deepest part; anything deeper than that would cause lodging. Northern wild rice (*Z. palustris* var. *palustris*) is, however, grown at somewhat greater depths (Table 2). Our preliminary observations suggest that the most suitable water depths for wild rice production would range from 20 cm to 70 cm, as in deeper water the plants do not produce seeds. Moreover, development seems to be faster in shallow than in deep water, resulting in a shorter period from emergence to maturity. The first roots of wild rice are modest and the changes in water level, especially during the floating-leaf stage, may cause some uprooting of plants. Once the

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aerial leaves are established, changes in water level are not so damaging. One disadvantage is that this can lead to a decrease in reproductive growth (Stevenson and Lee 1987).

Weeds

Competitive weeds may cause some problems in both lake and paddy-grown wild rice. Canada, unlike the USA, strictly forbids the use of herbicides for wild rice (Archibold 1995). The most damaging weeds in paddy-grown wild rice are bur reed (*Sparganium eurycarpum* Engelm), common arrowhead (*Sagittaria latifolia* Willd), common water plantain (*Alisma triviale* Pursh) (Ransom and Oelke 1982), cattail (*Typha latifolia* L.), cursed crowfoot (*Ranunculus sceleratus* L.), water starwort (*Callitriche heterophylla* Pursh) and small pondweed (*Potamogeton pusillus* Fern) (Aiken et al. 1988, Archibold 1995). Potential competitors, in Finland, are cattail, cursed crowfood, small pondweed, *Callitriche cochocarpa* Sendtner, *C. palustris* L., *Alisma plantago-aquatica* L., *Sagittaria sagittifolia* L., *S. natans* Pallas (possibly), and *Sparganium*; all of these species are very common in our rivers, lakes, ditches and uncultivable areas (Retkeilykasvio 1986).

Common water plantain, a 1-m tall, erect, aquatic perennial grows from seeds and rootstocks (corms) and causes significant yield reductions because it shades the emerging wild rice plants (Ransom and Oelke 1982 and 1983). The corms can be destroyed by fall flooding (Ransom and Oelke 1983) and effectively controlled by treating the stands with 2,4-D [(2,4-dichlorophenoxy)acetic acid] and MCPA [(4-chloro-2-methylphenoxy)acetic acid] at the stem elongation stage (Ransom et al. 1983, Ransom and Oelke 1988). Giant bur reed – a perennial, broadleafed, aquatic monocotyledonous plant – is another weed causing significant economic losses to wild rice growers in the USA because it reduces the capture of photosynthetically active radiation in the wild rice canopy by as much as 35% (Clay and Oelke 1987). Giant bur reed can be controlled by bentazon, propanil and 2,4-D treatments, although wild rice, too, is susceptible to these herbicides (Clay and Oelke 1988 and 1990). Under non-flooded conditions, these weeds can be effectively controlled with glyphosate treatments (Leif and Oelke 1990).

Diseases

Wild rice canopies can be severely infested by fungal and bacterial pathogens, many of which are related to the pathogens of rice (*Oryza sativa* L.) (Berger et al. 1981). In Minnesota, fungal brown spot disease (FBS), which is caused by the facultative pathogens *Bipolaris oryzae* (Breda de Haan) Shoemaker and *B. sorokiniana* Luttrell, is common in wild rice grown on organic, peat soil, but uncommon in stands on mineral soils (Percich 1982, Malvick and Percich 1993). The windborne fungal spores are produced in spring. Fungi of FBS can survive on grasses and on wild rice stubble and seeds (Percich 1982). In plant canopies, it occurs on leaves, stems and flowers, causing up to 67% losses in yield (Kohls et al. 1987). The disease produces evenly distributed, uniform brown leaf spots, often with yellow margins. Later, the spots grow together and cover the leaves, leaf sheaths and panicles, resulting in broken stems and a reduction in the yield and quality of the seed (Percich 1982). In the USA, the disease can be controlled by fungicide sprays applied on the basis of weather forecasts and calendar scheduling from early July onwards (Percich and Nickelson 1982, Kohls et al. 1987, Percich 1989). Essential tools in controlling the disease in Minnesota and California are the use of fertilisers, clean seed material and FBS resistant crops in rotation (Percich 1982).

Other pathogens recorded in wild rice are *Fusarium* spp. (Nyvall et al. 1994), *Phytophthora erythroseptica* sensu lato (Gunnell and Webster 1988) *Drechslera gigantea* (Kardin et al. 1982) and *Claviceps zizania* (Fyles) (Percich 1982). *Fusarium* spp. cause necrosis on the surface of kernels, hinder germination and may even produce toxins, which are especially harmful as seeds are utilised in the food chain (Nyvall et al. 1994). *Phytophthora* infections have been noted in Californian rice paddies, where they cause drought symptoms, even under flooded conditions. The crown, adventitious roots, internodes and leaf sheaths may become necrotic during different phenological growth stages. Finally, the crown rots, tillers separate, and the plants become brittle and tanned (Gunnell and Webster 1988). In Minnesota, *Drechslera gigantea* has been reported to cause zonate eyespot of wild rice leaves with damage varying from slight to considerable (Kardin et al. 1982). Ergot [*Claviceps zizania* (Fyles)], reported to occur mainly in natural wild rice habitats in Minnesota, gives rise to the production of a sweet, sticky liquid that attracts insects carrying spores from other plants. The fungus forms hard, dark sclerotia in place of the grain (Percich 1982).

In Canada, diseases do not cause severe yield losses, even though pesticide use is forbidden there (Archibold 1995). The only disease with economic implications for wild rice production in Canada is stem smut [*Entyloma lineatum* (Cke.) Davis]. It forms glossy black lesions on the heads, culms and stems of mature plants, eventually elongating and girdling the stem (Percich 1982). We therefore hypothesise that diseases may not have significant effects under Finnish growing conditions either, although in-depth investigations are needed before wild rice can attain recognition as a crop plant in Finland. Our observations in 1996–1998 do not indicate any major problems with diseases. Our only negative observation is from 1998, when some black spots were seen on the leaf surfaces of wild rice plants. The possible pathogen is under investigation, but the symptoms may also have been caused by physiological injury.

Pests

One of the most damaging insects in Canadian grown wild rice is the wild rice worm [*Apamea apamiformis* (Guenee)] (Archibold 1995), a moth that reaches its adult stage at the time the plant begins to flower. The adults feed mainly on milkweed (*Asclepias* spp.) which is not known to exist in Finland (Retkeilykasvio 1986). We therefore hypothesise that the wild rice worm would not restrict wild rice production in Finland. Similar damage is caused by midges of the Chironomidae and Dixidae families. The mosquito-like fly (*Cricotopus* spp.: Dixidae) causes severe damage to first-year wild rice fields by laying its eggs in moist soil, after which the hatched larvae spin webs attached to the developing plants. Larval feeding causes leaf curling and frayed leaf edges. In addition, the webs are usually covered by mud, which prevents the plants from emerging from the water (Noetzel 1982). Finland has about 600 species of Chironomidae, but no Dixidae (Chinery 1988). Another harmful insect is the rice stalk borer (*Chila plejadellus* Zincken), which is light-tan coloured at the adult-stage and appears from mid-June to early August (Archibold 1995). Its circular, flat, cream-coloured eggs are visible on floating wild rice leaves at the end of June, and after hatching the larvae feed initially on leaves and leaf sheaths. Later, the larvae bore their ways into the main stem, causing white panicles and stem breakage. Other pests of wild rice canopies are rice water weevils, rice leafminers, rice stem maggots, crayfish, blackbirds, water birds and some mammals, such as raccoon, mink, skunk, deer, moose and muskrat (Noetzel 1982). Berger et al. (1981) have reported that the mite (*Aceria tulipae* Keif.), which is commonly found on wild rice and is effectively transported by wind, transmitted wheat streak mosaic virus and caused infections in the plant. It is speculated that because wild rice is not native to Finland, growers will be unlikely to face serious pest problems. This conclusion is supported by the findings of our preliminary, albeit small scale, experiments, which showed no signs of pest damage. However, expansion of the wild rice habitat might lead to an increase in pests and damage, especially as one small-scale experimental area of wild rice is known to have been

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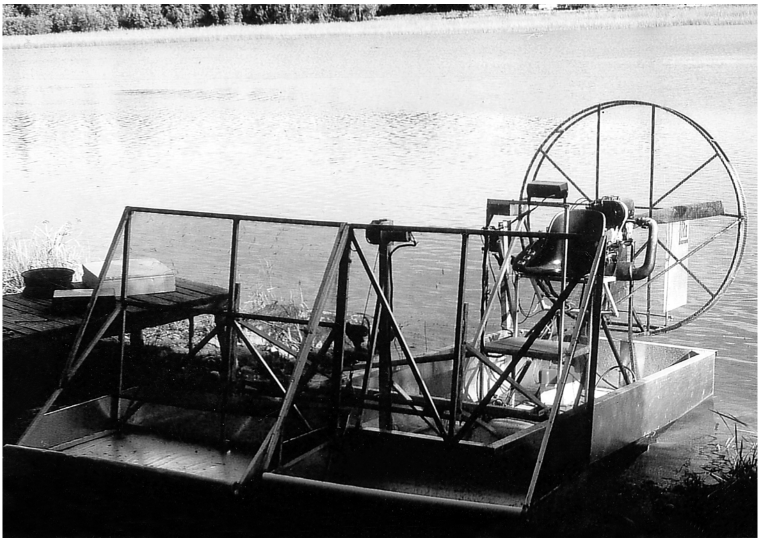

Fig. 2. Canadian airboat harvester with speedhead for catching grains in the front (O.W. Archibold).

destroyed by muskrats (Inkilä 1958). Although this is not considered a potential risk, the existence of all possible pests in wild rice stands should be recorded.

Harvesting

In Canada, wild rice is harvested by boat (Archibold and Reed 1990a, 1990b), but in the USA also from on drained paddies (Schertz 1982). Traditionally wild rice was collected by a two-man canoe, in which one person paddled while the other bent the stalks over the side of the canoe and tapped off the ripe grain with a stick. Crops were harvested several times during a season and the daily yield could be up to 200 kg (Archibold 1995). The propeller-driven airboat harvesters used today are ideally suited for lake-grown wild rice, whereas modified combine harvesters are more appropriate for paddy-grown wild rice (Archibold and Reed 1990a and 1990b). The airboat harvesters have a speedhead of simple design without moving parts (Fig. 2). It strikes the plants with the rounded leading edge, causing the mature kernels to dislodge from the panicle and fall to the bottom of the speedhead (Archibold and Reed 1990b). For mechanical harvesters, the speed is critical. The recommended speed is 12–15 km h^{-1}; at lower speeds the rice tends to be knocked into the water rather than into the speedhead but at faster speeds the panicles are broken off. A wild rice stand can be harvested 6 or 7 times during a harvest season with a mechanical harvester operated at the appropriate speed, resulting in yields of up to 350 unprocessed kg ha^{-1} (Aiken et al. 1988).

Lake-grown wild rice needs to be harvested several times at the end of the growing season because the kernels mature gradually. About 3–6% of the potential yield matures each day and shatters readily. Thus, the harvest period typically lasts for 15–30 days and crops are harvested every 4–7 days to minimise loss of grain (Archibold and Reed 1990b). A breeding programme to develop non-shattering cultivars was conducted at the University of Minnesota in an attempt to reduce losses due to shattering. Elliott and Perlinger (1977) worked with a wild rice mutant that did not shed its staminate florets and had only a moderate degree of seed shattering. Later work by Everett and Stucker (1983) confirmed that shattering is the dominant trait of the recessive two-complementary-gene system, a finding that explains the good results obtained with conventional breeding methods. Shattering is due to plasmolysis of the separation layer parenchyma cells followed by separation of the layers by dissolution of the middle lamella and fragmentation of cell walls soon after pollination. Thus, in nonshattering types of wild rice, the mass of cells forming the cone are better developed, although it is not clear whether vascular bundles play a role in seed abscission of wild rice varieties (Hanten et al. 1980). One of the goals of the breeding programmes was to establish intraplant heading date synchrony (i.e., between mainstem and tillers) in an attempt to reduce mainstem shattering while the seeds in the tillers are still maturing and thus to increase yield (Hayes and Stucker 1987). The results showed, however, that this could only be achieved through long-term selection effort.

The date of harvest in Canada can be estimated from the full flowering stage and usually commences about 4 weeks after flowering. The kernels should be firm and dark brown, and fall when the stem is gently shaken. Another option is to use floating trays (100 x 10 cm) and calculate the daily seed-loss (Archibold 1995). Freshly harvested wild rice is greenish-black, and has a moisture content of 35–50%. Current grower and retail prices – especially European wild rice retail prices (White and Jayas 1996, Oelke 1982d) – suggest that wild rice production might have economic potential in Finland. Moreover, growers would not need enormous investments as several growers could form a cooperative, permitting them to purchase and use a single airboat harvester and so share operating and maintenance costs. The protracted harvesting period of wild rice would allow effective use of a jointly owned harvester. Additional economic returns could be gained from the use of previously uncultivated areas for wild rice.

Post-harvest handling

Wild rice must be processed before it can be consumed (Strait 1982). In Canada and Minnesota processing involves a curing period of up to 10 days accompanied by fermentation and enzyme activity. The rice is spread over a flat surface to a depth of 0.3–0.6 m, kept moist (to prevent self-heating and drying) and turned twice a day to allow the grains to mature and acquire their typical flavour and black or brown colour (Strait 1982). The grain is then heated in closed steam parchers in the course of which the starch granules gelatinise. The seeds are then dried in rotary drum driers at 135ºC for approximately 2 hours to reduce the kernel moisture content from 40–50% to 7% (Hoover et al. 1996, White and Jayas 1996). Finally the wild rice is dehulled, scarified, cleaned, graded and bagged. During processing, wild rice seeds lose their germinability (Strait 1982, White and Jayas 1996).

Processed wild rice seeds can be stored for many months if kept cool and at less than 70% relative humidity. However, some fungi, e.g. *Eurotium amstelodami* Mangin (*Aspergillus glaucus* group), *Rhizopus* spp., *Cladosporium* spp. and *Penicillium* spp. remain and may cause deterioration. Similarly, insects such as *Tribolium* spp., *Rhizopertha dominica*, *Sitotroga cerealella*, *Oryzaephilus* spp., and *Cryptolestes pusillus*, can sometimes cause problems with stored wild rice grain and flour (White and Jayas 1996).

Nutritional value and use

Traditionally wild rice has been used as a staple food by Indians in the Great Lakes region of North America (Archibold & Reed 1990a, and 1990b). Hulless wild rice seeds are black, either 14–15 mm long (*Z. palustris* var *interior*) or up to 20 mm *long (Z. palustris* var *palustris*), and 2 mm in diameter (Fig. 3). The pericarp of wild rice is thin and the germ is large compared with other cereals. The endosperm and aleurone contribute about 90% of the kernel, and the pericarp and germ the remaining 5% (Hoover et al. 1996). The composition of wild rice is close to

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that of oats in that the protein, carbohydrate and mineral contents are high but the fat content is low (Table 3). Wild rice seems to be comparable to other cereals in nutritive value but its fatty acid composition is superior to that of other cereals as it contains a high level of linolenic acid. Moreover, it is a good source of B-vitamins and is low in calories: 250 ml of cooked wild rice contains approximately 130 calories (Oelke 1982e, Archibold 1995).

Wild rice is still an expensive gourmet food, especially when grown under natural conditions as in Canada (grain size approximately 20 mm, *Z. palustris* var *palustris*) (S. Aiken, pers. comm.). It is traditionally served with game but due to the availability of field grown wild rice in the USA it is gradually becoming an everyday food used instead of potatoes or rice, and in rice mixes and in casseroles, soups and salads. Nearly half of the wild rice produced in the USA is processed. Less than half is used by restaurants, hotels, caterers, grocery chains and speciality shops, which prefer the more expensive, naturally grown Canadian wild rice (Oelke 1982e, Archibold 1995).

According to Wu et al. (1994), wild rice could also be utilised in food processing because it contains phytate, which is known to have antioxidant properties. Addition of ground wild rice to canned, refrigerated or frozen, precooked meat products has increased consumer preference, not only because of its antioxidant properties (i.e., no rancidity) but also because of its flavour and nutritional values (Wu et al. 1994, Hoover et al. 1996). A decline in the cholesterol and fat percentage of raw and cooked ground beef patties has been reported to whereas cooking yields have increased when cooked wild rice was added to patties (Minerich et al. 1991). Sausages to which wild rice has been added scored higher for texture, juiciness, flavour, visual appeal and overall liking but lower for toughness, rancidity and cohesiveness (Rivera et al. 1994). Hoover et al. (1996) have moreover suggested that, as the starch, which is the main constituent of wild rice seed, has a low degree of retrogradation, wild rice could be used in the textile, paper and adhesive industries where changes in prepared batches of pastes are undesirable.

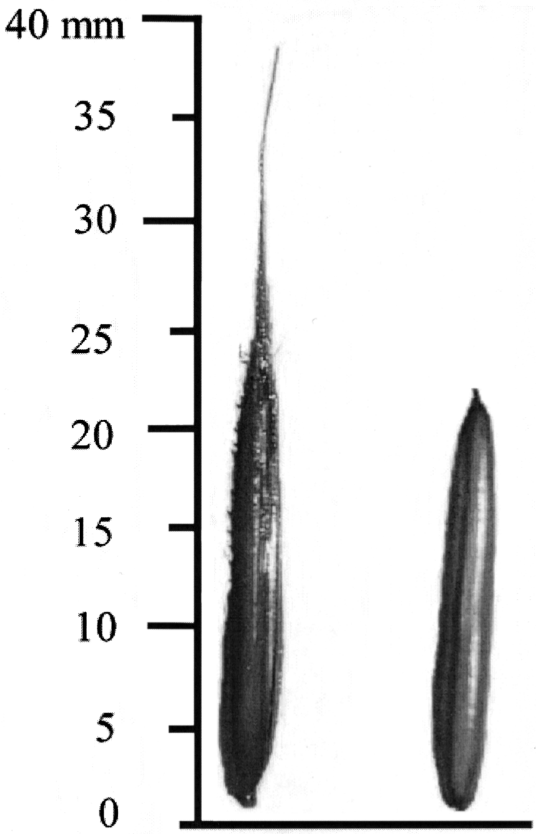

Fig. 3. Mature unprocessed Finnish wild rice seeds (P. Mäkelä).

Conclusions

Humans have been using wild rice as food for thousands of years. Its nutritional value is well established and it is even considered a gourmet delicacy. Nowadays paddy-grown wild rice often replaces potatoes, pasta and white rice. In addition to its conventional use as a food, there is accumulating interest in alternative uses of wild rice, such as in convenience food process-

Table 3. Nutritional value of wild rice and some other cereals (according to Anderson 1976, Oelke 1982e, Aiken et al. 1988, Archibold 1995).

Component		Wild rice	Brown rice	White rice	Corn	Wheat	Oats
Vitamins				mg /100 g DM			
	Thiamine	0.45	0.34	0.07	0.37	0.52	0.60
	Riboflavin	0.63	0.05	0.03	0.12	0.12	0.14
	Niacin	6.2	4.7	1.6	2.2	4.3	1.0
Minerals				mg /100 g DM			
	Calcium	17–22	32	24	22	46	53
	Iron	4	2	1	2	4	3
	Magnesium	80–161	–	28	147	144	160
	Potassium	55–344	214	92	284	352	370
	Phosphorus	298–400	221	94	268	405	354
	Zinc	3–6	–	1	2	3	3
Fatty Acids				% of fatty acids			
	Palmitic acid	14	20	4	–	24	16
	Stearic acid	1	2	4	–	1	2
	Oleic acid	6	41	43	–	2	41
	Linoleic acid	8	34	18	–	56	9
	Linolenic acid	30	1	1	–	4	2
Others				%			
	Oils and Fats	0.8	2.6	–	4.7	1.8	6.5
	Protein	12.4–15.0	7.5	6.7	8.9	12.3	14.2
	Ash	1.2–1.4	1.2	0.5	1.2	1.7	1.9
	Crude Fibre	0.6–1.1	0.9	0.3	2.0	2.3	1.2
	Tot. Carbohyd.	72.3–75.3	77.4	80.4	72.2	71.7	68.2
Sugars				g / 100 g DM			
		1.7	2.3	–	2.3	1.7	1.4

DM, dry matter.

ing. A growing demand for wild rice is therefore anticipated. However, in Canada the habitat available for expanding wild rice production is declining. Natural conditions in Finland, such as day length, daily temperatures and lake morphology, are similar to those in Canada. Moreover, our preliminary experiments have shown that wild rice grows and reproduces well in this country. Another reason why Finland might offer a favourable environment for wild rice production is the smaller number of economically harmful pests and diseases here. Wild rice could further have environmental value as it thrives on soil with relatively high phosphorus and nitrogen concentrations. Therefore, it is speculated that wild rice has potential to reduce the effects of nutrient leaching and eutrophication of water systems. Such benefits can be enhanced if the crop is well managed, i.e. straw residues are removed, thus ensuring that nutrients do not enter waters, and no additional fertilisers or pesticides are used. Closed industrial peat bogs and other uncultivable land areas could also be effectively utilised in wild rice production. These would offer new habitats for birds and mammals and would also improve the aesthetics of landscapes from which peat has been removed. As wild rice is a newly introduced plant species in Finland, experimental cultivation should first be established on a small scale by developing techniques specific to Finnish conditions. This was indeed the objective of our initial experiments. The main

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purpose of our studies is, however, to cultivate wild rice as an 'organically' grown food in Finland, without the use of herbicides, insecticides or fertilisers. The introduction of any new plant species must be carefully monitored to ensure that it does not have adverse effects on the environment. For wild rice we must take particular care to prevent it from spreading uncontrolled into Finnish lakes and rivers, where it could cause irreversible damage to natural ecosystems. Finally, Finnish production of wild rice is not expected to have an adverse economic effect on the incomes of Canadian wild rice growers as the demand for ecologically grown wild rice currently far exceeds supply.

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SELOSTUS

Villiriisi – mahdollinen uusi viljelykasvi Suomen oloihin

Pirjo Mäkelä, O. William Archibold ja Pirjo Peltonen-Sainio

Helsingin Yliopisto ja Saskatchewanin Yliopisto

Villiriisi on Pohjois-Amerikassa kasvava yksivuotinen heinäkasvi. Se viihtyy järvissä ja hitaasti virtaavissa joissa. Intiaanit ovat käyttäneet villiriisiä viljojen tapaan ravinnoksi vuosituhansien ajan. Villiriisi kylvetään syksyllä, jolloin se alkaa itää toukokuun alussa itämislevon murruttua. Tuleentuakseen se tarvitsee noin 100 vuorokautta itämisestä. Kasvustoja ei tarvitse ensimmäisen vuoden jälkeen kylvää uudelleen, koska osa siemenistä varisee heti tuleennuttuaan, mikä toisaalta tekee villiriisin korjuusta hankalaa. Satoa korjataan yleensä neljästä seitsemään kertaan syksyllä erityisrakenteisella veneellä (hydrokopteri). Minnesotassa jalostettujen villiriisilajikkeiden sadonkorjuu voidaan kuitenkin tehdä kerralla hieman normaalista muunnellulla leikkuupuimurilla kuivatulla maalla. Kanadalainen villiriisi on hinnaltaan hieman USA:ssa tuotettua kalliimpaa johtuen mm. siitä, että Kanadassa villiriisi tuotetaan luonnontilaisissa joissa ja järvissä ja kasvinsuojeluaineiden ja lannoitteiden käyttö on kiellettyä.

Villiriisi on tähän asti ollut lähinnä hinnakas herkku, jota on käytetty erityisesti riistaruokien lisukkeena. Nykyisin, hintojen laskettua, villiriisiä on alettu käyttää jokapäiväisenä ruokana perunan, riisin ja pastan korvikkeena tai osana pataruokia ym. Uusien tutkimusten perusteella villiriisin käyttö erilaisiin valmisruokateollisuuden sovellutuksiin, kuten jauhelihapihveihin ja makkaroihin, parantaa näiden laatua huomattavasti. Koska villiriisin kysyntä maailmalla on ollut jatkuvassa kasvussa ja sen tuottajahinta on melko korkea, voidaan villiriisin viljelyn Suomessa olettaa muodostuvan taloudellisesti kannattavaksi. Villiriisi on menestynyt Suomessa erinomaisesti järjestämissämme esikokeissa ja tuottanut satoa sekä lisääntynyt. Tulevaisuudessa olisi kuitenkin tarkemmin selvitettävä villiriisin kasvupaikkaedellytykset ja siihen liittyvät tekijät sekä sadonmuodostus Suomen oloissa, jotta mahdollinen kaupallinen tuotanto saataisiin hyvälle pohjalle. Tutkimustemme eräänä lähtökohtana on ollut villiriisin ekologinen tuotanto ilman kasvinsuojeluaineita ja lannoitteita kanadalaisen mallin mukaisesti. Perusedellytykset villiriisin tuotantoon Suomessa ovat hyvät, sillä vesistöissä on riittävästi ravinteita, erityisesti fosforia ja typpeä. Villiriisi saattaisikin olla hyvä vesistöihin huuhtoutuneen typen ja fosforin sitoja, estäen järvien rehevöitymistä tai mahdollisesti vähentäen jo rehevöityneiden järvien ravinnepitoisuuksia, erityisesti mikäli myös korret poistettaisiin vesistöistä. Lisäksi mm. vanhoja, käytöstä poistettuja turvesoita ja muita vastaavia vesijättöalueita olisi mahdollista hyödyntää villiriisin tuotantoalueina, jolloin alueet olisivat kauniita maisemallisesti ja toimisivat kosteikkoalueina monille linnuille ja nisäkkäille.