Journal of the Professional Association for Cactus Development

Leaf production and gel quality of *Aloe vera* (L.) Burm. F. under irrigation regimens in northern Mexico

Aurelio Pedroza-Sandoval[1], Nidia Susana Sifuentes-Rodríguez[1], Ricardo Trejo-Calzada[1], Jorge A. Zegbe-Dominguez[2*], Rafael Minjares-Fuentes[3], José A. Samaniego-Gaxiola[4]

[1] Universidad Regional Universitaria de Zonas Áridas. Universidad Autónoma Chapingo. Km.40 Carretera Gómez Palacio-Chihuahua CP. 56230. México.

[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Zacatecas, Km. 24.5 Carretera Zacatecas-Fresnillo, Calera de V.R., Zacatecas, 98500, México.

[3] Facultad de Ciencias Químicas de la Universidad de Juárez del Estado de Durango, Av. Universidad s/n. Fraccionamiento Filadelfia, C.P. 35010. Gómez Palacio, Durango, México.

[4] Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias. Campo Experimental La Laguna. Boulevard José Santos Valdez 1200 Pte. C.P. 27440, Matamoros, Coahuila. México.

* Corresponding author: zegbe.jorge@inifap.gob.mx

Citation: Pedroza-Sandoval, A., Sifuentes-Rodríguez, N. S., Trejo-Calzada, R., Zegbe-Dominguez, J. A., Minjares-Fuentes, R., Samaniego-Gaxiola, J. A. 2022. Leaf production and gel quality of *Aloe vera* (L.) Burm. F. under irrigation regimens in northern Mexico. *Journal of the. Professional Association for Cactus Development. 24:* 139-148. https://doi.org/10.56890/jpacd.v24i.497.

Associate Editor: José Luis García-Hernández

Technical Editor: Tomas Rivas-Garcia

Received date:19 January 2022

Accepted date:11 August 2022

Published date:17 August 2022

Abstract. The derivatives of aloe plant leave [*Aloe vera* (L.) Burm. f.], such as gel, juice, and powder, are highly appreciated in the industrial sector. This study evaluated the effect of different soil moisture contents on the growth, production, and gel quality of aloe grown in an arid region of Mexico. The study was conducted in a randomized complete block design with three replicates. Base on the percentage of field capacity (FC), three irrigation treatments were tested: 42%, 72%, and 100% of FC corresponding, on average (± standard deviation), to 0.12 ± 0.02 $m^3 m^{-3}$ (as control), 0.18 ± 0.02 $m^3 m^{-3}$, and 0.24 ± 0.02 $m^3 m^{-3}$ of soil water content, respectively. Aloe plants watered with 72% of FC had greater plant height and leaf width than plants watered at 42% of field capacity, while plants with 100% of FC treatment had the longest (56.1 cm) and thickest (1.5 cm) leaves. Aloe plants irrigated at either 72% or 100% of field capacity produced the freshest leaf biomass and gel. In contrast, plants grown at 42% of field capacity treatments had the highest pH (4.94), total soluble solids (1.77 °Brix), ash content (0.62%), methanol-precipitated solids (1.24%), and total solids (1.88%) of aloe gel. Even though the lowest soil moisture content (42% of field capacity) reduced plant and leaf growth and leaf and gel yields, gel quality was enhanced, meeting the gel quality standards demanded by the international market.

Keywords: *Aloe vera* (L.) Burm. f.*; soil moisture content; irrigation; crop yields; gel quality.*

Introduction

Aloe [*A. vera* (L.) Burm. f.] is a popular industrial crop worldwide that provides the raw materials for the processing of different industrial products (Artunduaga *et al*., 2021). Leaf gel of aloe contains mannose polymers with various sugars that are useful in the pharmaceutical and cosmetics industries (Javed and ur-Rahman, 2014).

Aloe leaf gel can be used for effective encapsulation systems for nutraceutical, functional, and other pharmaceutical products to replace maltodextrin (Medina-Torres *et al*., 2019) or to preserve perishable fresh produce based on its rheological properties (Nicolau-Lapeña *et al*., 2021; Minjares-Fuentes *et al*., 2017; Ortega-Toro *et al*., 2017). Aloe leaf contains active compounds such as aloesaponarin-I and aloe-emodin, which are used as a natural dye and as antimicrobial agents in polyester fabrics in the textile industry (Canche-Escamilla *et al*., 2019). Aloe gel extracts have insecticidal properties, with repellent and toxic action against the maize storage pest *Sitophilus oryzae* L. (Mallavadhani *et al*., 2016).

Asian and European countries are the main market niche for processing organic products derived from the aloe leaf, while Latin American countries such as Mexico, Costa Rica, and the Dominican Republic are suppliers of the powder, gel, and juice as raw material for different industrial purposes (Piña-Zambrano and Chirino, 2008). Because of the type of industrial uses, commercial aloe leaf gel must have certain qualitative characteristics provided by various chemical compounds (Shrivastava *et al*., 2019).

Aloe is a crop with high tolerance to environmental stress. Stress can reduce production volume, but produces a higher quality gel by concentrating certain chemical components (Niechayev *et. al*., 2019; Baghalian *et al*., 2011). These phytochemicals include acemannan (Minjares-Fuentes *et al*., 2018), anthraquinones, and glycosides (Baruah *et al*., 2016).

Because of its industrial and economic importance, aloe is a crop with great potential for cultivation in marginal lands in arid zones. However, these regions are characterized by extreme temperatures, the presence of salts and heavy metals in the soil, drought events, and water scarcity that limits agricultural activities (Azpilcueta-Pérez *et al*., 2018). Although aloe is a crassulacean acid metabolism plant and therefore a high water use efficient (WUE) species (Gil-Marín *et al*., 2006), irrigation water is needed for commercial cultivation. Both aerial biomass and gel yield were maximized by applying 11 L plant^{-1} during the growing season (Ahmad *et al*., 2018). The WUE, measured as leaf mass, the aerial part of the plant, and gel yield on a dry weight basis, increased when plants were watered with 13 L plant^{-1} (De la Torre-Herrera *et al*., 2010). In contrast, WUE was reduced when plants were irrigated with 22.5 L plant^{-1} or 1.6 L plant^{-1} (100% and 25% of field capacity, respectively). Therefore, the objective of this study was to quantify the effect of irrigation on leaf and gel yields and some gel quality attributes on aloe plants grown at different soil moisture contents in an arid region of Mexico.

Material and Methods

Study area location and plant material

The study was conducted in the experimental area of the Unidad Regional Universitaria de Zonas Áridas (URUZA) of Universidad Autónoma Chapingo (UACh) in Bermejillo, Durango, Mexico. The area is located at 23º 54’ N and 103º 37’ W at an elevation of 1,130 masl. It has a very dry climate with summer rainfall, average annual rainfall of 239 mm, a percentage of winter rainfall of less than 5%, and a thermal oscillation that ranges from 7 to 17 ºC (Medina-García *et al*., 2005). Forty-two-month-old plants of aloe [*Aloe vera* (L.) Burm. f.] were placed at 1 m x 1 m between and within rows, respectively. Except for the irrigation, plants were handled with local agricultural practices.

Experimental design and treatments

The experiment was conducted during the spring and fall of 2017 in a randomized complete block design with three replicates. The replications consisted of three rows, 6 m long and 1 m wide each, where the four central plants were chosen randomly for all determinations. Based on the soil type and water retention curve (Richards, 1948), the physical parameters were established at 0.13 m^3 m^{-3} (-1.5 MPa) and 0.25 m^3 m^{-3} (0.0 MPa) for permanent wilting point (PWP) and field capacity (FC), respectively. Three irrigation treatments were based on the FC percentage: 42%, 76%, and 100% of FC corresponding, on average (± standard deviation), to 0.12 ± 0.02 m^3 m^{-3} (as control), 0.18 ± 0.02 m^3 m^{-3}, and 0.24 ± 0.02 m^3 m^{-3}, respectively. As the PWP for aloe is unknown (Silvera *et al*., 2015), in the control treatment, soil moisture content (θ) was allowed to drop until 0.10 m^3 m^{-3}.

Experimental setup

The irrigation treatments were applied through the main irrigation line (2") with perpendicular irrigation lines (1/2") per row. The irrigation supplies were controlled by on-off valves. One self-compensating dripper (Hydro Environment CHD) that emitted 2 L h^{-1} was used on each plant. At the start of the experiment, the three irrigation treatments were watered to FC. The θ was determined regularly in real-time with a digital tensiometer (Soil Tester® model HB-2 Ontario, Canada). When the θ reached the lowest limit of a treatment, irrigation was resumed until approximately the upper limit of each irrigation treatment. The recovery irrigation took around 4 h for each treatment.

Response variables

Morphometric variables

Plant height and leaf length were measured with a measuring tape. Leaf width and thickness were measured with a hand-held caliper (Truper Model 14388, China). Fresh leaf biomass and gel weight were measured with a digital scale (Torrey L-PCR 20, Mexico). Leaves were measured at harvest (eight-month-old leaves) when the three outermost leaves of each plant were collected. Finally, based on the plant population established (10,000 plants ha^{-1}) a yield estimate per unit area of leaf and gel was made using the following equation:

$$PLY = \frac{[Leaf\ weight]x[10{,}000]}{1000}(6)$$

where PLY is the potential leaf yield ha^{-1}, leaf weight (g), and six (6) is the average number of leaves per plant picked at commercial harvest.

Leaves were harvested in the fall of 2017, about six months after the start of the experiment, and when leaves were well developed. Gel yield was calculated by substituting gel weight for leaf weight in the PLY equation. The gel was extracted manually from each leaf by cutting the tip and lateral margins of the leaf to separate the upper and lower cuticle with a spatula, and then, a crystalline sample gel was obtained. The extracted gel was homogenized in a blender (Oster model 450-20, Mexico) at room temperature for subsequent analysis.

Determination of gel quality

Ash percentage was determined according to the official Mexican standard NMX-F-066-S-1978 (1978), with modifications as described (Wang and Strong, 1995). A porcelain crucible was placed in an incinerator (muffle) at 540 °C for 2 h and afterward removed. Then 2 mL concentrated nitric

https://www.jpacd.org Electronic ISSN: 1938-6648

acid was added and the crucible was dried on an electric heating plate (Thermo Scientific SP131635Q) to evaporate the acid and left to cool for 1 h in the desiccator. Its final weight was determined on an analytical balance (Shimadzu AY220 model) with an accuracy of 0.0001 g (W1). Approximately 2 g gel was added (W2). Then the crucible with the sample was placed inside the incinerator, which was closed and turned on, allowing it to reach a temperature of 540 °C for 2 h. After that, it was turned off and the temperature was allowed to drop below 200 °C. The crucible was then removed and allowed to cool for about 1 h. Finally, the crucible with the dried sample was weighed to the nearest 0.0001 g (W3) and the ash percentage was calculated with the following equation:

$$Ash\% = [W_3 - W_1/W_4][100]$$

where W1 is the weight of empty crucible, W2 is the weight of crucible plus fresh or partially dry sample, W3 is the weight of crucible plus ash, and W4 is the weight of the fresh or partially dry sample (W2-W1).

Acidity (pH) was measured with a potentiometer (Conductronic model PH140, Mexico), and total soluble solids content (sugar content, °Brix) was determined with a refractometer (AT, model PAL-1, Mexico). Both measurements were made at room temperature. Total solids were determined with 2 g gel in a porcelain crucible (analytical balance, Shimadzu model AY220). Gel samples were oven-dried to constant weight at 105 ºC for 24 h. The methanol-precipitated solids were derived from the weight of total solids. Then, to each dry gel sample, 25 mL of 99% methanol was added, placed in 50 mL Eppendorf tubes, and the tubes were shaken at medium speed (shaker, Thermo scientific 2346) for 30 min at room temperature. The tubes were allowed to stand for 12 h and then centrifuged. The precipitate was washed three times with 25 mL methanol. The samples were placed in test tubes and oven-dried for 24 h at 45-60 ºC. Finally, the test tubes were placed in a desiccator to cool at room temperature.

Data analysis

Data were analyzed with a randomized complete block model. Treatment means were grouped by the Tukey's range test and regression analysis was performed with the statistical analysis system (Version 9.0; SAS Institute Cary, NC, USA).

Results and Discussion

Plant and leaf growth

The aloe plants at 100% of field capacity (FC) had the greatest plant height and leaf length, width, and thickness (Table 1). Aloe plants are well-adapted to arid and semiarid environments due to their crassulacean acid metabolism (CAM) (Quezada *et al*., 2017). CAM plants store water in their leaves and stems and can withstand long periods of drought, but watering enhances plant growth and increases leaf fresh mass (De la Torre-Herrera *et al*., 2010; Hazrati *et al*., 2017). The last results support the findings here. Although aloe is a water stress-tolerant plant, under stress it responds to promote survival rather than productivity (Grace *et al*., 2015; Pedroza-Sandoval and Gómez-Lorence, 2006).

https://www.jpacd.org Electronic ISSN: 1938-6648

Table 1. Morphometric (cm) measurements of aloe plants exposed to irrigation treatments (IT) at different percentages of field capacity (FC).

IT (% FC)	Plant height	Leaf length	Leaf width	Leaf thickness
42	63.6 ± 0.8 b[†]	48.2 ± 0.6 c	7.3 ± 0.1 b	1.2 ± 0.03 c
72	73.8 ± 0.8 a	53.6 ± 0.5 b	8.5 ± 0.1 a	1.4 ± 0.09 b
100	74.6 ± 0.8 a	56.1 ± 0.5 a	8.5 ± 0.2 a	1.5 ± 0.02 a

[†]Within columns, mean values (± standard deviation) followed by different lowercase letters differ significantly according to Tukey's Honest Significant Difference test at $p \leq 0.05$.

Leaf biomass and gel production

Compared to plants given 42% of FC, the aloe plants with 76% and 100% of FC produced fresher leaf biomass, fresh leaf yield, gel weight, and gel yield (Table 2). When plants experience favorable conditions for growth, regardless of their photosynthetic pathway, it is reflected in their growth and productivity (Kumar *et al*., 2017). This increased growth was seen in aloe plants under 76% and 100% of FC (De la Torre *et al*., 2010; Hazrati *et al*., 2017). The opposite occurs when growth conditions are unfavorable (Osakabe *et al*., 2014), as with the aloe plants exposed to 42% of FC. These plants had the lowest fresh leaf biomass, fresh leaf yield, gel weight, and gel yield (Table 2). Similar effects occurred in succulent CAM plants such as pineapple (*Ananas comosus*; Ríos *et al*., 2020) and cactus pear (*Opuntia* spp.; Zegbe and Servín-Palestina, 2021) when exposed to water deficit. Drought stress status is relevant when the objective is to maintain high plant productivity in the face of market demand, in this particular case, for aloe leaf extracts.

Table 2. Fresh leaf biomass and gel yields of aloe plants exposed to irrigation treatments (IT) at different percentages of field capacity (FC).

IT (% FC)	Fresh leaf biomass (kg plant^{-1})	Fresh leaf biomass yield[†] (t ha^{-1})	Gel weight (kg plant^{-1})	Gel yield[a] (t ha^{-1})
42	0.24 ± 0.01 b [‡]	14.4 ± 5.6 b	0.093 ± 0.005 b	5.6 ± 3.0 b
72	0.42 ± 0.02 a	25.2 ± 10.3 a	0.220 ± 0.013 a	13.2 ± 6.7 a
100	0.43 ± 0.04 a	25.8 ± 19.7 a	0.226 ± 0.022 a	13.5 ± 11.7 a

[†]Based on a density of 10,000 plants ha^{-1} and an average of six leaves plant^{-1} harvest^{-1}.
[‡]Within the columns, mean values (± standard deviation) followed by different lowercase letters differ significantly according to Tukey's Honest Significant Difference test at $p \leq 0.05$.

Some gel quality indicators

The aloe gel from plants with 42% of FC treatment had the highest ($p < 0.05$) pH (4.94), soluble solids content (sugar content; 1.77%), ash content (0.62%), methanol-precipitated solids (1.24%), and total solids (1.88%). The respective values for the 100% of FC treatment were 4.79, 1.35%, 0.47%, 0.70%, and 1.38% (Table 3). CAM plants under water deficit sacrifice growth and biomass production (Niechayev *et al*., 2019). These plants, via secondary metabolism, also accumulate oligosaccharide compounds, oxilipines, traumatic acid an abiotic stress-related hormone, and 34 more unknown metabolites that are assumed to be involved with the plant's resilience and tolerance to water deficit (Mayer *et al*., 2021). However, the enhanced gel quality attributes measured here in aloe plants under the lowest irrigation treatment could be associated with a dilution phenomenon. Such an effect has been observed in other plant species (Mpelasoka *et al*., 2000; Zegbe-Domínguez *et al*., 2003), including *Opuntia* species (Zegbe, 2020), under water deficit. Regardless of aloe plant reduction, the gel quality enhancement found in the 42% FC irrigation treatment, has an important commercial impact on the aloe plant industry. For instance, high ash content in the plant tissues indicates high concentrations of mineral nutrients (K, Ca, Mg, Ca, and others) desired by the industry (Sifuentes-Rodríguez *et al*., 2020; Cabrera-Suárez *et al*., 2012). Similarly, the pH values reported in this study are similar to those found in gels used as raw material for making different industrial products (Choi and Chung, 2003). The greatest soluble solids and precipitable solids in methanol, at the lowest irrigation treatment, represent an alternative management strategy for obtaining the commercial standards established by the International Aloe Science Council (IASC) (2008). These two gel quality components were also improved in aloe plants exposed to saline stress (Sifuentes-Rodríguez *et al*., 2020).

Table 3. Influence of irrigation treatments (IT) at three percentages of field capacity (FC) on pH, soluble solids content (SSC), ash content (AC), methanol-precipitated solids (MPS), and total solids (TS) of aloe gel.

IT (% FC)	pH	SSC (°Brix)	AC (%)	MPS (%)	TS (%)
42	4.94 ± 0.04 a[†]	1.77 ± 0.18 a	0.62 ± 0.02 a	1.24 ± 0.01a	1.88 ± 0.04 a
72	4.84 ± 0.06 b	1.35 ± 0.13 b	0.42 ± 0.03 b	0.83 ± 0.04 b	1.35 ± 0.05 b
100	4.79 ± 0.07 c	1.35 ± 0.16 b	0.47 ± 0.03 b	0.70 ± 0.02 c	1.36 ± 0.03 b

[†]Within the columns, mean values (± standard deviation) followed by different lowercase letters differ significantly according to Tukey's Honest Significant Difference test at $p \leq 0.05$.

Conclusions

This study quantified the effect of different soil moisture contents on leaf and gel yields and gel quality attributes of aloe plants grown in an arid zone of Mexico. Aloe plants watered at either 72% or 100% of field capacity improved leaf and gel yields. Aloe plants watered at 42% of field capacity had enhanced gel quality, measured as pH, total soluble solids, ash content, methanol-precipitated solids, and total solids. These quality attributes are part of the quality standards established for aloe gel in the international market. Thus, this study suggests two irrigation alternatives for aloe growers can consider.

Acknowledgments

We thank Dr. Mary Lou (University of California, Davis) for improving the presentation of this manuscript.

Ethics statement

Not applicable

Funding

This research was partially supported by the Dirección General de Investigación de la Universidad Autónoma Chapingo through the strategic project: "Integral management of water in arid lands", number of reference 2017-EI.

Consent to publication

Not applicable

Data availability

Not applicable

Competing interests

The authors declare that they have no competing interests in this section.

Author contributions

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, APS and NSSR; methodology, APS and JAZ; software, JASG; validation, RTC, RMF and APS; formal analysis, APS and JAZ.; investigation, APS and NSSR; resources, RTC; data curation, APS and RMF; writing—original draft preparation, APS and NSSR; writing—review and editing, APS and JAZ; visualization, RTC and RMF; supervision, JASG; project administration, APS; funding acquisition, APS", please turn to the credit taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

References

Ahmad, M. A., Gupta, L., Gupta, M., and Gupta, N. K. 2018. Influence of irrigation schedules on growth, yield and water use efficiency in aloe (*Aloe barbadensis*). *Indian Journal of Agricultural Sciences. 88*(2): 245–248.

Artunduaga, K., Vargas, D., and Barrera, O. 2021. Conservación de las propiedades nutraceúticas del Aloe vera (*Aloe barbadensis* Miller), mediante técnicas de secado. *Revista Ingeniería y Región. 25*: 6-23. https://doi.org/10.25054/22161325.2818.

Azpilcueta-Pérez, M. E., Pedroza-Sandoval, A., Trejo-Calzada, R., Sánchez-Cohen, I., and Jacobo-Salcedo, M. R. 2018. Chemical residuality in maize (*Zea mays* L.) fields irrigated with deep well water. *Revista Ecosistemas y Recursos Agropecuarios. 5*(13): 111-117. https://doi.org/10.19136/era.a5n13.1311.

Baghalian, K., Abdoshab, Sh., Khalighi-Sigaroodi, F., and Paknejad, F. 2011. Physiological and phytochemical response to drought stress of German chamomile (*Matricaria recutita* L.). *Plant Physiology and Biochemistry. 49*(2): 201-207. https://doi.org/10.1016/j.plaphy.2010.11.010.

Baruah, A., Bordoli, M., and Deka Baruah, H. P. 2016. *Aloe vera*: A multipurpose industrial crop. *Industrial Crops and Products. 91*: 951-963. https://doi.org/10.1016/j.j.indcrop.2016.08.034.

Cabrera-Suárez, H. R., Morón-Rodríguez, F. J., Victoria-Amador, M. C., García-Hernández, A. I., and Acosta de la Luz, L. 2012. Composición fitoquímica de partes aéreas frescas de *Phania* matricarioides. *Revista Cubana de Plantas Medicinales. 17*(3): 268-278.

Choi, S., and Chung, M. H. 2003. A review on the relationship between *Aloe vera* components and their biologic effects. *Seminars in Integrative Medicine. 1*(1): 53-62. https://doi.org/10.1016/S1543-1150(03)00005-X.

Canche-Escamilla, G., Colli-Acevedo, P., Borges-Argaez, R., Quintana-Owen, P., May-Crespo, J.F., Cáceres-Farfan, M., Yam Puc, J.A., Sansores-Peraza, P., and Vera-Ku, B. M. 2019. Extraction of phenolic components from an Aloe vera (*Aloe barbadensis* Miller) crop and their potential as antimicrobials and textile dyes. *Sustainable Chemistry and Pharmacy. 14*: 100168. https://doi.org/10.1016/j.scp.2019.100168.

De la Torre-Herrera, J., Delfino, I., Salinas, C., Silva, H., and Cardemil, L. 2010. Irrigation restriction effects on water use efficiency and osmotic adjustment in *Aloe vera* plants (*Aloe barbadensis* Miller). *Agricultural Water Management. 97*(10): 1564–1570. https://doi.org/10.1016/j.agwat.2010.05.008.

Gil-Marín, J. A., Rodríguez, R., Jasso-Cantú, D., and Zermeño, A. 2006. Resistencia estomática, transpiración y potencial hídrico en sábila con diferentes condiciones ambientales. *Terra-Latinoamericana*. *24*(3): 355-365.

Grace, O. M., Buerki, S., Symonds, M. R. E., Forest, F., van Wyk, A. E., Smith, G. F., and Rønsted, N. 2015. Evolutionary history and leaf succulence as explanations for medicinal use in aloes and the global popularity of *Aloe vera*. *BMC Evolutionary Biology. 15*: 29. https://doi.org/10.1186/s12862-015-0291-7.

Hazrati, S., Tahmasebi-Sarvestani, Z., Mokhtassi-Bidgoli, A., Modarres-Sanavy, S. A. M., Mohammadi, H., and Nicola, S. 2017. Effects of zeolite and water stress on growth, yield and chemical compositions of *Aloe vera* L. *Agricultural Water Management. 181*: 66–72. https://doi.org/10.1016/j.agwat.2016.11.026.

International Aloe Science Council (IASC). 2008. Aloe Scientific Primer. International Aloe Science Council. Silver Spring, Maryland, USA. 17 p. http://allaboutaloe.org/resources/Aloe%20Scientific%20Primer.pdf (accessed 25 October 2018).

Javed, S., and ur-Rahman, A. 2014. Aloe Vera Gel in Food, Health Products, and Cosmetics Industry. In: Studies in Natural Products Chemistry. Elsevier B.V. 41:261-285 https://doi.org/10.1016/B978-0-444-63294-4.00009-7.

Kumar, V., Sharma, A., Soni, J. K., and Pawar, N. 2017. Physiological response of C3, C4 and CAM plants in changeable climate. *Pharma Innovation. 6*(9): 70-79.

Mallavadhani, U. V., Rajendra, P. B., Lakshmi, S. P., Babu, R. M., and Ratanlal, M. 2016. *Aloe vera* (L.) Burm. f.: A highly useful Indian traditional plant for the management of maize storage pest, Sitophilus oryzae L. (Coleoptera: *Curculionidae*). *Journal of Biopesticides. 9*(2): 157-166.

Mayer, J. A., Wone, B. W. M., Alexander, D. C., Guo, L., Ryals, J. A., and Cushman, J. C. 2021. Metabolic profiling of epidermal and mesophyll tissues under water-deficit stress in *Opuntia* *ficus-indica* reveals stress-adaptive metabolic responses. *Functional Plant Biology. 48*(7): 717-731. https://doi.org/10.1071/FP20332.

Medina-García, G., Díaz-Padilla, G., López-Hernández, J., Ruiz-Corral, J. A., and Marín-Silva, M. 2005. Estadísticas Climatológicas Básicas del estado de Durango. (Periodo 1961 – 2003). Campo Experimental Valle del Guadiana. Centro de Investigación Regional Norte Centro-Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Libro Técnico № 1. p. 240. http://www.inifapcirne.gob.mx › Publicaciones (accessed 24 June 2020).

Medina-Torres, L., Núñez-Ramírez, D. M., Calderas, F., González-Laredo, R. F., Minjares-Fuentes, R., Valadez-García, M. A., Bernad-Bernad, M. J., and Manero, O. 2019. Microencapsulation of gallic acid by spray drying with aloe vera mucilage (*Aloe barbadensis* Miller) as wall material. *Industrial Crops and Products. 138*: 111461. https://doi.org/10.1016/j.indcrop.2019.06.024.

Minjares-Fuentes, R., Medina-Torres, L., González-Laredo, R. F., Rodríguez-González, V. M., Eim, V., and Femenia, A. 2017. Influence of water deficit on the main polysaccharides and the rheological properties of Aloe vera (*Aloe barbadensis* Miller) mucilage. *Industrial Crops and Products.* 109: 644-653. https://doi.org/10.1016/j.indcrop.2017.09.016.

Minjares-Fuentes, R., Femenia, A., Comas-Serra, F., Rodríguez-González, V. M. 2018. Compositional and structural features of the main bioactive polysaccharides present in the *Aloe vera* plant. *Journal of AOAC International*. *101*(6): 1711-1719. https://doi.org/10.5740/jaoacint.18-0119.

Mpelasoka, B. S., Behboudian, M. H., Dixon, J., Neal, S.M., and Caspari, H. W. 2000. Improvement of fruit quality and storage potential of 'Braeburn' apple through deficit irrigation. *Journal of Horticultural Science and Biotechnology. 75*(5): 615-621. https://doi.org/10.1080/14620316.2000.11511296.

Niechayev, N.A.; Pereira, P.N.; Cushman, J.C. 2019. Understanding trait diversity associated with crassulacean acid metabolism (CAM). *Current Opinion in Plant Biology* 49: 74–85. https://doi.org/10.1016/j.pbi.2019.06.004

Nicolau-Lapeña, I., Colás-Medá, P., Alegre, I., Aquiló-Aguayo, I., Muranyi, P., and Viñas, I. 2021. Aloe vera gel: An update on its use as a functional edible coating to preserve fruits and vegetables. *Progress in Organic Coatings. 151*: 106007. https://doi.org/10.1016/j.porgcoat.2020.106007.

Norma Oficial Mexicana Nmx-f-066-s-1978. 1978. Determinación De Cenizas En Alimentos. https://xdoc.mx/documents/nmx-f-066-s-1978-determinacion-de-cenizas-en-alimentos5f9b9221d6381+&cd=1&hl=es&ct=clnk&gl=mx (accessed 25 May 2021).

Ortega-Toro, R., Collazo-Bigliardi, S., Roselló, J., Santamarina, P., and Chiralt, A. 2017. Antifungal starch-based edible films containing *Aloe vera*. *Food Hydrocolloids. 72*: 1-10. https://doi.org/10.1016/j.foohyd.2017.05.023.

Osakabe, Y., Osakabe, K., Shinozaki, K., and Tran, L. S. P. 2014. Response of plants to water stress. *Frontiers in Plant Science. 5*: 1-8. https://doi.org/10.3389/fpls.2014.00086.

Pedroza-Sandoval, A, and Gómez-Lorence, F. 2006. La sábila (*Aloe* spp.). Propiedades, Manejo agronómico, Proceso Agroindustrial y de Mercado. Departamento de Publicaciones de la

Dirección General de Difusión Cultural y Servicio. Editorial Chapingo. DR © Universidad Autónoma Chapingo. Chapingo, México. 147 p.

Piña-Zambrano, H., and Chirino, L. 2008. Mercado de la sábila (*Aloe vera* L.) en el estado Falcón. *Revista de la Facultad de Agronomía. 25*(2): 364-392.

Quezada, M. P., Salinas, C., Gotteland, M., and Cardemil, L. 2017. Acemannan and fructans from aloe vera (*Aloe barbadensis* Miller) plants as novel prebiotics. *Journal of Agricultural and Food Chemistry. 65*(46): 10029-10039. https://doi.org/10.1021/acs.jafc.7b04100.

Richards, L. A. 1948. Porous plate apparatus for measuring moisture retention and transmission by soil. *Soil Science*. 66:105-110.

Ríos, V. M, Gómez Herrera, M. D., Hitoshi-Sugita, N., and Alayón-Luaces, P. 2020. Water status response of pineapple using destructive and non-destructive indicators and their relations in two contrasting seasons. *Journal of the Saudi Society of Agricultural Sciences. 19*(8): 538-547. https://doi.org/10.1016/j.jssas.2020.10.002.

Shrivastava, N., Mahajan, S., Jain, A., Sharma, P., Kharakwal, A., and Varma, A. 2019. Mutualistic Interaction of Piriformospora indica (*Serendipita indica*) with *Aloe vera*, the wonder plant for modern living. *American Journal of Plant Sciences. 10*: 2002-2011. https://doi.org/10.4236/ajps.2019.1011140.

Sifuentes-Rodríguez, N. S., Pedroza-Sandoval, A., Zegbe, J. A., and Trejo-Calzada, R. 2020. Indicadores de productividad y calidad de gel de sábila en condiciones de estrés salino. *Revista Fitotecnia Mexicana. 43*(2): 181-187. https://doi.org/10.35196/rfm.2020.2.181.

Silvera, K., Kurt, M. N., Whitten, W. M., Williams, B. N. H., Winter, K., and Cushman, J. C. 2015. Evolution along the crassulacean acid metabolism continuum. *Functional Plant Biology. 37*: 995–1010.

Wang, Y., and Strong, K. 1995. A two-year study monitoring several physical and chemical properties of field grown *Aloe barbadensis* Miller leaves. *Subtropical Plant Science. 47*: 34-38.

Zegbe-Domínguez, J. A., Behboudian, M. H., Lang, A., and Clothier, B. E. 2003. Deficit irrigation and partial rootzone drying maintain dry mass and enhance fruit quality in 'Petopride' processing tomato (*Licopersicum esculentum*, Mill). *Scientia Horticulturae.* 98: 505-510. https://doi.org/10.1016/S0304-4238(03)00036-0.

Zegbe, J. A. 2020. Quality and storability of cactus pear fruit as improved by supplemental irrigation. *Journal of the Professional Association for Cactus Development. 22*: 1-17. https://doi.org/10.56890/jpacd.v22i.21.

Zegbe, J.A.; Servín-Palestina, M. 2021. Supplemental irrigation to save water while growing cactus pear in semi-arid regions. *Irrigation and Drainage. 70*(2): 269-280. https://doi.org/10.1002/ird.2542.