ALKALOID CONTENT IN RELATION TO ETHNOBOTANICAL USE OF *TRICHOCEREUS PACHANOI* AND RELATED TAXA

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by

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ABSTRACT

Trichocereus pachanoi Britton & Rose and related psychoactive cactus species native to the Andean region of South America prominently feature in the religion and socio-cultural lives of the people in that area. These high-altitude plants contain the hallucinogen mescaline and other alkaloids in varying quantities. These cacti have, over the centuries, been employed in spiritual and therapeutic practices which have a botanical/pharmacological basis. These practices depend on the psychoactive properties of alkaloids in the plants, especially mescaline. The mescaline content of the various *Trichocereus* taxa and cultivars is controversial, as different methods and procedures have been employed by researchers to extract and quantify alkaloids in these species, resulting in markedly different published values for the mescaline contents of these plants. Part of the variation among these results is expected to be attributable to phylogenetic differences among the taxa of *Trichocereus* sampled, as well as environmental factors including variation in temperature, rainfall, and edaphic conditions. But it was suspected that a major part of the reported variation in mescaline content of *Trichocereus* species could be attributable to interlaboratory differences in techniques. Therefore, this study was designed to confirm or reevaluate the earlier studies, using uniform procedures for the extraction of mescaline from the cactus specimens, separation and quantification of mescaline by high-pressure liquid chromatography (HPLC), and confirmation of the identity of mescaline in the HPLC peaks by gas chromatography/mass spectrometry (GC-MS). Of the 14 taxa/cultivars of *Trichocereus* analyzed for mescaline content, all contained measurable concentrations of mescaline. *Trichocereus pachanoi* (Matucana) had the highest mescaline content at 4.7% of

chlorenchyma tissue dry weight. This was followed by *T. pachanoi* cv. Juul's Giant at 1.36% and *T. peruvianus* (KK242) at 1.19% mescaline content. *Trichocereus bridgesii* (Gillette), *T. puquiensis*, and *T. uyupampensis* yielded the lowest mescaline contents, with 0.18%, 0.13% and 0.053%, respectively.

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

List of Figures, continued

CHAPTER I

INTRODUCTION

Trichocereus pachanoi Britton & Rose, also known as *Echinopsis pachanoi* (Britton & Rose) H. Friedrich & G. D. Rowley, is a psychoactive cactus commonly known as San Pedro. *Trichocereus pachanoi* (Fig. 1) is native to the Andes of South America, occurring at altitudes of 2000–3000 m in southern Ecuador, Peru (where the plant is locally known as "huachuma"), and Bolivia (where it is known as "achuma") (Britton and Rose 1920). It is a columnar cactus which normally attains a height of 3 to 5 meters, with mature stems measuring about 10 cm in diameter. This cactus usually has several erect branches arising from the base. Its dark-green stem is cylindrical and has from 4 to 6 ribs. Spines of *T. pachanoi* are often small or rarely absent (Britton and Rose 1920; Anderson 2000; Trout 2005). It forms natural fencing when planted on field edges and is used as an ornamental hedge plant. This cactus commonly grows on very steep, rocky slopes and cliffs (Britton and Rose 1920). The plant has been cultivated for such a long time that it is difficult to determine its geographical origin and natural habitat (Britton and Rose 1920; Yetman 2007). A brief description of the other *Trichocereus* species investigated for alkaloid content in this study is given below. I largely follow Ritter (1980) in his taxonomic treatment of the genus.

Trichocereus pachanoi cv. (Tom) JUUL'S GIANT

The exact identity of this cultivar has been the subject of controversy, as it has been

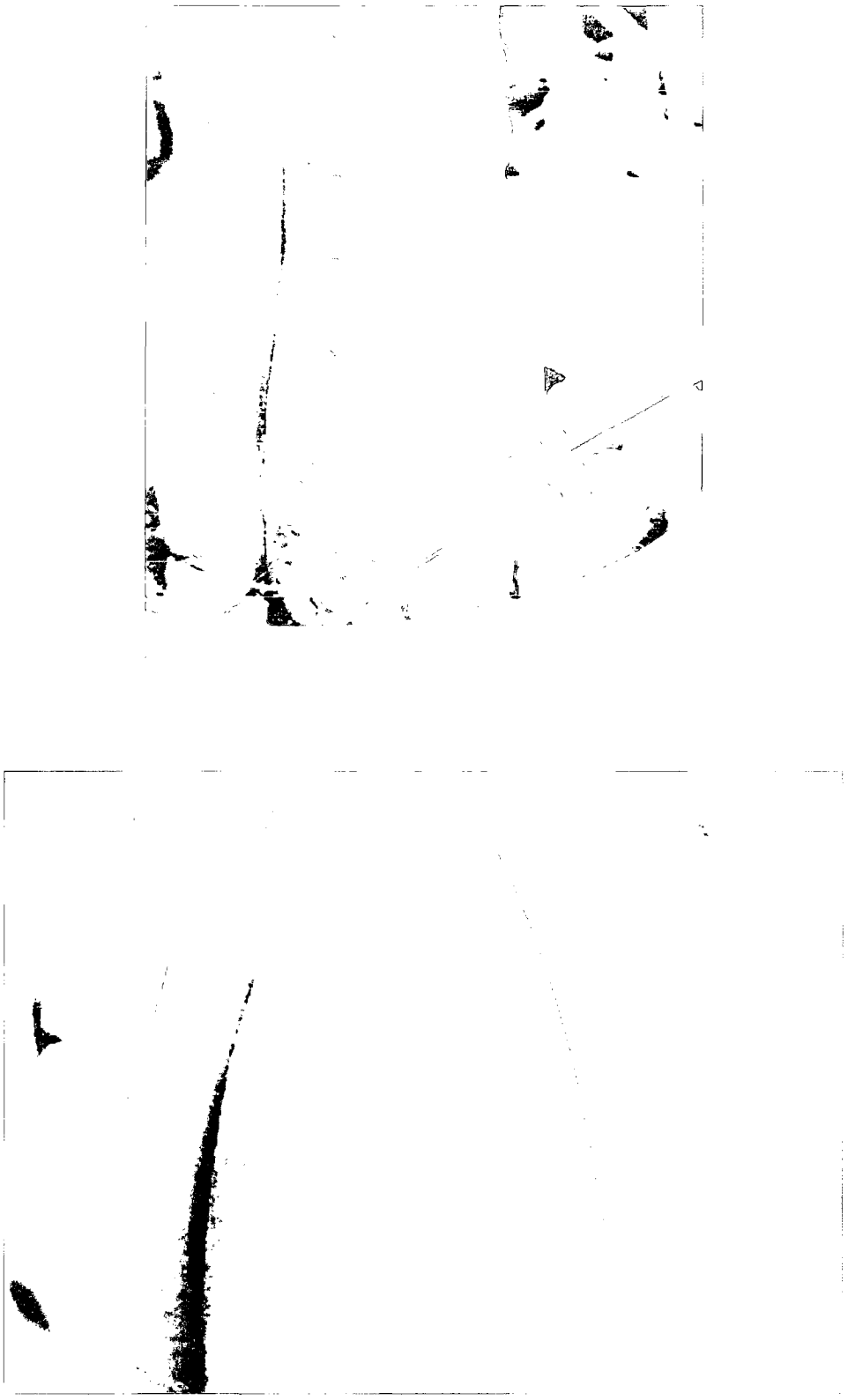


Fig. 1. *Trichocereus pachanoi* (Matucana), lateral (above) and apical (below) views.

variously described as a form of several known species of *Trichocereus* (Trout 2005). As with other cultivars of *T. pachanoi*, its geographic origin is unclear (Trout 2005). Juul's Giant (Fig. 2) is an erect, columnar cactus that freely branches from its base. Cultivated plants grow up to 3 m tall and spread up to 2 m around (Trout 2005). The epidermis is often mottled, olive-green in appearance. Branches are club-like toward the tip and grow from 8–13.5 cm in diameter. Ribs number 5–10, though more commonly 6–8, and are broadly rounded in shape. Areoles vary from oval to round and are typically about 4 mm long and 3 mm wide, with spacing of 11–25 mm between successive areoles in a given rib. Spines vary from 0–12 mm in length and are most frequently 1–3 mm long, with one spine longer than the other two. The spines, which are typically straight, change from yellowish to brownish or grayish with age (Trout 2005).

Trichocereus pachanoi (HUANCABAMBA)

This cultivar of *T. pachanoi* (Fig. 3) was collected as seed by Van Geest in the vicinity of Huancabamba, Peru (M. Terry, pers. comm.).

Trichocereus scopulicola RITTER

Trichocereus scopulicola (Fig. 4) was collected by Ritter (collection number FR 991) near the town of Tapecua, O'Connor Province, Bolivia, at 1000–1500 m altitude (Ritter 1980). Its habitat is mountainous terrain strewn with boulders and rocks. *Trichocereus scopulicola* grows to 3–4 meters in height and is erect in habit with a dark stem 8–10 cm in diameter. Its stems are simple or branching, usually near the ground. It has a dull to dark green epidermis which, under 10X magnification, appears coarsely grainy,

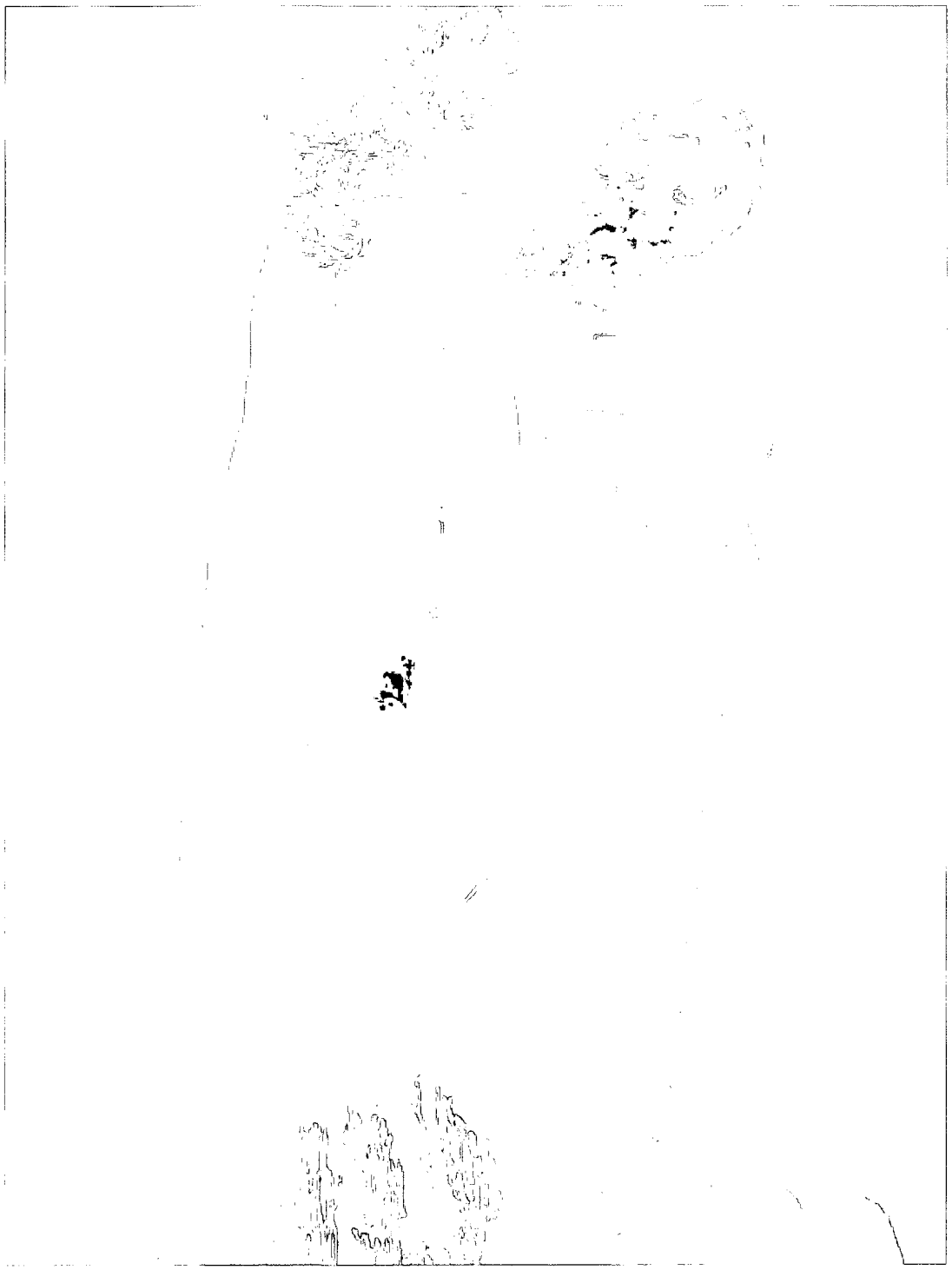


Fig. 2. *Trichocereus pachanoi* cv. Juul's Giant.

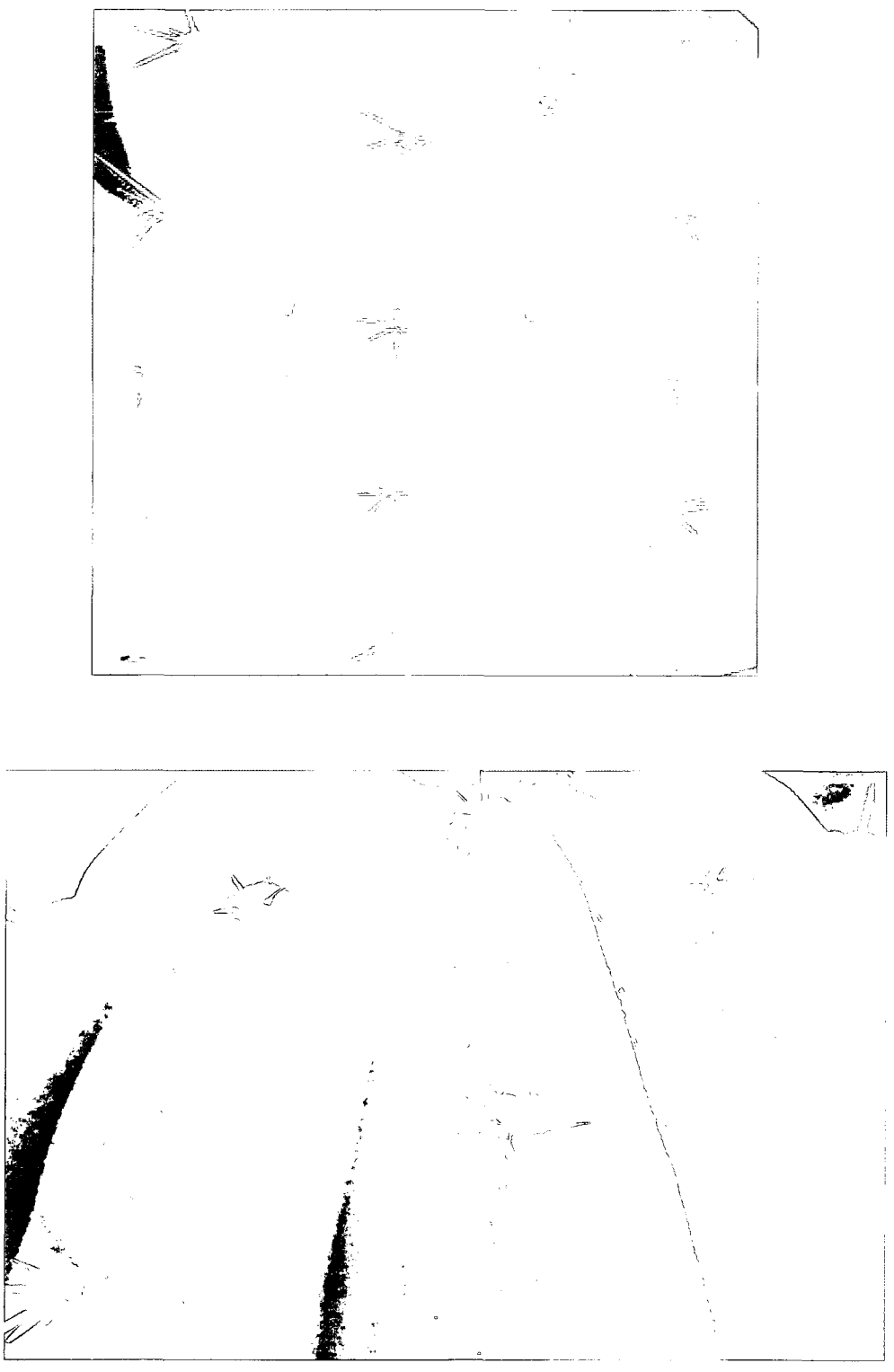


Fig. 3. *Trichocereus pachanoi* (Huancabamba), lateral (above) and apical (below) views.

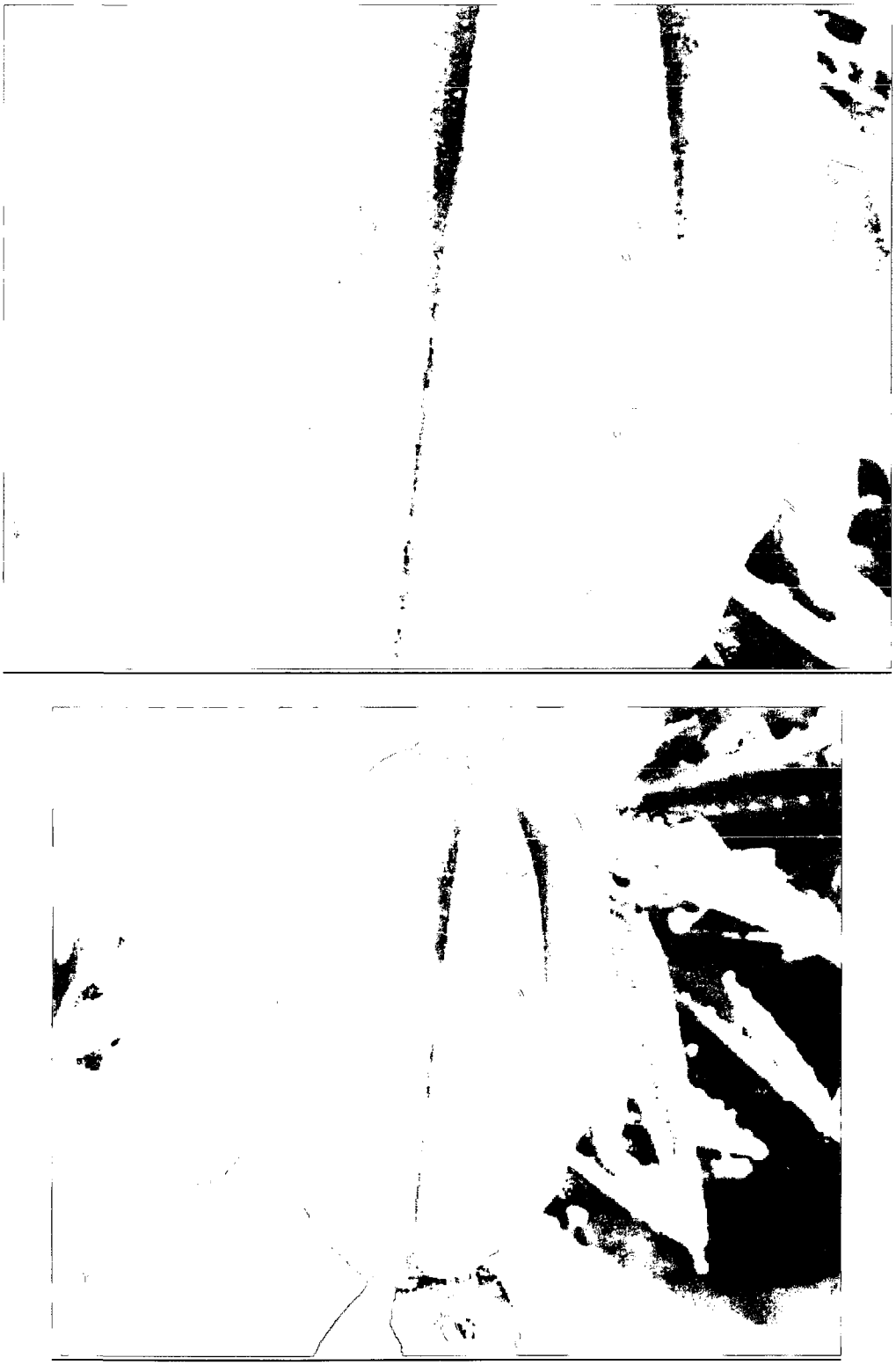


Fig. 4. *Trichocereus scopulicola*, close-up (above) and more distant (below) views.

contrasting with the fine and closely packed grain seen in *T. pachanoi.* The ribs number 4–6 and are 3–4 cm wide, blunt and rounded (Ritter 1980). It also has no indentations or grooves above the areoles, but with age develops sloping depressions below the areoles (Ritter 1980). Bigger *T. scopulicola* plants have 3–5 spines, which measure 1 mm in height and are awl-like, per areole. The shapes of the areoles vary from rounded to oval. Areoles are about 1–3 mm long and 1 mm broad, usually set low, sunken and with white felt; they are spaced 15–30 mm apart (Ritter 1980).

Trichocereus pachanoi (HUTCHISON)

This plant was collected in Peru (exact location unknown) in the 1950s by Paul Hutchison in one of the U.C. Berkeley expeditions. The plant analyzed in this study (Fig. 5) is a vegetative clone of the original specimen, which resides in the U.C. Berkeley Botanical Garden.

Trichocereus pachanoi (VAN GEEST)

This cactus (Fig. 6) is from seed collected near Huancabamba, Peru, by R. Van Geest (M. Terry, pers. comm.). It is not known whether the seed was from a single plant or was a mixture from several different individuals. In any case, these plants are morphologically distinct from those known as the *T. pachanoi* Huancabamba cultivar (cf. Fig. 4).

Trichocereus bridgesii (SALM-DYCK) BRITTON and ROSE

Trichocereus bridgesii is commonly grown as a hedge plant in Bolivia (Trout 2005) and also placed on top of walls for the protection of gardens. Individuals are typically

Fig. 5. *Trichocereus pachanoi* (Hutchison), basal stem (above) and apical stem (below).

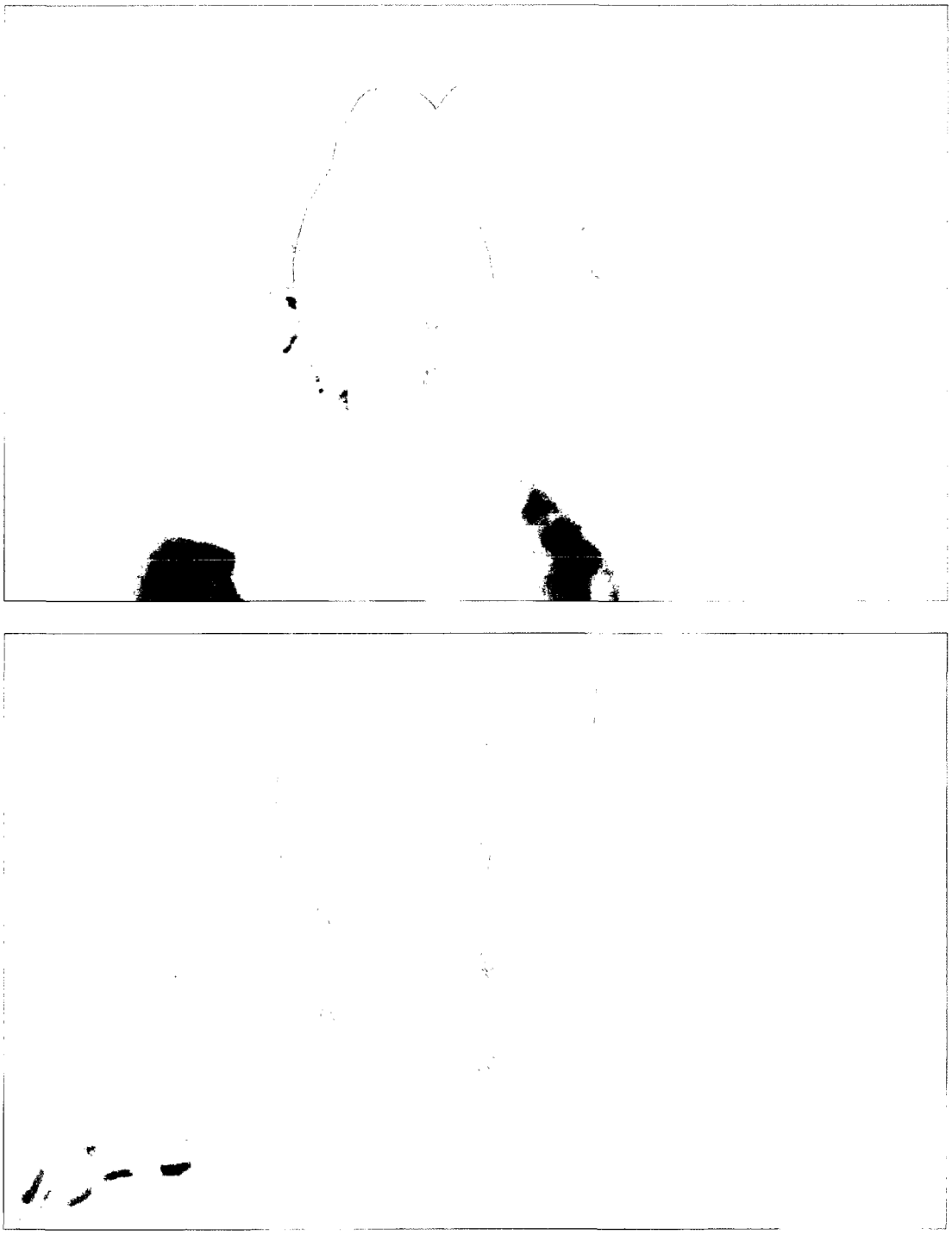


Fig. 6. *Trichocereus pachanoi* (Van Geest), apical (above) and basal (below) views.

treelike and branching, with stems to 5 m in height and up to 15 cm in diameter (Anderson 2001). The pale-green stems usually have from 4–8 ribs; ribs are obtuse and separated by broad, shallow sulci; areoles are large and about 2 cm apart. Yellowish spines number 2–6, not swollen at the base, acicular to subulate, unequal, and up to 10 cm in length. One of the cultivars analyzed in this study is a monstrose form attributed to Backeberg (Fig. 7).

Trichocereus pallarensis RITTER *NOM. NUD.*

Trichocereus pallarensis (Fig. 8) was originally collected by Friedrich Ritter (1980) at Llacanora, near Catamarca, and in Pallar and to the east of the Cordillera Blanca, Departmento, Ancash, Peru, where it grows at an altitude of 2400 to 3000 meters. Ritter (1980) assigned the collection number FR 676 to it. Plants grown from seed with this Ritter number were sold by Hildegard Winter in Germany beginning 1961. This species is bluish-green with erect stems that grow to 4 m or more in height and 7.5–12.5 cm in diameter. It branches freely from the base. The ribs number about 5–8. Areoles are variable in size with a v-mark merged with the upper portion. Spines number from 2–7 (usually 3–4) and are usually reddish brown in color (Trout 2005).

Trichocereus riomizquensis RITTER

Trichocereus riomizquensis (Fig. 9) was collected near the Río Mizque, Province of Campero, Bolivia, by Ritter (FR 856, 1980), who describes it as being morphologically similar to *T. scopulicola.*

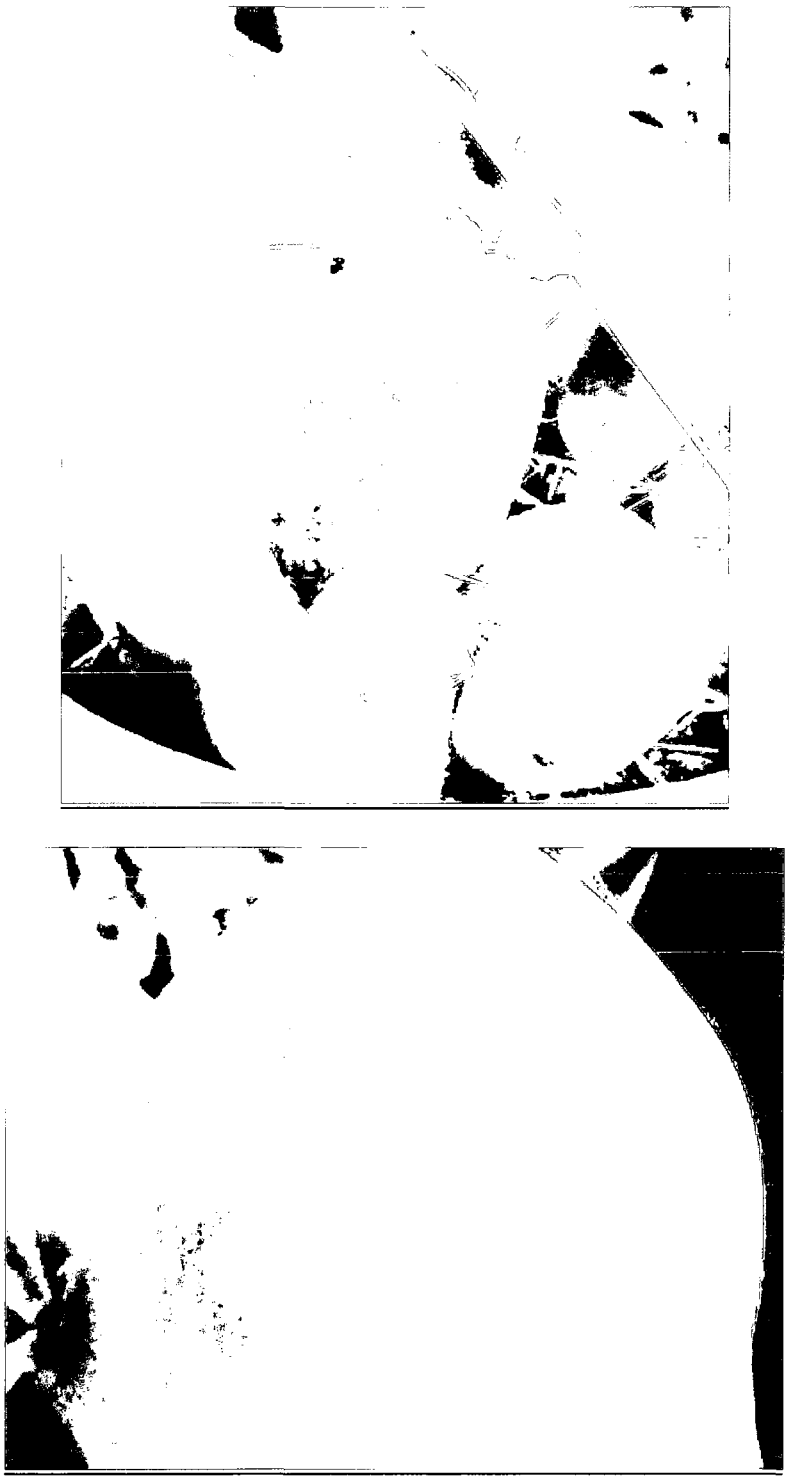


Fig. 7. *Trichocereus bridgesii* (Monstrose), whole plant (above) and apical stem (below).

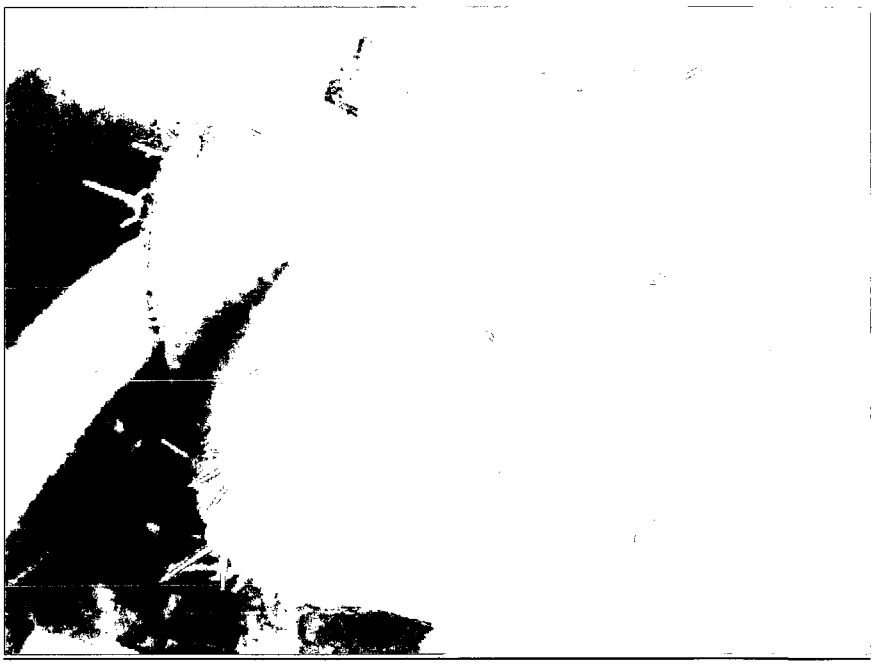


Fig. 8. *Trichocereus pallarensis*, apical view.

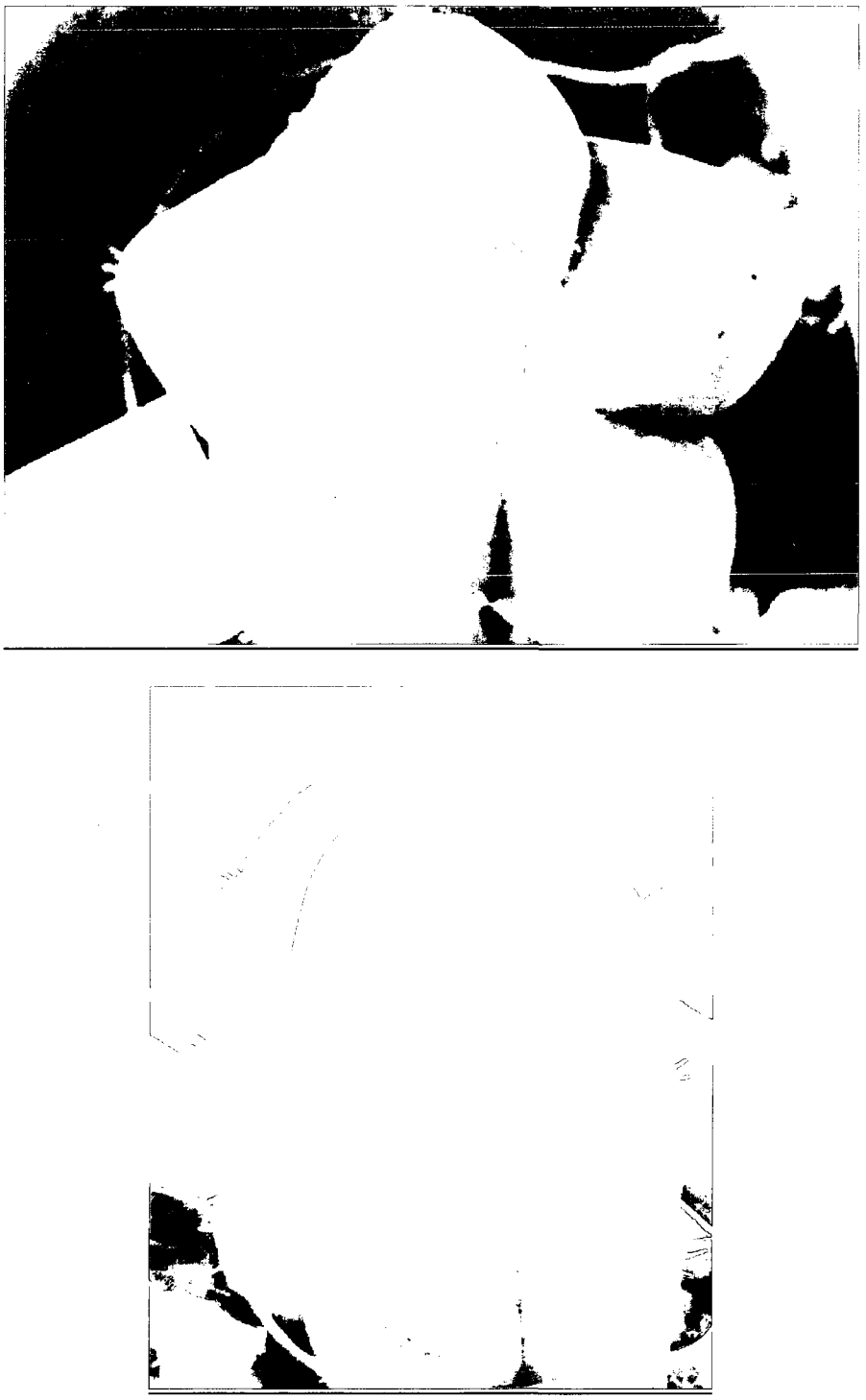


Fig. 9. *Trichocereus riomizquensis*, apical (above) and lateral (below) views.

Trichocereus santaensis RAUH and BACKEBERG

Trichocereus santaensis (Fig. 10) is a species in the *T. pachanoi* complex that is little known morphologically and pharmacologically. *T. santaensis*, according to Anderson (2001), is distributed in the valley of the Río Santa, at about 2000 m altitude, in central Peru. *Trichocereus santaensis* is a columnar cactus that grows to a height of 5 m, with basal branches and erect stems (Britton and Rose 1920; Anderson 2001). Its grayish-green stems are cylindrical, with 6–7 ribs that are broad and flat with a horizontal furrow and a V-shaped notch above the areole (Britton and Rose 1920; Trout 2005). Spines of *T. santaensis* are brownish and consist of one central spine measuring up to 4 cm in length and 2 to 3 radial spines up to 2 cm in length (Britton and Rose 1920; Trout 2005). Confirmation of the presence of mescaline in *T. santaensis* would imply that this species could have been used in spiritual and religious practices in the areas of Peru to which it is endemic. Though anecdotal human bioassay reports suggest the presence of mescaline in *T. santaensis*, no published analytical data are available on the mescaline concentration in the plant (Trout 2005).

Trichocereus peruvianus BRITTONA and ROSE

This cactus species (Fig. 11) occurs at an altitude of 2100 meters around and above Matucana in the Andean Central Peru (Britton and Rose 1920). Dr. and Mrs. Rose first collected this species on 9 July 1914. It is arborescent, with branches that can be erect or prostrate, and commonly grows from 2–4 meters in height (Britton and Rose 1920). Its stems appear bluish green and can be up to 20 cm in diameter (Trout 2005). *Trichocereus peruvianus* usually has 6–8 broad and rounded ribs with large areoles 2–2.5

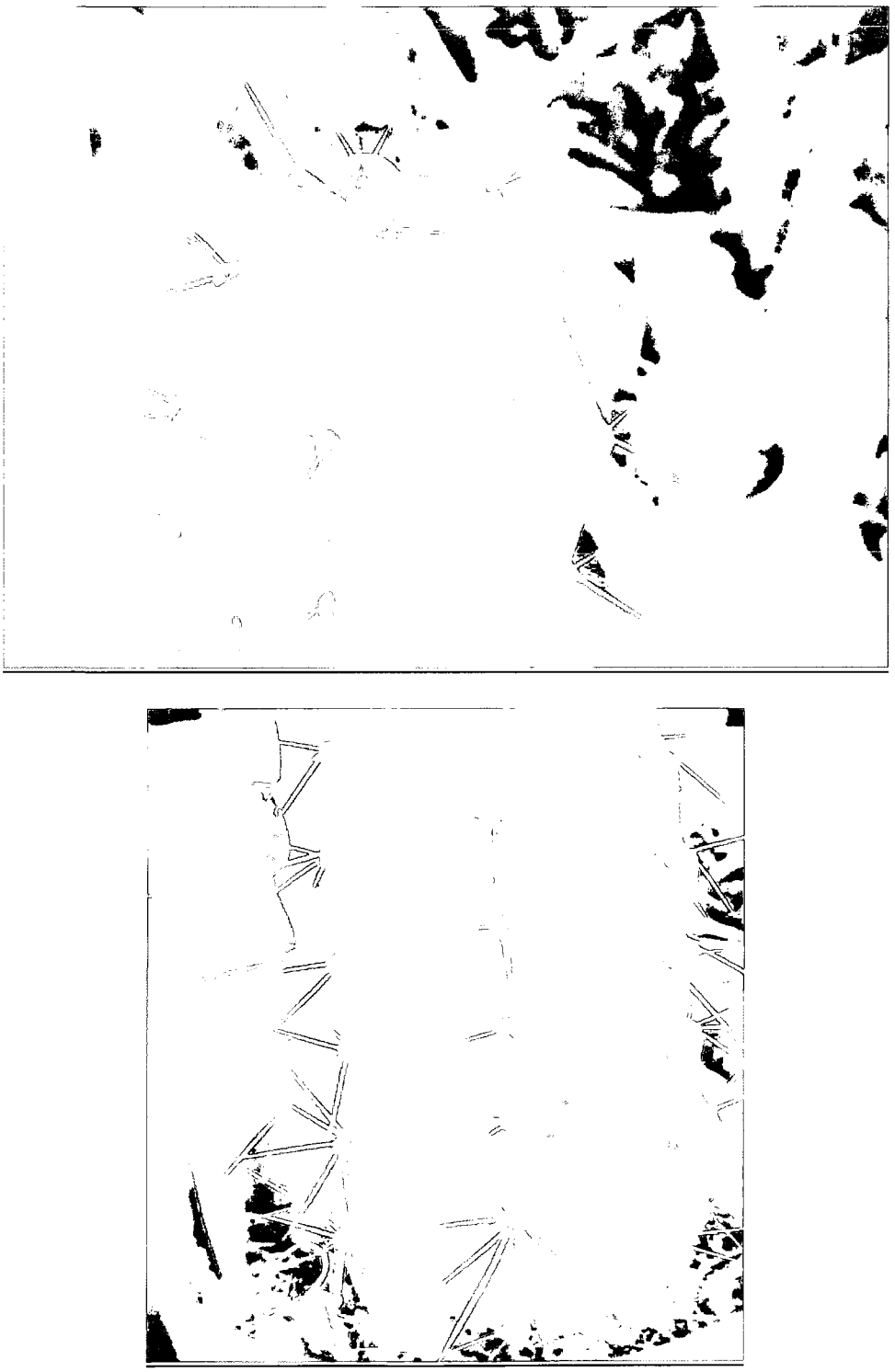


Fig. 10. *Trichocereus santaensis*, apical (above) and basal (below) stem.

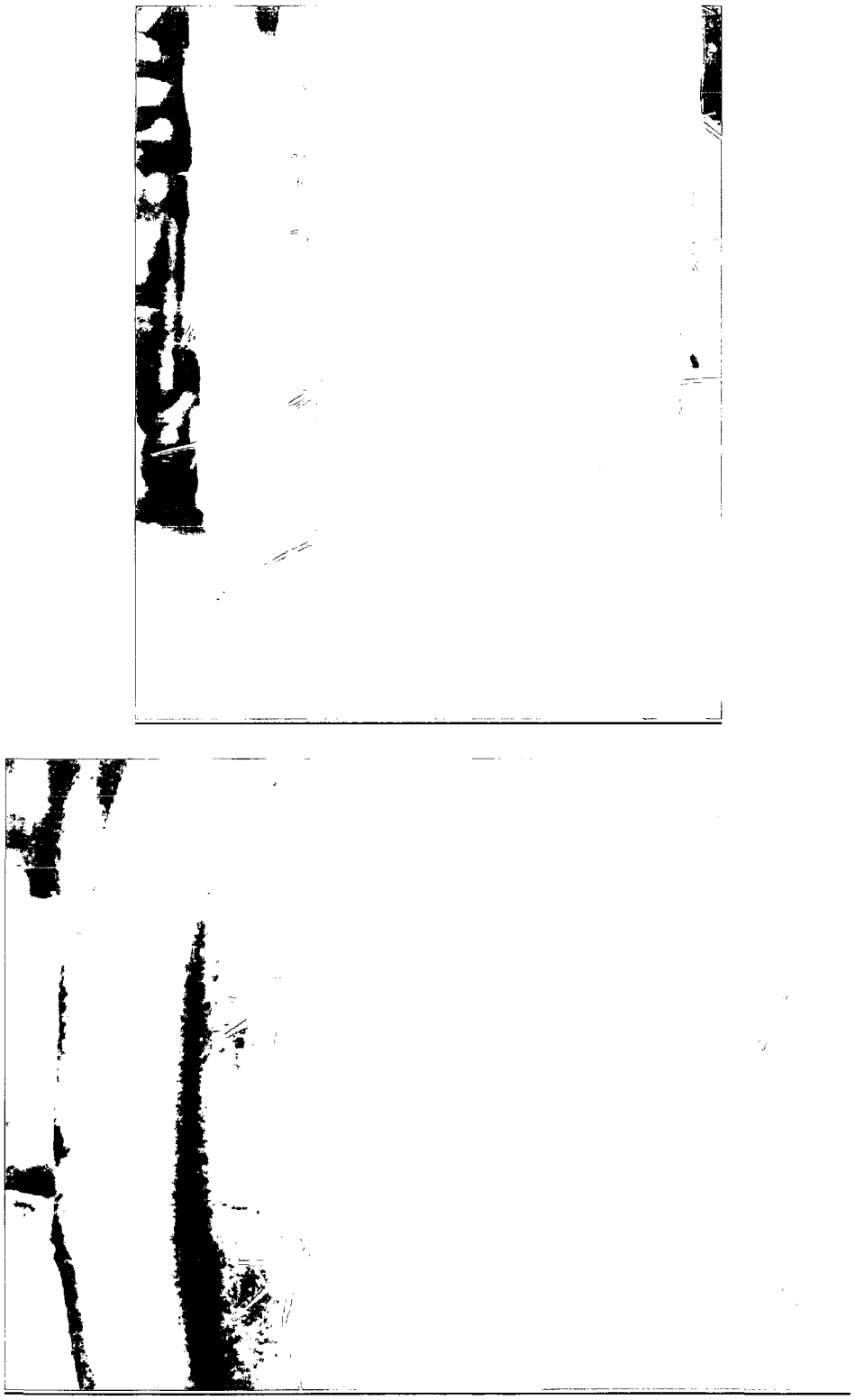


Fig. 11. *Trichocereus peruvianus* (KK #242), basal (above) and subapical stem (below).

cm apart that have V-shaped notches above. There are up to eight radial spines about 1 cm long. The usually single central spine can be up to four cm long (Trout 2005).

Trichocereus bridgesii (GILLETTE)

The second cultivar of this species analyzed in the present study is the form of *T. bridgesii* (Fig. 12) initially distributed in the United States by the nurseryman Bob Gillette (Trout 2005). The species *Trichocereus bridgesii* is synonymous with *Echinopsis lageniformis,* not *Echinopsis bridgesii.* It is native to Bolivia.

Trichocereus puquiensis RAUH and BACKEBERG

Unlike *T. peruvianus, T. puquiensis* (Fig. 13) branches at about five centimeters above the ground. It is erect and grows up to four meters in height. The branches appear bluish-green and are about 15 cm in diameter with a swollen appearance (Trout 2005). This plant has from 8–10 ribs which are not traversed by furrows but are swollen around the areoles. The ribs measure about two cm in height. The round areoles measure ca. 1 cm in diameter. The spines, which number from 10–12, appear chestnut brown but later fade to very light brown. The plant has about 10 radial spines that measure 1–2 cm long. It has two central spines, of which one is usually erect and up to 10 cm long, and the other usually pointing downward and measuring up to 5–8 cm long (Trout 2005).

Trichocereus uyupampensis BACKEBERG and KNUTH

This species (Fig. 14) is distributed in Peru and Bolivia. The cactus is densely branched and usually has branches that can be prostrate and/or pendant. Its stems are cylindrical and grow up to 3.5 cm in diameter. This cactus has about nine ribs that are narrow, flat and tuberculate. The areoles are usually small and light brown in color. Its

dark spines point irregularly, number from 8–10, and grow from 2–6 mm long (Anderson 2001).

ETHNOBOTANICAL AND ARCHEOBOTANICAL BACKGROUND TO THE ALKALOID ANALYSIS

Trichocereus pachanoi has over the centuries been employed in spiritual and religious practices, and from a botanical/pharmacological point of view, the spiritual practices can be seen to be integrated with the psychoactive properties of alkaloids of the plant, particularly mescaline (Dobkin de Ríos 1972). Religious use of San Pedro (*T. pachanoi*) dates back at least to the Chavín culture, regarded as one of the oldest civilizations in Peru, (Sharon 1978), and Chavín archaeological artifacts with San Pedro motifs recovered in Peru indicate the religious use of San Pedro about 3000 years B. C. (Dobkin de Ríos 1972; Sharon 1978, Sharon 2000; Cordy-Collins 1982).

Until recently, considerable confusion surrounded the true identity of the ritual psychoactive plant popularly called San Pedro. Authors express different opinions about the appropriate taxonomy of species in the genus *Trichocereus*. Friedrich and Glaetzle (1983), relying on seed morphology, lumped these species (which up to that time were universally recognized as the genus *Trichocereus*, rather than a subgenus) into the genus *Echinopsis*, a move that Anderson (2001) described as being greeted with "little controversy". However, Trout (2005), who referred to such lumping as a "devil may care expansion of *Echinopsis*" concluded that such absorption of *Trichocereus* into *Echinopsis* created more problems than it solved, and preferred to leave *Trichocereus* as a separate

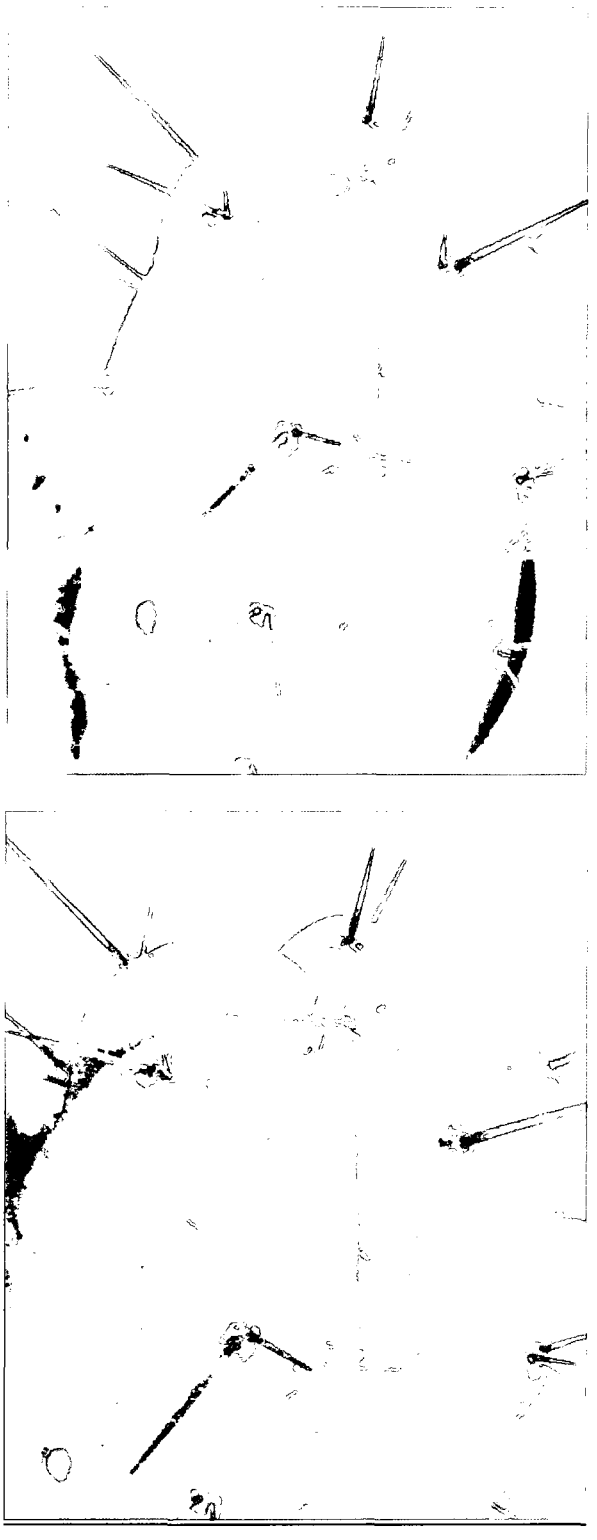


Fig. 12. *Trichocereus bridgesii* (Gillette), apical stem (above) and close-up (below).

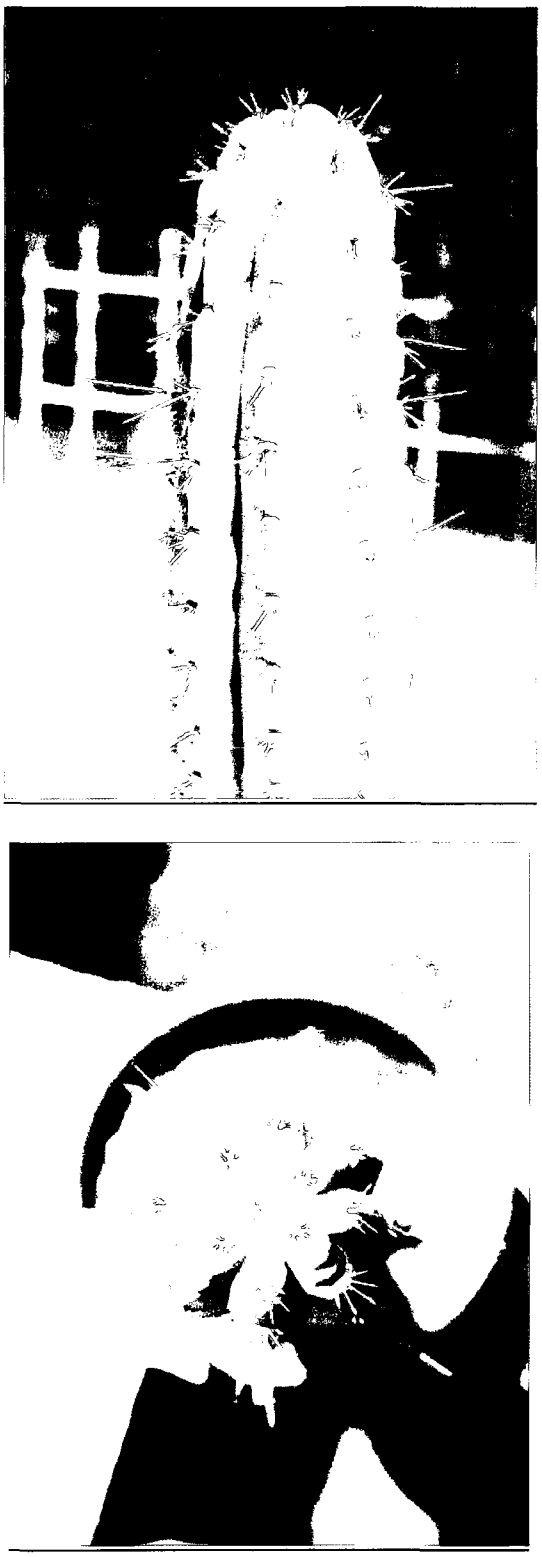


Fig. 13. *Trichocereus puquiensis*, lateral (above) and apical (below) views.

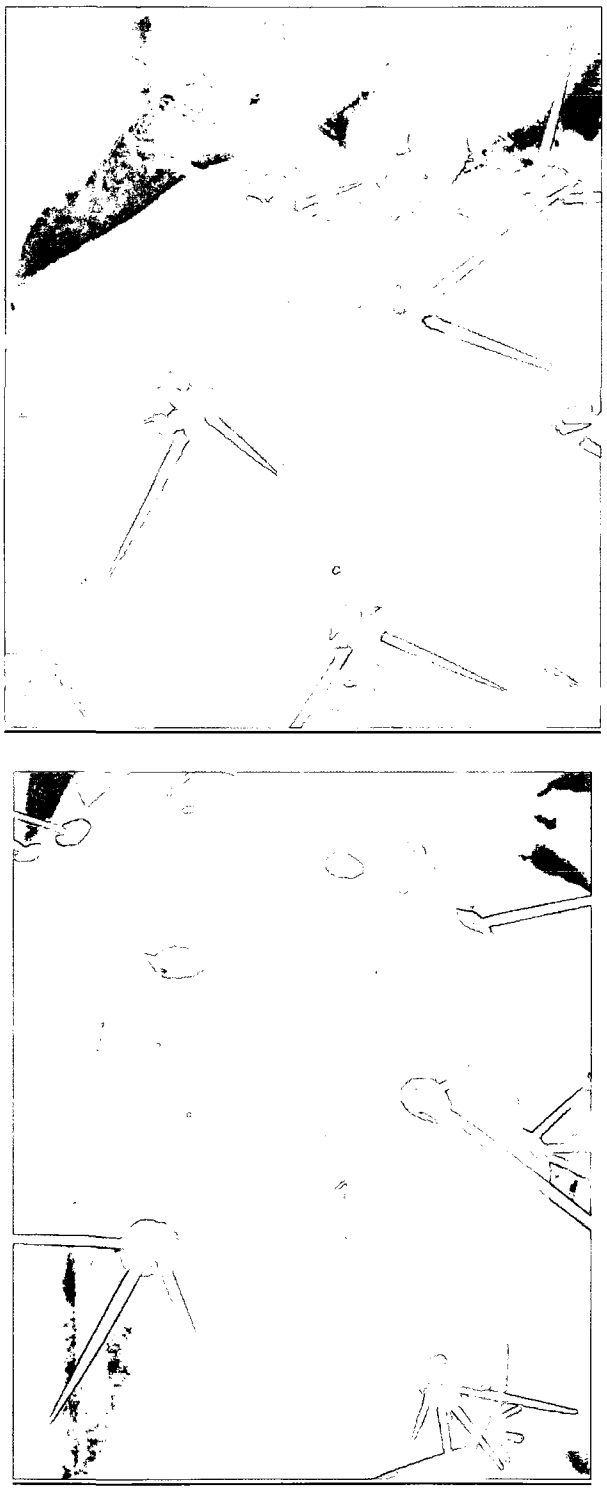


Fig. 14. *Trichocereus uyupampensis*, young stem (above), older stem (below).

genus. Trout (2005) advocated the employment of both morphology and chemotaxonomy for distinguishing *Trichocereus* species from *Echinopsis* species.

Earlier analytical and pharmaceutical reports from South America identified the specimens that were chemically assayed as *Opuntia cylindrica* (Schultes and Hofmann 1980). Similarly, Turner and Heyman (1960) and Marini-Bettòlo and Coch Frugoni (1958) employed electrophoresis to separate alkaloids including mescaline from tissue extracts of a plant they identified as *Opuntia cylindrica.* Poisson (1960) was the first person to isolate mescaline from a validly identified San Pedro (*Trichocereus pachanoi*) from Friedberg's (1959) voucher material. Further, Poisson (1960) noted the occurrence in the Huancabamba region of Northern Peru of a cactus named San Pedro that the natives employed as a euphoriant and hallucinogen. Friedberg (1959) was the first to report that the ritual drug plant popularly known as San Pedro corresponds to that described by Britton and Rose (1920) as *Trichocereus pachanoi.* It also turned out that Friedberg (1959) was the first person to submit properly documented material for chemical analysis, which was done by Poisson (1960). Trout (2005) has, however, remarked that Friedberg was probably not the first person to observe that *T. pachanoi* was called San Pedro in Peru. The time and place where westerners became aware of the psychoactive properties of *T. pachanoi* as a species are not known (Trout 2005).

Backeberg (1959), who claimed credit for the introduction of *T. pachanoi* into the western world, further stated that *T. pachanoi* was called San Pedro in Northern Peru. The account of Father Anello Oliva (1895), a Spanish priest, has been cited as the earliest extant written description of San Pedro usage. This account expressed Christian bias against the use of San Pedro, thus being reminiscent of the terms of condemnation used

by the Catholic Church to describe peyote in Mexico as the plant with which the Devil deceived the Indians (Sharon 1978). Healers who employed hallucinogenic San Pedro have been described as doing so to influence and deceive those who patronize their services (Trout 2005). Sharon (2000) gave an account of a 1782 legal case involving a healer accused of healing with a brew of San Pedro in which the description of his healing ritual, methods, and accoutrements were similar to those seen today.

In spite of severe persecution of such healing practices, their eventual toleration and acceptance by the Church was predicated on healers, refraining from invocation of the Devil in their healing sessions (Sharon 1978). Such a compromise might have largely been responsible for early adaptation of Christianity into San Pedro healing rituals. Even though it is not certain when San Pedro rituals and beliefs commenced, their acceptance and practice are deeply rooted in religious development and the expression of works of art in Peru (Sharon 1978). Sharon (2000) presented a Chimu culture vessel that portrayed a curandera bearing a four-ribbed San Pedro. Schultes and Hofmann (1980) showed a Chimu culture ceramic pot (ca. 1200 A.D.) that portrayed an owl-eyed herbalist or shaman holding a San Pedro section that appeared to have had its spines removed. Interestingly, it has been shown that women shamans/herbalists engaged in the sale of San Pedro are locally believed to associate with the owl. Reference has also been made to Nazca culture urns portraying *T. pachanoi* which have also been described as appearing to be like mummy bundles carrying a stem of San Pedro on each shoulder (Schultes and Hofmann 1980; Yetman 2007).

Sharon (2000) showed that past civilizations in Peru had unequivocal, clear, San Pedro portrayals on ceramics. The Nazca civilization which thrived in southern coastal

Peru from 100–800 A.D. had a wealth of ceramics and textiles that indicated their employment of wilka snuff made from a mixture of *Anadenanthera peregrina* and San Pedro (Cordy-Collins 1982). On the northern coast of Peru, between 100 B.C. and 700 A.D., the Mochica culture extensively employed San Pedro in rituals (Sharon 1978; Cordy-Collins 1982). The extensive use of San Pedro in both Mochica and Nazca cultures was elaborately intertwined within the social structures of both cultures and not confined solely to the Shamans (Cordy-Collins 1982).

In the description of Moshe art of northwestern Peru from around 100 B.C. to 70 A.D., San Pedro was frequently portrayed as a shawl-wrapped female figure in a healing context and often bore owl-like attributes that at times had outstretched hand on which was a slice of San Pedro (Sharon 1978; Schultes and Hofmann 1980). Sharon (2000) presented a ceramic portrayal of a four-ribbed San Pedro dated to 400-200 B.C., which was made in the Salinar style of the northern coast of Peru with one of the vessels made such that a branch like that of San Pedro projected from its side. A stone carving excavated from Chavín de Huántar in the northern Peruvian Andes and radiocarbon dated to about 1300 B.C. represents the most significant of these artifacts. According to Schultes and Hoffmann (1980), this stone carving depicts a god-like figure holding in its hands the stem of a columnar cactus interpreted to be San Pedro. Shultes and Hofmann further noted that the San Pedro was portrayed in Chavín textiles with jaguars and hummingbirds. An example of Chavín textile referred to as Shamanism Textile, now fragmentary and measuring about 54.61 × 68.58 cm with religious messages written on it, was excavated in the coastal region of Peru (Cordy-Collins 1982). This textile, thought

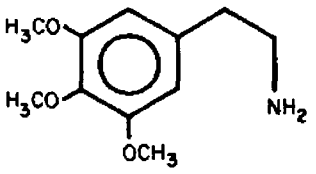
to be originally from the Chavín de Huántar area and dated to 100 B.C., shows San Pedro cactus along with a jaguar, an animal that symbolizes intoxication and an altered state of consciousness to shamans all over the Andean region of South America (Cordy-Collins 1982). There is a good photograph of a vessel artifact dated to 1200–600 B.C., which depicts a jaguar with dilated pupils (caused by stimulation of the sympathetic nervous system by phenethylamines such as mescaline) among branches of San Pedro with swirls thought to represent hallucinogenic action of the cactus (Sharon 2000). There are in existence five other vessels (from ca. 700–500 B.C.) which portray a spotted jaguar and spiral designs with four-ribbed San Pedro (Sharon 1978). A ceramic deer was also recovered in Northern Peru from the Chavín civilization that has been radiocarbon dated to 1000–700 B.C. (Sharon 1978). Another interesting discovery was what looked like cigars made from the "bark" (presumably epidermis and cuticle) of cactus. These unusual objects were found in Chavín refuse and were radiocarbon dated to approximately 800 B.C. (Sharon 1978). Although the species of the cactus could not be determined, these cigar-like, artifacts were assumed to have been used for hallucinogenic purposes due to the evidence that the Chavín employed only cacti for hallucinogenic purposes. But Trout (2005) noted that mescaline-containing cacti were never known to have been smoked for hallucinogenic purposes. Cordy-Collins (1982) also suggested the alternative possibility that the rolled-up, cigar-like objects could be have been used as tea. Chemical analysis of these artifacts (using very small samples of the irreplaceable archaeological plant material) would likely help to resolve the interpretation of their function in the Chavín culture.

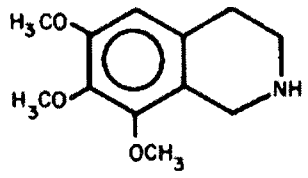
Several Chavín carvings of stone heads portray mucus exuding from the nostrils, similar to what is observed in users of hallucinogenic snuffs like the ones made from *Virola* or *Anadenanthera* plants (Sharon 1978, 2000). These stone carvings appeared much earlier than other known San Pedro depictions (Sharon 1978). The tropical, lowland forest further east in South America is believed to be the original homeland of the Chavín, and these people became accustomed to San Pedro after their mass exodus into the Andean region where San Pedro flourished around 2000–1500 B.C. (Cordy-Collins 1982). The Chavín, it appears, while maintaining their traditional use of *Anadenanthera* snuff, integrated the use of San Pedro (Cordy-Collins 1982).

In the northern coastal region of Peru, San Pedro has long been employed for diagnosis as well as for healing purposes (Dobkin de Ríos 1972). Cimora, a concoction involving different species of plants including San Pedro, is associated with moon rites of the religion that uses it. Besides the fact that a number of plants are used as additives to San Pedro, there is also substantial variation among healers and shamans concerning the mode of preparation and the potential components of the San Pedro concoction. The most common method is to cut the cactus in pieces and boil it in water for 2–7 hours (Dobkin de Ríos 1972; Sharon 1978; Cordy-Collins 1982), which can be expected to yield a crude aqueous extract with a pharmacologically effective concentration of mescaline.

MESCALINE DISCOVERY AND SYNTHESIS HISTORY

Mescaline, or 3, 4, 5-trimethoxy-β-phenethylamine (Fig. 15), is primarily responsible for the psychoactive activity of pachanoid and peruvianoid *Trichocereus* species (Anderson 1996; Anderson 2001; Trout 2005). Mescaline is a phenethylamine and not a





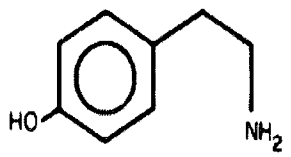


Fig. 15. Top: Mescaline, a non-phenolic phenethylamine; middle: Anhalinine, a non-phenolic tetrahydroisoquinoline; bottom: Tyramine, a phenolic phenethylamine.

true indole alkaloid (Anderson 1996). A white, odorless crystalline solid at room temperature, mescaline has a melting point of 35–36°C (Merck Index 1976; Anderson 1996). Mescaline has a molecular formula of $C_{11}H_{17}NO_3$ and a molecular weight of 211.25 (Merck Index 1976; Anderson 1996) and is soluble in chloroform, alcohol, and water and less soluble in ether (Anderson 1996). Mescaline is usually isolated from plant materials in the form of mescaline sulfate, which is precipitated in pure, crystalline form by virtue of its low solubility in a cold solution of alcohol and water. The sulfate has a melting point of 183–186°C and forms distinctive, brilliant prisms (Anderson 1996). Due to their solubility and ease of handling, mescaline sulfate and mescaline hydrochloride are the commonly preferred preparations for use in biomedical experiments (Anderson 1996).

Alkaloids from most cacti that have been analyzed (e.g., *Trichocereus* spp. and *Lophophora* spp.) consist largely of phenethylamines and/or tetrahydroisoquinolines. Mescaline is an example of a phenethylamine that basically has the structure of a benzene ring with an ethylamine side chain (Fig. 15). Beta-phenethylamine results from protein decomposition and is not a primary plant product (Anderson 1996). Isoquinolines range from simple to complex in nature and can be derived from the corresponding, substituted β-phenethylamines. Anhalinine is an example of a simple tetrahydroisoquinoline that is closely related to mescaline (Fig. 15).

Mescaline history commenced when the German pharmacologist Lewin (1888) published the first paper on peyote chemistry. Hefter (1898), encouraged by Lewin's work, and through self-experimentation, became the first person to isolate, identify, and name mescaline. Späth (1919) and his colleagues published several papers on peyote

chemistry, in which they described five more peyote alkaloids, which include anhalidine, anhalanine, N-methylmescaline, N-acetylmescaline and ortho-methylmescaline. Späth (1919) became the first person to successfully synthesize mescaline. Späth further showed that peyote alkaloids could be classified as phenolic and non-phenolic compounds based on their functional groups. In a phenolic compound, a hydrogen atom on the aromatic ring was replaced by a hydroxyl group. An example of a member of the phenolic group is tyramine (Fig. 15). In a non-phenolic compound, another substituent like a methyl or methoxy group replaces a hydrogen attached to a carbon in the aromatic ring. An example of a non-phenolic compound is mescaline (Fig. 15).

PROBLEMS IN THE CHEMICAL ANALYSIS OF MESCALINE CONCENTRATION IN *TRICHOCEREUS* SPECIES

While there seems to be universal agreement among scientists that the predominant (though not the only) psychoactive principle in *Trichocereus pachanoi* is mescaline, the mescaline content of this cactus has long been a subject of controversy and confusion. Different authors, employing various methods and instrumentation, have published markedly different mescaline contents for the plant. Agurell (1969a) obtained 0.395 g of nonphenolic alkaloids (predominantly mescaline) from 875 grams of fresh cactus material, which corresponds to 0.04% mescaline by fresh weight or 0.67% by dry weight. Agurell (1969b) published his results in tabular form, expressing concentrations in ranges rather than individual sample concentrations of alkaloid yield. These results were tabulated semiquantitatively as +++ (>50 mg of total alkaloids per 100 grams of fresh cactus material), ++ (10–50 mg/100g), + (1–10 mg/100g), or trace (<1 mg/100 g). *T. pachanoi* showed total alkaloid content in the +++ range, but the percentage of mescaline

in the total alkaloid fraction was reported as only 3%, which is equivalent to about 0.03% mescaline on a dry-weight basis. Bruhn and Lundström (1976), starting with live plants that weighed from 30 to120 grams, published total alkaloid recovery of 20–90 mg, which corresponds to mescaline content of 0.067–0.079% by fresh weight, or 1.1–1.3% mescaline by dry weight. Poisson (1960), analyzing *T. pachanoi* material obtained from Huancabamba by Friedberg (1959), published a mescaline yield of 2% on a dry-weight basis, extracted from 180 grams of fresh cactus material. Turner and Heyman (1960), who `first moistened their cactus material with methanol-ammonium hydroxide (20:1), obtained what they described as a "white crystalline" material which was three times recrystallized from water-ethanol and identified as mescaline based on the melting point of the sulfate. No quantities were indicated. Crosby and McLaughlin (1973) had a total mescaline recovery of 0.331% from freeze-dried plant material.

Variations among these published results may be partially attributable to real differences in mescaline content among the various cultivars of *T. pachanoi* sampled and among individuals of the same cultivar. Environmental factors that would be expected to contribute to geographical and/or temporal variation in mescaline content include variations in temperature and rainfall (which correlate with differences in altitude) as well as edaphic conditions. But it is suspected that a major part of the reported variation in mescaline content of *T. pachanoi* might be attributable to inter-laboratory 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 current, uniform, analytical methods in a single laboratory to determine the mescaline contents of *Trichocereus pachanoi* and related taxa. All analyses were conducted by the same investigator using the same procedures, the same experimental conditions, and the same equipment. A secondary objective was to examine the relationship between mescaline concentration in *Trichocereus* taxa/cultivars and the prevalence of the use of those taxa/cultivars by indigenous shamanic practitioners. My hypothesis was that the cacti with the highest mescaline tissue concentrations would be more likely to be used and that such use would be reflected in the literature or in the results of my own research.

CHAPTER II

MATERIALS AND METHODS

In view of the taxonomic uncertainty that surrounds the genus *Trichocereus* and the ethnobotanical uncertainty about how the various species and cultivars are used by practitioners of different cultures over the large geographic area to which the genus is endemic, 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 and geographic origin, or (b) the plants exhibited documented use for shamanic, therapeutic purposes, or (c) in the single case of *T. pachanoi* cv. Juul's Giant, the plant is widely available as a cultivar in the United States, but the geographic region of Peru to which it is native is not known.

Due to the difficulty of obtaining reliably documented specimens, I 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.

PREPARATION OF MESCALINE STOCK SOLUTION

A sample of authentic mescaline hydrochloride (purchased from Grace Davison by my research project supervisor, M. Terry, DEA Researcher Registration No. RT 0269591) was weighed out to 4.30 mg. To determine the amount of pure mescaline alkaloid in the mescaline hydrochloride, the weight of 4.30 mg of mescaline hydrochloride was multiplied by the molecular weight of pure mescaline, 211.25, and the product was divided by the molecular weight of mescaline hydrochloride, 247.70, which

yielded 3.67 mg as the weight of pure mescaline alkaloid in the weighed sample of mescaline hydrochloride. Next, 50 mL of HPLC-grade methanol was measured in a volumetric flask, and the weighed sample of mescaline hydrochloride was dissolved in it. The concentration of mescaline alkaloid in this standard solution was obtained by dividing the weight of 3670 μg of mescaline alkaloid by the volume of 50 mL of methanol, to give a concentration of 73.3 μg/mL of mescaline alkaloid. Thus 73.3 μg/mL was the mescaline concentration of the standard solution of the highest concentration. Standard solutions of progressively lower concentrations of mescaline were prepared by serial dilution, taking, for example, 1.0 mL of the high-concentration standard solution and diluting it with an equal volume of methanol, to yield a solution with a concentration exactly half that of the high-concentration solution. Thus, 1.0 mL of 73.3 μg/mL mescaline solution plus 1.0 mL of methanol gives a solution with a mescaline concentration of 36.7 μg/mL. Similarly,

1.0 mL 36.7 μg/mL mescaline plus 1.0 mL MeOH = 18.3 μg/mL mescaline;

1.0 mL 18.3 μg/mL mescaline plus 1.0 mL MeOH = 9.17 μg/mL mescaline;

1.0 mL 9.17 μg/mL mescaline plus 1.0 mL MeOH = 4.59 μg/mL mescaline.

ESTABLISHMENT OF A STANDARD CURVE

The high-performance liquid chromatography (HPLC) column (Phenomenex Luna 3-μm 250 mm x 4.6 mm ID reverse phase C-18) was thoroughly cleaned and stabilized by running through it pure, distilled water for 20 minutes, then 50% water and 50% methanol for another 20 minutes, and, finally 100% methanol for 20 minutes. This washing of the column was carried out to prevent residual analytes with long retention times from bleeding out into a subsequent run of a cactus sample to give false results.

The recording of a continuous, straight line on the chart paper for at least 45 minutes was taken as evidence that the column was clean. All organic solvents and water were of HPLC grade. Additionally, all glassware and syringes were cleaned and rinsed with HPLC-grade acetone to remove any trace of substances that could give false peaks in the chromatograms generated by the HPLC instrument. The sensitivity of the instrument was set such that responses from all working standard solutions remained on scale, allowing the measurement of peak heights, which are directly proportional to the concentration of the analyte producing a given peak. Once the conditions under which the chromatograph would yield appropriate separation and quantification of analyte in an unknown sample had been empirically established, those conditions were used to run standard solutions for a standard curve. Twenty μg of HPLC-grade methanol without mescaline was injected into the HPLC. The shape and retention time of the peak it produced were noted as characterizing the solvent peak. Then the standard solution of lowest mescaline hydrochloride concentration was injected, and its response in terms of peak shape and retention time was observed and noted. The remaining concentrations of mescaline standard were sequentially injected into the HPLC, and the corresponding responses in peaks were observed and noted. Caution was particularly taken to ensure that all mescaline peaks were on scale and at least 2.5 times the amplitude of any noise on the recorder, with none of them giving the same response as methanol. The mescaline standard solution with the highest concentration was injected last. The syringe was rinsed several times when changing from one standard concentration to the other. Mescaline peak heights were measured in cm, and their values (five injections at each

concentration) were recorded for each concentration of mescaline in the series of standard solutions.

Mescaline standard solution concentrations and the corresponding mean HPLC peak heights were plotted in a standard curve and correlated using a Labworks spreadsheet. A dataset was considered acceptable if the correlation coefficient was ≥ 0.999.

MESCALINE EXTRACTION FROM CACTUS TISSUE

A fresh sample of chlorenchyma from the outer cortex of the stem of each *Trichocereus* species to be assayed was weighed, sliced, and cut into cubes ca. 1 cm^3 and then desiccated for ca. 30 hours at room temperature and weighed in the dried state. The dried material was then ground into fine particles with mortar and pestle. A quantity of 2.0 grams of the desiccated chlorenchyma tissue was weighed out, transferred into a Soxhlet cellulose thimble, and extracted with HPLC-grade methanol in a Soxhlet apparatus for approximately 8 hours at a temperature of 40°C. The extract was then evaporated to dryness in a rotary evaporator. The extract (which normally had a dark green, resinous appearance) was redissolved in 150 mL of distilled water and empirically acidified dropwise with concentrated hydrochloric acid to pH 3.0 to ensure 100% protonation of the mescaline. The acidified aqueous extract was transferred to a separatory funnel, and 50 mL of methylene chloride (dichloromethane) were added. The separatory funnel was then gently shaken, mixing the aqueous phase and the organic solvent phase together, whereupon the built-up pressure was released. This procedure was repeated with increasingly vigorous shaking until pressure no longer built up. The separatory funnel and its contents were then allowed to stand until there was a clear

separation between the (upper) aqueous layer and the (lower) organic solvent layer. The methylene chloride layer was then drained out of the separatory funnel and discarded, and the aqueous layer was retained. This process of washing the acidified, aqueous extract with methylene chloride was repeated once. The aqueous phase was then transferred to a 500 mL beaker, and 5 N NaOH was added dropwise until the solution was alkalinized to pH 12.0, in order to deprotonate 100% of the mescaline (the pK_a of the amine group of mescaline being 9.5). The alkalinized, aqueous solution containing the extracted mescaline was then transferred to a clean separatory funnel and extracted with 50 mL methylene chloride. The contents of the separatory funnel were allowed to stand until complete separation between the aqueous layer and the methylene-chloride layer occurred. The methylene-chloride layer (now containing the extracted mescaline) was collected into an appropriate-sized beaker, and the aqueous layer was then discarded. The methylene-chloride extraction process was repeated once and the two extracts combined. The methylene-chloride was evaporated to dryness, and the extract was redissolved in 10.0 mL of methanol and filtered through a 0.2 μm pore size nylon filter attached to a 5.0 mL Hamilton syringe to remove particles too large to be suitable for HPLC. This filtered extract in methanol was stored in a glass vial and kept in the refrigerator until ready for HPLC separation.

MESCALINE SEPARATION ON HPLC

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 made by Spectra Physics, USA

and a Kipp and Zonen BE 8 multi-range recorder. Alkaloid separation was carried out isocratically with a Phenomenex Luna 3-μm 250 mm x 4.6 mm ID reverse phase C-18 column at 25°C. The mobile phase consisted of HPLC-grade acetonitrile 108 mL (10.8%), water 892 mL (89.2%) and trifluoroacetic acid 1 mL (0.10%), at a flow rate of 0.5 mL per minute. The detector wavelength was set at a known UV-absorbance maximum of 205 nm (Helmlin and Brenneisen 1992), and the sensitivity, measured in absorbance units full scale (AUFS), was set at an appropriate level according to the mescaline concentration in the tissue extracts of the different cactus species analyzed, so that the mescaline peak would remain on scale. In order to achieve on-scale, quantitative determination of mescaline in this project, the minimum sensitivity used was at a setting of 0.2 AUFS, and the maximum sensitivity used was at a setting of 0.1 AUFS. The HPLC injection volume was 20 μL of cactus extract in methanol for every sample.

The filtered cactus extract in methanol was serially diluted with increasing volumes of methanol until the HPLC peak it produced was on scale. The eluate was collected in a 1-mL GC-MS glass vial (Varian) while the recorder of the HPLC was tracing the expected mescaline peak on the chart paper.

CALCULATION OF MESCALINE CONCENTRATION IN CACTUS TISSUE

The percentage of mescaline in a sample of dry stem tissue was arrived at as follows: The mescaline concentration injected into the HPLC was obtained from the standard curve, according to the equation $y = 1.39x - 0.29$, where x is HPLC peak height in cm and y is the mescaline concentration (in μg/mL) injected on HPLC. The mescaline concentration injected was then multiplied by the inverse of the dilution factor (the

dilution of the extract required to bring the magnitude of the HPLC peak down to an on-scale height that could be manually measured in cm with a ruler). That result was multiplied by the total volume of the original extract (10.0 ml), which yielded the number of micrograms of mescaline in the original 2.0 g of tissue sample. This latter figure was multiplied by the sensitivity factor (either 1 or 2) to compensate for any adjustment in sensitivity. This result was then divided by 2.0 grams (the weight of dry chlorenchyma tissue from which the extract was made), and that result was divided by 1,000,000 μg/g to convert all units to micrograms of mescaline per microgram of dry tissue and then multiplied by 100%. The overall product of these calculations was the concentration (w/w) of mescaline in dry cactus chlorenchyma tissue, expressed as a percentage.

CHAPTER III

RESULTS

Extracts of desiccated chlorenchyma tissue from the outer-stem cortex of a total of 14 taxa and cultivars of *Trichocereus* cacti from different locations or collections were analyzed for mescaline content, and all 14 specimens analyzed were found to contain some detectable level of mescaline (Table 1). Each species/cultivar had 2.0 g of dried tissue analyzed by uniform procedures. The mescaline chromatogram peak of each sample analyzed exhibited a retention time of 14 minutes, which was very consistent for all samples analyzed. Confirmation of the identity of mescaline in the mescaline HPLC peak was carried out with GC-MS. Mescaline chromatogram peak confirmation was first done with mescaline standard, and a mescaline molecular ion of m/z 211 was confirmed (Fig. 16). Secondly, the mescaline chromatogram peak for a sample of extract of *Trichocereus pachanoi* (Matucana) tissue was confirmed by GC-MS, which yielded characteristic ion mass peaks (Fig. 17). Similar mass spectroscopy results (Fig. 18) were obtained by Rösner et al. (2007), further confirming that the primary solute in the HPLC eluate producing our peak with a retention time of 14 minutes was mescaline. The mass spectra also showed minor impurities in the HPLC peak and artifacts from previous studies that bled from the GC column.

Table 1. Mescaline content of *Trichocereus* species/cultivars in order of decreasing concentration by dry weight of cactus tissue.

Cactus species/cultivar	HPLC Peak Height (mm)	Mescaline concentration in extract (μg/mL)	Mescaline conc. (% of dry weight of cactus tissue)
T. pachanoi (Matucana)	133	18.2	4.7
T. pachanoi cv. Juul's Giant	155	21.2	1.4
T. pachanoi (Huancabamba)	136	18.5	1.2
T. scopulicola	98	13.3	0.85
T. pachanoi (Hutchison)	48	6.36	0.82
T. pachanoi (Van Geest)	123	16.7	0.54
T. bridgesii (Monstrose)	110	14.9	0.48
T. pallarensis	55	7.33	0.47
T. riomizquensis	92	12.4	0.40
T. santaensis	59	7.89	0.32
T. peruvianus (KK242)	57	7.61	0.24
T. bridgesii (Gillette)	164	22.5	0.18
T. puquiensis	50	6.64	0.13
T. uyupampensis	26	3.31	0.053

Trichocereus pachanoi (Matucana) had the highest mescaline concentration at 4.7% (Table 1; Figs. 19, 20). The *Trichocereus* species and cultivars analyzed in this study are arranged in decreasing order of mescaline tissue concentrations in Tables 1 and 2. The highest mescaline concentrations in my analysis tend to be associated with shamanic use (Table 2).

Table 2. Mescaline content, previously published analysis, and reported shamanic use of *Trichocereus* species/cultivars, in order of decreasing mescaline content.

Cactus species/cultivar	Mescaline conc. (% of dry weight of cactus tissue)	Previously analyzed (Reference)	Reported use by indigenous shamans (Reference)
T. pachanoi (Matucana)	4.7	No (Anon.)[1]	Yes
T. pachanoi cv. Juul's Giant	1.4	No	N/A[2]
T. pachanoi (Huancabamba)	1.2	?	Yes (Poisson 1960) (Friedberg 1959)
T. scopulicola	0.85	No	No
T. pachanoi (Hutchison)	0.82	No	No
T. pachanoi (Van Geest)	0.54	No	No
T. bridgesii (Monstrose)	0.48	No	No
T. pallarensis	0.47	No	No
T. riomizquensis	0.40	No	No

Table 2. Mescaline content, previously published analysis, and reported shamanic use of *Trichocereus* species/cultivars, in order of decreasing mescaline content, continued.

T. santaensis	0.32	No (Palomino Yamamoto 1972)	No
T. peruvianus (KK242)	0.24	Yes (Pardanani et al. 1977)	No
T. bridgesii (Gillette)	0.18	Yes (Agurell 1970)	No
T. puquiensis	0.13	Yes (Serrano 2008)	No
T. uyupampensis	0.053	No	No

[1] An indigenous supplier of *T. pachanoi* to traditional witches' markets, who requested anonymity,
[2] This is a well-known cultivar in the United States, but its geographic origin in Peru is unknown.

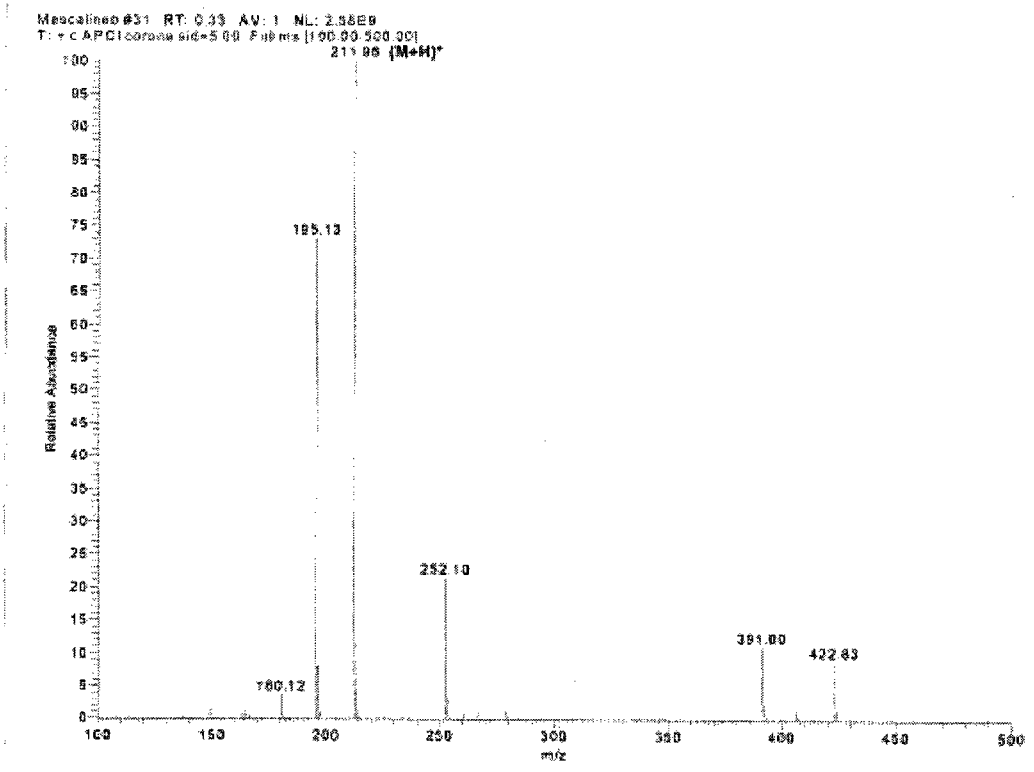


Fig. 16. Mass spectrum of pure mescaline standard (protonated) in HPLC peak.

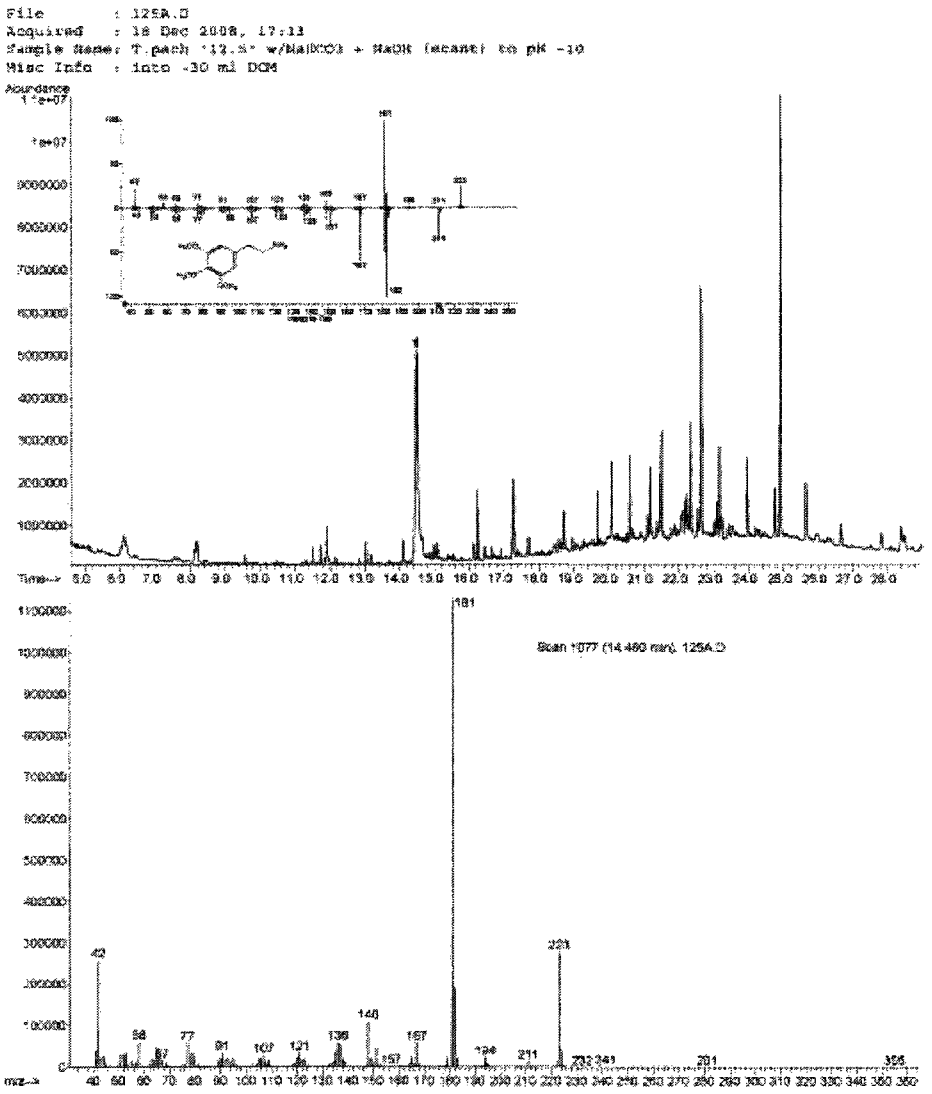


Fig. 17. GC-MS confirmation of mescaline in the mescaline HPLC peak from the extract of *Trichocereus pachanoi* (Matucana). Note the 211 mass peak of the molecular ion, as well as the characteristic mass peaks at 194, 181 and 167. The mass peak at 223 is a common artifact (see Fig. 18). Minor impurities associated with imperfect HPLC separation and artifacts associated with compounds from previous studies that bled from the GC column are also apparent.

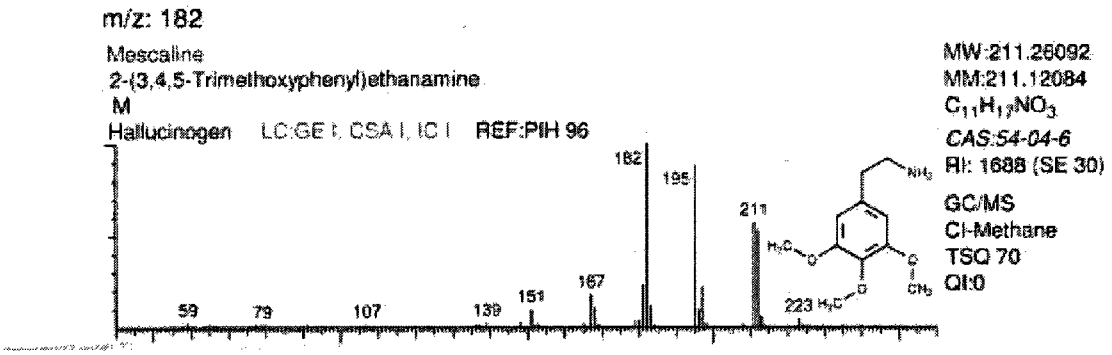


Fig. 18. Recent mass spectrum of mescaline by Rösner et al. (2007). Note molecular ion at m/z 211 and artifactual peak at m/z 223.

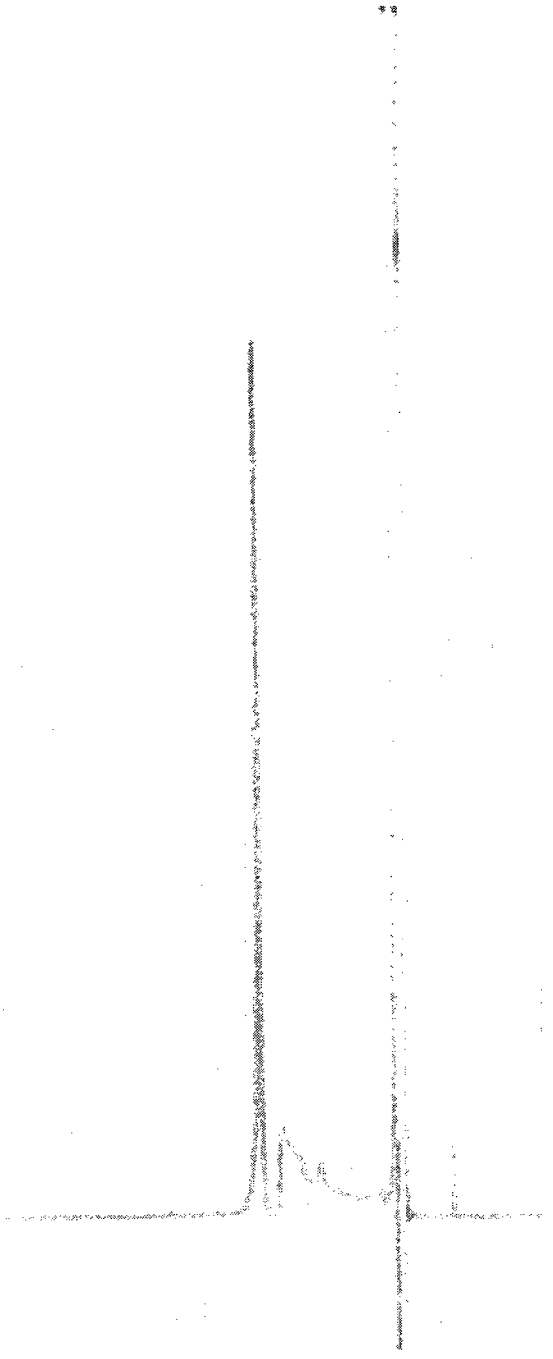


Fig. 19. HPLC chromatogram of alkaloid extract of *Trichocereus pachanoi* (Matucana). The 1.3 cm peak on the right is the injection event peak (t = 0). The off-scale peak at t = 4 minutes is the solvent peak. The 13.3 cm peak on the left is the mescaline peak at a retention time of t = 14 minutes.

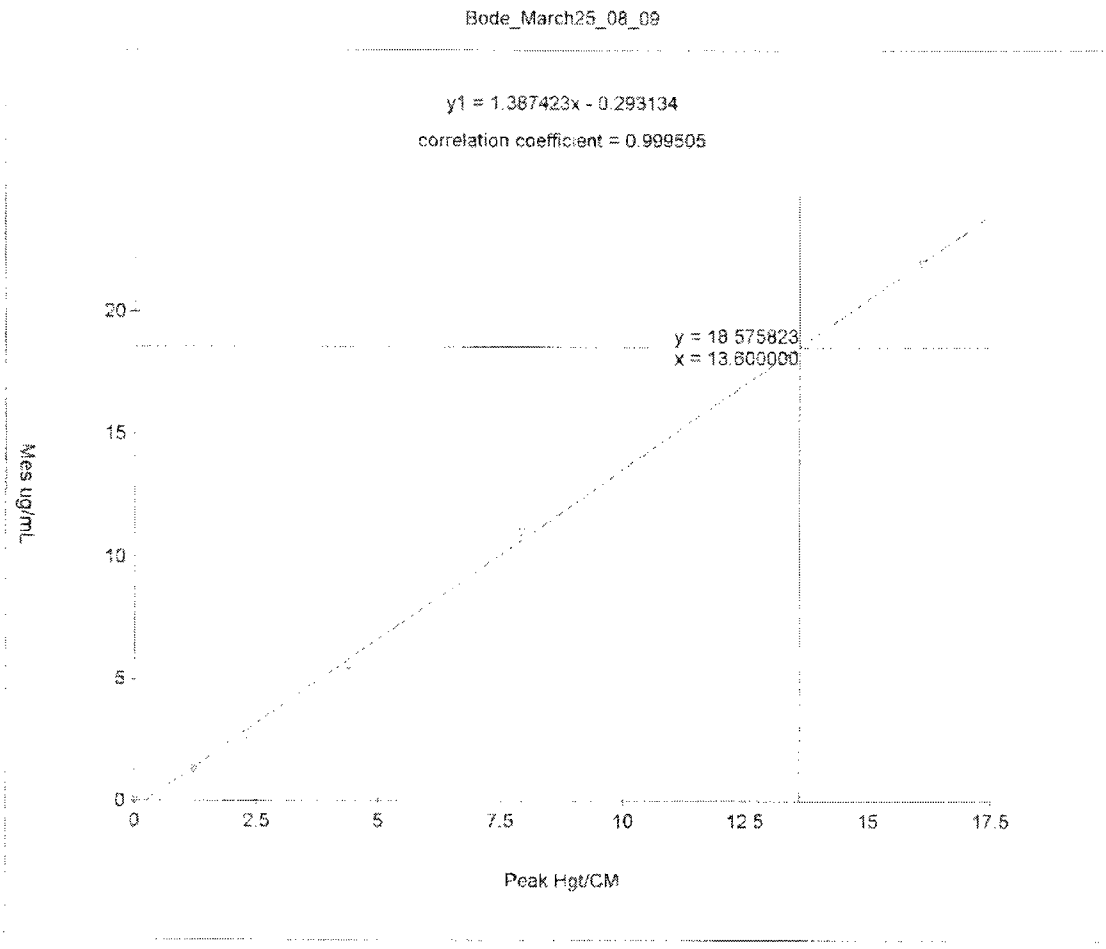


Fig. 20. Standard curve showing linear relationship between mescaline HPLC peak height (*x* axis) and mescaline concentration in the extract of *Trichocereus pachanoi* (Matucana) (*y* axis). The correlation coefficient of 0.9995 indicates adequate linearity.

CHAPTER IV

DISCUSSION

The analytical results of 14 *Trichocereus* species and cultivars in Table 1 clearly indicate that *T. pachanoi* (Matucana) possesses the greatest concentration of mescaline in dry-stem chlorenchyma tissue (4.7%). This superior 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, civilizations, and peoples of Peru and other countries contiguous to the Andes region. In earlier analyses of the species *T. pachanoi*—but probably not this particular Peruvian cultivar—Turner and Heyman (1960) had reported the recovery of 0.9% (w/w dry weight) of "crude base" which was determined to be mescaline by the melting point of the sulfate salt, whereas Crosby and McLaughlin (1973) reported a recovery of 0.331% mescaline from freeze-dried material. Agurell and Lundström (1968) found concentrations of 0.067% to 0.079% mescaline on a fresh-weight basis, which is approximately equivalent to 1.1% to 1.3% on a dry-weight basis. Poisson (1960) reported 2% mescaline recovery (dry-weight basis). The fact that my yield was considerably higher, at 4.7%, could be attributed in part to the genetic superiority of the Matucana cultivar, but another likely factor is that I analyzed only the photosynthetic outer layer of the cortical parenchyma (i.e., chlorenchyma), which evidently has a higher mescaline content than the rest of the cactus stem (Cruz Sánchez 1948; Gonzalez Huerta 1960).

Trout (2005) stated that a common error embedded in the literature is reference to *T. peruvianus* as being 10 times more "potent" than *T. pachanoi.* My results would indicate the opposite, namely that *T. pachanoi* contains a considerably higher

concentration of mescaline than *T. peruvianus* (Table 1). To add support to the notion that some *T. pachanoi* cultivars can be very high in mescaline content, Helmlin and Brenneisen (1992), who chemically assayed six Swiss cultivars of *T. pachanoi* obtained from retail and private collections, discovered one Swiss-grown *T. pachanoi* specimen which they adjudged to have a mescaline concentration 22 times greater than other Swiss-grown *T. pachanoi* species.

Another interesting comparative result is that of Gennaro et al. (1996), who reported the mescaline content of three, Italian-grown *T. pachanoi* plants that averaged 0.13% by fresh weight or 2.06 % by dry weight, which was higher than the mescaline content of two, Italian-grown *Lophophora williamsii* specimens which averaged 1.75% by dry weight. Though my result for *T. pachanoi* (Matucana) was higher than the results of Gennaro et al. for both of the species they analyzed, the direct comparison of the mescaline levels in my field-collected *T. pachanoi* (Matucana) and those of field-collected *L. williamsii* is an intriguing prospect yet to be realized.

Two cultivars of *T. pachanoi,* which may be closely related, were examined in this project. One of them, *T. pachanoi* (Huancabamba), yielded a mescaline concentration of 1.19% in cortical-stem chlorenchyma on a dry-weight basis—the third-highest result in the study (Table 1). The other, *T. pachanoi* (Van Geest), showed a mescaline concentration of 0.54%, the sixth-highest result in the present study (Table 1.). This difference in mescaline content between two plants of common origin—both being derived from cuttings of plants grown from seed collected by Dick Van Geest in the 1960s and widely distributed by Mesa Gardens—is particularly interesting in that it shows a greater-than-twofold difference in mescaline content in a study where procedural

variation was eliminated completely, and genetic variation was limited to individual variation among individuals produced from field-collected seed. That leaves ontogenic variation (differences in age and degree of maturity of the plants), environmental variation (differences in horticultural conditions), and temporal variation in rates of alkaloid biosynthesis and degradation as possible explanations for the observed variation in the mescaline levels.

The *T. peruvianus* cultivar examined in this study, *T. peruvianus* (KK242), yielded 0.24% mescaline content on a dry-weight basis (Table 1). Curiously, an earlier *T. peruvianus* analysis did not show any presence of mescaline (Agurell 1969). The reason for this absolute difference in results could be varietal or procedural. There are many diverse cultivars of *T. peruvianus*, and different, anecdotal, human-bioassay accounts show various results (Trout 2005). However, Pardanani et al. (1977) reported a mescaline recovery of 0.82% (dry weight) for an unspecified cultivar of *T. peruvianus*, which is similar to the values for several of the other *Trichocereus* species/cultivars analyzed in this study, though not for *T. peruvianus*.

Two cultivars of *T. bridgesii* were analyzed for mescaline content in this project. *T. bridgesii* (Monstrose) showed 0.48% mescaline content on a dry-weight basis, ranking seventh in the study (Table 1). *T. bridgesii* (Gillette) showed 0.18% mescaline content on a dry-weight basis, ranking eleventh in the study (Table 1). By comparison, Trout (2005) reported a mescaline content of about 25 mg per 100 gram of fresh weight for *T. bridgesii*, which amount is equivalent to about 0.4% mescaline content in dry tissue. Serrano (2008) recently reported a mescaline content of 0.56% for *T. bridgesii* from the eastern side of Lapazi, Bolivia, at an altitude of 3400 meters. These published figures for

T. bridgesii compare favorably with the figure reported for mescaline content of *T. bridgesii* (Monstrose) in Table 1.

Trichocereus *puquiensis* ranks thirteenth in the study with a mescaline content of 0.13% (Table 1). Quite recently Serrano (2008) published some quantitative data on the mescaline content of *T. puquiensis* harvested from different altitudes and locations in Peru, and reported 0.28% mescaline content for T. *puquiensis* grown on the western side of Chavina, Ayacuto, Peru, at an altitude of 3100–3300 meters. At an altitude of 3020 to 3050 m on the western side of Chumpi, Ayacuto, Peru, Serrano found that the same species contained 0.13% mescaline content dry-weight basis. On the western side of Incuyo, Ayachuco, Peru, at an altitude of 3330 m the same species had a mescaline content of 0.11%. But T. *puquiensis* grown on the eastern side Lucanas, Ayacucho, Peru, at an altitude of 3350 meters had a mescaline content of 0.50%. The first three results he obtained for *T. puquiensis* compare favorably with the mescaline content of 0.13% by dry weight reported in this thesis.

Trichocereus uyupampensis has no published analytical data on its mescaline content. In this project the mescaline content by dry weight is found to be 0.053%, the lowest of the 14 specimens analyzed. It would be reasonable to speculate that such a large amount of tissue from this taxon would have to be used to obtain a psychoactive quantity of mescaline that it seems unlikely that this species of *Trichocereus* would be used for mescaline-based therapeutic and diagnostic purposes, as are other species such as *T. pachanoi, T. peruvianus and T. bridgesii.*

My hypothesis that *Trichocereus* taxa/cultivars with the highest tissue concentrations of mescaline would be preferred by indigenous shamanic practitioners appears to be

borne out 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, *T. pachanoi* (Matucana), and the third, *T. pachanoi* (Huancabamba), are known to be used by practicing shamans in Peru (Friedberg 1959; Anonymous 2007). The plant with the second-highest mescaline content, *T. pachanoi* cv. Juul's Giant, cannot be meaningfully assessed for indigenous shamanic use (hence the designation "N/A" in the third column of Table 2), as its geographic origin in Peru is not currently known (Trout 2005). Thus, there are positive reports of shamanic use for the first and third plants ranked in order of decreasing mescaline content, a noninformative status for the second plant, 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, but the fact remains that the Peruvian *T. pachanoi* with the highest mescaline concentrations and known locality data are in shamanic use.

Various researchers have, in the past, employed different extraction procedures, different varieties of plants, and different tissues, all of which may account for disparities in 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. Interestingly, my results agree very well with those of Cruz-Sánchez (1948), at 5%, and Gonzales Huerta (1960), at 4.5% both of whom analyzed *T. pachanoi* from Peru and both of whom analyzed only stem chlorenchyma. The age of plant, variety, and nutritional and seasonal variations are some of the factors that affect mescaline recoveries during extraction processes. Cactus origin, soil, and altitude affect mescaline recovery, as well.

Other factors include environmental conditions, strain of plants, and diurnal fluctuations in pH within any single cactus. Serrano (2008) reported variations in mescaline recoveries in plants from different altitudes and slopes (east vs. west slopes of the Andes). All these factors, which could affect mescaline levels in *Trichocereus* species either alone or in combination, await future investigation.

CHAPTER V

LITERATURE CITED

Agurell, S. 1969a. Identification of Alkaloids Intermediates by Gas Chromatography-mass spectrometry. I. Potential Mescaline Precursors in *Trichocereus* Species. Lloydia 32 (1):40–45.

_____, 1969b. Cactaceae Alkaloids I. Lloydia 34 (2):206–216.

_____, J. Lundström, 1968. Apparent Intermediates in the Biosynthesis of Mescaline and Related Tetrahydroisoquinolines. Chemical Communications 1968: 1638–1639.

Anderson, E. F. 1996. Peyote: The Divine Cactus. Second Edition. The University of Arizona Press, Tucson.

Anderson, E. F. 2001. The Cactus Family. Timber Press, Portland, Oregon.

Backeberg, C. 1959. Die Cactaceae. Handbuch der Kakteenkunde, Vol. II. Gustav Fischer, Jena.

Britton, N. L., and J. N. Rose. 1920. *The Cactaceae* Volume 2. Dover Publications, New York, New York.

Bruhn, J. G., and J. Lundström. 1976. A Student's Experiment in Pharmacognosy: Biosynthesis of Mescaline in the Cactus *Trichocereus pachanoi*. American Journal of Pharmaceutical Education 40:159–160.

Cordy-Collins, A. 1982. Psychoactive Painted Peruvian plants. The shamanism textile. Journal of Ethnobiology 2 (2):144–153.

Crosby, D. M. and J. L. McLaughlin. 1973. Cactus Alkaloids. XIX. Crystallization of Mescaline HCl and 3-Methoxytyramine from *Trichocereus pachanoi*. Lloydia 36(4): 416–418.

Cruz Sánchez, G. 1948. Estudio Farmacológico de la *Opuntia cylindrica*. Thesis. Instituto de Farmacología y Terapéutica, Universidad Nacional Mayor de San Marcos, Lima.

Dobkin De Ríos, M. 1972. Plant Hallucinogens and the Religion of the Mochica, an Ancient Peruvian People. Economic Botany 31:189-203.

Friedberg, C. 1959. Rapport sommaire sur une mission au Pérou. Journal d'Agriculture Tropicale et de Botanique Appliquées 6:439-450.

Friedrich, H., and W. Glaetzle. 1983. Seed Morphology as an Aid to Classifying the Genus *Echinopsis* Zucc. Bradleya 1:91–94.

Gennaro, M. C., E. Giaonnini D. Giacosa, and D.Siccardi. 1996. Determination of Mescaline in Hallucinogenic *Cactaceae* by Ion-Interaction HPLC. Analytical Letters 29(13):2399-2409.

Gonzalez Huerta, I. 1960. Identificación de la mescalina contenida en el *Trichocereus pachanoi* (San Pedro). Revista del Viernes Médico [Lima] 11(1):133–137.

Hefter, A. 1898. Ueber Pellote. Ein Beitrage zur pharmakologischen Kenntnis der Cacteen. II. Mitteilung. Naunyn-Schmeidebergs Arkiv für experimentelle Pathologie und Pharmakologie 40:385-429.

Helmlin, H. and R. Brenneisen. 1992. Determination of Psychotropic Phenylalkylamine Derivatives in Biological Matrices by High-Performance Liquid Chromatography with Photodiode-Array Detection. Journal of Chromatography 593:87–94.

Lewin L. 1888. *Anhalonium Lewinii*. Therapeutic Gazette. Ser. 3. 4:231–237.

Marini-Bettòlo, G. B. and J. A. Coch Frugoni. 1958. Determination of Mescaline in Hallucinogenic Cactaceae. Journal of Chromatography 1:182–185.

Merck Index. 1976. 9th ed. Merck and Company, Rahway, New Jersey.

Oliva, A. 1895. Historia del Reino y Provincias del Perú. Imprenta y Librería de San Pedro, Lima. [First edition: 1631.]

Palomino Yamamoto, Manuel. 1972. Ph.D. Dissertation. Farmacoquímica de Cactaceae peruana. Universidad Nacional Mayor de San Marcos, Lima.

Pardanani, J. H., J. L. McLaughlin, R. W. Kondrat, and R. G. Cooks. 1977. Alkaloids. XXXVI. Mescaline and Related Compounds from *Trichocereus peruvianus*. Lloydia 40(6):585–590.

Poisson, J. 1960. Presence de mescaline dans une Cactacee péruvienne. Annales pharmaceutiques francaises 18:764–765.

Ritter, F. 1980. Kakteen en Südamerika, Vol. 2, pp. 559–567, and Vol. 4, pp. 1324–1329. Friedrich Ritter Selbstverlag, Spangenberg, Germany.

Rösner, P., T. Junge, F. Westphal, and F. Fritschi. 2007. Mass Spectra of Designer Drugs. Vol. 2, WILEY –VCH Verlag GmbH.

Schultes, R. E. and A. Hofmann. 1980. Botany and Chemistry of Hallucinogens, 2nd ed. Charles C. Thomas, Springfield, Illinois.

Serrano, C. A. 2008. Avances en la fitogeografía química del género *Trichocereus* en el sur del Perú. Quepo 22:29–34.

Sharon, D. 1978. Wizard of the Four Winds: A Shaman's Story. The Free Press, Collier MacMillan Publishers, New York, New York.

_____, 2000. Shamanism and the Sacred Cactus: Ethnoarcheological Evidence for San Pedro Use in Northern Peru. San Diego Museum of Man, San Diego, California

Späth, E. 1919. Über die Anhalonium-Alkaloide 1. Anhalin und Mezcalin. Monatshefte fuer Chemie 40:129–154.

Trout, K. 2005. Trout's Notes on San Pedro and Related *Trichocereus* Species, Sacred Cacti, 3rd ed., Part B, 310 pp. Better Days Publishing, Austin, Texas.

Turner, W. J. and J. Heyman. 1960. The Presence of Mescaline in *Opuntia cylindrica.* Journal of Organic Chemistry 25:2250–2251.

Yetman, D. 2007. The Great Cacti. University of Arizona Press, Tucson, Arizona.

APPENDIX

HPLC CHROMATOGRAMS OF TRICHOCEREUS SPECIMENS ANALYZED

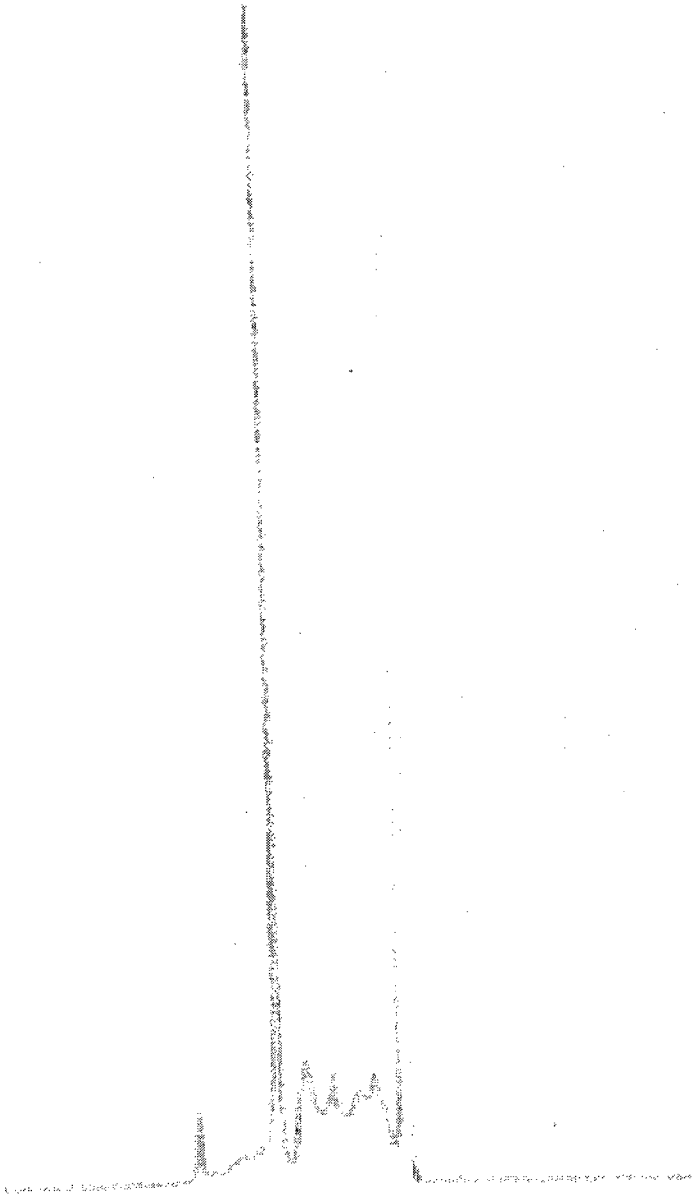


Fig. A1. **HPLC mescaline chromatogram peak height of *Trichocereus pachanoi* cv. Juul's Giant: 15.5 cm.**

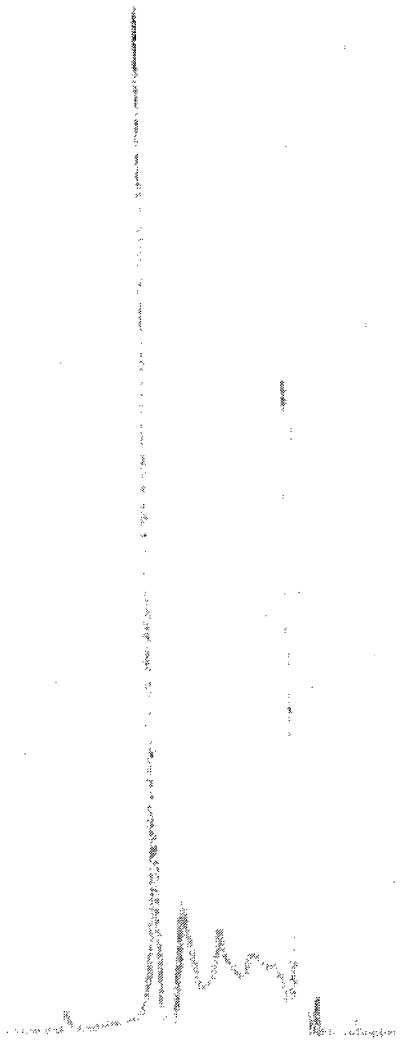


Fig. A2. HPLC mescaline chromatogram of *Trichocereus pachanoi* (Huancabamba). Mescaline peak height of original was 13.6 cm.

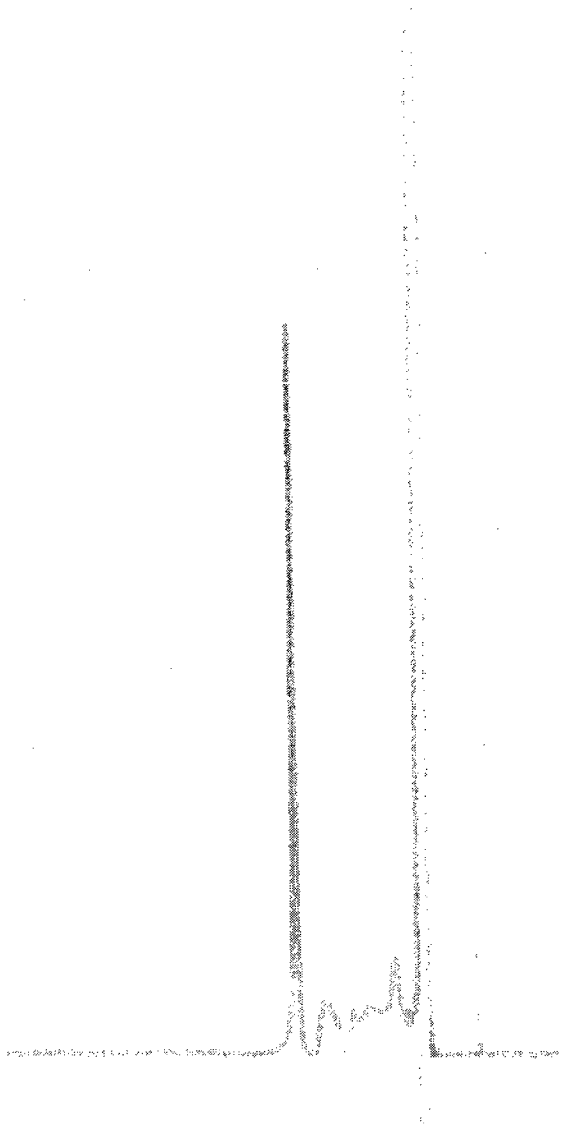


Fig. A3. HPLC mescaline chromatogram peak height of *Trichocereus scopulicola*: 9.8 cm.

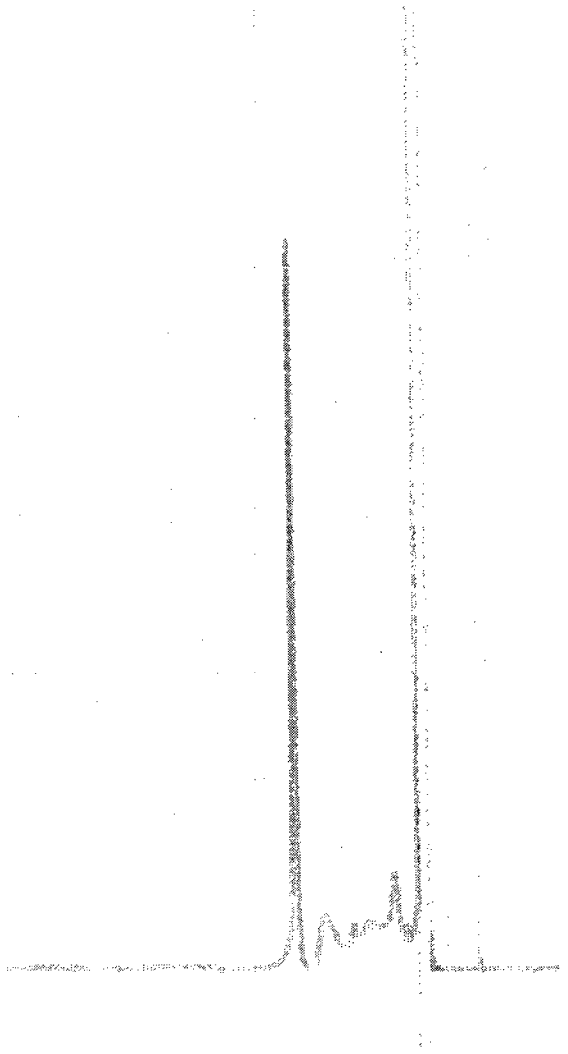


Fig. A4. HPLC chromatogram mescaline peak height of *Trichocereus pachanoi* (Hutchison): 4.8 cm.

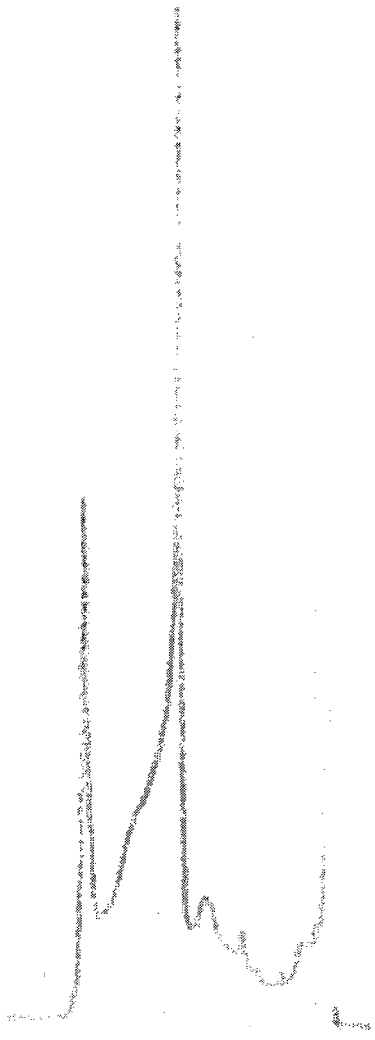


Fig. A5. HPLC chromatogram mescaline peak height of *Trichocereus pachanoi* (Van Geest): 12.3 cm.

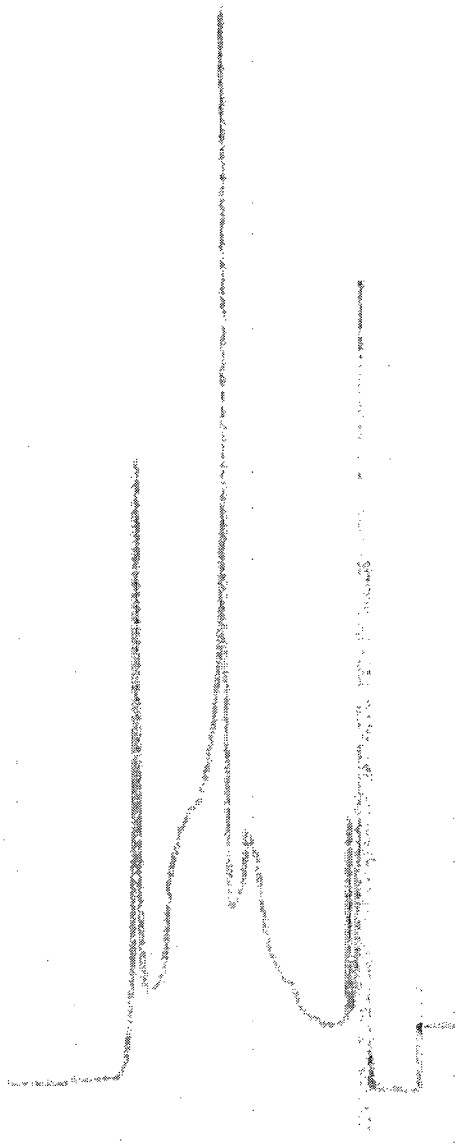


Fig. A6. HPLC chromatogram mescaline peak height of *Trichocerus bridgesii* (Monstrose): 11.0 cm.

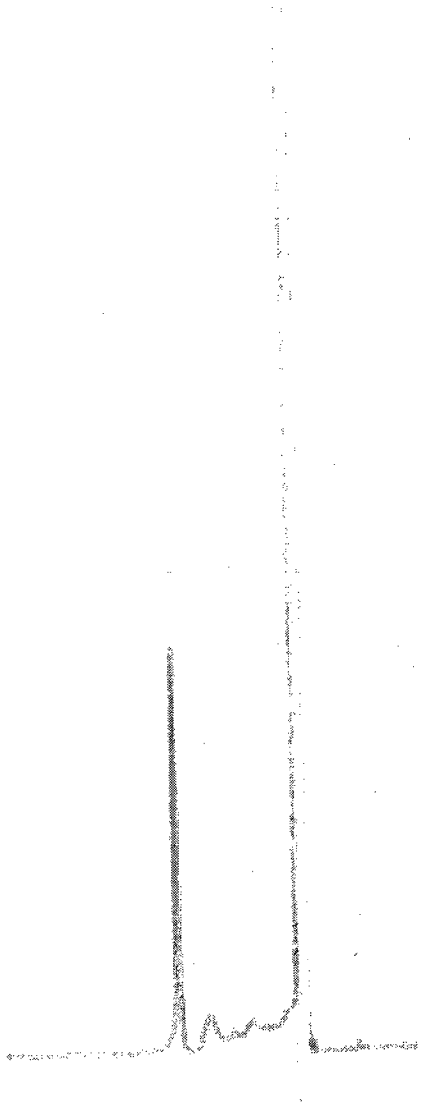


Fig. A7. HPLC mescaline chromatogram peak height of *Trichocereus pallarensis*: 5.5 cm.

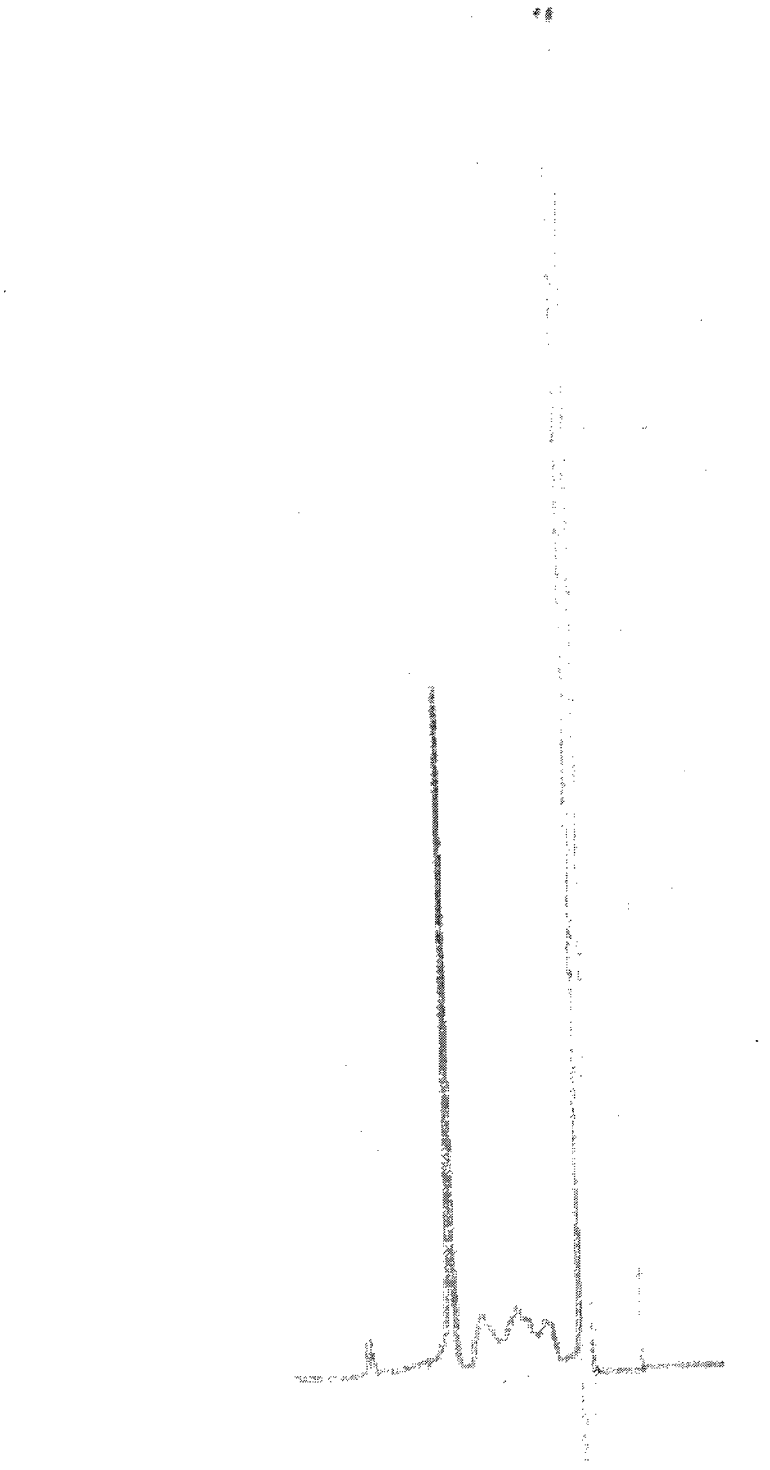


Fig. A8. HPLC mescaline chromatogram peak height of *Trichocereus riomizquensis*: 9.2 cm.

Fig. A9. HPLC mescaline chromatogram peak height of *Trichocereus santaensis*: 5.9 cm.

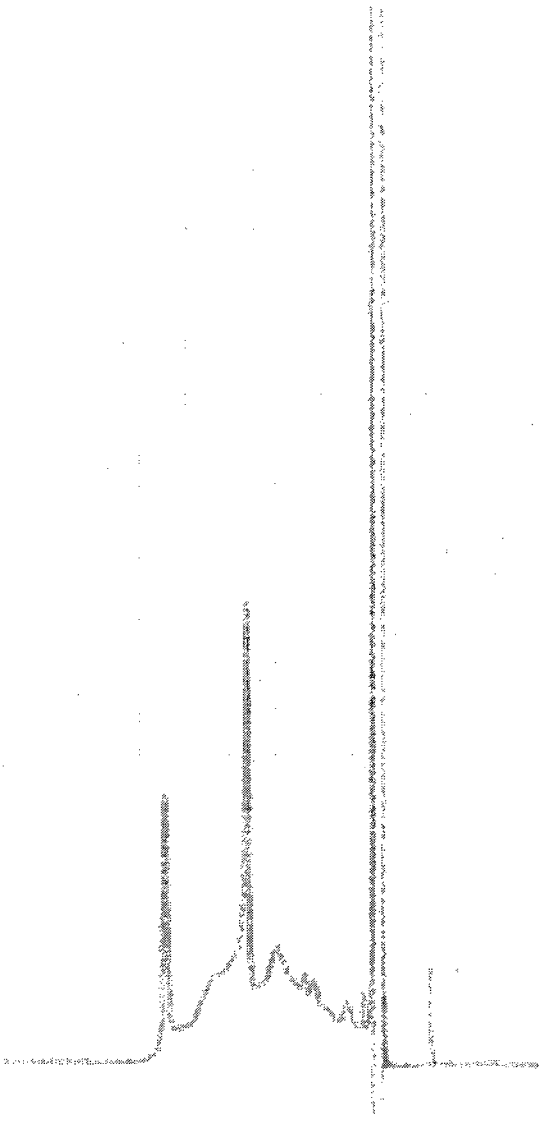


Fig. A10. HPLC mescaline chromatogram peak height of *Trichocereus peruvianus* (KK 242): 5.7 cm.

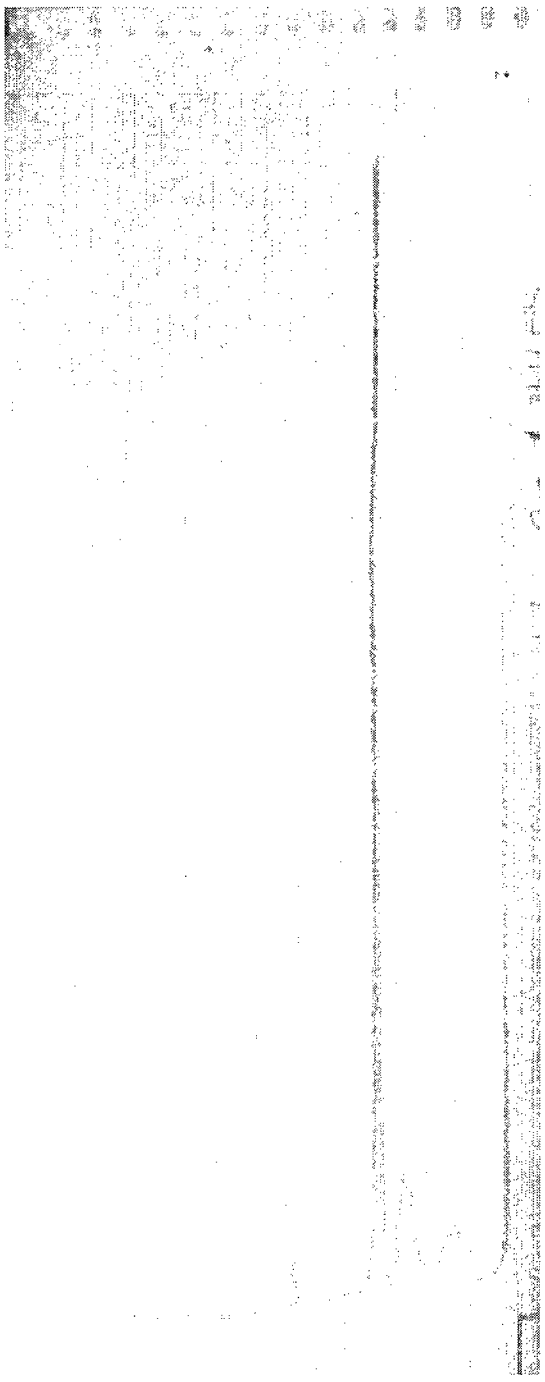


Fig. A11. HPLC mescaline chromatogram peak height of *Trichocereus bridgesii* (Gillette): 16.4 cm.

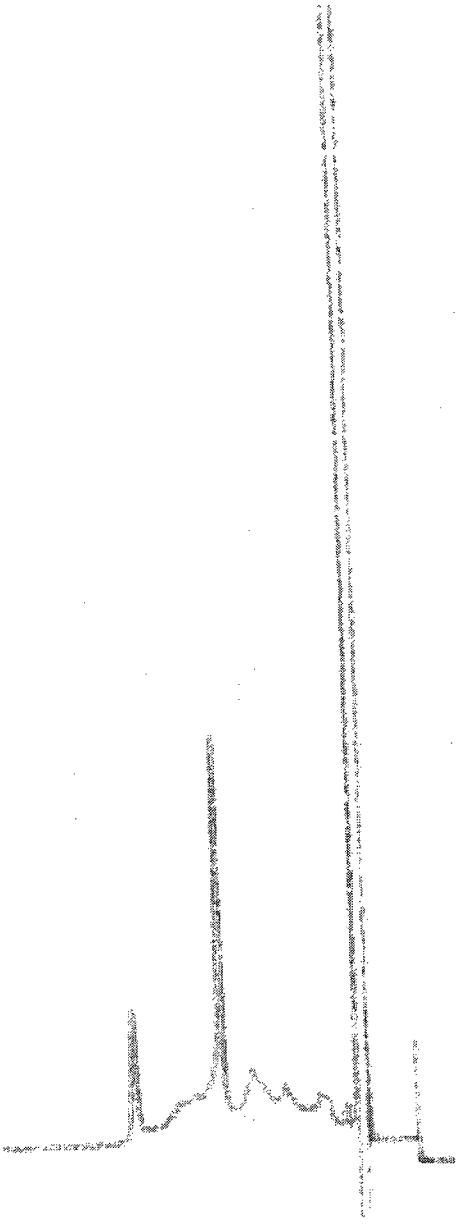


Fig. A12. HPLC mescaline chromatogram peak height of *Trichocereus puquiensis*: 5.0 cm.

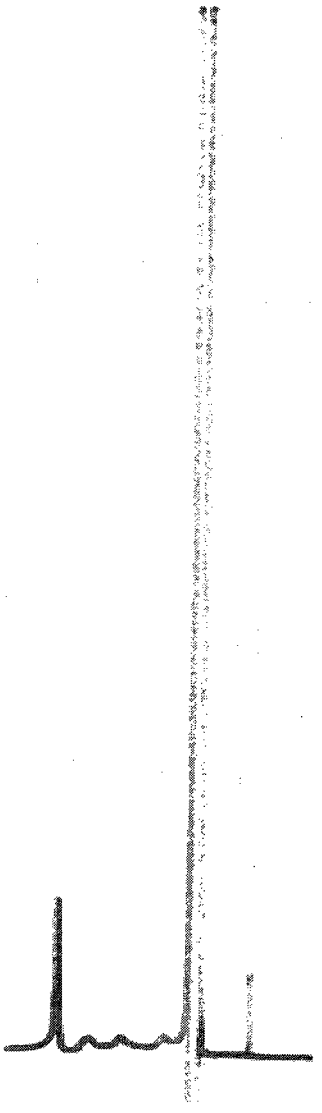


Fig. A13. HPLC mescaline chromatogram peak height of Trichocereus uyupampensis: 2.6 cm.