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New mescaline concentrations from 14 taxa/cultivars of *Echinopsis* spp. (Cactaceae) ("San Pedro") and their relevance to shamanic practice

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ABSTRACT

Aim of the study: The aim of the present study is to determine in a procedurally uniform manner the mescaline concentrations in stem tissue of 14 taxa/cultivars of the subgenus *Trichocereus* of the genus *Echinopsis* (Cactaceae) and to evaluate the relationship (if any) between mescaline concentration and actual shamanic use of these plants.
Materials and methods: Columnar cacti of the genus *Echinopsis*, some of which are used for diagnostic and therapeutic purposes by South American shamans in traditional medicine, were selected for analysis because they were vegetative clones of plants of documented geographic origin and/or because they were known to be used by practitioners of shamanism. Mescaline content of the cortical stem chlorenchyma of each cactus was determined by Soxhlet extraction with methanol, followed by acid–base extraction with water and dichloromethane, and high-pressure liquid chromatography (HPLC).
Results: By virtue of the consistent analytical procedures used, comparable alkaloid concentrations were obtained that facilitated the ranking of the various selected species and cultivars of *Echinopsis*, all of which exhibited positive mescaline contents. The range of mescaline concentrations across the 14 taxa/cultivars spanned two orders of magnitude, from 0.053% to 4.7% by dry weight.
Conclusions: The mescaline concentrations reported here largely support the hypothesis that plants with the highest mescaline concentrations – particularly *E. pachanoi* from Peru – are most associated with documented shamanic use.

1. Introduction

The portion of the genus *Echinopsis* (Cactaceae) that was formerly known as *Trichocereus* (Friedrich, 1974; Rowley, 1974) consists of largely columnar cacti native to the Andean slopes of Ecuador, Peru, northern Chile, and Bolivia. Several species of *Echinopsis* are used for diagnostic and therapeutic purposes by indigenous practitioners. Such use is evidently based on their psychoactive properties due to their mescaline content (Dobkin de Ríos, 1972). The species most widely and frequently used in this manner, viz., *Echinopsis pachanoi* (Britton and Rose) Friedrich and Rowley (*E. pachanoi*), *Echinopsis peruviana* (Britton and Rose) Friedrich and Rowley (*E. peruviana*) and *Echinopsis lageniformis* (Foerster) Friedrich and Rowley (*E. lageniformis*), are often referred to in Spanish as San Pedro, alluding to St. Peter's role as the gatekeeper to heaven (Schultes and Hofmann, 1980).

The single most commonly utilized species, *E. pachanoi*, has been cultivated for such a long time that it is difficult to determine its geographic origin and natural habitat (Britton and Rose, 1920; Yetman, 2007).

Abbreviations: AUFS, absorbance units full scale; C, centigrade; ca., circa (approximately); cf., confer (compare); cm^3, cubic centimeter; CAS, Chemical Abstracts Service; Cl, chloro; CSA 1, Schedule 1 in the US Controlled Substances Act; cv., cultivar; *E.*, *Echinopsis*; Dept., Department; et al., et alii (and others); FR, a collection number of Friedrich Ritter; g, gram; GC–MS, gas chromatography–mass spectroscopy; GE, substance listed in German Controlled Substances Act (BtMG); HPLC, high-performance liquid chromatography; IC, substance under international control (United Nations); ID, internal diameter; in litt., in litteris (in a note or email); IOS, International Organization for Succulent Plant Studies; KK, Karel Knize; L, liter; M, mescaline; m, meter; mg, milligram; mL, milliliter; MSD, mass-selective detection; MW, molecular weight; *m/z*, mass-to-charge ratio; µL, microliter; µg, microgram; N, normal; N/A, not available; nm, nanometer; NMCR, New Mexico Cactus Research; OST, a collection number of Carlos Ostolaza; PCH, a collection number of Paul C. Hutchison; PIH, PIHKAL (Shulgin and Shulgin1991); pKa, ionization constant; Prov., Province; QI, quality index of spectra; Rd., road; REF, reference; RI, gas chromatographic Kovats retention index; SE 30, a standard GC column; s.l., sensu lato; sp., species; s.s., sensu stricto; ssp., subspecies; *T.*, *Trichocereus*; TSQ, a MS data system; UV, ultraviolet; viz., videlicet (namely); w/w, weight per weight (expression of concentration).

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Earlier analytical and pharmaceutical reports identified specimens chemically assayed as *Opuntia cylindrica* (Cruz Sánchez, 1948; Marini-Bettòlo and Coch Frugoni, 1958; Turner and Heyman, 1960). Friedberg (1959) was the first investigator to report that the ritual drug plant popularly known as San Pedro corresponds to that described by Britton and Rose (1920) as *Trichocereus pachanoi* (=*Echinopsis pachanoi*). Poisson (1960) was the first to isolate mescaline from a San Pedro validly identified as *Trichocereus* (*Echinopsis*) *pachanoi*, using Friedberg's (1959) voucher material.

While there seems to be universal consensus among scientists that mescaline is the active principle in *Echinopsis* species underlying their use, the mescaline content of these cacti has long been a subject of controversy. Different authors employing various methods and instrumentation have published markedly different mescaline contents for these plants (Table 1).

Part of the variation among these published results for the subgenus *Trichocereus* of the genus *Echinopsis* may be attributable to real genetic differences in the regulation of mescaline biosynthesis among the various species/cultivars sampled, as well as among populations within a given species/cultivar and individuals within a given population. Environmental factors, including variation in temperature and rainfall (which correlate with differences in altitude), as well as edaphic conditions, could also be expected to contribute to geographic and/or temporal variation in mescaline content. But it was suspected that a significant part of the reported variation in mescaline content of *E. pachanoi* and related taxa might be attributable to interlaboratory differences in technique. This latter source of variation amounts to noise that may seriously confound previously reported results, precluding a valid comparison among them. It is also noteworthy that much of the published research in this area dates to the 1960s and 1970s, when differences among laboratories were likely greater than at present. There is therefore the need for confirmatory studies to evaluate these earlier results.

The primary objective of this project was thus to employ modern, uniform analytical methods in a single laboratory, to determine the mescaline contents of *E. pachanoi* and related taxa, including some cultivars. All analyses were conducted by the same investigator (Ogunbodede) using the same procedures, the same experimental conditions, and the same equipment. A secondary objective was to examine the relationship, if any, between mescaline concentration in *Echinopsis* taxa/cultivars and any documented use of those taxa/cultivars by indigenous shamanic practitioners. The hypothesis was that the cacti with the highest mescaline tissue concentrations would be more likely to be used in shamanic practice and that such use would be reflected in the literature.

2. Materials and methods

2.1. Plant selection and extraction

In addition to the taxonomic uncertainty that surrounds the genus *Echinopsis*, there is ethnobotanical uncertainty as to how the various species and cultivars are used by practitioners of different cultures over the large geographic area to which the genus is endemic. Accordingly, the criteria for selecting plants for analysis were that (a) the plants had a reasonable amount of credible botanical documentation as to their collection data, with emphasis on geographic origin, and/or (b) the plants exhibited documented use for shamanic therapeutic purposes. The exception was the single case of *E. pachanoi* cv. Juul's Giant. This plant is documented as a cultivar in the United States, but the geographic region of Peru to which it is native is not known. It bears close resemblance to plants encountered around Arequipa (Trout, 2005).

Due to the difficulty of obtaining reliably documented specimens, we decided at the outset to analyze only one individual to represent each taxon/cultivar. Thus, the study design expressly ignores the (probably considerable) variation in mescaline content among individuals within a given taxon. Temporal variation in mescaline content that may be associated with age/size of the plant, season of the year or time of day, was also not controlled. Living voucher specimens of cacti used in this study are being maintained in our greenhouse. Photographs of these specimens can be found at www.cactusconservation.org/botany/Ogunbodede.html.

A fresh sample of chlorenchyma from the green outer cortex of the stem of each *Echinopsis* species to be assayed was weighed, sliced and cut into cubes ca. 1 cm^3, desiccated for ca. 30 h at room temperature, and weighed in the dried state. The dried material was finely ground with mortar and pestle. Two (2.0) grams of the dry, ground chlorenchyma tissue was extracted with methanol in a Soxhlet apparatus for 8 h at 40 °C. The extract was evaporated to dryness at 40 °C in a rotary evaporator, redissolved in 150 mL of distilled water, and acidified with concentrated hydrochloric acid to pH 3.0. The acidified aqueous extract was defatted twice with 50 mL of dichloromethane. The aqueous layer was alkalinized to pH 12.0 with 5 N sodium hydroxide (the pK_a of the protonated amino group of mescaline being 9.5), and extracted twice with 50 mL dichloromethane. The aqueous layer was discarded, and the dichloromethane evaporated to dryness. The extract was redissolved in 10.0 mL of methanol, filtered through a 0.2-μm micropore filter to remove particulates, and stored in a glass vial at 4 °C, pending high-pressure liquid chromatography (HPLC).

2.2. Analytical instrumentation and methodology

The HPLC instrumentation consisted of a Beckman 322 gradient liquid chromatograph fitted with a Beckman 110A solvent-metering pump, Beckman 421 controller, a Spectra 100 variable-wavelength detector (Spectra Physics), and a Kipp and Zonen BE 8 multirange recorder. Alkaloid separation was carried out isocratically with a Phenomenex Luna 3-μm 250 mm × 4.6 mm ID reverse phase C-18 column at 25 °C. The mobile phase consisted of 10.8% acetonitrile, 89.2% water, acidified with 0.10% trifluoroacetic acid, at a flow rate of 0.5 mL per min. The detector wavelength was set at a known UV absorbance maximum of 205 nm (as per Helmlin and Brenneisen, 1992).

The HPLC fractions were injected into an Agilent 6890 gas chromatograph (GC) with a 5972 mass-selective detector (MSD) operating in 70 eV electron ionization mode, using Agilent Chemstation (v. C.00.00) data acquision software. Mass spectra were obtained with the Chemstation analysis utilities, and compared with both standards and library spectra (using MSSearch 2.0, NIST, 1998).

Authentic mescaline hydrochloride (Grace Davison, purchased by M. Terry, DEA Researcher Registration No. RT 0269591) was used as the mescaline reference standard. The concentrations of the standard solutions and the corresponding mean HPLC peak heights were plotted in a standard curve and correlated using a Labworks spreadsheet. The range of mescaline concentrations covered by the standard solutions was 4.59–73.3 μg/mL. A dataset was considered acceptable if the correlation coefficient was ≥0.999.

3. Results

All specimens analyzed contained detectable levels of mescaline (Table 2). The mescaline HPLC peaks of all samples analyzed exhibited a consistent retention time of 14 min. Mescaline HPLC peak confirmation was first demonstrated by co-elution with the

Table 1
Reported concentrations (in %) of mescaline in *Echinopsis* cacti with affinities to *E. pachanoi* and *E. peruviana*. CP: chlorophyllaceous parenchyma only. WP: whole plant.

Species	%	Form/part	Locale or source	Reference
E. lageniformis	>0.25	Dry/WP	Horticulture, European	Agurell (1969b)
	0.56	Dry/CP	La Paz, Bolivia	Serrano (2008)
E. cuzcoensis	0.0	Dry/CP	Cotaruse, Arequipa, Peru	Serrano (2008)
	0.0	Dry/CP	Huaytampo, Cuzco, Peru	Serrano (2008)
	0.0	Dry/CP	Huacarpay, Cuzco, Peru	Serrano (2008)
	0.0	Dry/CP	Capacmarca, Cuzco, Peru	Serrano (2008)
	0.005–0.05	Fresh/WP	Horticulture, Germany	Agurell et al. (1971)
E. pachanoi	5	Dry/CP	Cultivated, Lima, Peru	Cruz Sánchez (1948)
	4.5	Dry/CP	Cultivated: Lima, Peru	Gonzalez Huerta (1960)
	2.06	Dry/WP	Horticulture, Italy	Gennaro et al. (1996)
	0.109–2.375	Dry/WP	Horticulture, Switzerland	Helmlin and Brenneisen (1992)
	1.2	Dry/WP	Huancabamba, Peru	Poisson (1960)
	0.9	Dry/WP	Peruvian drug material	Turner and Heyman (1960)
	0.331	Dry/WP	Horticulture, California	Crosby and McLaughlin (1973)
	>0.025	Fresh/WP	Horticulture, European	Agurell (1969b)
	0.04–0.067	Fresh/WP	Horticulture, European	Agurell (1969a)
	0.067–0.079	Fresh/WP	Horticulture, European	Bruhn and Lundström (1976)
	0.15–0.155	Dry/WP	Horticulture, California	Pummangura et al. (1982)
	0.78	Dry/CP	Chiclayo, Peru	Reyna Pinedo and Flores Garcés (2001)
	1.4	Dry/CP	Barranca, Peru	Reyna Pinedo and Flores Garcés (2001)
	0.00	Dry/CP	El Alisal, San Marcos, Cajamarca, Peru	Cjuno et al. (2009)
	0.00	Dry/CP	Cataratas, Otuzco, La Libertad, Peru	Cjuno et al. (2009)
	0.23	Dry/CP	Moyán, San Vincente, Lambayeque, Peru	Cjuno et al. (2009)
	0.28	Dry/CP	Puykate, Ferreñafe, Lambayeque, Peru	Cjuno et al. (2009)
	0.38	Dry/CP	Yanasara, Sánchez Carrión, La Libertad, Peru	Cjuno et al. (2009)
	0.45	Dry/CP	KunturWasi, San Pablo, Cajamarca, Peru	Cjuno et al. (2009)
	0.94	Dry/CP	Tocmoche, Chota, Cajamarca, Peru	Cjuno et al. (2009)
	1.14	Dry/CP	Laquipampa, Ferreñafe, Lambayeque, Peru	Cjuno et al. (2009)
E. peruviana	0.25	Dry/CP	Chavin de Huantar, Huari, Ancash, Peru	Cjuno et al. (2009)
	0.0	Dry/WP	Horticulture, European	Agurell (1969b)
	0.0	Dry/WP	Wild harvested in Peru	Djerassi et al. (1955)
	0.817	Dry/WP	KK242 seed from Matucana, Peru grown in California	Pardanani et al. (1977)
E. puquiensis	0.28	Dry/CP	Chaviña, Lucanas, Ayacucho, Peru	Serrano (2008) and Cjuno et al. (2009)
	0.13	Dry/CP	Chumpi, Parincochas, Ayacucho, Peru	Serrano (2008) and Cjuno et al. (2009)
	0.11	Dry/CP	Incuyo, Parincochas, Ayacucho, Peru	Serrano (2008) and Cjuno et al. (2009)
	0.50	Dry/CP	Vado, Lucanas, Ayacucho, Peru	Serrano (2008) and Cjuno et al. (2009)
E. santaensis	0.31	Dry/CP	Mancos, Yungay, Ancash, Peru	Cjuno et al. (2009)
E. schoenii	0.22	Dry/CP	Cotahuasi, La Unión, Arequipa, Peru	Serrano (2008) and Cjuno et al. (2009)
	0.20	Dry/CP	Pampacola, Castilla, Arequipa, Peru	Serrano (2008) and Cjuno et al. (2009)
	0.14	Dry/CP	Huambo, Arequipa, Peru	Serrano (2008) and Cjuno et al. (2009)

Table 2
Identity, mescaline content, collection number (if any) or geographic origin, and material originally collected (seed or cutting) of *Echinopsis* (Cactaceae) species/cultivars examined, in order of decreasing mescaline content.

Cactus species/cultivar	Mescaline conc. (% of dry weight of cactus tissue)	Collection number or origin, material originally collected
E. pachanoi	4.7	Matucana, Lima Region, Peru Cutting[a]
E. pachanoi cv. Juul's Giant	1.4	Cultivar Cutting
E. pachanoi (long spined)	1.2	Huancabamba, Piura Region, Peru Seed (Van Geest)
E. scopulicola	0.85	FR 991: Tapecua, O'Connor Prov., Bolivia Seed (Hildegard Winter)
E. pachanoi	0.82	Hutchison et al. 6212: Rio Marañon above Chagual, La Libertad Dept., Peru Cutting
E. pachanoi (short spined)	0.54	Huancabamba, Piura Region, Peru Seed (Van Geest)
E. lageniformis (monstrose)	0.48	Cultivar Cutting
E. pachanoi complex cf. *T. pallarensis* Ritter	0.47	FR 676: Pallar, Ancash Dept., Peru Seed (Hildegard Winter)
E. pachanoi complex cf. *T. riomizquensis* Ritter	0.40	FR 856: Chuyllas, on the Rio Mizque, Prov. Campero, Bolivia Seed (Hildegard Winter)
E. santaensis	0.32	OST 92701: Santa Valley, Ancash Dept., Peru Seed (Ostolaza)
E. peruviana	0.24	KK 242: Matucana, Lima Region, Peru Cutting from Karel Knize
E. lageniformis	0.18	Cultivar Cutting (Gillette)
E. puquiensis	0.13	P.C. Hutchison 1256A: Nazca-Puquio Rd., across canyon from Pachan, Ayacucho Dept., Peru Cutting
E. uyupampensis	0.053	Backeberg (Monaco #3487) Cutting

[a] Collector was an indigenous supplier of *E. pachanoi* to traditional Peruvian shamans' markets, who requested anonymity.

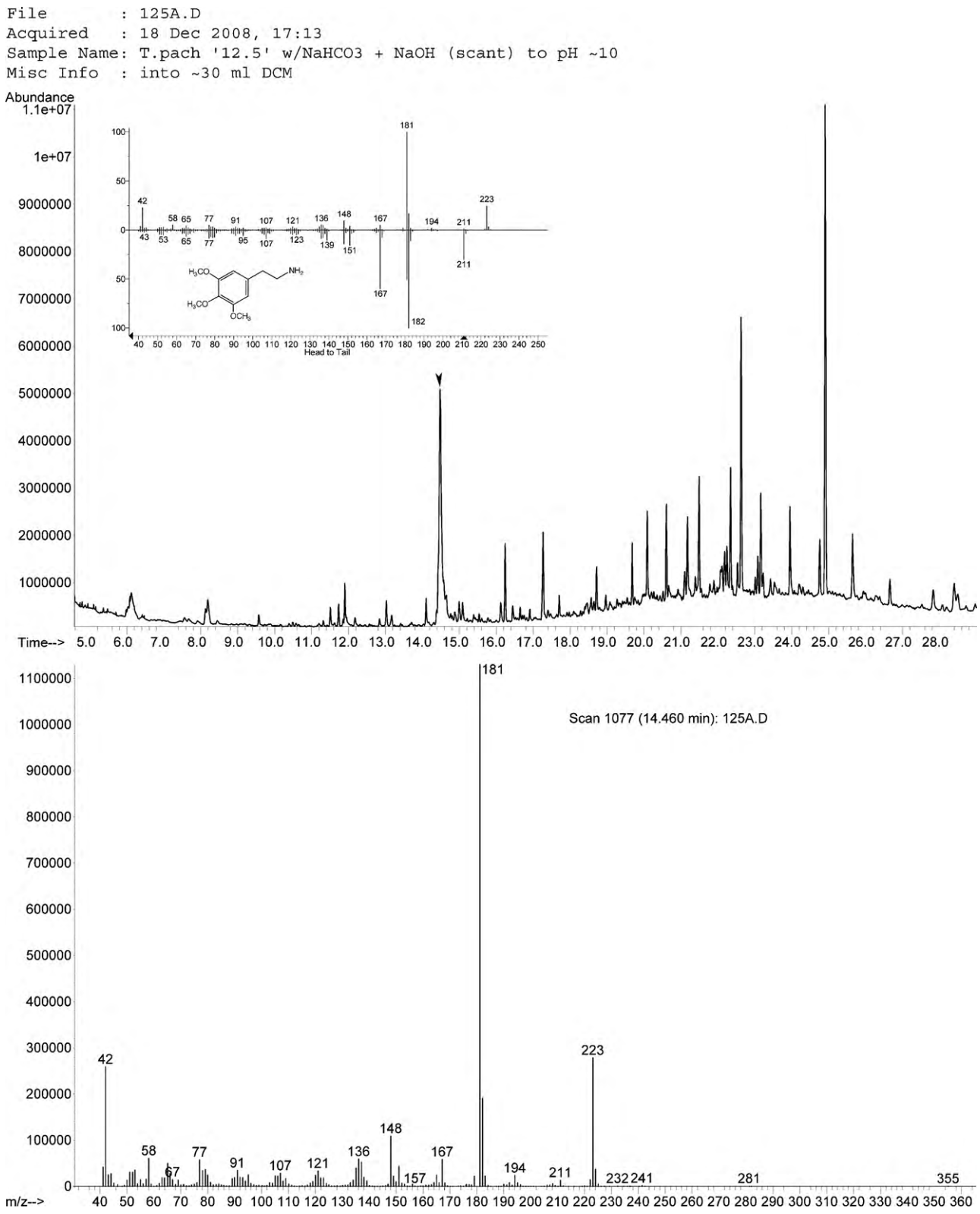

Fig. 1. GC–MS confirmation of mescaline in the mescaline HPLC peak from the extract of *Echinopsis pachanoi* (Matucana). Note the 211 mass peak of the molecular ion, as well as the characteristic mass peaks at 194, 181 and 167. The mass peak at 223 is a common artifact (see Fig. 2).

mescaline standard (Grace Davison). When the mescaline HPLC peak obtained for a sample of extract of *E. pachanoi* (Matucana) tissue was analyzed by gas chromatography–mass spectrometry (GC–MS), the mass spectrum showed the characteristic molecular ion mass peak and fragment peaks for mescaline (Fig. 1). We noted that with this instrument, in addition to the expected molecular mass of 211 there were apparent adduct ions detected at an m/z of 223. Examination of standard runs with this system revealed that this adduct was not always present, and was not accompanied by any shift in chromatographic behavior (retention time, slight

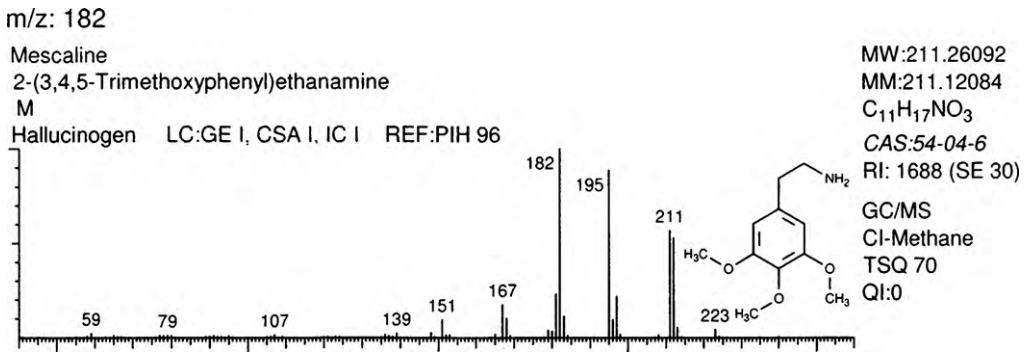

Fig. 2. Recent mass spectrum of mescaline by Rösner et al. (2007). Note the artifactual peak at *m*/*z* 223, which we also observed. Abbreviations: CAS, Chemical Abstracts Service; Cl, chloro; CSA 1, Schedule 1 in the US Controlled Substances Act; GE, substance listed in German Controlled Substances Act (BtMG); IC, substance under international control (United Nations); M, mescaline; MW, molecular weight; *m*/*z*, mass-to-charge ratio; PIH, PIHKAL (Shulgin and Shulgin, 1991); QI, quality index of spectra; REF, reference; RI, gas chromatographic Kovats retention index; SE 30, a standard GC column; TSQ, a popular MS data system.

peak asymmetry). Similar mass spectroscopy results (Fig. 2) were obtained by Rösner et al. (2007), although these data were obtained with a chemical ionization instrument. We conclude that the MSD did reliably identify mescaline, yet note there appears to be some ionization chemistry taking place that is not entirely understood.

4. Discussion

The analytical results of the *Echinopsis* species and cultivars in Table 2 clearly indicate that the specimens showing the greatest concentrations of mescaline in dry stem chlorenchyma tissue belong to (or have affinities with) the species *E. pachanoi*. This elevated mescaline content raises interesting questions about the variation observed in the use of this species for religious and healing purposes dating back to ancient times among various cultures of Peru and other countries of the Andes region. The markedly high mescaline concentration of *E. pachanoi* (Matucana) in the present study, at 4.7%, could be attributed in part to the genetic capacity of the Matucana cultivar, but another important consideration is the analysis of only the chlorophyllaceous outer layer of the cortical parenchyma (i.e., chlorenchyma). This tissue has been reported to exhibit a higher mescaline concentration than the rest of the cactus stem (Janot and Bernier, 1933; Reti and Castrillón, 1951). Cruz Sánchez (1948), Gonzalez Huerta (1960), Serrano (2008) and Cjuno et al. (2009), other workers analyzed the outer layer separately in order to overcome the difficulties posed by mucilage in the isolation of alkaloids. Our result of 4.7% for *E. pachanoi* (Matucana) agrees very well with those of Cruz Sánchez (1948), at 5%, and Gonzalez Huerta (1960), at 4.5%. Both of those workers analyzed *E. pachanoi* from the Lima Region of Peru, and both analyzed only stem chlorenchyma. While the concentration of mescaline in chlorenchyma tends to be higher than that in the intact stem as would be used for ingestion by shamans, the selection of only the chlorenchyma layer for analysis permits direct comparison between species.

Trout (2005) stated that a common error embedded in the literature is reference to *E. peruviana* as being 10 times more "potent" than *E. pachanoi*. Our results indicate that *E. pachanoi* contains a considerably higher concentration of mescaline than *E. peruviana* (Table 2). To add support to the notion that some *E. pachanoi* cultivars can be very high in mescaline content, Helmlin and Brenneisen (1992) spectroscopically assayed six Swiss cultivars of *E. pachanoi* obtained from retail and private collections, and reported that one Swiss-grown *E. pachanoi* specimen had a mescaline concentration 22 times greater than other Swiss-grown *E. pachanoi* specimens.

Two apparently closely related cultivars of *E. pachanoi* were examined in this study. One of them, *E. pachanoi* (Huancabamba long spine), yielded a mescaline concentration of 1.2% in cortical stem chlorenchyma on a dry-weight basis (Table 2). The other, *E. pachanoi* (Huancabamba short spine), showed a mescaline concentration of 0.54% (Table 2). This difference in mescaline content between two plants of common origin – both derived from cuttings of plants grown from seed collected by Dick Van Geest in the 1960s – is particularly interesting in that it shows a greater-than-twofold difference in mescaline, representing the extent of individual variation among individuals produced from field-collected seed. Ontogenic variation (age and degree of maturity of the plants), environmental variation (differences in horticultural conditions), and temporal (seasonal and diurnal/nocturnal) variation in rates of alkaloid biosynthesis and degradation could also contribute to the observed variation in the mescaline levels.

The *E. peruviana* cultivar examined in this study, *E. peruviana* KK 242, yielded a comparatively low value of 0.24% mescaline content on a dry-weight basis (Table 2). Curiously, an earlier *E. peruviana* analysis did not detect any presence of mescaline (Agurell, 1969b). The reason for this absolute difference in results could be varietal or procedural. There are many diverse cultivars of *E. peruviana*, and anecdotal human bioassay accounts suggest widely variable mescaline concentrations (Trout, 2005). However, Pardanani et al. (1977) reported a mescaline recovery of 0.82% (dry weight) for seed-grown *E. peruviana* KK 242, which is similar to the values for several of the other *Echinopsis* species/cultivars analyzed in this study, though not for *E. peruviana*, in the present work.

Two cultivars of *E. lageniformis* (=*Trichocereus bridgesii* ≠ *E. bridgesii* Salm-Dyck) were analyzed for mescaline content. *E. lageniformis* (monstrose) showed 0.48% mescaline content on a dry-weight basis (Table 2). *E. lageniformis* (Gillette) showed 0.18% mescaline content on a dry-weight basis (Table 2). By comparison, Agurell (1969b) reported a mescaline content of about 25 mg per 100 g of fresh weight for intact stem tissues of *E. lageniformis*, an amount equivalent to about 0.4% mescaline content in dry tissue. Serrano (2008) recently reported a mescaline content of 0.56% for *E. lageniformis* from the eastern side of La Paz, Bolivia, at an altitude of 3400 m. These published figures for *E. lageniformis* compare favorably with the figure reported for the mescaline content of *E. lageniformis* (monstrose) in Table 2.

Recently Serrano (2008) published some quantitative data on the mescaline content of *Echinopsis puquiensis* (Rauh and Backeberg) Friedrich and Rowley (*E. puquiensis*), harvested from different altitudes and locations in Peru (Table 1), and reported values which largely compare favorably with the mescaline content of 0.13% determined for *E. puquiensis* in this study (Table 2). Similarly, the mescaline concentration value of 0.32% obtained in our study for *Echinopsis santaensis* (Rauh and Backeberg) Friedrich and Rowley (*E. santaensis*) was virtually identical to that reported recently by Cjuno et al. (2009).

Echinopsis uyupampensis (Backeberg) Friedrich and Rowley (*E. uyupampensis*) has no published analytical data on its mescaline content. The same is true of *Echinopsis scopulicola* (Ritter) Mottram (*E. scopulicola*). In this study the mescaline content of *E. uyupampensis* by dry weight was found to be 0.053%, the lowest of the 14 specimens analyzed. It would be reasonable to deduce that an extremely large amount of tissue from this taxon would have to be used to obtain an efficacious psychoactive dose of mescaline. Thus, it seems unlikely that *E. uyupampensis* would be used for mescaline-based therapeutic and diagnostic purposes as are other species such as *E. pachanoi* and *E. peruviana*. Consistent with this inference is the fact that we can locate no anthropological reports suggesting those applications for *E. uyupampensis*. The mescaline concentration of 0.82% found for *E. scopulicola*, on the other hand, is in the top third of the results for our samples, placing it in a cluster of high-mescaline-content *E. pachanoi* taxa. Two other taxa whose mescaline concentrations are reported here for the first time, are (1) *Echinopsis pachanoi* complex ssp. *riomizquensis* (*T. riomizquensis* Ritter), sensu Taylor (2007) (*E. pachanoi* complex ssp. *riomizquensis*), and (2) *Echinopsis pachanoi* complex ssp. *pallarensis* (*T. pallarensis* Ritter), sensu Taylor in his treatment of *E. pachanoi* spp. *riomizquensis* (Taylor, 2007) (*E. pachanoi* complex ssp. *pallarensis*). These two taxa, which, along with other members of the *E. pachanoi* complex, are clearly in need of study, show mescaline concentrations of 0.47% and 0.40%, respectively, placing them at the upper end of the lowest one-third of the samples analyzed in the present study. Their use by shamanic practitioners has not been documented.

The hypothesis that *Echinopsis* taxa/cultivars with the highest tissue concentrations of mescaline would be preferred by indigenous shamanic practitioners, appears to be largely supported by the results of the present study (Table 2). Of the three plants showing the highest percentages of mescaline in dried stem chlorenchyma, the first, *E. pachanoi* (Matucana), and the third, *E. pachanoi* (Huancabamba short spine), are known to be used by practicing shamans in Peru (Anon., 2007 and Friedberg, 1959, respectively). The plant with the second-highest mescaline content, *E. pachanoi* cv. Juul's Giant, cannot be meaningfully assessed for indigenous shamanic use because of its lack of collection data, despite its close resemblance to material encountered in the Arequipa shamans' market (Trout, 2005). Thus there are positive reports of shamanic use for *E. pachanoi* from Matucana and Huancabamba, the known employment of *E. peruviana* by Peruvian shamans (Reyna Pinedo and Flores Garcés, 2001; Carlos Ostolaza, in litt.; a commercial Peruvian plant supplier requesting anonymity, in litt.), a noninformative status for the *E. pachanoi* Juul's Giant cultivar, and a lack of positive data on shamanic use for the remaining plants that showed lower mescaline concentrations in this study. That is not to imply that some of the plants with lower mescaline content are not usable – or even that they are not actually used – indeed, one Peruvian informant asserted that several species/cultivars of the genus *Echinopsis* appear to be viewed and used interchangeably by indigenous shamans in the Matucana area, without regard to their taxonomic identities (Anon., 2007). But the fact remains that in the set of *Echinopsis* cacti with adequate collection data, the Peruvian *E. pachanoi* cacti with the highest mescaline concentrations predominate in current documented shamanic use.

5. Conclusion

Echinopsis researchers in the past have examined various tissues of a broad set of taxa/cultivars of plants, employing different extraction and analytical procedures, all of which may account for disparities in alkaloid recoveries. In the present study, by extracting only the cortical stem chlorenchyma, we almost certainly overestimated the average mescaline content of the plant as a whole, but obtained comparable concentrations that facilitated the ranking of 14 species and cultivars of *Echinopsis* with mescaline contents that spanned two orders of magnitude, from 0.053% to 4.7% by dry weight. The mescaline concentrations reported here largely support the hypothesis that plants with higher mescaline concentrations are associated with documented shamanic use. The numerous populational, environmental and temporal factors which, either alone or in combination, could affect mescaline levels in *Echinopsis* species, await future investigation.

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