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Review of *Aloe* Species' Medicinal Properties and Bioactive Compounds

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ABSTRACT

Aloe species are used for medicinal and cosmetic purposes since ancient times. There are 300 species but only a few have purported curative properties. This work reports on *Aloe* classification of species as well as their reported medicinal uses; the information also considers the chemical structure and bioactive compounds identified in several species. The crassulacean acid metabolism of species is reviewed for photosynthesis and transpiration processes. Finally, *Aloe vera* is discussed in detail for botanical classification, cropping and alternatives for bioprocessing including the results obtained by our research group.

1. INTRODUCTION

Aloe plants are known since ancient times because of their purported curative properties of the gel, juice and whole leaf. Among these properties, antibacterial activity is found; the microbiological effects of *Aloe* on microorganisms have received considerable interest. However, there are contradictory reports indicating that the activity is observed only at high concentrations and may be due to high osmotic properties of the gel. Another effect is toxicity on epithelial and fibroblast cell lines, but there are reports about effects *in vitro* not observed *in vivo* giving origin to the speculation about development of antibacterial activities of anthraquinone such as emodin and rhein, that are present in the plants. Despite the fact that there are 300 species of *Aloe*, only a few are important in medicine, the most important is *Aloe vera* which means "the true *Aloe*". The commercial exploitation actually is focused on *Aloe vera* using gel and juice in different presentations with applications in cosmetics and pharmacy.

The present paper reports on the chemical composition and uses of different species of *Aloe* that have been studied and reported in the open scientific literature.

Fig. 1 *Aloe africana*.

2. CLASSIFICATION AND SPECIES

The term *Aloe* is derived from the Arabic word "alloeh" and Hebrew synonym "hallal" used to define a bitter, bright substance. The other name (sabila) is attributed to a deformation of the Arabic word "cabila", used for thorny plants (Taylor-Donald 1981). Its classification is: Kingdom (Plant), Division (Embryophita), Class (Angiosperma), Sub-class (Monocotiledonae), Order (Liliflorae), Family (Liliaceae recently ubicated in Asphodolaceae), Genus (*Aloe*).

There are more than 300 species of *Aloe* in Europe, Asia, Africa, and Madagascar. They are particularly abundant at the Cape of Good Hope. In the Iberia Peninsula they grow wild (Benson 1957). *Aloe* is native to Africa (West and South) and was introduced to the Antilles and Mexico by the Spanish (Moroni 1982). In this paper, 25 species were reviewed for reports on uses and chemical composition: *Aloe africana* (**Fig. 1**), *Aloe arborescens* (**Figs. 2A**, **2B**), *Aloe bohri*, *Aloe boylei*, *Aloe buettneri*, *Aloe ciliaris*, *Aloe comptonii*, *Aloe dichotoma*, *Aloe ferox*, *Aloe humilis* (**Figs. 3A**, **3B**), *Aloe macra*, *Aloe maculata*, *Aloe marlothii*, *Aloe mitriformis*, *Aloe perryi*, *Aloe plicatelis*, *Aloe pratensis*, *Aloe pretorienses*, *Aloe secundiflora*, *Aloe vahombe* (**Fig. 4**), *Aloe vanbalenii*, *Aloe variegata*, *Aloe vera* (**Figs. 5A**, **5B**, **5C**), *Aloe wickensii* (**Figs. 6A, 6B**).

Aloe varieties and synonyms for the reviewed plants are shown in **Table 1**.

Table 1 *Aloe* species and synonyms

Species	Synonyms (common name, English)
Aloe africana	no synonyms
Aloe arborescens	*Aloe perfoliata var. eta, Aloe perfoliata var. arborescens, Aloe arborescens var. pachythyrsa, Aloe natalensis, Aloe fruticosa, Aloe frutescens, Aloe arborescens var. natalensis, Aloe arborescens var. milleri, Aloe arborea, Catevala arborescens.* (Tree Aloe, Krantz Aloe, Candelabra Aloe)
Aloe bohri	no synonyms
Aloe boylei ssp. Boylei frutescens	*Aloe agrophila, Aloe micracantha*
Aloe buettneri	*Aloe paludicola, Aloe barteri, Aloe barteri var. dahomensis, Aloe barteri var. sudanica*
Aloe ciliaris var. ciliaris	*Aloe ciliaris, Aloe ciliaris var. flanaganii* (Climbing Aloe)
Aloe comptonii	no synonyms
Aloe dichotoma	*Aloe montana, Aloe ramosa, Aloe dichotoma var. Montana*
Aloe ferox	*Aloe socotorina, Aloe subferox, Aloe ferox var. subferox, Aloe galpinii, Aloe ferox var. incurva, Aloe ferox var. hanburyi, Aloe ferox var. erythrocarpa, Aloe candelabrum, Aloe supralaevis, Aloe perfoliata var. ferox, Aloe perfoliata var. zeta, Aloe perfoliata var. gamma, Aloe perfoliata var. epsilon, Aloe muricata, Aloe perfoliata, Aloe horrida, Aloe ferox var. galpinii, Aloe pseudoferox* (Tap Aloe, Bitter Aloe, Cape Aloe)
Aloe humilis	*Aloe subtuberculata, Aloe humilis var. acuminata, Aloe humilis var. echinata, Aloe humilis var. incurva, Aloe humilis var. semiguttata, Aloe humilis var. suberecta, Aloe humilis var. subtuberculata, Aloe suberecta var. acuminata, Aloe humilis var. semiguttata, Aloe tuberculata, Aloe incurva, Aloe acuminata, Aloe humilis var. candollei, Aloe humilis var. minor, Aloe acuminata var. major, Catevala humilis, Aloe humilis, Aloe humilis var. humilis, Aloe perfoliata var. humilis, Aloe suberecta, Aloe echinata* (Spider Aloe)
Aloe macra	*Lomatophyllum macrum*
Aloe maculata, A. Latifolia, Aloe saponaria	*Aloe latifolia, Aloe saponaria var. saponaria, Aloe saponaria var. ficksburgensis, Aloe saponaria var. brachyphylla, Aloe leptophylla, Aloe leptophylla var. stenophylla, Aloe umbellata, Aloe saponaria var. latifolia, Aloe saponaria, Aloe perfoliata var. saponaria, Aloe perfoliata var. lambda, Aloe perfoliata var. theta, Aloe maculosa, Aloe disticha, Aloe maculata*
Aloe mitriformis	*Aloe perfoliata var. xi, Aloe xanthacantha, Aloe perfoliata var. eta, Aloe mitriformis var. humilior, Aloe mitriformis var. elatior, Aloe parvispina, Aloe perfoliata var. mitriformis* (Gold Tooth Aloe)
Aloe perryi	no synonyms (Perry's Aloe)
Aloe plicatilis	*Aloe plicatilis var. major, Aloe lingua, Aloe tripetala, Aloe disticha var. plicatilis, Aloe flabelliformis, Aloe linguaeformis* (Fan Aloe)
Aloe pratensis	no synonyms (Rosette Aloe)
Aloe pretoriensis	no synonyms
Aloe secundiflora var. secundiflora	*Aloe floramaculata, Aloe marsabitensis, Aloe engleri*
Aloe vahombe var. vahombe	no synonyms
Aloe vanbalenii	no synonyms
Aloe variegata	*Aloe variegata var. haworthii, Aloe punctata, Aloe ausana* (Partridge Breast Aloe, Tiger Aloe)
Aloe vera chinensis	*Aloe vera var. chinensis, Aloe vulgaris, Aloe vera var. lanzae, Aloe indica, Aloe barbadensis var. chinensis, Aloe vera var. wratislaviensis, Aloe elongata, Aloe vera var. littoralis, Aloe perfoliata var. vera, Aloe perfoliata var. barbadensis, Aloe flava, Aloe chinensis, Aloe barbadensis, Aloe lanzae* (Medicinal Aloe)
Aloe wickensii	no synonyms

3. REPORTS OF MEDICINAL PROPERTIES AND USES

Aloe is called “the thousand uses plant” and presently there are a great number of industrial companies that industrialize different products (Sánchez-Robles 2002) derived from *Aloe*.

The use of *Aloe* in cosmetics is due to its characteristic of penetrating the epidermis, dermis and hypodermis expulsing bacteria and grease from the pores, and stimulating new cell production, thus accelerating healing. The main therapeutic and clinical uses of *Aloe* include: use in the mouth to prevent bleeding, decrease swelling, cure of aftas in mouth, esophagus and stomach, and to remedy ulcers. It may also be used for reduction of allergic reactions. For burning lesions, *Aloe* may reduce pain, prevent infections and help cicatrisation, and protect against sun-burn. In several countries work is carried out to evaluate the action of *Aloe* for curing cancer (Sánchez-Robles 2002). The main medicinal uses for the previously mentioned species are presented in **Table 2**.

Table 2 Reported medicinal uses for *Aloe* species.

Species	Medicinal uses	References
Aloe africana	Anti-diabetic activity	Hikino *et al*. 1986
	Anti-cancer (pulmonary, stomach, colon)	Soeda 1969
Aloe arborescens	Inhibition of pain-producing substances such as bradykinin or tromboxane	Fujita *et al*. 1976
	Mitogenic activity against human lymphocytes	Suzuki *et al*. 1979
	Inhibition of fibrosarcoma growth *in vivo*	Imanishi *et al*. 1981
	Arthritis control	Saito *et al*. 1982
	Inhibition of uptake of foreign erythrocytes by activated rat macrophages	Ohuchi *et al*. 1984
	Reduction of gastric lesions and ulcers	Saito 1993, Teradaira *et al*. 1993
	Reduction of asthma	Shida *et al*. 1985
	Anti-diabetic activity	Ajabnoor 1990
	Anti-cancer in rat liver	Tsuda *et al*. 1993, Inahata and Nakasugi 1995, Kim and Lee 1997
	Anti-leukemic	Kupchan and Karim 1976, Grimaudo *et al*. 1997
	Anti fungal; Trichophyton mentagrophytes	Fujita *et al*. 1978
	Bradykininase and carboxypeptidase activity	Fujita *et al*. 1979
Aloe ferox	Reduction of gastric lesions and ulcers	Yamamoto 1970 1973
	Anti-diabetic activity	Hikino *et al*. 1986
	Anti-cancer (pulmonary, stomach, colon)	Soeda 1969
	Anti-fungal; Trichophyton; *Candida albicans*	Soeda *et al*. 1966
	Hyperosteogeny	Zhang *et al*. 2005a
	Acne prevention	Zhang *et al*. 2005b
	Cosmetic	Shin *et al*. 2005
	Sexually transmitted infections treatment	Kambizi *et al*. 2004

	Anti-inflammatory	Speranza *et al*. 2005
	Protections against solar radiation (UVV)	Coppini *et al*. 2001
Aloe maculata	Inhibition on the histamine synthetic enzyme	Yamamoto 1970
	Stimulation of immune reactions against human, canine and baboon sera	Winters *et al*. 1981
	Blastogenesis	Winters 1991
	Inhibition of tumor cells growth	Winters *et al*. 1981
	Antibradykinin activity	Yagi *et al*. 1982
	Antioxidant	Jia and Farrow 2003
	Inhibition of carragenin induced hind paw edema at 50 m/kg ip in rats	Yagi *et al*. 1984
Aloe perryi	Anti-diabetic activity	Hikino *et al*. 1986
Aloe vahombe	Bactericide and fungicide	Brossat *et al*. 1981
Aloe vera	Moisturizing agent	Meadows 1980, Watson 1983, Natow 1986, Danof 1987, McKeown 1987, Fox 1990, Marshal 1990, Briggs 1995
	Inhibition of histamine by hysidine decarboxilase	Rubel 1983, Natow 1986, Marshal 1990, Shelton 1991, Canigueral and Vila 1993
	Inhibition of pain-producing substances such as bradykinin or tromboxane	Rubel 1983, Natow 1986, Danof 1987, Fox 1990, Marshal 1990, Shelton 1991, Canigueral and Vila 1993
	Action on immune system	Rubel 1983, Griggs 1996
	Antifungal, antibacterial, antiviral	Klein and Penneys 1988, Marshal 1990, Ahmad *et al*. 1993, Jasso de Rodriguez *et al*. 2005
	Antioxidant	Reynods and Dweck 1999
	Burns and incisions	Grindlay and Reynolds 1986
	Anti-inflammatory	Davis *et al*. 1987
	Arthritis adjuvant	Saito *et al*. 1982
	Control of fibroblast proliferation	Brasher *et al*. 1969, Danof and McAnalley 1983
	Growth of new blood capillaries	Lee *et al*. 1995
	Phagocytes formation and activity	Imanishi and Suzuki 1984
	Inhibition of arachidonic acid oxidation	Penneys 1982
	Stimulation of prostaglandin synthesis	Capasso *et al*. 1983
	Stimulation of immune reactions against human, canine and baboon sera	Winters *et al*. 1981
	Blastogenesis	Winters 1991
	Reduction of gastric lesions and ulcers	Saito 1993, Bland 1985, Sakai *et al*. 1989, Blitz *et al*. 1963
	Anti-diabetic activity	Agarwal 1985, Noel *et al*. 1997, Ghannam *et al*. 1986, Ajabnoor 1990, Yongchaiyudha *et al*. 1996, Bunyapraphatsara *et al*. 1996
	Anti-cancer (pulmonary, stomach, colon)	Soeda 1969
	Anti-bacterial	Gottshall *et al*. 1949, Lorenzetti *et al*. 1964, Reynolds 1966, Robson *et al*. 1982, Kaufman *et al*. 1989, Levin *et al*. 1988, Heggers *et al*. 1995, Cera *et al*. 1980, Azghani *et al*. 1995, Bunyapraphatsara *et al*. 1996
	Anti-fungal	Stuart *et al*. 1997
	Antiviral	Pulse and Uhlig 1990, McDaniel *et al*. 1987 1988, Nordgren *et al*. 1992, Sharma *et al*. 1994, Ritchie *et al*. 1994, McAnalley *et al*. 1988, Yates *et al*. 1992, Kemp *et al*. 1990, Kahlon *et al*. 1991, Marshal and Druck 1993, Imanishi and Suzuki 1984, Montaner *et al*. 1996, Sydiskis *et al*. 1991, Syed *et al*. 1996, Saoo *et al*. 1996
	UV and X-Ray burns treatment	Crowell *et al*. 1989, Danof 1993, Stachow *et al*. 1984, Lindblad and Thul 1994, Lee *et al*. 1997, Sabeh *et al*. 1996
	Cholesterol reduction	Dixit and Joshi 1983
	Hormone control	Herlihy *et al*. 1998
	Psoriasis	Syed *et al*. 1996b
	Hyperosteogeny	Zhang *et al*. 2005a
	Femur head necrosis	Zhang *et al*. 2005a
	Acne prevention	Zhang *et al*. 2005b
	Inhibitory effect on carrageenan-induced edema	Vázquez *et al*. 1996
	Inhibition of the production of PGE_2 *in vitro*	Vázquez *et al*. 1996

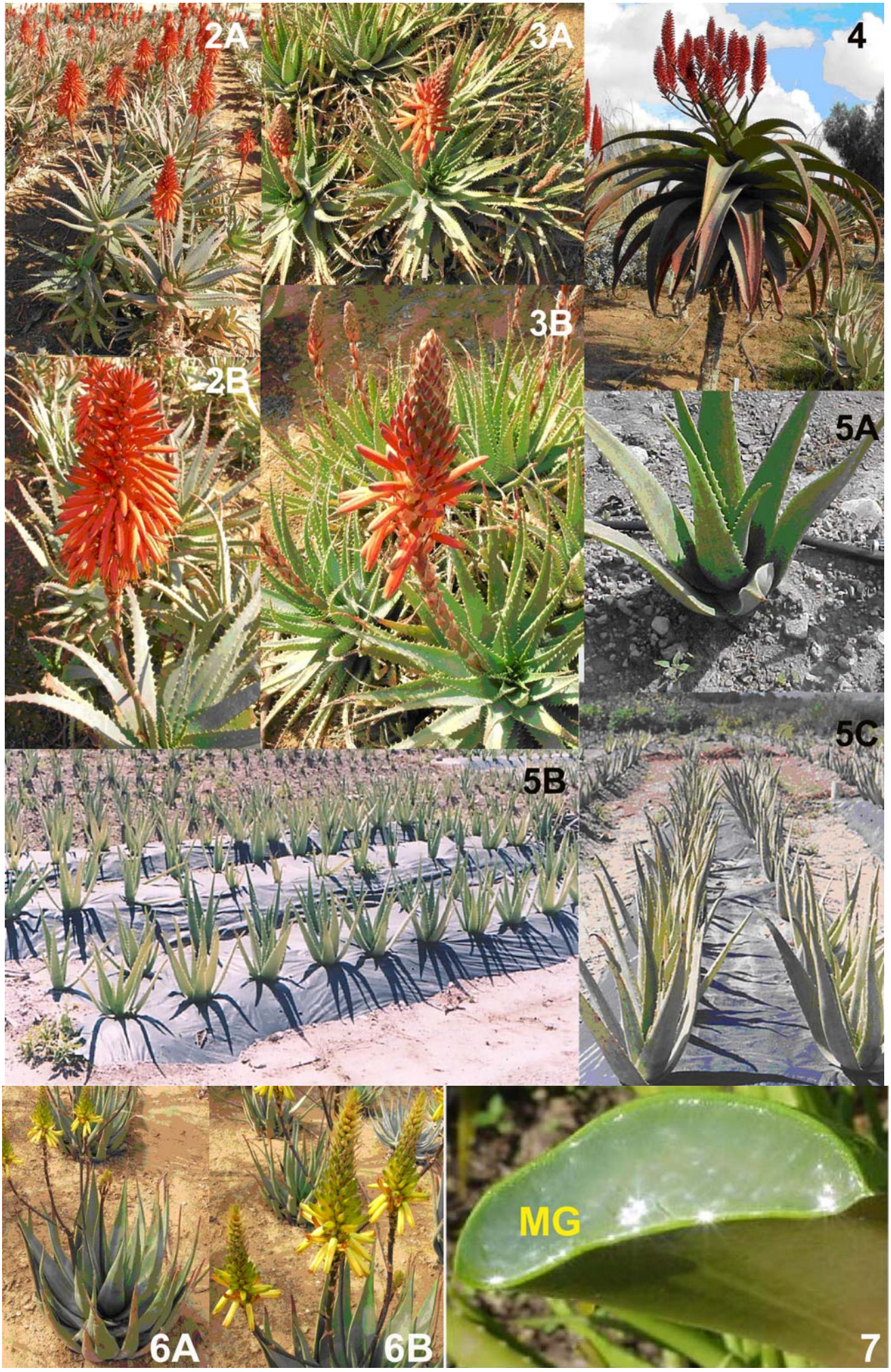
4. REPORTED CHEMICAL COMPOUNDS

Aloe vera leaves produce a bitter liquid fraction named acibar or juice. Generally it is obtained by free flowing liquid from the leaves after transversal cutting; this juice is concentrated by evaporation changing color from brown to black in the form of lumps that must be protected against moisture (Quer 1978).

The acibar chemical composition is a function of the *Aloe* species, harvesting date, and preparation method (Ray 1979). However, we can mention that water content is around 6-10% and those with high quality produce 2% ash. Resin is the most variable component in the range 40 to 80%. The resin does not have medicinal interest; it corresponds to an ester of para-coumaric acid and a resin alcohol, aloeresinetanol. Beside there are up to 20% of aloins. On hydrolysis aloins yield emodin that is the active component of the acibar (Ray 1979).

Aloe also contains aloemocin which is a strong anti-swelling agent and is analgesic, and aloeuricin that activates and fortifies epithelial cells that make *Aloe* useful for gastric ulcer treatment (Cutak 1962)

Acibar contains a great quantity of amino acids such as valine, methionine, phenylamine, lysine and leucine. Besides there are lignins, glucomannan and other glucides like pentose, galactose and uronic acids that promote a deep cleaning of the skin. Among the constitutive elements are iodine, copper, iron, zinc, phosphorous, sodium, potassium, manganese, sulfur magnesium and a great amount of calcium. *Aloe* is one of the few species that contain vitamin B12 besides A, B1, B2, B6 and C. It also contains germanium that acts as a purification agent for the organism, eliminates poisons and cell detritus, reactivates bone marrow and the immune system, stimulates the production of endorphins (Martínez 1978) identified that *Aloe* gel (**Fig. 7**) produces six antiseptic agents with high anti-microbial activity: cinnamonic acid, a type of nitrated urea, lupeol, phenol, sulfur, folic acid and a natural salicylic acid that, combined with lupeol has analgesic effects (Ray 1979).


2A
3A
4
3B
2B
5A
5C
5B
6A
6B
MG
7

Figs. 2-7 (previous page) (**2A**) *Aloe arborescens* in flower, (**2B**) close up of *A. arborescens* inflorescence. (**3A**) *Aloe humilis* in flower, (**3B**) close up of *A. humilis* inflorescence. (**4**) *Aloe vahombe*. (**5A**) *Aloe vera*, (**5B**) *A. vera* in the UAAAN University field, (**5C**) *A. vera*, mulched plants, in the University field. (**6A**) *Aloe wickensii* in flower, (**6B**) close up of *A. wickensii* inflorescence. (**7**) *A. vera* leaf cross-section showing mucilaginous gel (MG).

Chemical compounds in the mentioned species and the corresponding bibliographic references are presented in **Table 3**.
The reported chemical compounds identified at the gel or juice fractions of *Aloe* species are presented in **Table 4**.

Table 3 Reported chemical compounds for *Aloe* species.

Species	Chemicals	References
Aloe africana	Alomicin	Soeda 1969
Aloe arborescens	Carboxy peptidase	Fujita *et al*. 1979
	Serine carboxypeptidase	Ito *et al*. 1993
	Glyco protein	Yagi *et al*. 1987, Winters *et al*. 1981
	β-sitosterol	Yamamoto *et al*. 1986
	Lectines	Fujita *et al*. 1978, Winters *et al*. 1981,Yagi *et al*. 1985, Yoshimoto *et al*. 1987, Winters 1993
	Proline and cystein	Yagi *et al*. 1987
	Polypeptides	Winters and Bouthet 1995
	Mannose, glucose, galactose, N-acetyl galactosamine	Bouthet *et al*. 1996
	Aloctin A, Aloctin B	Imanishi *et al*. 1981, Saito *et al*. 1989
	Acemannan	Plemons *et al*. 1994
	Aloe-emodin	Inhata and Nakasugi 1995
	polysaccharides	Winters *et al*. 1981
	ATF 1011 (lectin fraction)	Yoshimoto *et al*. 1987
	Aloe mannan	Yagi *et al*. 1977
	Barbaloin	Kawai *et al*. 1998
	Aloenin, aloe-emodin, barbaloin, Mg lactate, succinic acid	Hirarta and Suga 1977, Gutterman and Chauser-Volfson 2000, Chauser-Volfson and Gutterman 2004
	Aloin	Zhi-hua *et al*. 2001
Aloe boylei	Aloin A, aloin B	Lindsay *et al*. 2002
Aloe ferox	Aloe ulcin	Yamamoto 1970 1973
	Alomicin	Soeda 1969
	Anthraquinone	Feng *et al*. 2004
	1,8-dihydroxy-3-hydroxy methyl-9; 10-anthracenedione (1,aloe-emodin); 1,8-dihydroxy-3-methyl-9, 10-anthracenedione (2, chrysophanol); and 10-C-β-D-glucopyranosyl-1,8-dihydroxy-3-hydroxy methyl-9-anthracenone (3, aloin A)	Kambizi 2004
	1,1-diphenyl ethane derivative	Speranza *et al*. 1994
	Anthrone-C-glucosyls	Rauwald and Beil 1993
	Feroxins A and B; 2O-glucosylated 1-methyl tetralins	Speranza *et al*. 1992
	C-glucosylated 5-methyl chromone; 8-C-β-D-[2-O-(E)-p-coumaroyl] glucopyranosyl-2-[(R)-2-hydroxy] propyl-7-methoxy-5-methyl chromone	Speranza *et al*. 1986
	2-acetonyl-7-O-β-D-glucopyranosyl-8-C-β-D-[2´-O-(E)-p-coumaroyl] glucopyranoyl-5-methyl chromone	Speranza *et al*. 1985
Aloe humilis	flavanones	Lindsay *et al*. 2002
Aloe maculata	Bradykinase	Yagi *et al*. 1982
	Polypeptides	Bouthet *et al*. 1996
	Lectines	Winters *et al*. 1981
	7-hydroxychromone	Jia and Farrow 2003
	Aloin	Zhi-hua *et al*. 2001
	1,4-linked β-D-mannopyranose polymer (MW=15000)	Yagi *et al*. 1984
	1,4-linked α-D-mannopyranose polymer containing a single branch on the principal chain consisting of D-glucose residues linked at C-2 and C-4 (MW=66000) with 10% acetyl groups (acemannan 2)	
Aloe mitriformis	Homonataloin	Lindsay *et al*. 2002
Aloe pratensis	flavanones	Lindsay *et al*. 2002
Aloe pretoriensis	flavanones	Lindsay *et al*. 2002
Aloe vahombe	Glucomannan	Ralamboranto *et al*. 1987
Aloe vera	Salicylates	Robson *et al*. 1982, Klein and Penneys 1988, Marshall 1990, Shelton 1991, Canigueral and Vila 1993
	Magnesium lactate	Rubel 1983, Natow 1986, Marshall 1990, Shelton 1991, Canigueral and Vila 1993
	Polysaccharides: acemannan	Schechter 1994, McAnalley 1988, Agarwal 1985
	Lupeol, cholesterol, campestrol, β-sitosterol	Waller *et al*. 1978, Ando and Yamaguchi 1990
	β-sitosterol-3-glucoside and the 6´-palmitate	Kinoshita *et al*. 1996
	Aloin	Capasso *et al*. 1983, Zhi-hua *et al*. 2001
	Anthraquinones	Heggers and Robson 1985
	Aloctin A	Ohuchi *et al*. 1984
	Polypeptides	Bouthet *et al*. 1996
	Alomicin	Soeda 1969
	Lectines	Winters *et al*. 1981
	Acemannan	Peng *et al*. 1991
	Acetylated mannan	Peng *et al*. 1991
	Phenols	Reynolds 1985
	Aloe emodin	Fairbairn 1980
	Barbaloin	Vázquez *et al*. 1996
Aloe wickensii	Anthrones and chromones (homonataloin, aloin)	Lindsay *et al*. 2002

5. TOPICS ON CRASSULACEAN ACID (CAM) PLANT METABOLISM

5.1. Plants with CAM metabolism

Photosynthesis is the main process for CO_2 fixation in green plants. However, some succulent and semi-succulent plants may fix CO_2 during the night, or in darkness, increasing acidity due to malic acid accumulation. When they are exposed to sunlight acidity decreases. This process was discovered in *Bryophyllum calycinum* (Salisbury and Ross 1997) a species belonging to the *Crassulaceae*, hence it was called crassulacean acid metabolism (CAM). Other genera that also perform CAM include the *Bromeliaceae*, *Agavaceae*, *Orchidaceae*, *Cactaceae*, *Compositae*, *Amaryllidaceae*, and *Euphorbiaceae*.

Plants which perform CAM are found in semiarid regions where the stoma are closed by day, preventing water loss by transpiration, and constitute an ecologic advantage. Circadian cycles have two phases: one dark that acidifies the vacuoles because malic acid accumulates when stoma are open, and a second, with light, where decarboxylation of malic acid occurs yielding piruvic acid and CO_2, this takes place with closed stoma. However, frequently direct CO_2 fixation may be carried out besides CAM (Azcón–Bieto and Talón 1993).

Table 4 Reported chemical compounds in the gel and juice fractions of *Aloe* species.

Species	Chemicals		References	
	Gel	Juice	Gel	Juice
Aloe arborescens	Polysaccharides		Grindlay and Reynolds 1986, Yagi *et al.* 1986, Wozniewski *et al.* 1990	
	Arabino galactans			
	Rhamnogalacturonans			
	Glucomannan		Yaron 1991	
	Mannan, acetylated mannan, glucan		Yagi *et al.* 1986	
	Acetylated glucorhamnogalactan, manoglucan		Hikino *et al.* 1986	
	Acetylated glucomannan		Wozniewski *et al.* 1990	
Aloe ferox	Polysaccharides, arabino galactans, rhamnogalacturonans	Aloin, rhamnosides of Aloin: Aloinoside A and B	Mabusela *et al.* 1990	Mc Carthy and Van Rheede Van Oudtshoorn 1996
	Glucomannan		Yaron 1991	
	Arabinorhamnogalactan, arabinorhamnogalacturonan, xylorhamnogalacturan, xyloglucan		Mabusela *et al.* 1990	
		5, methyl chromone moiety glucoside; indomethacin		Speranza *et al.* 2005
Aloe maculata	Polysaccharides, arabino galactans, rhamnogalacturonans		Gorda 1980	
	Glucomannan		Yaron 1991	
	Glucan, glucogalactomannan, acetylated mannan, acetylated glucomannan		Gorda 1980, Yagi et al. 1984	
Aloe plicatilis	Polysaccharides, arabino galactans, rhamnogalacturonans, glucomannan		Yaron 1991	
Aloe vahombe	Polysaccharides, arabino galactans, rhamnogalacturonans		Gowda 1980	
	Glucomannan		Yaron 1991, Vilkas and Radjabi Nassab 1986	
	Acetylated glucomannan		Radjabi *et al.* 1983, Radjabi-Nassab *et al.* 1984, Vilkas and Radjabi- Nassab 1986	
Aloe vanbalenii	Glucan, glucogalactomannan, acetylated mannan		Gowda 1980	
Aloe vanballenii pillans	Polysaccharides, arabino galactans, rhamnogalacturonans		Gowda 1980	
	Glucomannan		Yaron 1991	
Aloe vera	Polysaccharides, arabino galactans, rhamnogalacturonans		Grindlay and Reynolds 1986	
	Glucomannan, acetylated glucomannans		Yaron 1991, Farkas 1967, Gowda *et al.* 1979, Mandal and Das 1980	
	Galactogalacturan		Mandal *et al.* 1983	
	Glucogalctomannan		Haq and Hannan 1981	
	Galactoglucoarabinomannan		t´Hart *et al.* 1989	
	Acetylated mannan		McAnalley 1988, Manna and McAnalley 1993	
	Alkaloids, cardiac glycosides, flavonoids, tannins, coumarins, anthraquinones, saponins, sterols, triterpenes		Dominguez 1973, Harborne 1984	
	Carbohydrates, anthraquinones, pectines, anthraglycosides, reductor sugars, mucilagus, sterols type Δ^5, naftoquinones; barbaloin		Vázquez *et al.* 1996	

6. *ALOE VERA*

6.1. *Aloe vera*, botanical description

Aloe is a plant belonging to the Liliaceae family, similar to agaves, growing in gardens or field surrounded by small sprouts. It does not require a large amount of water because the leaves accumulate liquid that allows the plant to survive long times even if uprooted (Jacobsen 1946).

Aloe species are generally woody but with big and fat leaves set in rosettes, with a thorn at the end and marginal, smaller thorns. Flowers are tubular because the six parts forming the floral cover are united in a tube. They are generally reddish, orange or yellow. The number of flower

stamens is also six, starting from the flower bottom, bellow the pistil. The fruit is a triangular capsule with non consistent walls. In the case of plants without a stem the leaves are located at successive stages, alternated in 2 x 2 as in *A. saponaria variegata* or 3 x 5 as in *A. barbadensis* variety *mitriformis* or in radical rosettes with four or more leaves as in *A. vulgaris*. The plants with stem have one or more axial boards ending in bouquets (Jacobsen 1946).

6.1.1. Leaf

Hurtado and Martínez (1983-1984) reported that the epidermal cells are strongly cutinized. Below the epidermis mesophillous tissue is located differentiated into a cortex, externally, and a central internal zone (**Fig. 8**). The cortical zone has several layers of cells with abundant chloroplasts and some with calcium oxalate crystals. The central zone corresponds to approximately 3/5 of the total leaf diameter, integrated with transparent, thin walled cells containing mucilaginous fluid. At the two zones limit are bundles and multiple pericyclic, long, tubular, thin-walled cells containing a bitter juice, acibar.

Moroni (1982) and Quer (1978) reported that the leaves are fat, thick and grow forming rosettes with thorns at the end, 50 cm in length, 10-20 cm wide, and 5 cm thick; the color of mature leaves is grayish-green. Leaves may close stoma to prevent water loss and are capable of replacing the epidermis rapidly after fracture or cutting of the surface.

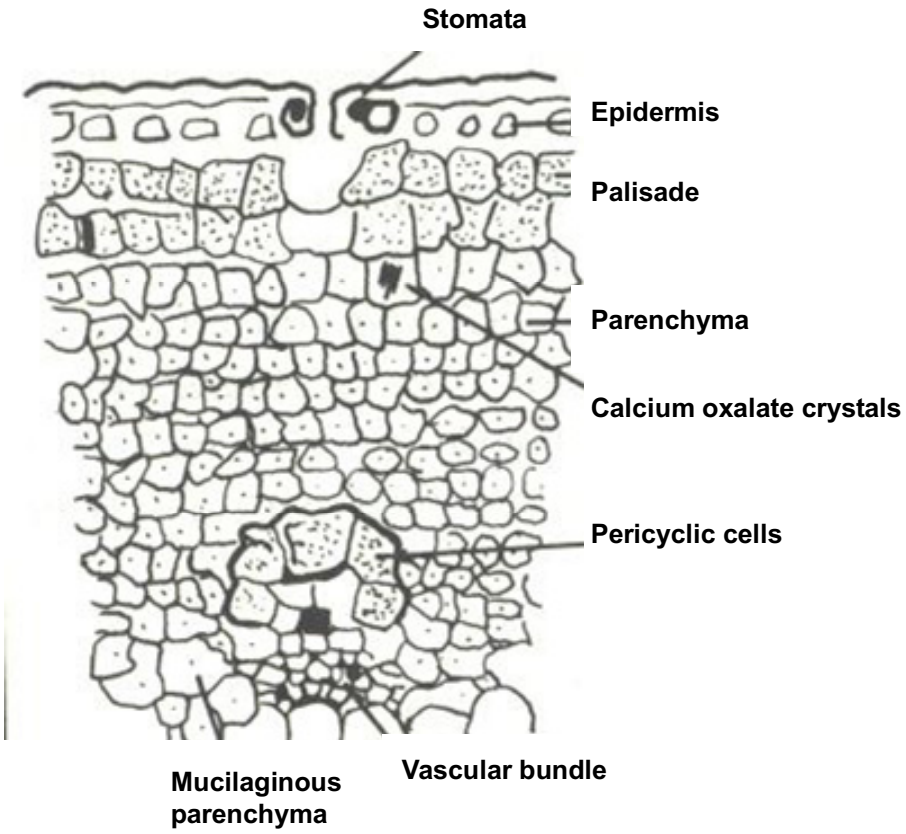


Fig. 8 Anatomy of the *Aloe vera* leaf (cross-section).

6.1.2. Flowers

Flowers are colorful, tubular, and integrated by six petals forming a floral canopy and fused forming a tube mostly straight and sometimes curved with a slight broadening in the fixing part, where the sexual organs are located. Flowers are found in bunches that may be vertical or dangling. The color may be reddish, white, pink, orange or yellow. The stamens are also six, with long filaments (Conzatti 1947).

6.1.3. Fruits

The fruit is a capsule, consisting of three valves, oblong and triangular (Sapre 1974). According to studies carried out during meiosis and mitosis, the fruit formation is very rare. Capsules are long and seed hybrid (Conzatti 1947). Seed may be abundant or scarce (Hutchinson 1926).

6.2. Cropping of *A. vera*

Aloe vera grows well in semiarid lands, from sea level up to 2,500 m asl. The average annual temperature is between 21-27°C and is sensitive to frost below 4°C. However, some reports indicate that the plants can survive down to –2°C. Water requirements are among a broad range of rainfall (590 to 4030 mm per year) but it can not survive floods. It is resistant to drought, high temperature, and grows in almost any type of soil. *Aloe* requires direct sun light hence it is recommended to grow in the absence of other crops.

Commonly, *A. vera* is transplanted at the start of the rainy season, selecting the plants with height above 30 cm and sowing directly in rows. Spacing between plants may be 0.5-0.7 m and 0.7-1.0 m between rows. Plant density is from 16,000 to 20,000 plants ha^{-1}. In our studies (Hernandez-Cruz *et al*. 2002) we used densities of 25,000 plants ha^{-1}. Two or three fertilizer applications are required during crop development. However, our results for *A. vera* cropping in Mexico (Hernandez-Cruz *et al*. 2002) showed that the plants may develop without fertilizer applications. Irrigation is used more frequently to accelerate development and increase yield; water is applied every 20 days after crop establishment, with 10 to 15 cm of irrigation depth (Sanchez-Robles 2002).

Pharmaceutical applications do not allow the use of herbicides for weed control hence hand labor must be used for this process.

Harvesting is carried out when the plants are approximately 18 months old and production lasts from 8 to 10 years. Plant yield stabilizes at the third year for rainfed conditions and at two years for irrigated plants. For the rainfed crops it is recommended to carry out two cuts during July to August and November to December. In many cases this is dependent of the climatic conditions. Generally only one cut is performed. For irrigated crops four cuts may be performed during the year but avoiding frost seasons it is recommended during March and November (Sanchez-Robles 2002).

6.3. New alternatives for bioprocessing *Aloe*

For the industrial sector, *Aloe* represents a very important plant. All their varieties can be biotechnologically treated to protect and to improve

them through studies of culture techniques and gene engineering. Also to increase their productivity and potential use as source of medically effective compounds. In the particular case of *Aloe,* several biotechnological efforts have been carried out trying to approach it in phytotherapy and alternative medicine. In this section we describe the two most important biotechnological aspects: propagation and bioprocessing.

There have not been many contributions to *Aloe* cell cultures, but it is known that callus formation is possible from the roots of *A. saponaria*, tissue culture of the stamen of *A. bellatura*, or of *A. barbadensis* leaf. Kawai *et al.* (1993) reported the culture conditions for callus induction in the tissue of *Aloe arborescens*. Recently, Zhi-hua *et al.* (2004) successfully transplanted young plantlets from *Aloe* tissue culture demonstrating that *in vitro* propagation can be a useful tool in the conservation of *A. chinese*. These reports proved that, when small pieces of *Aloe* leaf are cultured under adequate conditions, they can grow to form callus due to the genetic maintenance capacity of proliferation. It is known that when these callus cells are incubated in the presence of growth regulators (naphthalene acetic acid and benzylamino purine), regeneration of whole plants can be induced. It is also possible to introduce exogenous genetic material into callus cells by gene transfection or cell fusion (protoplasts) derived from different species (Kawai *et al.* 1993).

Biotechnology, related to propagation, could provide to the *Aloe* farmers the ability to quickly adopt superior plants produced by *Aloe* improvement programs. The ability for rapid response and flexibility for changing planting materials, may offer immediate gains to farmers. Besides, it would bring the opportunity for the *Aloe* industry to work with all varieties of *Aloe*. Elite cloned populations would provide not only agronomic benefits, but could also open the doors for processing and consumer benefits.

On the other hand, microorganisms or enzymes are unique “live tools” able to value *Aloe* materials, in particular compounds with high pharmaceutical potential. The general protocol for this kind of bioprocessing of *Aloe* includes the use of different parts of the plant as carbon or inducers sources in different bioreactors, through liquid or solid state microbial cultures (**Figs. 9, 10**).

Solid state fermentation is an excellent bioprocess for fungal transformation of plant materials mainly because it permits high invasion rates of the mycelyal cells and high productivities of the microbial metabolites in short cultures times. For this reason new bioreactors (**Fig. 11**) have been developed to improve the biotransformation of plants or agroindustrial byproducts through solid state fermentations.

Microbial and enzymatic bioprocesses can be applied to recover several compounds present in *Aloe*, among which it is possible to release anthraquinones such as aloin A, emodin (Warner *et al*. 2003), soluble carbohydrates (Paez *et al.* 2000), several kinds of enzymes such as polysaccharidases able to degrade cellulose, hemicellulose and pectin. Also polyketide synthases able to produce a variety of plant secondary metabolites such as chalcones, stilbenes, benzophenones, acrydones, phloroglucinols, resorcinols, pyrones and chromones (Abe *et al*. 2005). Other type of products can also be released, polyphenols and related compounds which can be associated to a reduction in oxidative stress and related complications during diabetes (Rajasekaran *et al*. 2005, Belmares-Cerda 2005). Polysaccharides such as mannans, glucomannans, galactomannans, arabinogalactans and their oligosaccharides (Yeh *et al*. 2003, Leung *et al*. 2004).

Ventura-Sobrevilla (2005) have focused the use of *Aloe* as raw material for the production of antioxidant compounds derived from the microbial biodegradation of polyphenols present in *Aloe* leaf. However, up to date, the information in this topic is scarce and necessary.

Recently, two novel bioprocesses for use of *A. vera* have been reported. These bioprocesses include the application of *Aloe* as a bioremediation tool or as support for solid state cultures (Murugan and Subramanian 2002, Saucedo *et al*. 2005). The use of *Aloe* leaves for fluoride biosorption in contaminated water demonstrated the great potential of the plant in bioremediation (Murugan and Subramanian 2002).

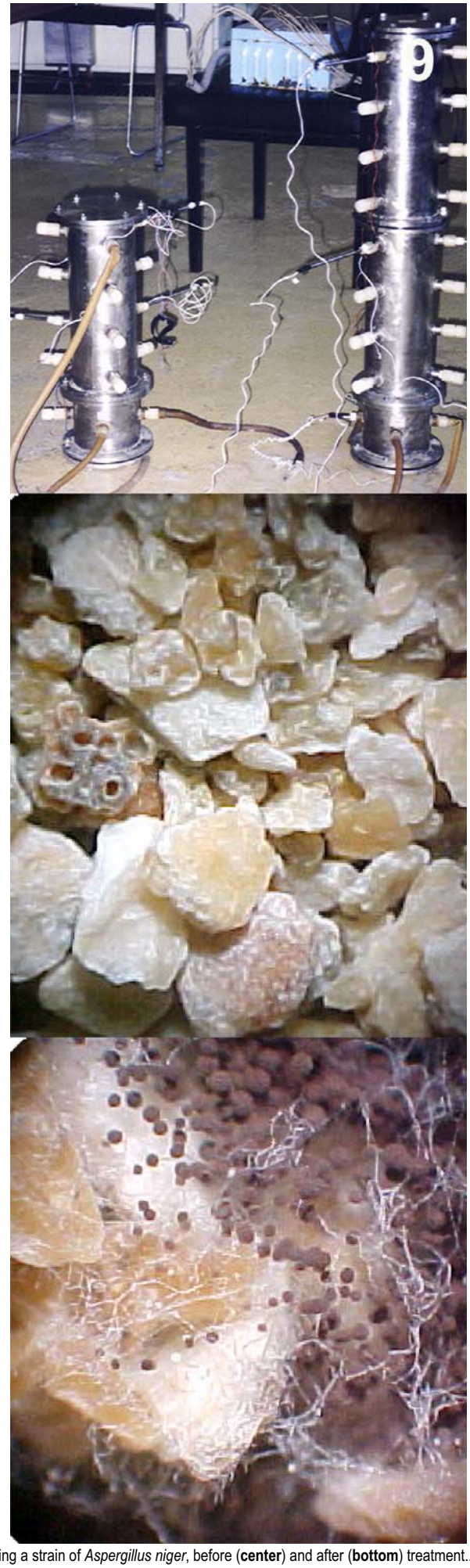


Fig. 9 Column bioreactors (**top**) for solid state fermentation of dehydrated residues of plants using a strain of *Aspergillus niger*, before (**center**) and after (**bottom**) treatment..

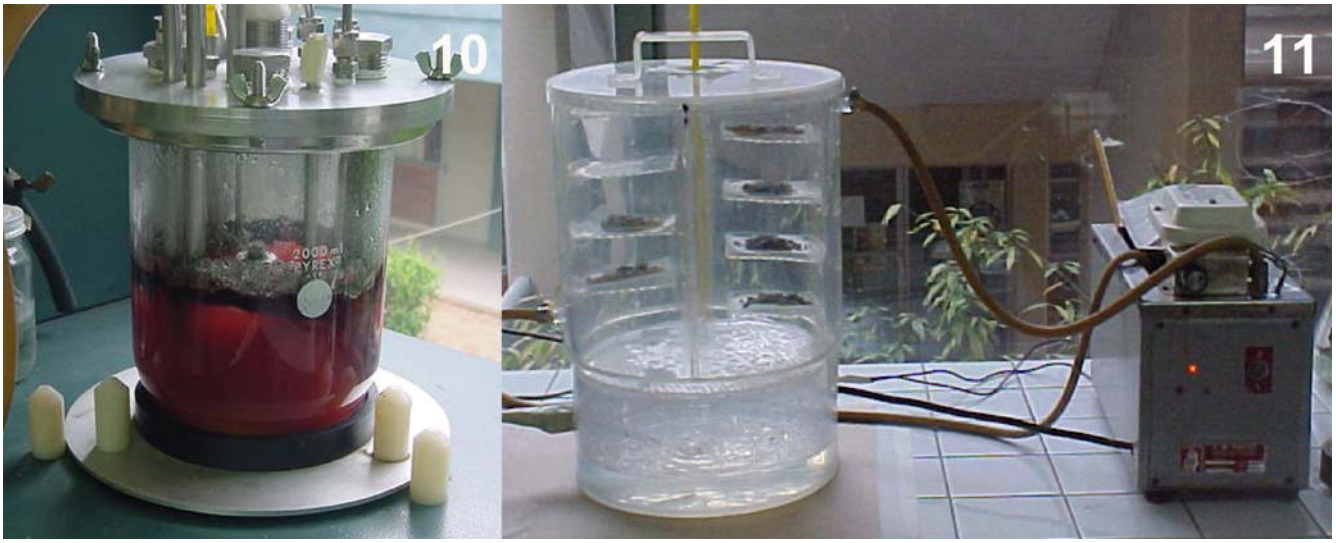


Fig. 10 (left) Liquid state fermentation of plant extracts using a strain of *Penicillium purpurogenum*. **Fig. 11 (right)** New bioreactor for solid state fermentation of plant materials applied to produce biopharmaceuticals or nutraceuticals.

6.4. Consumption trends

Aloe commercialization in Mexico is mainly directed to international markets. It is exported as raw materials fulfilling the requirements of standards and specifications of very specific international companies. The products are gel, juice and powder. The Mexican Food Industry market is developing and presently offers only a few products, such as juice at different concentrations, natural and flavored. However, consumption is low due to a lack of promotion about the benefits of *Aloe* in personal health. Actual *A. vera* products volume was not possible to obtain because of the different international negotiation forms and products (Sanchez-Robles 2002).

The Mexican and International markets are promising for the near future but advertising must be encouraged to promote the use of different raw and elaborated products. *Aloe* products may be promoted based on the world tendency for natural products uses. Industrial exploitation also may be focused at the regions that allow the cropping of *Aloe* and do not allow growing of traditional crops. Semiarid lands in Mexico are large, approximately 50% of the country area, and constitute a good option for *Aloe* cropping due to the commercial importance and possibly social improvement of their inhabitants. To support these possibilities, *Aloe* leaf processing in communal industrial plants may integrate producers and allow the proposal of projects that could be financed by government and private capitals, increasing the cultivated areas.

Pharmaceutical and cosmetic applications are increasing and will support *Aloe* product commercialization. It may be noted that immunostimulation is frequently appearing (Reynolds and Dweck 1999) and this is associated with the presence of polysaccharides in the gel. Research for new products and applications is currently been carried out, looking for active chemicals as those reported in previous sections. It may be noted that *Aloe* is being used in medicinal treatments against cancer, diabetes and AIDS (McDaniel *et al*. 1987 1988, McAnalley *et al*. 1988, Kemp *et al*. 1990, Montaner *et al*. 1996).

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