ELSEVIER

Postharvest Biology and Technology 13 (1998) 37–43

Postharvest Biology and Technology

Development of chilling injury in five jicama cultivars

Edmundo Mercado-Silva [a], Rafael Garcia [a], Adelberto Heredia-Zepeda [b], Marita Cantwell [c,*]

[a] *Departamento Investigación y Posgrado en Alimentos, Universidad Autonóma de Querétaro, Querétaro, Mexico*
[b] *Bajio Research Station, CIRCE, INIFAP, Apdo. Postal 112, C.P. 38000 Celaya, Guanajuato, Mexico*
[c] *Department of Vegetable Crops, University of California, Davis, CA 95616, USA*

Received 19 July 1997; accepted 26 October 1997

Abstract

Five commercially important jicama (*Pachyrhizus erosus*) cultivars ('Agua Dulce', 'Cristalina', 'San Juan', 'San Miguelito', and 'Vega de San Juan') were stored at 10°C and 13°C to study postharvest quality changes and chilling susceptibility. Decay development, weight loss after storage, internal color and texture, respiration rates and ion leakage were the parameters used to evaluate differences in chilling susceptibility. All cultivars were very chilling sensitive, with symptoms of injury occurring after 1 week at 10°C plus 1 week at room temperature. Roots of cvs 'Vega de San Juan' and 'San Miguelito' were the most and least tolerant to 10°C storage, respectively. Roots stored at 13°C showed few internal quality changes over a 5-month period, although weight loss exceeded 35%. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Pachyrhizus erosus; Decay; Weight loss; Color; Texture; Respiration; Ion leakage

1. Introduction

The jicama or yam bean (*Pachyrhizus erosus* L. Urban) is a leguminous root crop native to Mexico and Central America, but now is produced in many tropical and subtropical areas (Sørensen, 1996). It is consumed fresh for its crisp, succulent starchy-sweet white pulp. Recent research suggests that the jicama has potential for more widespread exploitation. It has good adaptability to a wide range of climates and soils, the plant has a high capacity to fix nitrogen, yields can be high, and the root has a good compositional balance between carbohydrates and protein (Sørensen, 1996).

An important complement to genetic and horticultural research on the jicama is the evaluation of postharvest handling requirements for efficient commercialization of new cultivars and hybrids.

* Corresponding author. Tel.: +1 916 7527305; fax: +1 916 7524554.

PII S0925-5214(97)00071-9

Common postharvest problems of the jicama include sprouting, mechanical damage, decay development and dehydration (Bruton, 1983; Paull and Chen, 1988; Cantwell et al., 1992). Jicama roots are also susceptible to chilling injury, and storage at 10°C or below results in chill damage within about 2 weeks (Bergsma and Brecht, 1992; Cantwell et al., 1992; Mercado-Silva et al., 1996). Decay is the main external symptom of chilling, and discoloration and loss of crisp texture are the main internal symptoms. Chilling injury is not a problem for roots marketed in Mexico, but does occur when jicama is shipped to the U.S. and distributed under refrigeration (Cantwell et al., 1992).

Mercado-Silva et al. (1996) reported that cv 'Agua Dulce' roots from the central Bajio region were less chilling tolerant than roots produced in the coastal state of Nayarit. Variation in chilling sensitivity attributed to growing conditions and cultivar selection has been described for numerous plant species (Patterson and Reid, 1990). The objectives of this study were to compare the chilling susceptibility of five commercial jicama cultivars and to objectively evaluate color and texture changes in roots stored at chilling and nonchilling temperatures.

2. Materials and methods

Seeds of five commercially important cultivars were planted on February 28, 1996 at the research station of INIFAP in Celaya in rows >100 m. Normal production practices were followed. The plants were irrigated every 15 days from seeding, but did not receive fertilization or insecticides, except Carbofuran (FMC Corp., applied as a powder at 20 kg/ha) at planting to control soil insects. Flowers were removed on May 15, June 15 and June 30 to permit development of well-formed commercial size roots. Mature medium to large size (350–700 g) roots of five cultivars were dug manually. Harvest date was based on criteria used commercially: number of days from seed planting and the rupture of the soil surface by the mature root. Roots of cv 'Vega de San Juan' were harvested on September 4 (average weight 580 g), cvs 'Agua Dulce' and 'Cristalina' were harvested on September 26 (average weights 540 and 610 g), and cvs 'San Juan' and 'San Miguelito' were harvested on October 21 (average weights 680 and 580 g). The latter two cultivars reached harvest maturity 2 weeks before digging, but were left in the ground as is routinely done for commercial harvests.

Roots were selected for freedom from defects, trimmed, numbered and weighed, and placed in bulk in large unsealed polyethylene bags (0.5 ml) on shelves at 10°C or 13°C (RH $>95\%$) for 1, 2 or 3 weeks. After storing 1 or 2 weeks, the roots were transferred to plastic crates at 20–23°C (RH $\sim 70\%$) for 7 days. Five roots per sample period were evaluated for weight loss, decay, and internal color and texture. Roots were also stored for up to 5 months in plastic crates at 13°C without humidity control (RH $\sim 80\%$).

Decay was evaluated on a scale of 1 to 5, where 1 = none, 2 = slight (1 or 2 infections), 3 = moderate ($<5\%$ of the surface affected), 4 = moderately severe (5–15% of the surface was affected, and 5 = severe with $>15\%$ of the root surface affected. Whole root firmness was evaluated on a 4 to 1 scale, where 4 = very firm, no compression, 3 = firm, slight compression, 2 = moderately firm, moderate compression, and 1 = easily compressed with finger pressure. CIELAB color values were obtained on the internal pulp of halved roots using a Minolta (model CR-2002) colorimeter with illuminant A and 10° viewing angle, calibrated on a white tile. Three measurements per root were taken on the interior part of the pulp after cutting the root at the equator. Chroma and hue values were calculated (McGuire, 1992). After measurement of color, the maximum force to rupture and the distance to rupture point were determined on a TA-HD texture analyzer equipped with a 5-mm probe penetrating at a velocity of 1 mm/s to a final depth of 8 mm. Two measurements per root were made on the interior part of the root halved at the equator.

To determine respiration rates, a minimum of five roots per cultivar and temperature were enclosed individually every 2 days in 2-l glass jars at 10, 13 or 20°C. After 1 h, a 1-ml gaseous sample was taken and injected into a 20-μl automatic

sampling loop on a Perkin-Elmer gas chromatograph with a thermal conductivity detector for CO_2 determination. These same roots were weighed every 2 days to calculate weight loss. Electrolyte leakage was determined on eight discs (5 mm × 1 cm) taken with a cork borer from halved roots 2 cm from the surface. Discs were agitated at 20°C in 10 ml deionized water for 30 min. Ion leakage, based on the difference in conductivity of the agitated solution at 0.5 and 3 h, was expressed as a percentage of total ion leakage. Total electrolyte leakage was determined after freezing and thawing of the discs (Cabrera and Saltveit, 1990).

Data are based on five roots per treatment per evaluation and were calculated as averages ± standard deviation or were analyzed by ANOVA with mean separation by Duncan's multiple range test at the 5% probability level.

3. Results

3.1. Storage characteristics of five cultivars

Storing the jicamas in plastic bags at 10°C resulted in high humidity conditions and induced a high level of decay and deterioration of the root surface (Fig. 1). At 10°C, macroscopic decay began to appear between days 10 and 14, and increased after transfer to ambient temperature. Roots of cvs 'San Juan' and 'San Miguelito' had a sticky surface after storage at 10°C but we did not determine if that was due to pathogen growth or to a root exudate. Roots stored at 13°C remained in good visual quality over the 2-week storage period with little decay after transfer to ambient conditions (Fig. 1). Whole root firmness was maintained in jicama stored at 13 C, whereas firmness decreased notably in roots stored at 10°C (Fig. 1).

Weight loss of jicama during storage at 10°C was less than that of roots stored at 13°C (Fig. 2). After transfer to 20°C, however, the rate of weight loss of the roots stored at 10°C was much higher than that of the roots stored at 13°C. Post-storage weight loss increased the longer the roots were stored at 10°C, increasing from 0.85% per day after 1 week of storage to 1.28% per day after 2 weeks at 10°C.

At harvest, the L^* color values of pulp of cv 'San Juan' and 'San Miguelito' were lower than values for the other three cultivars (Table 1). The L^* values of roots stored at 13°C did not change over the 2-week period. The pulp of the five cultivars had significant discoloration after 7 days storage at 10°C plus 1 week at 20°C. Since the color values were obtained on the interior part of the halved roots and discoloration progressed from the external surface, the L^* did not decrease notably until after 2 weeks of storage at 10°C (Table 1).

The crisp texture of jicama roots was maintained during storage at 13°C. At harvest, force to penetrate averaged 24 N and distance to rupture averaged 1.1 mm. Values did not change generally during 2 weeks at 13°C (Table 1). Depending on

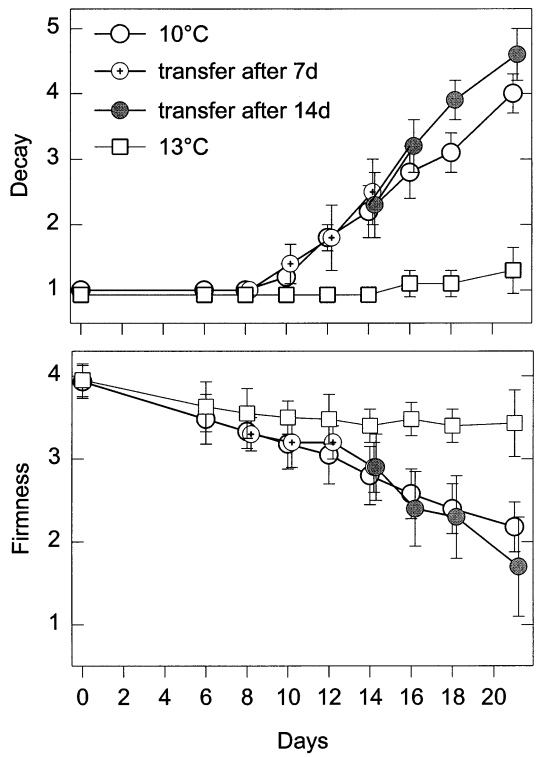

Fig. 1. Decay and whole root firmness scores of jicamas stored at 10°C or 13°C for 0, 1 and 2 weeks. Roots were transferred to 20°C after 7 and 14 days. Data are averages from 5 roots × 5 cultivars ± standard deviation.

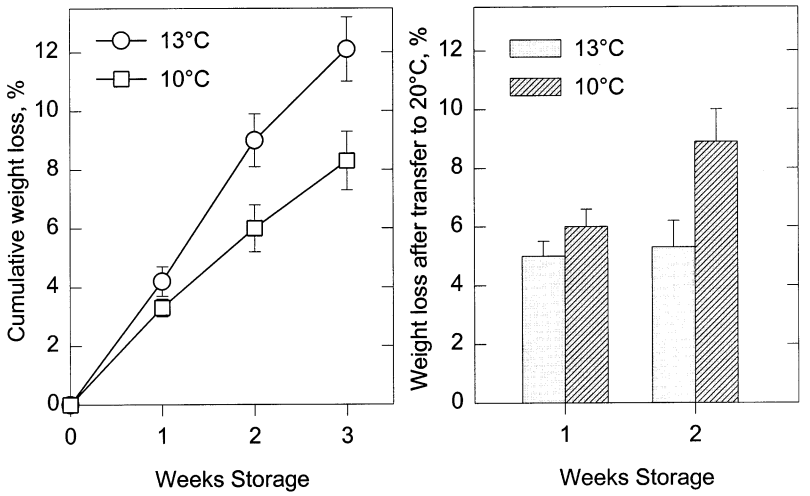

Fig. 2. Weight loss of jicamas during storage (left) and after transfer to 20°C for 7 days (right). Data are averages of 15 determinations from cvs 'Agua Dulce', 'Cristalina' and 'Vega de San Juan' ± standard deviation.

cultivar, penetration force of roots stored at 10°C did not change or increased slightly. However, distance to rupture increased with increased storage time at 10°C (Table 1).

The respiration rates of jicama stored at 10°C increased from 14 to 26 mg CO_2 kg^{-1} h^{-1} over a 3-week period (Fig. 3). When roots were transferred to 20°C after 1 week, an increase in respiration rate was observed. Roots transferred after 2 weeks at 10°C had markedly increased respiration rates, reaching a maximum of 128 mg CO_2 kg^{-1} h^{-1}. The respiration rates of roots stored at 13°C decreased slowly from 20 to 10 mg CO_2 kg^{-1} h^{-1} over 3 weeks. When these roots were transferred to 20°C after 1 and 2 weeks, respiration rates did not increase. Respiration rates of roots of the other four cultivars stored at 10°C and 13°C were similar to those of cv 'San Miguelito'. Roots of cv 'Vega de San Juan' had the lowest respiration rates among the five cultivars.

The initial electrolytic conductivity of disks prepared from jicama pulp was similar for three cultivars (11.3 ± 1.1%) and much higher for cvs 'San Miguelito' and 'San Juan' (35.0 ± 2.0%). After 1 week at 10°C, electrolyte leakage of three cultivars increased to 20%, but did not increase in tissue from cvs 'San Miguelito' and 'San Juan'.

3.2. Quality after long-term storage at 13°C

Roots of cvs 'San Juan', 'San Miguelito', 'Vega de San Juan' stored at 13°C retained good quality for 5 months. No decay was observed on the roots, but some sprouting occurred. Whole root firmness decreased only slightly during this period, although weight loss reached 35–38%. Penetration force changed little, but distance to rupture increased from an average 1.1 mm at harvest to 2.9 mm after 5 months at 13°C. This change was probably related to the high total weight loss and not indicative of chilling injury. No important changes in L^* and a^* color values were observed during the 5 month period, but b^* and chroma values increased notably in the three cultivars (Table 2). These changes corresponded to a slight yellowing of the pulp.

4. Discussion

There was a high level of decay in the storage experiment. This was probably due to the very high humidity conditions maintained during storage in the polyethylene bags. In previous work, decay was much less a problem when roots were stored in a flow-through system with nonhumi-

Table 1
Internal color and texture of pulp of jicama roots stored for 0, 7 or 14 days at 10°C or 13°C

Cultivar	Days								
	L^* Color value			Force (N)			Distance to rupture (mm)		
	0	7	14	0	7	14	0	7	14
13°C									
Agua Dulce	79.8c	79.3c	79.3c	22.7a	24.9abc	26.0bcd	1.02a	1.99cd	1.50 abc
Cristalina	79.9c	80.7c	79.6c	25.9bc	28.9c	28.0cd	1.25ab	1.71bc	1.54 abc
San Juan	74.0b	75.9b	76.8bc	22.8a	22.2a	24.6abc	0.83a	1.24ab	1.43 ab
San Miguelito	76.9bc	76.1bc	76.4bc	24.0ab	22.0a	23.9ab	1,48ab	1.32ab	1.41 ab
Vega de S.J.	79.1c	78.7c	79.8c	24.5ab	27.2cd	27.9cd	1.09a	1.67abc	1.50 abc
Average	77.9	78.1	78.4	24.0	25.0	26.1	1.13	1.58	1.48
10°C									
Agua Dulce		78.6bc	74.5b		29.6d	26.0bcd		1.91cd	1.78 bc
Cristalina		78.8c	74.0b		26.6bcd	25.6abc		1.79bc	2.72 de
San Juan		75.5b	67.0a		22.8a	23.3ab		1.39ab	2.10 cd
San Miguelito		73.5b	67.0a		26.6bcd	23.9ab		1.79bc	2.98 e
Vega de S.J.		77.3bc	74.1b		24.0ab	24.1ab		1.44ab	2.25 cd
Average		76.7	71.3		25.9	24.6		1.66	2.36

Roots were transferred to 20°C for 7 days before evaluation.
Data are the averages of three observations per each of four roots per evaluation.
Data for a given parameter followed by different letters are significantly different at the $P \leq 0.05$ level.

dified air (Cantwell et al., 1992) or in plastic crates at 80–85% relative humidity (Mercado-Silva and Cantwell, 1997).

Discoloration of the pulp is a common symptom of chilling injury in jicama stored at 10°C (Cantwell et al., 1992; Mercado-Silva et al., 1996). Within the same root, there could be highly discolored areas and tissue with no color change. Physical damage and decay enhanced discoloration. The discolored areas generally developed from the exterior part of the root towards the interior, and are probably due to polymerization of phenolics. The content of phenolic compounds in the jicama was low, but increased during storage at both 12.5°C and 22°C (Paull and Chen, 1988). The absence of browning in the interior of the root may be due to loss of membrane integrity (Murata, 1990). Another possible explanation is that phenolic compounds and enzymes involved in phenolic polymerization may be more abundant in external than in internal tissues.

Most of the weight loss of jicama is due to water loss. We estimate that roots at 13°C lose about 2 g per kg per month due to respiratory metabolism. High respiration rates after storage at 10°C would increase metabolic weight loss for only a few days. The increased weight loss after transfer from 10 to 20°C is probably due to loss of cellular integrity (Saltveit and Morris, 1990).

Ion leakage has been considered a physiological indicator of chilling injury (Cabrera and Saltveit, 1990; Murata, 1990). The increase in electrolyte leakage in three of the five jicama cultivars stored at 10°C is evidence of substantial loss of cellular integrity. Cantwell et al. (1992) also documented a dramatic increase in ion leakage when jicama roots were stored at 10°C.

Respiration rates of the five cultivars at 13°C were about double the rates reported for roots of cv 'Agua Dulce' from Nayarit (Cantwell et al., 1992). The increased respiration rates with storage time at 10°C have also been observed in other studies (Bergsma and Brecht, 1992; Cantwell et al., 1992). The very high respiration rates after transfer from 10 to 20°C were of a similar magnitude to those reported for 'Agua Dulce' roots (Cantwell et al., 1992). Roots held continuously at 20°C had respiration rates of 8–10 mg CO_2 kg^{-1} h^{-1} (Cantwell et al., 1992).

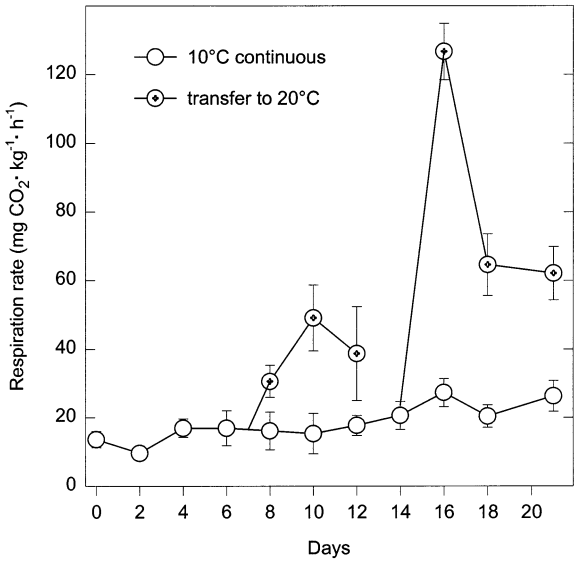

Fig. 3. Respiration rates of jicama cv 'San Miguelito' stored at 10°C. Some roots were transferred to 20°C after 7 and 14 days. Data are the averages from a minimum of five roots ± standard deviation.

Although 12.5°C was considered a nonchilling temperature, a slight increase in respiration rate after 4 weeks was noted with transfer to 20°C in conjunction with a slight internal discoloration (Cantwell et al., 1992). In the present study, there was no evidence of respiratory or quality changes in the 13°C stored roots during 5 months, other than a slight yellowing of the pulp. The yellowing was distinct from the brown pigmentation observed at 10°C, and was characterized by an increase in b^* and chroma values with little change in L^* values.

In comparison to previous results, the five cultivars were very susceptible to chilling injury at 10°C, and there were few postharvest differences among them. The cultivars studied are relatively close in genetic origin. They were derived from a series of individual clonal selections from jicama collections made in the central part of Mexico (Heredia-Zepeda and Heredia-Garcia, 1994). Cultivars 'Cristalina' and 'Agua Dulce' were the first named cultivars of jicama in Mexico and were derived about 25 years ago. A broader base of genetic material from central Mexico was used in the development of the other three cultivars, and they are notable for their high yields and wide adaptability. 'San Miguelito', 'San Juan' and 'Vega de San Juan' were derived from genetic materials collected in the states of Guanajuato, San Luis Potosi, and Jalisco, respectively (Heredia-Zepeda and Heredia-Garcia, 1994).

Postharvest evaluations of more genetically diverse materials may be useful. Various *Pachyrhizus* species and interspecific hybrids are being bred and evaluated for horticultural characteristics in Mexico (Heredia-Garcia, 1994) and around the world (Sørensen, 1996). We are continuing postharvest studies with these materials to determine if there are important differences in chilling susceptibility.

Table 2
Internal color of pulp of three cultivars of jicama stored at 13°C for 0 and 5 months

Cultivar	Months									
	L^* Color value		a^* Color value		b^* Color value		Chroma		Hue	
	0	5	0	5	0	5	0	5	0	5
San Juan	72.4a	77.6b	−1.6a	−2.2b	7.7a	13.0bc	7.9a	13.2bc	78.3a	80.5b
San Miguelito	76.6ab	79.5b	−1.8a	−2.4b	9.4ab	13.8c	9.6ab	14.0c	79.2a	80.3ab
Vega de S.J.	79.7b	80.0b	−2.2b	−2.3b	10.9b	15.7c	11.1b	15.8c	78.8a	81.5b
Average	74.9	79.1	−1.8	−2.3	9.3	14.2	9.5	14.3	78.7	80.8

Data are the averages of three observations per each of five roots per evaluation.
Data for a given parameter followed by different letters are significantly different at the $P \leq 0.05$ level.

5. Conclusions

There were few notable differences in postharvest behaviour among five commercial cultivars of jicama produced in the Bajio region of Mexico. This was probably due to the close genetic origin of all five cultivars. Roots from all cultivars were very chilling sensitive, with visible damage occurring within 1 week at 10°C. External decay and internal discoloration and loss of crispness were the most obvious symptoms of chilling injury. At 13°C, jicama roots retained their internal quality for 5 months.

References

Bergsma, K.A., Brecht, J.K., 1992. Postharvest respiration, moisture loss, sensory analysis and compositional changes in jicama (*Pachyrrhizus erosus*) roots. Acta Hortic. 318, 325–332.

Bruton, B.D., 1983. Market and storage diseases of jicama. J. Rio Grande Valley Hortic. Soc. 36, 29–34.

Cabrera, R.M., Saltveit, M.E. Jr, 1990. Physiological response to chilling temperatures of intermittently warmed cucumber fruit. J. Am. Soc. Hortic. Sci. 115, 256–261.

Cantwell, M., Orozco, W., Rubatzky, V., Hernández, L., 1992. Postharvest handling and storage of jicama roots. Acta Hortic. 318, 333–343.

Heredia-Zepeda, A., Heredia-Garcia, E., 1994. 'San Miguelito', 'San Juan', y 'Vega de San Juan' nuevas variedades de jicama para el Bajio. In: Sørensen, M., (Ed.), Proceedings of the First International Symposium on Tuberous Legumes. Jordbrugsforlaget, Frederiksberg, Denmark, pp. 257–271.

Heredia-Garcia, E., 1994. Observación de materiales segregantes y evaluación de germoplasma de jicama (*Pachyrhizus* spp.) en Mexico. In: Sørensen, M., (Ed.), Proceedings of the First International Symposium on Tuberous Legumes. Jordbrugsforlaget, Frederiksberg, Denmark, pp. 273–282.

McGuire, R.G., 1992. Reporting of objective color measurements. HortScience 27, 1254–1255.

Mercado-Silva, E., Cantwell, M., 1997. Quality changes in jicama roots stored at chilling and nonchilling temperatures. J. Food Qual. (in press).

Mercado-Silva, E., Rubatzky, V., Cantwell, M.I., 1996. Variation in chilling susceptibility of jicama roots. Acta Hortic. (in press).

Murata, T., 1990. Relation of chilling stress to membrane permeability. In: Wang, C.-Y., (Ed.), Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, FL, pp. 201–209.

Patterson, B.D., Reid, M.S., 1990. Genetic and environmental influences on the expression of chilling injury. In: Wang, C.-Y., (Ed.), Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, FL, pp. 87–112.

Paull, R.E., Chen, N.J., 1988. Compositional changes in yam bean during storage. HortScience 23, 194–196.

Saltveit, M.E., Jr., Morris, L.L., 1990. Overview of chilling injury of horticultural crops. In: Wang, C.-Y., (Ed.), Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, FL, pp. 3–15.

Sørensen, M., 1996. Yam bean (*Pachyrhizus* DC.). Promoting the conservation and use of underutilized and neglected crops. 2. Institute of Plant Genetics and Crop Plant Research. Gatersleben/Int. Plant Genet. Resour. Inst., Rome.