Europ.J.Hort.Sci., **71** (3). S. 102–108, 2006, ISSN 1611-4426. © Verlag Eugen Ulmer KG, Stuttgart

Rootstock Influence on Fruit Yield, Growth and Mineral Nutrition of Mango (*Mangifera indica* L. cv. 'Keitt')

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Summary

Fruit yield, tree size, and trends in leaf-nutrient content (N, P, K, Ca, Mg, Fe, Zn, Mn, and Cu) have been studied for two years (2001–2002) in a mature orchard of mango trees (*Mangifera indica* L. cv. 'Keitt'), grafted onto four rootstocks: Gomera-1, Gomera-3, Turpentine, and 13/1. The fruit yield was the highest on Gomera-3 and lowest on Turpentine, the fruit being significantly smaller with Gomera-1 than the other rootstocks. In addition, the height, canopy volume and the trend of the trunk cross-sectional area (TCSA) were greater with Gomera-3. Higher macronutrient contents of cv. 'Keitt' were found on Gomera-3 and lower on 13/1 rootstock trees. A similar trend was found with the micronutrients but lower contents on Gomera-1. Thus, leaf-nutrient content correlated with fruit yield of cv. 'Keitt' on Gomera-3, indicating the effectiveness of this combination.

Key words. fruit yield – mangoes – nutrient level – rootstock – trunk cross sectional area

Introduction

Mango (*Mangifera indica* L.) production is rising in various subtropical zones throughout the world, particularly the Mediterranean basin, for international trade. More specifically, cultivation of the mango in south-eastern Spain is steadily increasing due to the high yield potential in the zone and the demand for the fruit in the Spanish and European markets (FAO-STAT 2004). Cultivation is feasible primarily in the provinces of Granada and Malaga, with some 800 ha of mango orchards soon to exceed a yield of 5.000 t year^{-1}. Practically all mango orchards are located on steeply sloped orchard terraces having a single row of trees. Under these conditions, little is known concerning the most favourable combination of cultivar and rootstock. Studies in many parts of the world have demonstrated the strong influence of mango polyembryonic rootstocks on the fruit yield growth and mineral nutrition of the cultivar (GOWDER et al. 1971; JAUHARI et al. 1972; SINGH and SINGH 1976; PÉREZ et al. 1987; REDDY et al. 1989; 2001; SIMAO et al. 1994; KURIAN et al. 1996; NARTVARANANT et al. 2003).

The main polyembryonic rootstocks, Gomera-1 and Gomera-3 (from the Canary Islands), are widely used in Spain (GALÁN and GARCÍA 1979). Other imported rootstocks are used on a smaller scale, such as the Turpentine, which is widely favoured in Florida (USA), and Central America (CRANE and CAMPBELL 1994), and the Israeli 13/1 (KADMAN et al. 1976; GAZIT and KADMAN 1983). The scions most commonly used in the zone, because of their excellent fruit flavour and commercial value, include the Florida cultivars 'Osteen', 'Keitt', 'Tommy Atkins', 'Irwin', 'Lippens', and 'Sensation' (GALÁN 1999). The cv. 'Keitt' is one of the most internationally marketable, being cultivated in Australia, Brazil, Costa Rica, Ecuador, Egypt, Israel, Mexico, Peru, South Africa, Spain, USA, and Venezuela (HOMSKY 1997; GALÁN 1997; LEAL et al. 1997; RIAD 1997; WONG et al. 1997).

Few studies have been made under subtropical conditions to address the effect of the rootstocks on fruit yield and leaf-mineral content of the cultivar (DURÁN et al. 2003, 2004a, b). In these marginal environments for this crop, it is important to determine the different rootstock qualities in order to optimise the fruit production.

The main objective of the present study was to evaluate the performance of mango cv. 'Keitt' on four rootstocks as measured by fruit yield, growth and mineral nutrition.

Materials and Methods

Plant material and growth conditions

The study, spanning two years (2001–2002) on the experimental farm "El Zahorí" in the area of Almuñécar (Granada-SE Spain), was conducted on terraces located at 160–170 m a.s.l. on a steep, south-facing slope cultivated with 14-year-old mango trees. The terraces, representative of those commonly found in the study area, had trees planted 3 m apart in single rows, with terraces stepped roughly every 5 m (planting grid 3 m x 5 m). A total of 16 mango trees cv. 'Keitt' (~630 trees ha^{-1}) grafted onto four rootstocks Gomera-1 (G1-Kt), Gomera-3 (G3-Kt), Turpentine (Tp-Kt) and 13/1 (13/1-Kt) were studied. The experimental design was a randomised com-

plete block with four replicates. Local cultivation techniques were used for all the trees: drip irrigation with 4 self-regulating emitters per tree for a flow of 4 l h^{-1} each. The fertilizer-application rate per tree was 240 g N, 31 g P, and 176 g K.

The soil was typical Xerorthent (Soil Survey Staff 1999). The characteristics of sandy loamy soil were 600 g kg^{-1} of sand, 270 g kg^{-1} of silt and 130 g kg^{-1} of clay, containing 11 g kg^{-1} of organic matter, and 6.0 g kg^{-1} N, with 67.0 mg P kg^{-1} and 178.1 mg exchangeable K kg^{-1}. The soil pH was 7.74 and electrical conductivity of the saturation extract at 25 °C was 0.89 dS m^{-1}. All determinations were performed according to the Official Methods of Soil Analysis (Mapa 1994).

Measurements, chemical analyses, and evaluation

At the end of each harvest, fruit yield was evaluated by measuring length, width and weight. Also, at this stage the height and canopy diameter as well as trunk circumference of tree (15 cm above the bud union) were recorded. Canopy volume was calculated using the equation for one-half of a proplate spheroid (Castle and Phillips 1980; Avilan et al. 1997a) and trunk circumference was converted into trunk cross-sectional area (TCSA). Yield efficiency was estimated as the ratio of cumulative yield to TCSA and canopy volume (Webster and Brozono 1980; Moreno et al. 1996).

Throughout the two study years, foliar samples were taken from grafted trees from the middle part of the canopy, following the cardinal points from the middle position of healthy branches with similar physiological age during dormancy, flowering, fruit set, fruit growth, and harvest. Leaf samples were chemically analysed after washing and rinsing with distilled water and drying at 70 °C for 48 h to constant weight. Afterwards, the material was ground and then screened at 0.5 mm. The K, Ca, Mg, Fe, Zn, Mn and Cu in the plant material were determined by atomic-absorption spectrophotometry (Chapman and Pratt 1961). The P was determined by the molybdenum-blue method (Fiske 1952), and the total N by the Kjeldahl method (Bremner 1965).

An analysis of variance (ANOVA) was performed to determine the effect of the rootstocks on fruit yield, TCSA, canopy volume and foliar-nutrient contents. The measurements were evaluated by Duncan's multiple-range test at a level of 0.01.

Results and Discussion

Fruit yield and tree size

Table 1 presents the yield and fruit dimensions for each combination tested, showing significantly higher values in G3-Kt for fruit yield with respect to the other combinations over the 2-year study. On the contrary, Tp-Kt produced the lowest fruit yield per tree. Taking into account the plant density (~630 trees ha−1) the production of G3-Kt and Tp-Kt was 13 and 9 t ha−1, respectively. Also, the weight of fruits with G3-Kt was bigger than with the other combinations. Statistical differences appeared in fruit length and width with G1-Kt, being smaller than the other combinations. There was no evidence of biennial bearing over the two-year study period, given that yields were similar ($P<0.01$).

Yield in the study zone differed appreciably from that of fully tropical climates, where both the size of the tree and yield are bigger. For trees of a similar age (14 years) of the cv. 'Haden' in Venezuela, Avilan et al. (1981) reported low, medium and high yields of 700, 800 and 1000 fruits $tree^{-1}$, respectively. The climatic conditions in southern Spain represent the marginal limit for the mango to develop normally, and therefore the dimensions of the tree and its yield are lower. However, this quality allows orchards to have a high density of trees, facilitating harvest and pesticide applications (Iyer et al. 1992; Reddy et al. 2002).

Table 1. Fruit yield and characteristics of cv. 'Keitt' fruits produced with different combinations during the study period (2001–2002).

Combination	Fruit yield (kg $tree^{-1}$)	Number (fruits $tree^{-1}$)	Fruit weight (g)	Length (cm)	Width (cm)
Tp-Kt	14.1a	16.9a	836.1ab	13.7a	10.4a
13/1-Kt	15.5ab	18.5a	835.5ab	13.6a	10.4a
G1-Kt	18.2bc	24.1b	755.6a	13.0b	10.1b
G3-Kt	20.5c	23.7b	867.7b	13.7a	10.4a
Year					
2001	17.9a	21.2a	845.0a	13.6a	10.4a
2002	16.2a	20.4a	802.4a	13.4a	10.2a
ANOVA					
R	**	**	**	**	**
Y	ns	ns	ns	ns	ns
R x Y	ns	ns	ns	**	ns

Values with different letters in the columns are significantly different according to Duncan's test at 0.01; ns: not significant; **: significant at 0.01;
R: Rootstock combination; Y: Year

Table 2. Effect of rootstocks on TCSA, tree size, and yield efficiency for cv. 'Keitt' during the study period (2001–2002).

Combination	TCSA (cm^2)	Canopy diameter (m)	Tree height (m)	Canopy volume (m^3)	Yield efficiency	
					($g\ cm^{-2}$)	($kg\ m^{-3}$)
13/1-Kt	495.2a	1.62a	2.0a	2.8a	31.8a	6.3a
Tp-Kt	511.1a	1.58a	2.3b	2.9ab	29.4a	5.2a
G1-Kt	590.8a	1.63a	2.5b	3.3ab	31.8a	5.8a
G3-Kt	655.0a	1.71a	2.9c	4.2b	33.6a	5.3a
Year						
2001	523.5a	1.60a	2.3a	3.1a	31.3a	5.7a
2002	602.5a	1.64a	2.5b	3.5a	31.9a	5.6a
ANOVA						
R	ns	ns	**	**	ns	ns
Y	ns	ns	**	ns	ns	ns
R x Y	ns	ns	ns	ns	ns	ns

Values with different letters in the columns are significantly different according to Duncan's test at 0.01; ns: not significant; **: significant at 0.01;
R: Rootstock combination; Y: Year; TCSA: Trunk cross-sectional area

In Australia, Smith et al. (1997) pointed out that cv. 'Tommy Atkins' yielded 43 % more on Turpentine rootstock than on Sabre, indicating the effect of the rootstock on fruit yield. Similar examples were reported in Venezuela (Chauran and Avilan 1981) and in India (Reddy et al. 2003). According to our results the influence of rootstock on fruit dimensions of the cultivar can be big especially with Gomera-1, in agreement with Avilan et al. (1997b) and Goncalves et al. (1998), who indicate the notable influence of the rootstock-scion combinations in the dimensions of the fruit, weight and shape.

Table 2 indicates that trees on Gomera-3 rootstock had the highest canopy volume and height, significantly differing from those of trees on the other rootstocks. Also the trends of TCSA and canopy diameter were greater with this rootstock. In this sense, Gomera-3 tended to be the most vigorous among the rootstocks tested.

The shortest trees were on 13/1 rootstock but did not differ significantly from those on Turpentine, Gomera-1 and Gomera-3 in terms of the canopy diameter.

Yield efficiency tended to be highest with Gomera-3 ($33.6\pm11.4\ g\ cm^{-2}$) and the lowest with Turpentine ($29.4\pm9.7\ g\ cm^{-2}$), whereas in terms of fruit yield per unit of canopy volume the 13/1 rootstock ($6.3\pm2.8\ kg\ m^{-3}$) registered the highest values. In the present experiment, yield efficiency expressed as fruit yield per unit of canopy volume ($kg\ m^{-3}$) correlated inversely with vigour components and canopy size of Gomera-3, in agreement with other studies on mango rootstock (Kurian and Iyer 1997) and on rootstocks in other trees species (Castle and Phillips 1980; Rose et al. 1989).

Effect of the rootstock on the foliar nutrient content

Table 3 presents the results for the analysis of variance, revealing significant differences for P and Mg foliar content of 13/1-Kt and for Ca content of G1-Kt with respect to the remaining combinations. Significantly higher contents in N and P levels were found with G3-Kt, and the trend was clear with the highest values of Ca with this combination. On the contrary, the 13/1-Kt had the minimum P content but the maximum for Mg. The K content for Tp-Kt and G1-Kt (0.53 %) was higher than 13/1-Kt and G3-Kt (0.43 %).

With regard to the micronutrients the Fe and Mn content with G3-Kt differed significantly from the other combinations. Also, comparing the combinations, G1-Kt had the lowest Cu content. As with the macronutrients, most of micronutrients tended to be higher with G3-Kt, except Cu, which was highest with 13/1-Kt. The average content of N, P, Ca, Mg, Mn and Cu was significantly higher during the second year.

The rootstock Gomera-3 (G3-Kt) reflects a root system with a higher capacity for uptake and transport of macro- and micronutrients than the other rootstocks, influencing the mineral nutrition of the scion, as shown in the foliar mineral content of the cv. 'Keitt'. A similar result was reported with the combination Gomera-3 and cv. 'Osteen' even under saline conditions (Durán et al. 2004b, c), and may be attributable to the vigorous root system of this rootstock, capable of providing the scion with effective mineral nutrition.

The foliar mineral concentrations in this study with cv. 'Keitt' closely approached levels considered adequate (Young and Koo 1971; Kumar and Nauriyal 1977; Bhargava and Chadha 1988; Tomlinson and Smith 1988).

Trends of the macro- and micronutrient contents in all combinations

During the production cycle, the mango tree varied notably in some of the macronutrient contents associated with the different states: dormancy, flowering, fruit set, fruit growth, and harvest. With this regard the variation in the P level (Fig. 1) was largely the reverse of those of Mg (Fig. 2). In addition, a comparison of combinations revealed few differences in the trends of any of the elements, but did reflect differences in the mag-

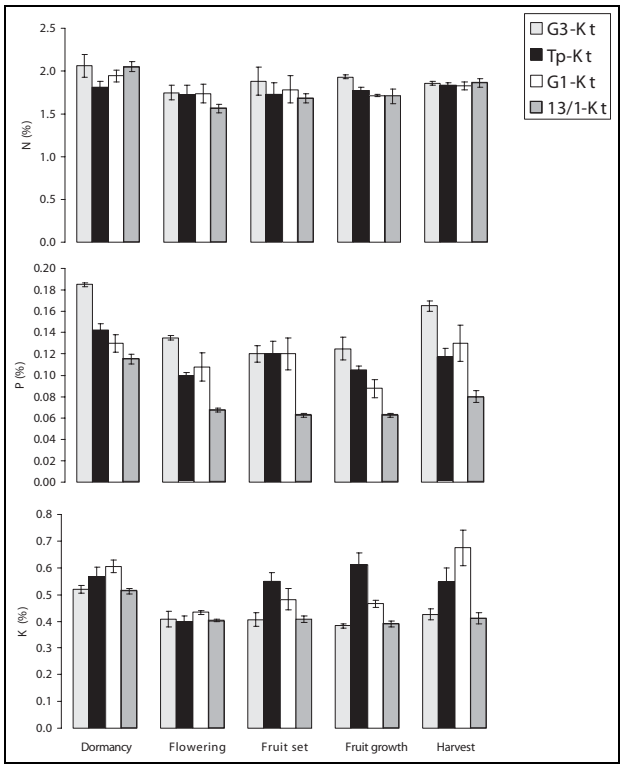


Fig. 1. N, P and K foliar content in mango cv. 'Keitt' during the different periods. Vertical bars represent SE (n=8).

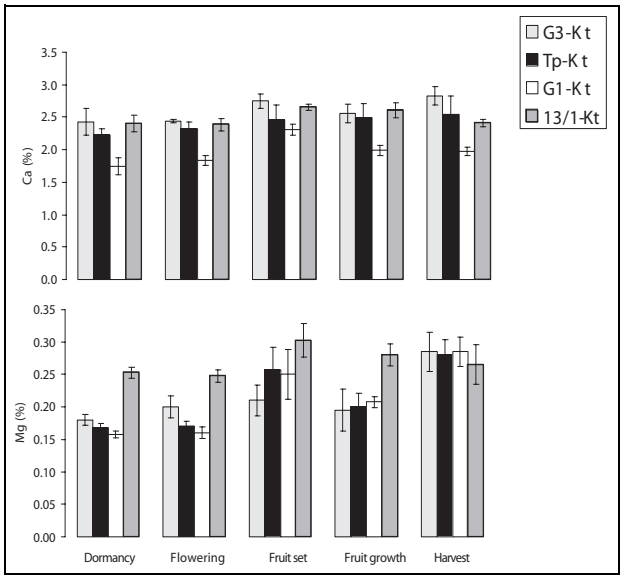


Fig. 2. Ca and Mg foliar content in mango cv. 'Keitt' during the different periods. Vertical bars represent SE (n=8).

nitude of the values, G3-Kt being higher for most nutrients.

The lower nutritional demand of trees during dormancy encouraged the foliar increase in N, P and K content with the exception in this latter element in G1-Kt, which decreased from 0.68 % in harvest to 0.61 % in this period. STASSEN and JANSE VAN VUUREN (1997) reported higher N content in the leaves, roots and trunk of the mango tree

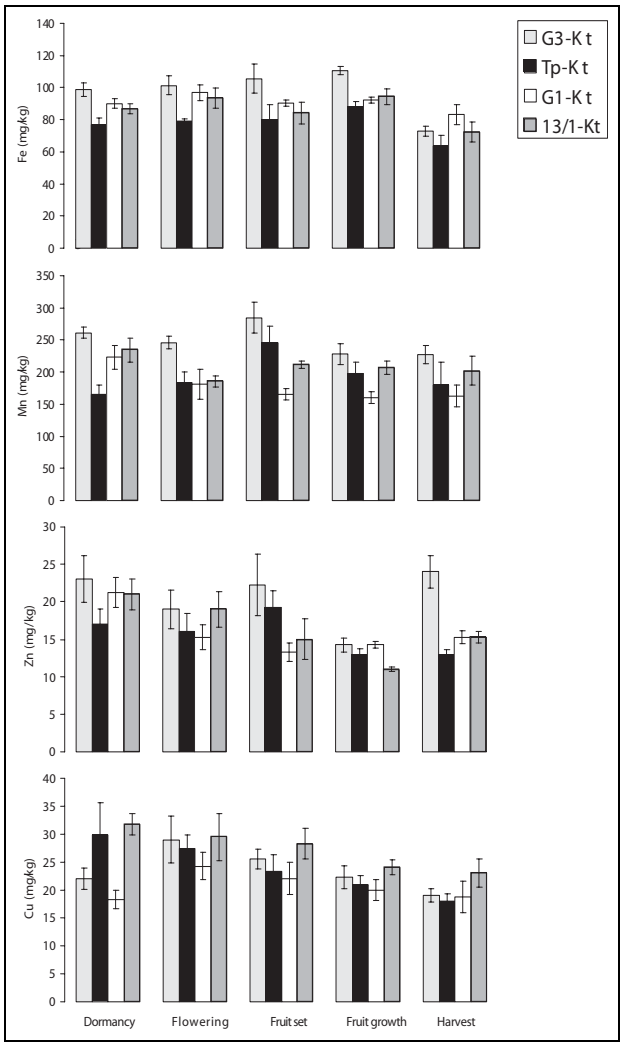


Fig. 3. Fe, Zn, Mn and Cu foliar content in mango cv. 'Keitt' during the different periods. Vertical bars represent SE (n=8).

during this period. In addition, JANSE VAN VUUREN and STASSEN (1997) indicated, in the roots and trunk of the tree, that K accumulated during this period, which notably diminished during flowering. By contrast, in our study, the contents in Ca and Mg at this stage diminished with respect to the harvest period (Fig. 3). It is well known that the relationship among K, Ca and Mg is antagonistic (in plant and soil), and thus the greater foliar K concentration at this stage could promote Mg translocation to other organs (ADISCOTT 1974; GUZMÁN et al. 1997a).

The N, P and K level at flowering in mango trees hardly changed with respect to the previous stage (dormancy), presumably because of the translocation towards new tissues. In this sense, the decrease in P content appears to be related to the high P concentration in flowers and in the small fruits during flowering and fruit set (JANSE VAN VUUREN and STASSEN 1997).

The results of the present study concerning the decline in N and K during flowering in mango agree with those reported by AVILAN (1971) and SERGENT et al. (1993). Meanwhile, during fruit set, the Ca and Mg contents tended to recover former levels in all combinations.

Table 3. Macro- and micronutrient foliar content in mango for cv. 'Keitt' during the study period (2001–2002).

Combination	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
Tp-Kt	1.77a	0.12a	0.53a	2.41a	0.21a	72a	16a	194a	27ab
13/1-Kt	1.75a	0.08b	0.43b	2.50a	0.27b	84b	16a	209a	31a
G1-Kt	1.80a	0.12a	0.53a	1.97b	0.21a	87bc	15a	181a	22b
G3-Kt	1.98b	0.15c	0.43b	2.58a	0.21a	93c	20a	249b	27ab
Year									
2001	1.68a	0.10a	0.50a	2.12a	0.20a	86a	20a	195a	22a
2002	1.94b	0.13b	0.46b	2.61b	0.25b	83a	13b	222b	30b
ANOVA									
R	ns	**	**	**	**	**	ns	**	ns
Y	**	**	**	**	**	ns	**	**	**
R x Y	ns	**	ns	ns	ns	ns	ns	**	ns

Values with different letters in the columns are significantly different according to Duncan's test at 0.01; ns: not significant; **: significant at 0.01;
R: Rootstock combination; Y: Year

During the harvest, the P content tended to recover their levels in most of the combinations, apparently for the lighter fruit load, as reported by Janse van Vuuren and Stassen (1997). Also, the Mg content during harvest significantly increased with all combination with the exception of 13/1-Kt.

In relation to micronutrients the Fe and Mn tended to increase from dormancy to fruit set and afterwards declined to harvest. On the contrary, the Zn and Cu continuously tended to decrease from dormancy to harvest (Fig. 3). As with the macronutrients, the combination G3-Kt reached the highest values for most micronutrients.

The content in Zn declined from dormancy to fruit growth, but no visual deficiency symptoms were detected for G1-Kt and G3-Kt. However, Tp-Kt and 13/1-Kt at fruit growth amounted to 13 and 11 mg Zn kg^{-1}, respectively, when the minimum content reported by Martin et al. (1975) is 15 mg Zn kg^{-1}.

Due to relatively easy mobility of Cu, the decline could be explained by the translocation from the mature leaves to the young ones (Tiffin 1972; Loneragan 1975) and towards the flowers, which were extremely dependent on this micronutrient (Reddy and Majumdar 1988). According to Guzmán et al. (1997b), Cu is concentrated in the seed during fruit growth, and Fe and Mn in the fruit skin during harvest, this perhaps prompting the decline in other organs such as leaves during this period.

Gomera-3 showed the highest transport capability for most of macro- as well as micronutrients from the roots to the aerial part than Gomera-1, Turpentine and 13/1. Despite the minimum contribution of nutrients to the scion with 13/1, this rootstock was able to transfer more Mg and Cu than was Gomera-3. Also, the maximum value of K was found with Gomera-1 (Table 3).

A high leaf-nutrient content (N, P, Fe, Zn, and Mn) correlated with increasing fruit yield of cv. 'Keitt' on Gomera-3, reflecting the effectiveness of this combination. Similarly, Reddy et al. (2001) reported that high-yielding trees had higher leaf-N content than low-yielding trees did.

Conclusions

The results of the present experiment demonstrate that fruit yield was greater with Gomera-3 and lower with Turpentine. The fruits obtained on Gomera-1 were significantly smaller than on the remaining rootstocks. The TCSA, height and canopy volume of cv. 'Keitt' was bigger on Gomera-3, which tended to be the most vigorous among the rootstocks tested.

Also, the root system of Gomera-3 has a higher capacity of uptake and transport of macro- and micronutrients than Gomera-1, Turpentine, or 13/1, as reflected in the foliar-mineral content of the scion.

In general, for all combinations, N, P and K followed almost similar trends, revealing an accumulation phase at the harvest-dormancy period and a decline during flowering. An inverse relationship between P and Mg contents was determined. With regard to the micronutrients, our study notes that Fe and Mn content tended to increase from dormancy to fruit set and afterwards declined to harvest, contrasting with Zn and Cu, which tended to decrease continuously from dormancy to harvest.

The direct link between the leaf-nutrient content and fruit yield of cv. 'Keitt' on Gomera-3 offers promising possibilities for boosting subtropical productivity in mango.

Acknowledgements

This study was partially supported by a Postdoctoral Fellowship Programme of the IFAPA, Consejería de Innovación, Ciencia y Empresas of Junta de Andalucía, Spain. Also we greatly appreciate the collaboration of Mr. Francisco Mamani Pati for chemical analytical analyses.

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Received February 7, 2005 / Accepted September 12, 2005

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