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I. INTRODUCTION

1.1. Distribution, cultivation, and uses

The genus *Pachyrhizus* consists of five different species. The Mexican yam bean (*P. erosus*), the Andean yam bean (*P. ahipa*) and the Amazonian yam bean (*P. tuberosus*) are cultivated, whereas *P. panamensis* and *P. ferrugineus* are only found wild (NRC, 1979; Sørensen, 1996). Yam beans *P. ahipa* and *P. tuberosus* are only of local importance in South America, whereas *P. erosus* is grown in many tropical and sub-tropical regions in South America, Asia, and Africa. Yam bean is exclusively used for its tuberous roots (Sørensen, 1996; Sørensen et al., 1997). The fleshy tuberous root has a white succulent interior, which is flavourful and can be eaten raw. All yam bean species are diploid with a basic chromosome number of n = 11, and interspecific hybridisation between all cultivated yam bean species results in fertile and vigorous hybrids (Sørensen, 1996; Heredia, 1996; Grüneberg et al., 2003). *P. erosus*, also called by the common name "jicama", is a favourite food of Central America and South-east Asia, and is becoming popular as a salad vegetable in the US (NRC, 1979; Hoof and Sørensen, 1989; Sørensen, 1996; Sørensen et al., 1997).

Yam bean *P. erosus*, the first *Pachyrhizus* species described scientifically by Linnaeus in 1753, is believed to be native in South-western Mexico (NRC, 1979). Archaeological evidence reveals that this species was grown by the early civilisations of Mexico and Central America, such as the Aztecs and the Mayas (NRC, 1979; Sørensen, 1996). The Spaniards probably introduced the yam bean *P. erosus* to Southeast Asia via the Philippines in the 16^{th} century (NRC, 1979;

Sørensen, 1996). Since then, the cultivation spread to Indonesia and the rest of the Far East as well as into parts of the Pacific (Sørensen, 1996; Hoof and Sørensen, 1989; Sørensen, et al., 1997). The French botanist and explorer, Perrotet, collected samples of the species from Mollucas islands (East Indonesia) in 1821 (Sørensen, 1996).

Yam bean *P. erosus* shows high yields, even without mineral fertiliser application (Heredia-Garcia 1994; Nielsen and Sørensen., 2000). Yields vary according to cultivation practices, plant density, the cultivar used and field irrigation applied. Cultivation practices however depend on socio-economic factors like labour, resource availability, markets and the farming system in which the crop has to fit (Grum, 1990). Tuber yield was about 27 t ha^{-1} in Mexico (Rivas, 1998), 30-40 t ha^{-1} in Ecuador (Arevalo, 1998b), 20-60 t ha^{-1} in Venezuela (Espinoza, 1998), and 50 t ha^{-1} in Brazil (de Melo et al., 1994). In Malaysia, yields of 7-10 t ha^{-1} have been reported (Sørensen, 1996), and in Thailand of 18-24 t ha^{-1} (Ratanadilok et al., 1998). In experimental trials, yields were 80 or 90 t ha^{-1} in the Philippines, Indonesia, and in Mexico (NRC, 1979). Removal of flowers results in higher tuber yield (Adjahossou and Ade, 1998) and biomass production (Arevalo, 1998a).

Yam bean *P. erosus* is an attractive alternative crop for cultivation on poorer soils. The crop has an efficient symbiosis with bacteria (*Bradyrhizobium* strains) and even enrich the soils with the residual nitrogen due to rhizobia bacteria in the root nodules of the plant (NRC, 1979; Grum and Sørensen, 1996; Castellanos et al., 1997). Moreover, root colonisation with arbuscular mycorrhizal fungi (AMF) supports yam beans growth under strong phosphate shortage (Grum, 1998).

Nitrogen fixation of around 200 kg ha^{-1} was recorded in Mexico over two seasons for *P. erosus* (Badillo and Castellanos, 1996; Castellanos et al., 1997). These levels were not affected by flower removal, and were more than twice that fixed by *P. ahipa* (Castellanos et al., 1997). Yam bean can be grown under small amount of additional supply of nitrogen fertiliser (Belford, et al., 2001). Traditionally, in Central and South America yam beans are inter-cropped with maize and common beans (Sørensen, 1996; Sørensen et al., 1997; Castellanos et al., 1997). Flower removal improves adaptation of the species to drought conditions (Diouf et al., 1998). Such characteristics suggest *P. erosus* as an important component of low-input farming system on marginal lands.

Yam bean *P. erosus* is grown in nearly all tropical countries of America, Africa, Asia and the Pacific (Sørensen, 1996; Rivas, 1998; Paull et al., 1988; Sen et al., 1996; Grum, 1990). The habitat of *P. erosus* is along forest edges and in scrub vegetation in areas with an annual dry season, on soil types ranging from deep clay to sandy loam. The species is found from 0 to 1750-m a.s.l., with the majority of records from 500 to 900 m a.s.l., with a rainfall from 250-500 mm to over 1500 mm (Sørensen, 1996). The optimal day/night temperature is about 30/20°C (Grum, 1990; Sørensen, 1996). Well-drained, sandy, alluvial soils are preferred in cultivation (Sørensen, 1996) while excess rainfall causes lower yields and tuber rot (Vaz et al., 1998). The photothermal sensitivity in *P. erosus* was analysed in many studies. In Hawaii, Paull et al. (1988) observed a significant overlap between flowering and tuberization during short days under field conditions. During long days, tuber growth is initiated after 4-6 weeks. Flowering was initiated when the daylight approaches 12.5 hours. During short days, there is an increase of tuber growth (Cotter and Gomez, 1979; Sørensen, 1996). All cultivated yam beans are propagated by seeds and grown as an annual crop, eventhough the plants have a perennial habit (Sørensen, 1996). Today, yam bean *P. erosus* is cultivated almost on the entire Indonesian archipelago (*pers. observation*).

Nutritional properties of *P. erosus* tubers are interesting. Based on 100 g fresh tuber weight, the tuber consists of 78 - 94 % water, 4.6 - 14.9 g carbohydrates, 1.0 - 2.2 g protein and 0.1 - 2.2 g lipids (from several authors compiled by Sørensen, 1996). Based on tuber dry matter weight, starch content is up to 68 % (de Melo et al., 1994). The amylose content of yam bean tuber is about 23 %, which is higher than the mean values found in cassava starch of 17%, but viscosity and absolute density of the starch were similar to cassava (de Melo et al., 1994). Based on dry matter weight, protein content in *P. erosus* is about 10 – 12 % (Evans et al., 1977; NRC, 1979; Zanklan, 2003) which is higher than 2.6 % in cassava, 7.2 % in yams, 5.4 % in sweet potato and 9 % in potato (Rehm and Espig, 1991). Two distinct pools of amino acids were found in *P. erosus* tubers, one utilised mostly for protein synthesis and the other probably stored in the vacuole (Vailant and Desfontaines, 1995). The soluble carbohydrates and the pattern of proteins remained unchanged during root development under long-day environment (Vaillant and Pilet, 1998). Removal of flowers results in higher sugar content (Arevalo, 1998a), and protein content (de Oliveira et al., 1999).

A common characteristic of the genus *Pachyrizus* is the presence of an insecticidal compound called rotenone. Mature seeds of *P. erosus* contain approx. 0.5% pure rotenone and 0.5% rotenoids and saponins (Duke, 1981; Sørensen, 1996). Powdered yam bean seed contains insecticides used against rice weevil *Sitophilus oryzae* (Bhusan and Ghatak, 1991) and rice moth *Corcyra cephalonica* Staint (Ghatak and Bhusan, 1995). Seed extracts are effective against *Callosobruchus analis* (Kardiman and Wikardi, 1997) and tobacco caterpillar *Spodoptera litura* but could not be used as a fumigant (Sahu and Hameed, 1989). Seed extracts are also effective against pepper bug as a major pest for pepper (*Capsicum spp.*) in Indonesia (Alwi and Soetopo, 2000). Because of rotenone the seeds are not suitable for human consumption, though they could be an interesting source of vegetable oil and protein. Mature seed of *P. erosus* contains 30% of vegetable oil (Duke, 1981; Sørensen, 1996). Santos et al., (1996) and Arellano et al., (2001) mentioned seed proteins have an excellent balance of all essential amino acids, except methionine. The major seed protein fractions of *P. erosus* are albumin (31.0 - 52.1 %) followed by globulin (27.5 %- 30.7 %), while the minor fraction is prolamins (0.8 %) (Arellano et al., 2001).

Yam bean *P. erosus* is recently becoming a more interesting crop in Indonesia. Traditionally yam bean is known as a vegetable tuber crop (Sørensen, 1996) for local markets, but recently it is also considered as a promising cash crop for more commercial purposes. Fresh tubers have been trading between islands mostly for vegetable purpose. “Banjar Titih“, a traditional vegetable market in Denpasar (Bali), has been supplied with about 30-40 ton of fresh tubers per day in peak season from East and Central Java (A rural-wholesaler, *pers. comm.*). Several commercial ready-food products, i.e. “Pikel“ (fermented tubers, vegetables and fruits, in 15-20 % salt solution), yam bean syrup and juice, “manisan bengkuang“ (fresh tuber in sugar solution) or “asinan bengkuang“ (fresh tuber in salt solution) have been developed. Furthermore, cosmetics using yam bean tubers on their products, i.e., "yam bean face tonic" (e.g. from Viva Cosmetics) and "yam bean masker" (e.g. from Mustika Ratu), "yam bean powder" (Indonesia: *Bedak dingin*), a traditional-natural cosmetics powder consisting of rice meal and yam bean starch, with spices and flowers, are commercialised in Java and Sumatra. Fermented yam bean leaves contain high crude protein and low crude fibre percentage and can be used with up to 12 percent in the broiler diet (Nuraini et al., 2000; Nuraini, 2000).

1.2. Germplasm variability

Yam bean *P. erosus* has a herbaceous vine with great variation in the shape of the leaflets, from dentate to palmate (Sørensen, 1996). Variation on morphological characters of the pods are also found within the species, as well as variation in seed colour, ranging from olive-green to brown or reddish brown (Sørensen, 1988, 1990, 1996). Wild specimen of *P. erosus* were clearly separated from the cultivated landraces (Døygaard and Sørensen, 1998). Hernandez (1992) has differentiated three groups within 40 accessions *P. erosus* of the Centro Agronomico de Investigaticon y Ensenanza (CATIE) collection based on 13 qualitative and 6 quantitative traits. The first group was dominated by Mexican accessions, the second was dominated by South American accessions and the third group was mixed of Mexican accessions with accessions from Costa Rica, Rep. of Dominica, and Mauritania. However, accessions from Thailand and Macao were included into the second group. Furthermore, a phylogeny study based on molecular markers conducted by Estrella et al. (1996) showed that the genus *Pachyrhizus* was separated into two main branches based on ecological adaptation. Areas with clear annual dry seasons in Central America are probably the origin of *P. erosus*, whereas the tropical and sub-tropical rain forest and Andean valleys are centre of diversity for *P. tuberosus* and *P. ahipa*.

The variation of the tuber dry matter content is generally low in the yam bean genpool. The average tuber dry matter content was 13.5 % in *P. erosus*, 20.5 % in *P. ahipa* and 21.1 % in *P. tuberosus* (from various authors compiled by Sørensen, 1996). An exception was found in *P. tuberosus* (Chuin type) from the tropical lowlands of Peru, which has a tuber dry matter content between 24 – 28% (Sørensen et al., 1997; Grüneberg et al., 1998). Forsyth and Shewry (2002) found that in *P. ahipa* tuber dry matter content was 20-25 % of dry weight. In recent studies Zanklan (2003) observed in sun dried sample tubers from unpruned and pruned plants dry matter content of 30% and 31.9% in *P. tuberosus*, 20.7% and 21.6 % in *P. erosus*, 22.3% and 23.0 % in *P. ahipa*, respectively. Zanklan (2003) concluded that there was no effect of pruning on tuber dry matter content. Genetic variation for tuber dry matter content was found within *P. tuberosus* and *P. ahipa* populations, but *P. erosus* showed no significant genetic variation for this trait (Zanklan, 2003).

1.3. Assessment of genetic diversity by morphology, agronomic traits and Random Amplified Polymorphic DNA (RAPD) markers

Morpho-agronomic traits are widely used for plant classification (Stuessy, 1990; Bretting and Widrlechner, 1995). Morphological traits are generally simple, rapid and inexpensive to score, even from preserved specimens (Bretting and Widrlechner, 1995; Arbizu et al., 1997). Hernandez (1992) reported that the flower and vegetative growth traits are the most important factors in classifying