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CHUFA *(CYPERUS ESCULENTUS* L.VAR. *SATIVUS* BOECK.): AN UNCONVENTIONAL CROP. STUDIES RELATED TO APPLICATIONS AND CULTIVATION

BERNARDO PASCUAL, J. VICENTE MAROTO, SALVADOR LÓPEZ-GALARZA, ALBERTO SANBAUTISTA, AND JOSÉ ALAGARDA

Tubers of Cyperus esculentus *were an important food in ancient Egypt. in Spain the tubers are used to make a beverage named* horchata, *and are also consumed as fresh after soaking. in other countries tubers are used in sweetmeats or uncooked as a side dish. New products obtained can enhance the interest in this crop: as a source of dietary jiber in food technology; as a high quality cooking/salad oil or as biodiesel fue/; as caramel to add body, flavor or color to other products; as a source of starch; as an antioxidant-containing food, etc. The results of a twenty-year research program on nutrition, fertilization, lodging control, planting date, soil texture and use of herbicides are shown. Three cultivars ('Ametlla Bonrepos', 'Gegant Africana', and 'Llargueta Alboraia') are selected and characterized using horticultura/ and morphological traits, the chemical composition of tubers and* horchatas, *and the RAPD technique.*

CHUFA *(CYPERUS ESCULENTUS* L. VAR. *SATIVUS* BOECK.): UN CULTIVO NO CONVENCIONAL. ESTUDIOS SOBRE SUS USOS Y SU CULTIVO. *Los tubérculos de* Cyperus esculentus, *que fueron un importante alimento en el antiguo Egipto, se utilizan, en España, para obtener una bebida refrescante denominada horchata y para consumo en fresco. En otros países se consume como entremés y en confitería. Su interés podría incrementarse con la obtención de nuevos productos de aplicación como materia prima en tecnología de alimentos (fibra; aceite de gran calidad, sustitutivo del aceite de oliva; aditivos de sabor, color y cuerpo; almidón; capacidad antioxidante), como combustible biodiesel, etc. Se presentan los resultados obtenidos en veinte años de investigación en aspectos agronómicos (nutrición, fertilización, control del encamado, fecha de plantación, textura del suelo y utilización de herbicidas) y de selección y caracterización varietal (características morfológicas y agronómicas, composición química de tubérculos y horchatas, utilización de la técnica RAPD), que han permitido la selección y caracterización de tres cultivares: 'Ametlla Bonrepos ', 'Gegant Africana', y 'Llargueta Alboraia '.*

Key Words: yellow nutsedge; tuber; cultivar; weed; antioxidant; *horchata.*

Cyperus esculentus L. is known as chufa, yellow nutsedge or tiger nut. lt grows wild as a weed, but also is grown as a crop; sometimes it is also called rush-nut. Although it can be found in cold regions, as Alaska (Holm et al. 1977: 125), it is considered a plant of warm areas, widespread in tropical and temperate zones around the globe (de Vries 1991). It is most troublesome in eastem and southem Africa and in North and Central America. Recently it has also spread to sorne European countries with colder climates such as the Netherlands (Rotteveel 1993; de Vries 1991), Switzerland (Gerhold 1992; Schmitt 1995; Schmitt and Sahli 1992), Germany and Austria (Gerhold 1992) and Hungary (Dancza 1994).

Kükenthal (1936) distinguished eight botanical varieties of *Cyperus esculentus.* Recently three of these varieties were rejected and only four wild varieties *(esculentus, leptostachyus, macrostachyus,* and *hermanii)* and the cultivated variety *sativus* are recognized today (ter Borg and Schippers 1992). This can explain the existence of two distinct groups of plants which have a similar morphology but differ widely in application and which are known by the same name: one is a weed and the other, a crop.

Since ancient times the chufa tuber has been considered a foodstuff; it was an important food product in ancient Egypt according the references of Teophrastus and Pliny (Negbi 1992; Serrallach 1927:7). Its dry tubers have been found in tombs from pre-dynastic times (fourth millennium B.C.; Serrallach 1927:7). The chufa is a crop of early domestication which was added to those of the Nile Valley (Zohary 1986); its dry tubers appear in large quantities in Egypt from pre-dynastic times on. According to Zohary and Hopf (1993) there are almost no contemporary records of this plant in other parts of the Old World. In Egypt the tubers *(malniathalle)* of *Cyperus esculentus* were roasted and used as sweetmeat. Tubers were also recorded as having medicinal properties (Negbi 1992).

In southem Europe chufa has been cultivated for several centuries. It seems to have been introduced in Europe during the Middle Ages by the Arabs after their expansion across the north of Africa. There are written records from the 13th century which mention the consumption of a drink made from chufa in the Mediterranean areas of the present day Valencian community (Spain). This beverage could be considered an ancestor of the *horchata* drink nowadays.

The chufa plant has been described by Holm et al. (1977) and Wills (1987), and its cultivation by Pascual et al. (1989).

REVIEW ON CROP AND ITS PRODUCT

The French chemist Lesant in 1822, the Italian researcher Semmola in 1835 and later the Spanish professor Torres Muñoz in 1851 were probably among the first to analyze the tubers of chufa; between 1921 and 1924 Pieraerts published works on the composition of the tubers and the cultivation of chufa in the Belgian colonies of that time (Serrallach 1927:6). At that time, in Egypt and other Mediterranean countries, the tubers were consumed after soaking or roasting and were also used as a substitute for coffee and chocolate; the fatty oil extracted from chufa tubers was used as a food product, as an ingredient in the manufacture of perfumed soap (Killinger and Stokes 1951), and also as a lubricant of fine apparatuses, while the residue was used as a valuable fodder (Negbi 1992). In the United States tubers were used as hog feed, pastured in the field in states such as Florida, Georgia, and Alabama (Killinger and Stokes 1951).

Nowadays chufa is cultivated in northem Ni- geria and Ghana, where it is made into a sweet- meat, and Togo, where it is used principally un- cooked as a side dish (Omode, Fatoki, and Ola- ogun 1995). These countries, and others as the lvory Coast, export yearly 2300 t of tubers to Spain. The chufa is also a representative crop of the Spanish Mediterranean Region (with nearly 900 ha and an annual production of 9000 t; Min- isterio de Agricultura Pesca y Alimentación 1997:128), where tubers are used to make a bev- erage called *horchata* or *horchata de* chufas (Fig. l). The milky-looking aqueous extract of chufa has a pleasant and characteristic flavor of vanilla and almonds. Morell and Barbee (1983) described the chemical composition and the process to obtain *horchata.* The popularity of this drink has recently extended to other countries such as France, Great Britain, and Argentina. In Spain the interest for this crop is increasing and so the regional administration of the Valencian community developed specific legislation re garding chufa and *horchata* qualitative parame- ters. Cantalejo (1996) describes the eight types of *horchata* cited by the specific legislation (Di- ario Oficial Generalidad Valenciana 1989): chilled, enriched, iced, concentrated, syrup, pasteurized, sterilized, and powdered. Tubers are also used to make a chufa ice cream, but fresh chufas can also be consumed on their own after soaking. In Spain the interest for this crop is increasing and so the regional administration of the Valencian community has developed specific legislation regarding chufa qualitative parame- ters. The mean chemical composition of chufa tubers and horchata are listed in Table 1.

Abundant research has been carried out on the biology, ecology, and control of *Cyperus escu- lentus* (Keeley and Thullen 1993), its morpho- logical characterization (Alonso, Eyherabide, and Leaden 1997) and genetic variation (Holt 1994; Okoli et al. 1997) of the chufa as weed. However, until recently, *Cyperus esculentus* as a cultivated plant had been rarely studied. Never- theless, the interest in this crop seems to be in- creasing worldwide and for this reason several articles on the distribution of chufa, including the cultivated plant (ter Borg and Schippers 1992; de Vries 1991) have been published in recent years. Likewise, research on new products obtained from the chufa tubers has also been carried out quite recently, as will be dis- cussed in this article.

Eerkens (1986) calculated that the production efficiency (Pey) rate of chufa amounted to 15; he thought that effective breeding could improve the yield and the Pey up to 17. He recommended that European Union entrepreneurs submit a sound holistic investment plan for the exploitation of new crops, such as the chufa, so they could obtain ample funding for their new industries using new raw materials.

Tubers of chufa have been identified as a valuable food for waterfowl and cranes. Bio- mass production of chufa was studied by Kelley (1990) in a managed, seasonally flooded wetland in southeast Missouri. He concluded that it may be possible to take advantage of chufa repro- ductive processes to increase tuber production for wildlife food.

Chufa tubers contain a rather high amount of dietary fiber (Linsen, Cozijnsen, and Pilnik 1989; Pascual et al. 1993). According to re- search done by Linsen, Cozijnsen, and Pilnik (1989) the majority of its dietary fiber consists of insoluble carbohydrates, mainly cellulose and lignin; xylose is present as a substantial proportion of the insoluble dietary fiber fraction. These researchers concluded that chufa could be useful as a good source of dietary fiber in food technology because of this large amount of dietary fiber and the pleasant, nutty flavor.

Oderinde and Tairu (1992) determined the tri- glyceride, phospholipid, and unsaponifiable fractions of tuber oil. According to these authors, chufa is potentially a commercial source of high-oleic acid vegetable oil and high-carbohydrate tuber cakes. They believe that tuber oil could be exploited in the same way as olive oil, i.e., for high-quality salad oil and as a source of medium-chain fatty acids for oleochemicals. Further improvements of tuber yield and characteristics after agronomic studies, coupled with the exploitation of its tuber carbohydrates, could serve to enhance the economic position of the chufa.

Omode, Fatoki, and Olaogun (1995) studied the viscosity, minerals, percentage of fatty acids, and other characteristics of the chufa oilseeds. Kapseu, Mbofung, and Kayem (1977) analyzed the fatty acids and triglycerides of tuber oil from chufas. This oil can be classified in the oleic- linoleic oil group. Because of the high contents of oleic acid (66%), chufas are an interesting addition to human foods. Chufa could be used as a potential supplement to or substitute for olive oil given its fatty acid composition and other physicochemical properties. It could also be use- ful in the coating industry and as diesel fuel due to its low viscosity value.

Componen!	Tubers (g/100 g DM)	Horchata (%)
Fat[2]	30.2	2.5
Starch[2]	35.0	2.2
Protein	12.0	1.8
Ash	1.2	0.4
Dietary fibre	9.8	0.1
Sucrose	11.8	
Soluble Solids (º Brix)2,3		4.5-12.0

' Sources: Diario Oficial Generalidad Valenciana 1989; Pascual et al. 1993.
[2] Minimum values required by Diario Oficial Generalidad Valenciana (1989).
'Values of unsweetened and manufactured horchata respectively.

Adebajo (1993) determined the relationship between microbial populations and inverted sugar levels in tubers of chufa stored at different temperatµres, in order to gain insight into the relevance of storage conditions on tuber quality. The results obtained in raw juice extracts suggest that yeast could possibly play a greater role than bacteria in the hydrolysis of sucrose in vivo. In their study on the improvement of the yield of ethanol from cheap and locally available substrates, Esuoso et al. (1993) determined the optimum substrate concentration, pH and temperature on the batch alcoholic fermentation of chufa. Zhang et al. (1996) measured the physical and fuel properties of oil extracted from the chufa cultivated in China, and concluded that the physical properties are similar to other vegetable oils. Additionally, they suggested that this oil may also be used as biodiesel fuel.

Cantalejo (1996) studied the differences among several products made with toasted tu- bers, with the aroma extracted from tubers by high vacuum distillation, and the mixture of both in different proportions in order to determine the acceptability and the potential market of new products derived from chufa: aqueous solutions (as a base for non-alcoholic beverages), milky solutions (as refreshing beverages or partial milk substitutes), as well as cookies and ice cream made with chufa. Because ftavor and aroma are fundamental attributes of the *horchata* and the *horchata* made from roasted tubers, Cantalejo (1997) analyzed the volatile aroma components of raw tubers and those developed in a roasting process. The main ftavor compounds identified in raw tubers were alcohols, whereas in roasted tubers, the majority of the volatiles identified suggest the flavor formation is achieved through the Maillard reaction, with pyrazines contribut- ing directly to the roasted flavor of the chufa.

Umerie and Enebeli (1996) reported on the preparation and characterization of caramel from malted tubers of *Cyperus esculentus.* This caramel appeared as a brown-black syrup which remained clear in 50% alcohol; it may be used to add body, flavor, or color to certain baked products, non-alcoholic malt beverages and dark beers, and in the production of condiments. Umerie, Obi, and Okafor (1997) reported on the isolation and characterization of starch from chufa tubers. They concluded that it was easily isolated and was suitable for many applications. The starches obtained from chufa and rice.

showed similar properties; the solutions of the starch exhibited a good paste stability, clarity, aNd adhesive strength. The study also indicated that the starch can be used in many starch-based foods as well as in the cosmetic industry, and for laundry, glazing, and stiffening. The extraction of oil from chufa tubers left a waste residue which could be further modified producing syrups, flours, or livestock feeds. Umerie and Uka (1998) studied the composition of the defatted grits and characterized the wort obtained by mashing the grits using commercial enzymes. They concluded that this material should be put to better uses, for instance in brew wort production in the brewing industry, instead of its primary utilization in livestock feedstuffs.

The total antioxidant capacity of aqueous ex- tracts of seventeen wild plants gathered from sub-Saharan Africa (Niger), among them the chufa, was measured by Cook et al. (1998). Their conclusions indicated that chufa tubers have a relatively high total antioxidant capacity, because they contain considerable amounts of water-soluble flavonoid glycosides. These glycosides are antioxidants with anticancer proper- ties, which could possibly contribute to reducing oxidative damage to human cells and tissues, given that oxidative stress characterizes many human diseases, as is the case of HIV. Research suggests that malnutrition reduces cellular immune function and the consumption of antioxidants could protect the immune system of mal- nourished populations. Thus, the intake of anti-oxidant-containing foods may in fact delay progression of HIV infection to AIDS, a disease which is widespread in sub-Saharan Africa. Due to the scarcity of resources for treating HIV-infected patients, the consumption of chufa tubers may be recommended for this-population.

Considering the aforementioned results, the growing interest in this crop is easily explained. Moreover, the research carried out by our team since 1978 has resulted in being particularly relevant given the scarcity of studies on the cultivation of chufa, as discussed in the preceding pages. Lack of studies on this topic could be due to the fact that the chufa, *Cyperus esculentus* L., is considered a weed in much of the world. Therefore, studies on its morphology, physiology, and control as a weed exist, but little re- search has been done regarding its cultivation.

STUDIES ON THE CULTIVATION OF CHUFA

Since 1978 our research team has carried out a number of studies related to the cultivation of the chufa. This research has included studies on, for example, the nutrients of the organs, tech- niques of agronornic management, as well as se- lection and characterization of cultivars carried out both in in-field and in pot cultivation, and in the latter case, using substrates such as sphag- num peat and perlite and nutritive solutions such as Hoagland's solution and a Meier-Schwarz modified solution

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NUTRIENT CONTENT OF THE DIFFERENT ORGANS OF THE CHUFA PLANT AND THE CORRELATION WITH PRODUCTION

Evaluation of Extractions

When establishing the bases for rational fertilization of any crop, it is necessary to have prior knowledge of global extractions and the absorption rate of different nutrients. Although there are interesting publications on the extraction of nutrients from horticultural plants (e.g., Maynard and Hochmuth 1997:158-159), nothing is usually said about the needs of chufa, which is logical given that interest in this plant so far is geographically confined to a few areas. Moreover, when the present research was begun, there were no publications regarding the rate of nutrient absorption.

Our research allowed us to determine the evolution of N, P, and K contents in the organs of the plant as well as to evaluate the needs in 240- 35-300 kg/ha respectively (Maroto and Pascual 1984) and determine the corresponding absorption rates. Likewise, research enabled us to determine the evolution in the content and total extractions of Ca, Mg, Fe, Cu, Zn, and Mn (Serra and Peiró 1984). Results confirmed that it is a species with considerable nutritional demands in comparison with the majority of vegetable crops, as tomato, potato, onion, lettuce, melon, etc. (Maynard and Hochmuth 1997:158-159). Table 2 shows the tuber nutrient content.

Further research together with fertilization tests analyzed the nitrogenous and potassic nutritional state of the plant as well as the correlation between different nutritional indexes and the tuber production. Throughout the cultivation cycle, the plants fertilized with high doses of N (390 and 520 kg N/ha) presented higher contents of N in the leaves than both plants fertilized with low doses (195 kg N/ha) and the control plants (0 kg N/ha). During most of the cycle, especially at the last stage, plants receiving low or null doses of N presented higher concentrations of K in the leaves. The ratio between *KIN* contents in the leaves varied throughout the cycle; this ratio showed significant differences in the sampling carried out in September depending on the N doses given, being higher the values corresponding to the control plant and lower those corresponding to higher doses. There was a high correlation between tuber production and the ratio *KIN* from September on (Pascual et al. 1997a), the time when the transport of photoassirnilates from the leaves to the tubers is particularly important. No antagonism was registered between N and K absorption.

FERTILIZATION

Just as the case with nutrition, there is little literature available regarding fertilization in chufa. The most relevant study in this field is probably the one that was carried out in Florida (Killinger and Stokes 1951) which analyzed the productive response to different fertilization rates of chufa plants, which were cultivated in small quantities as pig food. The authors stated that the response to the application of fertilizers was somewhat erratic.

During six campaigns different fertilization levels were used (Maroto et al. 1986a). In the range of 250-400 kg/ha, N doses had no effect on tuber production; higher amounts of N (520- 780 kg/ha) led to a reduction in production. It could be concluded that in the case of soils with an average fertility rate, the results of using high doses of N range from no increase in tuber production to negative responses. No relationship was found between leaf production and the doses of N. High N did not increase the height of plants at any of the stages of the cultivation cycle; on the contrary, they led to a lower rate of lodging.

LODGING CONTROL THROUGH GROWTH RETARDANTS

Under normal conditions, lodging usually occurs from mid-August on, after the leaves have become long. However, when plants grow too lavishly, lodging appears untimely, starting in July, so that the plant withers too early and production decreases. Around 1980 it was widely held that lodging was the result of too much N fertilization, but according to our aforementioned experiments on fertilization in this field, no clear relationship between N fertilization and untimely lodging could be identified.

Over a period of four years, tests with growth retardants were carried out both in in-pot and in- field cultivation (Pascual and Maroto 1984a). In pots a chlormequat chloride spray of 500-4000 ppm slowed down lodging for two weeks, but this led to no significant increase in tuber production or unit weight. In the in-field crop these treatments were not effective, but a direct effect of wind on the incidence of lodging was observed: those areas which were exposed to the dominant winds showed untimely lodging, which was not the case in more protected areas (Maroto et al. 1986b).

STUDIES ON THE ÜORMANCY OF TUBERS

Tuber germination can be inhibited by sub- stances produced at the base of the tuber (Tum- bleson and Kommedahl 1962). Chilling, scarification, and the use of hydrogen peroxide, were successful to enhance the germination of South African tubers, thanks to an increase in the oxygen supply which interrupted the dormancy mechanism in the tubers (Thomas 1967). Even though the intensity of this dormancy is of little interest for in-field cultivation, it is quite relevant when using the plant in the laboratory in order to obtain two crops per year so that re- search can be done more quickly.

One three-year study indicated that Valencian chufa populations did not show dormancy and the tuber sprouting improved with higher temperatures, being the optimum temperature around 30ºC (Pascual and Maroto 1984b). Our research in cultivation in-field in Valencia (Spain) has shown that tubers from Africa pre- sent a lower rate of sprouting and require more time to properly emerge than those Valencian populations. This fact is closely related to higher thermic needs (Pascual et al. 1997b). Washing the tubers with tap water did not increase sprouting of Valencian tubers, results which differ from those of Tumbleson and Kommedahl (1962) obtained with tubers harvested in Minnesota. This difference may be explained by the use of different vegetable material.

INFLUENCE OF THE PLANTING DATE ON YIELD

The date of cultivation of chufa tubers has varied throughout time. Formerly tubers were usually planted at the beginning of July after the wheat harvest. Later, planting started in June and more recently the first fortnight of May. In the early 1980s most farmers preferred to plant tu- bers even earlier in the year so as to increase production.

In-pot and in-field tests were carried out over four years. Planting in rnid-April increased tuber production; however, planting in April is not al- ways possible, since often previous crops, such as potato and onion, have yet to be harvested. Moreover, in Valencia, April is generally a rainy month, and rain usually impedes the preparation of the land for planting. However, weather and previous crops permitting, it is advisable to plant early, since in most years the temperature of the soil reaches the values necessary to allow for the adequate and early germination of tubers, which means an extension of the cultivation cycle and an increase in yield (Maroto et al. l986c; Pascual and Maroto 1984c).

INFLUENCE oF SoIL TEXTURE ON THE AMOUNT AND QUALITY OF TUBERS

The most appropriate soil texture for chufa cultivation is sandy-loam, due to its physical and chernical characteristics; additionally, it is loose enough so that when the upper 15-20 cm is sifted during harvest, the tubers collected are relatively free of soil. Although most soils in chufa- producing areas are sandy-loams, it was interesting for our research to determine objectively the influence of soil texture on the formation of tubers both in terms of yield and external appearance (i.e., quality), since chufa cultivation could be extended to other areas.

In-pot tests were carried out during two cam- paigns; four types of substrate were tested: clay soil, sandy-loam soil, river sand, and quarry sand. Significant differences were found as regards to the average tuber size and yield, which clearly favored plants grown in sand, whereas the mínimum values corresponded to plants grown in clay (Pascual and Maroto 1981). The diameter of tubers grown in sand was larger; tu- bers also had a larger number of roots. This was not a problem since roots can be easily elimi- nated by increasing the friction time among tu- bers during their washing. Obviously, sandy soil requires more frequent irrigation and fertilization than other soil types.

THE USE OF HERBICIDES

Weeds do not usually pose serious problems when growing chufas. However, when they do, herbicides or a great deal of manual labor must be used to eliminate them, since sorne weeds seem to have an advantage over the chufa at the earlier stages of growth.

Although there is much literature referring to the control of chufas as a weed, nothing could be found in the late 1970s on the subject of chemical weeding in chufa cultivation. Consequently, a number of herbicides were tested over a two-year period. Applied immediately after planting, linuron, alachlor + atrazine and simazine were most effective for controlling the weeds *Amaranthus blitum* L. ssp. *emarginatus, Amaranthus viridis* L., *Capsella bursa-pastoris* Moench., *Poa annua* L., *Portulaca oleracea* L., and *Urtica urens* L. Atrazine has a high residual effect that could affect posterior crops. When no pre-emergence treatment has been implemented, phendemipham + desmedipham, MCPA, or paraquat as a post-emergence treatment can be beneficial if weeds are at an early stage of their growth and if the chufa plants are not sprayed, since direct contact with these herbicides severely damages the chufa plant (Pascual et al. 1990).

SELECTION AND CHARACTERIZATION OF CHUFA CULTIVARS

Our research team has grown in-pot plants which belong to the botanic variety *esculentus* from Galicia (Spain) and Salta (Argentina). The characteristics of these tubers are completely different from those populations grown in Valencia, which belong to the botanic variety *sativus.* Clear differences also exist within the Valencian populations of chufa and the genetic variability of the current chufa populations has been verified (Pascual et al. 1997b).

The objective of a seven-year research project (Pascual et al. 2000) was to carry out a clonal selection and characterization of the selected clones on the basis of the following: horticultura} and morphological characteristics, the chemical composition of the tubers and the *horchata,* sensory analysis of *horchata,* a test based on protein pattems and random amplified polymorphic DNA (RAPD). With the results of each year, an estimation of the broad-sense heritability was obtained. Using the parameters that presented sufficient heritability, a discriminant analysis was carried out every year, which allowed for a separation of different clones into uniform clusters, as well as a reduction in the number of clones studied in successive programs, selecting within each cluster the clones that presented the best traits. Thus, the number of selected clones was reduced to eight.

The following traits showed high heritability: the number of leafy shoots per tuber, length, length/width ratio, unit weight of tuber, and number of tubers per plant. The remaining parameters studied showed lower heritability. The chemical composition of tubers presented, as a rule, low heritability. Discriminant analysis led to a reduction in the number of clones initially tested, and the existence of three groups clearly differentiated was verified. The differences shown by different groups allow them to be clas- sified as different cultivars, while the differences within each group are insufficient for them to be considered different cultivars. Therefore, the fol- lowing cultivars should, in our opinion, be included in the Register of Protected Varieties: 'Ametlla Bonrepos', 'Gegant Africana', and 'Llargueta Alboraia' (Fig. 2).

'Ametlla Bonrepos' produces small spherical tubers (length 12.4 mm, length/width ratio 1.16) with high fat content (25.5%), which is much appreciated in the production of *horchata;* it also has a good tuber yield (15 977 kg/ha).

'Gegant Africana' is characterized by its large size (length 17.3 mm, length/width ratio 1.62), the unit weight of their tubers (l.09 g), the low number of leafy shoots (40.2), the low number of tubers per plant (266.9) and their intense bloom (38 033 inflorescences/ha). Large tubers make this variety particularly suitable for its fresh consumption.

'Llargueta Alboraia' produces average size oval tubers (length 15.2 mm, length/width ratio 1.68) with high fat content (25.87%). It yields more than other cultivars (18 525 kg/ha); this cultivar is much appreciated in the production of *horchata.*

Total protein electrophoresis was unable to distinguish the different clones tested, but the RAPD technique was powerful enough both to discrirninate between the eight cultivated clones and the two weedy clones tested and to characterize them (Abad et al. 1998); the clones tested were classified in two groups, but two cultivated clones were more closely related to weedy clones than to other cultivated clones. This technique would improve the correct identification of chufa cultivars in order to protect patent rights.

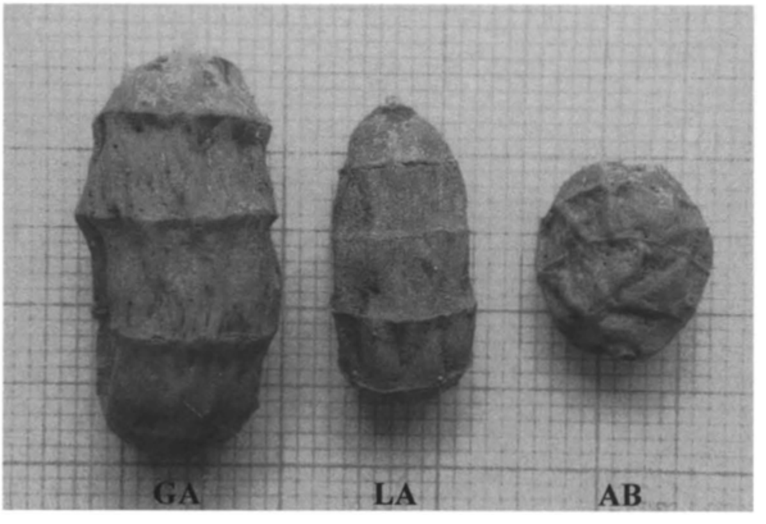

Fig. 2. Tubers of 'Gegant Africana' (GA), 'Llargueta Alboraia' (LA) and 'Ametlla Bonrepos' (AB) cultivars.

LITERATURE CITED

Abad, P., B. Pascual, J. V. Maroto, S. López-Gal- arza, M. J. Vicente, and J. Alagarda. 1998. RAPO analysis of cultivated and wild yellow nut- sedge *(Cyperus esculentus* L.). Weed Science 46: 319-321.

Adebajo, L. O. 1993 Microbial counts and invert sug- ars in juice extracts from stored tubers of *Cyperus esculentus* (earth almond). Nahrung 37:607-612.

Alonso, S. I., J. J. Eyherabide, and M. I. Leaden. 1997. Caracterización morfológica de clones de *Cyperus rotundus* and C. *esculentus* del sudeste de la provincia de Buenos Aires. Revista Facultad Agronomía, La Plata 102:33-44.

Cantalejo, M. J. 1996. Development of new products from earth-almond. Fruit Processing 3:87-91.

——. 1997. Analysis of volatile components de- rived from raw and roasted earth-almond *(Cyperus esculentus* L.). Journal of Agricultura! Food Chem- istry 45:1853-1860.

Cook, J. A., D. J. VanderJagt, A. Dasgupta, G. Mounkaila, R. S. Glew, W. Blackwell, and R. H. Glew. 1998. Use of the Trolox assay to eslimale the antioxidant content of seventeen edible wild plants of Níger. Life Sciences 63: 106-110.

Dancza, I. 1994. A mandulapalka (*Cyperus esculentus* L.) elofordulaca Kesthely-Heviz hataraban . Nove- nyvedelem 30:475-476.

de Vries, F. T. 1991. Chufa *(Cyperus esculentus, Cy- pera ceae):* a weedy cultivar or a cultivated weed?. Economic Botany 45:27-37.

Diario Oficial Generalidad Valenciana. 1989. Ordre per la qua! es regulen les denominacions especi- fiques "Xufa de Valencia" i "Orxata Valenciana de Xufes" i el seu Consell Regulador. Diari Oficial Generalitat Valenciana, Spain 1034:2031-2043.

Eerkens, C. 1986. An holistic approach to evaluate the polential productivity of unconventional crops.

Pages 104-114 *in* W. F. Raymond and P. Larvor, eds., Alternative uses for agricultura! surpluses. El- sevier Applied Science, London.

Esuoso, K. O., R. A. Oderinde, F. J. Vega-Catalán, and F. O. Bamiro. 1993. Optimization of batch alcoholic fermentation of *Cyperus esculentus.* Nah- rung 37:274-276.

Gerhold, K. H. 1992. Breitet sich Erdmandelgras wei- ter aus?. Pflanzenschutz Praxis 1:29.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1977. The world's worst weeds. Distribution and biology. Hawaii University Press, Honolulu.

Holt, J. S. 1994. Genetic variation in life history in yellow nutsedge *(Cyperus esculentus* L.) from Cal- ifornia. Weed Science 42:378-384.

Kapseu, C., C. M. F. Mbofung, and G. J. Kayem. 1997 Acides gras triglycérides des huiles de fruits de *Cyperus esculentus.* Sciences des aliments 17: 531-537.

Keeley, P. E., and R. J. Thullen. 1993. Weeds in cotton: their biology, ecology, and control. Tech. Bu!!. USDA, 1810, Shafter, CA.

Kelley, J. R. 1990. Biomass production of chufa *(Cy- perus esculentus)* in a seasonally flooded wetland. Wetlands 10:61-67.

Killinger, G. B., and W. E. Stokes. 1951. Chufas in Florida. Univ. of Florida, Agricultura! Experiment Station, Bull. 419, Gainesville, FL.

Kükenthal, G. 1936. Cyperaceae, Scirpoideae, Cyper- eae. Pages 116--121 *in* A. Elder, Das Pflanzenreich 4. 20. Verlag Engelman, Leipzig.

Linssen, J. P. H., J. L. Cozijnsen, and W. Pilnik. 1989. Chufa *(Cyperus esculentus* L.): a new source of dietary libre. Joumal Science Food Agricultural 49:291-296.

Maroto, J. V., and B. Pascual. 1984. Estudio sobre la respuesta productiva del cultivo de la chufa *(Cy- perus esculentus* L.) a diferentes combinaciones de fertilización mineral. Anales del Instituto Nacional de Investigaciones Agrarias. Serie Agrícola 25:55- 65.

———, ———, J. Alagarda, and S. López-Galarza. l986a. Respuesta productiva a distintos abonados nitrogenados en el cultivo de la chufa *(Cyperus es- culentus* L.). ITEA. 6:105-110.

———, ———, S. López-Galarza, and J. Alagar- da.1986b. Estudio sobre la hipotética influencia de la aplicación de un retardador del crecimiento sobre el encamado y la productividad del cultivo de la chufa *(Cyperus esculentus* L.). Agrícola Vergel 58: 571-573.

———, ———, J. Alagarda, and S. López-Galar- za.l986c. Estudio de la fecha de plantación sobre diversos parámetros productivos del cultivo de la chufa *(Cyperus esculentus* L.). Actas II Congreso Nacional de la Sociedad Española de Ciencias Hor- tícolas 1:450-458.

Maynard, D. N., and G. J. Hochmuth. 1997. Knott's handbook for vegetable growers. John Wiley & Sons, New York.

Ministerio de Agricultura Pesca y Alimentación. 1997. Anuario de estadística agraria. M.A.P.A., Se- cretaría General Técnica, Madrid, Spain.

Morell, J., and S. Barber. 1983. Chufa y horchata: características físicas, químicas y nutritivas. Instituto de Agroquímica y Tecnología de Alimentos (C.S.I.C.), Valencia, Spain.

Negbi, M. 1992. A sweetmeat plant, a perfume plant and their weedy relatives: a chapter in the history of *Cyperus esculentus* L. and *C. rotundus* L. Eco- nomic Botany 46:64-71.

Oderinde, R. A., and A. O. Tairu. 1992. Determi- nation of the triglyceride, phospholipid and unsa- ponifiable fractions of yellow nutsedge tuber oil. Food Chemistry 45:279-282.

Okoli, C. A. N., D. G. Shilling, R. L. Smith, and T. A. Bewick. 1997. Genetic diversity in purple nut- sedge *(Cyperus rotundus* L.) and yellow nutsedge (*Cyperus esculentus* L.). Biological Control 8:111- 118.

Omode, A. A., O. S. Fatoki, and K. A. Olaogun. 1995. Physicochemical properties of sorne under- exploited and nonconventional oilseeds. Joumal of Agricultura! Food Chemistry 43:2850-2853.

Pascual, B., and J. V. Maroto. 1981. Influencia de la textura en la cuantía y calidad de los tubérculos de las chufas *(Cyperus esculentus* L.). Agricultura 592:873-875.

———, and ———. l984a. Estudios agronómicos realizados en el cultivo de la chufa (*Cyperus es- culentus* L.). Diputación Provincial de Valencia, Spain.

——, and ——. 1984b. Estudio básico sobre la hipotética latencia de los tubérculos de las pobla- ciones valencianas de chufa *(Cyperus esculentus* L.). Anales del Instituto Nacional de Investiga- ciones Agrarias, Serie Agrícola 25:67-77.
——, and ——. 1984c. Ensayos en contenedores y en pleno campo sobre la influencia de la fecha de plantación del cultivo de la chufa (*Cyperus es- culentus* L.). Anales del Instituto Nacional de In- vestigaciones Agrarias, Serie Agrícola 25:79-86.
———, J. Alagarda, S. López-Galarza, and J. V. Maroto. 1989. El cultivo de la chufa *(Cyperus es- culentus* L.) en España. 4TH Symposium on weed problems in the mediterranean climates. European Weed Research Society: 141-151.
——, V. Castell-Zeising, S. López-Galarza, and J. V. Maroto. 1990. Ensayo de desyerbe químico en el cultivo de la chufa *(Cyperus esculentus* L.). Actas de Horticultura 5:326--331.
——, ——, M. Bono, and J. V. Maroto. 1993. Estudios de tipificación y selección de líneas clon- ales cultivadas de *Cyperus esculentus* L. Actas 11 Congreso Ibérico de Ciencias Hortícolas 2:1015- 1020.
———, J. V. Maroto, S. López-Galarza, V. Castell- Zeising, and J. Alagarda. 1997a. Fertilizacion y nutrición nitrogenada y potásica en el cultivo de la chufa. Actas de Horticultura 17:228-233.
———, ———, ———, J. Alagarda, and V. Cas- tell-Zeising. 1997b. El cultivo de la chufa *(Cyperus esculentus* L.). Estudios realizados. Generalitat Val448 enciana, Conselleria de Agricultura, Pesca y Ali- mentación, Valencia, Spain.
——, V. Castell-Zeising, S. López-Galarza, A. Sanbautista, and J. V. Maroto. 2000. Selectíon and characterisation of chufa cultivars *(Cyperus es- culentus* L. var. *Sativus* Boeck). Acta Horticulturae 523:37-44.
Rotteveel, A. J. W. 1993. Tien jaar knolcyperus (*Cy- perus esculentus* L.) in the Netherlands. Gorteria 19:65-73.
Schmitt, R. 1995. Die "neuen" unkrauter Knollchen- Zypergras und Aleppo-Hirse. Agrarforschung 2: 276-278.
——, and A. Sahli. 1992. Eine in der Schweiz als Unkraut neu auftretende Unterart des *Cyperus es- culentus* L. Landwirtschaft Schweiz 5:273-278.
Serra, J. A., and R. Peiró. 1984. Estudio analítico de la variación a lo largo del ciclo de cultivo del cal- cio, magnesio y principales micronutrientes en los distintos órganos de la planta de chufa, y evalua- ción de las extracciones totales. Pages 75-84 *in* B. Pascual, and J.V. Maroto, eds., Estudios agronóm- icos realizados en el cultivo de la chufa *(Cyperus esculentus* L.). Diputación Provincial de Valencia, Spain.
Serrallach, J. 1927. Die wurzelknolle von *Cyperus esculentus* L. Ph.D. thesís, University Frankfurt am Main.
Tackholm, V., and M. Drar. 1950. Flora of Egypt. Vol. II. Fouad University Press, Cairo.
ter Borg, S. J., and P. Schippers. 1992. Distributíon of varieties of *Cyperus esculentus* L. (yellow nutsedge) and their possible migration in Europe. IXe Colloque Intemational sur la biologie des mauvais- es herbes. Annales: 417-425.
Thomas, P. E. L. 1967. A preliminary study on the dormance of *Cyperus esculentus* tubers. PANS 13: 329-333.
Tumbleson, M. E., and T. Kommedahl. 1962. Fac- tors affecting dormancy in tubers of *Cyperus es- culentus.* Botanical Gazette 123:186-190.
Umerie, S. C., and J. N. Enebeli. 1996. Malt caramel from tubers of *Cyperus esculentus.* Bioresource Technology 57:215-216.
——, N. A. N. Obi, and E. O. Okafor. 1997. Iso- lation and characterization of starch from *Cyperus esculentus* tubers. Bioresource Technology 62:63- *65.*
——, and A. S. Uka. 1998. Brew wort from *Cy- perus esculentus* tubers. Bioresource Technology 66:83-85.
Wills, G. D. 1987. Description of purple and yellow nutsedge *(Cyperus rotundus* and C. *esculentus* L.). Weed Technology 1:2-9.
Zhang, H. Y., M. A. Hanna, Y. Ali, and L. Nan. 1996. Yellow nutsedge *(Cyperus esculentus* L.) tu- ber oil as fue!. Industrial crops and products 5: 177- 181.
Zohary, D. 1986. The origin and early spread of ag- riculture in the Old World. Pages 3-20 *in* C. Bar- igozzi, ed., The origin and domestication of culti- vated plants. Elsevier, Amsterdam.
——, and M. Hopf. 1993. Domestication of plants in the Old World. Clarendon Press, Oxford.