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Progress in Grain Pearl Millet Research and Market Development

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Pearl millet [*Pennisetum glaucum* (L.) R. Br., Poaceae] has been historically grown for forage production and cattle grazing in the US. It is widely grown as a multi-purpose cereal grain crop principally for food, and also for feed, fodder, fuel, and mulch on more than 26 million hectares, primarily in arid and semi-arid regions of India and Africa (FAO 2000). It is a staple grain for about 90 million people living in the semi-arid tropical regions of Africa and the Indian sub-continent. Besides its importance as food and feed crop, pearl millet is potentially an ideal species for genetic studies because of its small diploid genome with large chromosomes, abundant phenotypic variation, and protogynous flowering habit. As a new-use grain crop, it currently occupies relatively small acreage in the US, but has high potential because of its ability to tolerate drought and low fertility, better nutritive properties and diverse use over other cereals.

The genus *Pennisetum* contains about 140 grassy tropical species. Previous names for *P. glaucum* include *P. typhoides* (Burm) Stapf. & Hubb., *P. typhoideum* (L.) Rich., and *P. americanum* (L.) Leeke. The latter name may be because Clusius, in 1601, thought the type specimen he obtained from southern Spain had come from the Americas (Andrews et al. 1993). Pearl millet is considered to be domesticated some 3,000 to 5,000 years ago on the southern edge of the Sahara in Africa and subsequently spread to southern Asia (Harlan 1975; Brunken et al. 1977). The evolution, classification, domestication, biology, and adaptation of pearl millet have been discussed by Andrews et al. (1993). The importance and potential of pearl millet as a grain crop and its progress and potential in the US have also been reviewed by Stegmeier et al. (1990), Adeola et al. (1996), and Andrews et al. (1996). In this paper, we discuss the importance of pearl millet grain for its diverse uses, progress and potential of grain research in recent past, application of biotechnology to expedite breeding, and market development in the US.

IMPORTANCE OF PEARL MILLET AS GRAIN CROP

Feed and Food Grain

Pearl millet has significant potential as feed and food grain in addition to its current use as a forage. The agri-tourism and recreational wildlife industries are finding superior results from using pearl millet in rations for bobwhite quail production (Savage 1995), and for supplemental feeding. It also seems to be an excellent feed for other birds, including dove, turkey, song-birds, ducks, and swine. The large immigrant population from Africa and the Indian subcontinent where pearl millet is a staple food ensures a steady demand in the US in the foreseeable future. Being gluten-free, marketing opportunities for this grain also exists in the health-food outlets.

Pearl millet is well-adapted to the southeastern region's environment which produces about 60% of the broilers in the US, but produces only 10% of the grain used in the region's poultry rations (Radcliffe et al. 2001). Pearl millet is equal to or better than typical maize-soybean poultry diets for broiler production and can be fed at up to 10% of the ration without grinding (Davis et al. 2003; Hidalgo et al. 2004), thus reducing feed processing costs. Pearl millet grain is at par or even better than maize in poultry diets (French 1948; Singh and Barsaul 1976; Sharma et al. 1979; Stringhini and Franca 1999). Broilers fed on pearl millet rations were heavier and had better feed conversion rate than those fed on maize (Lloyd 1964), and mixed maize and sorghum (Sullivan et al. 1990). Kumar et al. (1991) studied feed efficiency of laying hens and found increased egg size and better feed conversion when pearl millet was substituted for maize at 60% by weight.

Swine may represent a second major market for pearl millet in the US. Various studies have shown that pigs fed 50% or 75% pearl millet reached slaughter weight 10 days earlier than maize-fed pigs (Calder 1955). The replacement of maize with pearl millet gives optimal growth performance (Murray and Lewis 1995) or equivalent gain and feed efficiency (Lawrence et al. 1995; Adeola and Orbain 1995).

Nutritional Facts

Pearl millet grain contains 27% to 32% more protein, higher concentration of essential amino acids, twice the extract (fat) and higher gross energy than maize (Ejeta et al. 1987; Davis et al. 2003). The energy density of pearl millet grain is relatively high, arising from its higher oil content relative to maize, wheat, or sorghum (Hill and Hanna 1990). Collins et al. (1997) noted commercial layers given feed containing pearl millet grain had lower omega-6 to omega-3 fatty acid ratio, endowing the eggs with a fatty acid profile more favorable to human health. The amino acid profile of pearl millet grain is better than that of normal sorghum or normal maize and is comparable to those of the small grains wheat, barley, and rice (Ejeta et al. 1987) with a less disparate leucine/isoleucine ratio (Hoseney et al. 1987; Rooney and McDonough 1987). The lysine content of the protein reported in pearl millet grain ranges from 1.9 to 3.9 g per 100 g protein (Ejeta et al. 1987). Pearl millet grain appears to be generally free of any major anti-nutritional factors, such as the condensed tannins in sorghum grain having a pigmented testa, which reduces protein availability.

Ethanol

Ethanol use as an additive in formulated gasoline will increase. Wu et al. (2006) observed that the rate of fermentation of pearl millet was 30% greater than rate of fermentation of corn, and distillers dried grains with solubles (DDGS) coproducts were higher in protein and fat. Less ethanol is produced from pearl millet fermentation, but because of its higher protein content, the yield and value of DDGS is greater, resulting in higher economic return from pearl millet than from corn. Experiments indicate that pearl millet can supplement maize and sorghum feedstocks for fuel ethanol production. Ethanol production is a potential future market for the grain, since few fermentation facilities currently exist or are under construction in Georgia.

ADAPTATION AND CULTIVATION

With its short crop life cycle, rapid grain filling, and exceptional ability to tolerate drought, pearl millet is well suited for food and feed grain production in regions too arid for sorghum and maize (Burton 1983). It grows well under high temperature conditions in sandy soils with low pH and low fertility and needs none or very little inputs while responding well to water and good management (Kumar 1989). This summer annual crop fits within double- or rotation-cropping systems in the southern US. Advantages of more efficient sowing and lower production costs through no-till planting (Spehar and Landers 1997) could be exploited by farmers.

Pearl millet is generally planted from May to August (Lee et al. 2004). Like other summer crops, the optimum stand establishment is obtained on a weed free and firm seedbed. Seed rate varies from 2.2–5.6 kg/ha depending upon the spacing between rows (35–76 cm). For consistent high grain yield, good protein content, efficient weed control and reduced damage from chinch bug (*Blissus leucopterus*), it is recommended to seed 1.3–2.0 cm deep and maintain 36–53 cm row spacing. Greatest yields are obtained with application of N at the rate of 90–112 kg/ha in soils with clay pan and 112–157 kg/ha in deep sands, although these rates may not be the most economical. The registration of herbicides, insecticides, and pesticides is progressing through the Inter-regional Research Project (IR-4) program. This program is the major resource for supplying pest management tools for specialty crops by developing research data to support registration clearances. Adaptation of exiting farm equipments for cultivation, harvesting, and handling may be necessary for pearl millet. Development of new hybrids with differing growth habits may also bridge the gap of using existing equipment in pearl millet production.

CONSTRAINTS IN CROP PRODUCTION

Crop Production and Management

Pests and diseases prevalent in the southeastern US can cause considerable yield losses. Rust (*Puccinia substriata* var. *indica*), *Pyricularia* leaf blight (*Pyricularia grisea*), and root knot nematode (*Meloidogyne arenaria*) have been shown to reduce the yield and quality of grain and forage (Wilson et al. 1991, 1996; Wilson and Gates 1993; Timper et al. 2002). The existence of pathogenic races of *P. substriata* var. *indica* (Tapsoba and Wilson 1996) requires more efficient screening of resistance genes during the breeding process. Stalk rot (*Fusarium moniliforme*) and grain molds (*Fusarium semitectum* and *F. chlamydosporum*) can also reduce yield. European corn borer (*Ostrinia nubilalis*), corn ear worm (*Helicoverpa zea*), green stink bugs (*Nezara viridula*) and chinch bugs can be problematic and occasionally require insecticide treatment. Bird damage is considerably greater in smaller fields than larger fields. Damage can be minimized by keeping pearl millet fields away from tree lines or woods if possible and crop monitoring for timely harvest. Much of the damage can be avoided by educating farmers on correct management practices. In the southeast, migratory birds tend to cause the most damage, so losses can be limited by using either early or late plantings that allow grain harvest respectively before or after the main migration period.

Institutional, Market, and Industry Related Risks

The main barriers limiting wide scale pearl millet cultivation include existing production systems, management practices, equipment availability, and market infrastructure. Crop risk management options such as pesticides and crop insurance are limited. Marketing channels are also fragmented and poorly developed. No base price is available for pearl millet which limits farmer interest in growing the crop. It will be necessary to work within the legislative process to get pearl millet recognized as a viable crop alternative. Grain storage infrastructure in the south has deteriorated, requiring renovation or reconstruction to develop acceptable storage and feed processing facilities. A tiered marketing strategy that focuses on premium-value markets first, and then high-volume, low profit markets will allow measured expansion of crop acreage.

BREEDING PROGRESS

History

Pearl millet was introduced in the US in 1860 and breeding was initiated in 1936. Development of the Tift 23A cytoplasmic male sterile (CMS) line by Glenn Burton at USDA-ARS, Tifton, Georgia revolutionized pearl millet hybrid production in India in 1960s and later in the US. Dwarfing gene stocks, early maturity, and other valuable information about pearl millet breeding and genetics have been developed by the USDA-ARS at Tifton, Georgia. Successful breeding programs for pearl millet grain and dual purpose hybrids were started in India in the 1960s. Breeders developed high yielding single-cross hybrids but these soon succumbed to downy mildew (*Sclerospora graminicola*) epidemics. In the late 1980s, USDA-ARS started developing dwarf parents to produce grain hybrids.

Pearl millet breeding for grain has been extensively carried out under the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program funded by the United States Aid for International Development (USAID). The research efforts for breeding, crop production, and use have been focused at Kansas State University, USDA-ARS, Tifton, Georgia, and the University of Nebraska-Lincoln (Andrews et al. 1993). The pioneers in pearl millet research in the US were Glenn Burton, Wayne Hanna from USDA-ARS, Tifton, Georgia, David Andrews and John Rajewski from the University of Nebraska, and Bill Stegmeier from Kansas State University. The deaths of Burton and Stegmeier and retirements of Andrews and Hanna have undeniably slowed down breeding efforts in pearl millet in the Great Plains. In the southeastern US multiple influences continue to drive pearl millet research: stress-prone and marginal crop production environments, massive and diverse markets in the poultry and recreational wildlife industries, and growing environmental concerns about poultry litter disposal and surface water pollution from waste nutrients. The pearl millet grain research program is a broad-based effort in collaboration with research extension and industry not only in Georgia but nationally and internationally. Research partnerships and linkages have been established between USDA-ARS, Tifton, Georgia, the University of Georgia, Fort Valley State University, and many research Institutes and Universities located in the US, India (ICRISAT), Australia, and several African countries.

Milestones Achieved

Since the development of CMS system, more than 70 single-cross F_1 grain pearl millet hybrids have been developed and released that occupy approximately 60% of the major pearl millet growing areas in India (Bhatnagar 2003). In the US, the breeding programs in Georgia, Kansas, Nebraska, and Indiana have led to development of a few multi-line cultivars, composite and synthetic varieties, and hybrids mainly for fodder but also for grain. Pearl millet cultivars released by USAD-ARS, Tifton, Georgia are listed in Table 1. Research efforts since the late 1980s have mainly focused on development of grain pearl millet hybrids and viable markets for its diverse end-uses. The details of the two hybrids developed for grain production are as follows:

'HGM 100' was released in 1991 and marketed by Agra Tech Ltd., of Atlanta. The production was mainly targeted to the poultry industry in the southeast. Substantial acreage was planted and most farmers were successful, even though it was a new crop. It was grown primarily in South Carolina, Georgia, and Florida on over 6300 ha in 1993 for broiler feed but reduced to 4000 ha in 1994 (Grabow and Wilson 1995) due to rust epidemics and production economics.

'Tifgrain 102' is a new generation pearl millet hybrid for grain with shorter height, earlier maturity with a slightly larger grain and greater ease of combining. This hybrid is resistant to root knot nematodes that affect cotton, peanut, and corn, tolerant to drought, has better rust resistance and produces grain without irrigation in sandy marginal soils. Hybrid seed was available to farmers on a limited basis beginning in 2002–2003 but later seed production was increased to meet the requirement of growers. It has minimal aflatoxins and fumonisins when produced in dry land production settings. The grain has high value as poultry feed and performance of broilers fed diets is equal to or better than those of broilers fed typical corn-soybean diets. This new hybrid can produce high quality grain without irrigation in Georgia and throughout the southern Coastal Plain and into the Great Plains states.

New rust and chinch bug resistant hybrids are being developed and evaluated for release by 2009. Efforts to identify production settings and use applications with superior economic returns are also on-going. In view of global warming, increasing water shortages, and deteriorating natural resources, pearl millet should provide a useful cropping option.

APPLICATION OF DNA MARKER TECHNIQUES

In the past, various selection and breeding methods and their modifications have been used for development of varieties, inbred lines and hybrids of pearl millet. As a result, significant improvements in grain productivity and resistance to insect-pests and diseases have been achieved. But the rate of progress has been slow due to the fact that conventional breeding methods are tedious, time consuming and require many years to achieve the objectives. Recent successful use of biotechnological tools has expedited the breeding of pearl millet by research institutes like International Crops Research Institute for Semi-Arid Tropics (ICRISAT) at Hyderabad, India. DNA marker techniques such as amplified fragment length polymorphism (AFLP), random amplified polymorphic DNA (RAPD), restriction fragment length polymorphism (RFLP), simple sequence repeat (SSRs/microsatellites), expressed sequence tag (EST), and single nucleotide polymorphism (SNP) have been developed and used for diversity analysis, linkage mapping, and marker-assisted selection (MAS) in pearl millet. Marker techniques can further be used to assess genetic diversity at the molecular level in germplasm collections to assist in making appropriate choice of parents for hybrid breeding, studying population structure, mapping and tagging genes/QTLs (quantitative trait loci) for agronomic traits and disease resistance. The first detailed RFLP marker-based genetic linkage map of pearl millet was published by Liu et al. (1994) and extended by Devos et al. (2000) and Qi et al. (2004). Genetic linkage maps in pearl millet have also been constructed and QTLs have been identified and mapped for downy mildew resistance (Jones et al. 1995, 2002; Breese et al. 2002; Gulia 2004; Gulia et al. 2007), rust and blast resistance (Morgan et al. 1998), drought tolerance and grain yield (Yadav et al. 2002, 2003, 2004), and for characters involved in domestication (Poncet et al. 2000, 2002). Environmental variation has also been observed to have significant effects on QTLs for yield and its components (Yadav et al. 2003). The first and only commercial pearl millet hybrid (HHB 67-2) until now incorporating resistance to downy mildew through marker-assisted breeding was released collaboratively by ICRISAT and the Haryana Agricultural University (HAU), India in January 2005 (ICRISAT 2005). A similar QTL mapping study for improvement of resistance to multiple pests and diseases has been initiated collaboratively by Fort Valley State University, USDA-ARS, Tifton and University of Georgia, Athens.

MARKETING PROGRESS AND DEVELOPMENT

United States has no cultural history or tradition of growing pearl millet for grain and therefore it is essentially a new crop. The marketing of pearl millet is not widespread and it is frequently confused by the sales of other unrelated species as generic "millets" that differ widely in feeding value. It is necessary to ensure that pearl millet is distinguished as a premium-value specialty grain in the market. Early differentiation can be accomplished by product branding (for example "Georgia Pearl," or "Southern Pearl") for its potential penetration in higher-value markets and expansion to Georgia and other states. A tiered marketing strategy based on potential profit per unit of product, volume required by market sector, and investment required for specialized packaging and processing equipment would allow specific and achievable benchmarks. Market deployment can be achieved in a phased manner based on priority targets starting with quail producers and wildlife, and followed by poultry ration, pet food, packaged birdseed, specialty grain for health food outlets, specialty grain products and export, and ethanol production upon demand.

A stable market for pearl millet will be achieved only when everyone in the production–storage–utilization chain makes money. At this point, acreage will expand. 'Tifgrain 102' produces 3360–4480 kg/ha when grown on marginal to goods soils. This yield level is too low at the current market prices to provide a reasonable level of return to growers and marketers. Even though production costs on pearl millet are low, grain yields must be increased through improved genetics and management to make the crop competitive on a larger crop area. The birdseed market could potentially absorb tens of thousands of hectares of pearl millet grain production. This market could generate higher prices for pearl millet than the feed market. Prices initially would depend on whether pearl millet was substituted for sorghum (*Sorghum bicolor*) (low value) or proso millet (*Panicum milaceum*) (moderate value) in birdseed mixes.

Though there are multiple markets for pearl millet, coordinated market activities are still lacking. Growers are independently identifying and protecting their "personal" markets, with limited opportunity for expansion. A grower's cooperative or association could help provide more stable product availability, establish product identity, and more effective penetration into diverse markets.

FUTURE CHALLENGES AND STRATEGIES

Though research efforts in southeast US have successfully achieved certain milestones since the last release of 'Tifgrain 102' in 2002, additional outreach, research, and market development efforts are needed. The future challenges and efforts should emphasize following priority categories involving multidisciplinary collaborations: (1) crop management practices including annual and perennial grass weed control, better herbicide tolerance, new herbicide evaluation, registration and label approval of available herbicides for grain production, insecticide evaluation, crop rotation, and cultural and tillage practices; (2) crop genetics and breeding comprising development of hybrids for higher and more stable grain yield with wider adaptation, improved grain quality, additional broad-spectrum resistance to diseases (rust and blight), nematodes (particularly root knot nematode) and chinch bug, better germination, cold tolerance and seedling vigor to permit earlier planting, better stalk strength to resist lodging or corn borer susceptibility, good threshability, release of new diverse hybrids specific to various requirements of growers and consumers, and incorporation of DNA marker technologies to expedite breeding programs; and (3) grain handling, use and marketing encompassing drying technology to handle and store seed and grain, identifying diverse utilization, outreach to penetrate premium-value consumer markets, establishing strong linkages and partnerships between public-private sectors and the stakeholders to boost the research and extension services, and continued end-use research and market development.

CONCLUSIONS

Ability to grow well in marginal sandy soils without irrigation and multiple uses for the grain makes pearl millet an attractive alternate crop for the southeast US. Recent efforts in cultivar development for grain production and market outlets have drawn the attention of farmers to the crop. However, much work remains. Increasing public awareness to the health benefit of pearl millet compared to other cereals and drawing industry's attention to its suitability for animal, bird feed, and biofuel will be essential for the creation of large scale demand for the crop. Improved cultural practices such as high yielding cultivars with wide resistance to diseases and pests, fertilizer rates, registered herbicides for weed control, suitable equipments for various mechanical operations, and post-harvest storage facilities are still not fully in place. Therefore, although pearl millet has started penetrating high value ethnic food markets and the quail feed industry, the increase in pearl millet acreage is projected only in a phased manner.

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