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Reciprocal hybridisation of *Aloe* species (*Aloe arborescens* with *A. vera*) and their characterisation in a highland region of Venezuela

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Abstract: *Aloe vera* and *A. arborescens* are succulent plants widely used in cosmetics, pharmaceuticals, and food supplements. The objective of this study was to perform interspecific crosses and agronomically characterise three genotypes cultivated in a Venezuelan highland region (altitude 1 727 m, 13–17.9 °C). Successful hybridisation was achieved only when *A. arborescens* pollen (P_1) was used on *A. vera* pistils (P_2), whereas the reciprocal cross was largely unsuccessful. Hybrid seed germination reached 11.86%, and adult hybrids exhibited significant vegetative superiority over P_1, particularly in leaf volume, leaf weight, and flower number. The progeny outperformed both parents in leaf base width and lateral tooth size, thereby enhancing its ornamental value. The expected $2n = 2x = 14$ karyotype was confirmed in the root meristems of hybrids. The analysis of leaf pulp processing indicated that the hybrid was promising for juice production (39.8% yield, 1 203 ppm acemannan), thus highlighting its potential for agro-industrial applications in tropical highlands or comparable temperate regions. Other agronomic traits, including number, thickness, colour, and shape of leaves; sprouting of stem branches and basal suckers, flowering period, inflorescence, eggs/ovary, and details of the colour and dimensions of bracts, perianth, pedicel, and ovary, were also evaluated.

Keywords: *Aloe* breeding; chromosomes; hybridisation; morphological markers

Aloe L. (1753) is a genus of succulent plants native to the African continent, the Arabian Peninsula, Madagascar, and several East African islands in the Indian Ocean (Bachheti et al. 2022). It is the largest genus in the Asphodelaceae family and exhibits the most diverse morphology (Smith et al. 1995). Of the more than 580 valid species within this genus (Govaerts 2024), *A. vera* and *A. arborescens* are the most widely distributed and extensively cultivated worldwide (Liao et al. 2006; GBIF 2023).

Aloe vera (L.) Burm f. (1768) is used in Ayurvedic, homoeopathic, and allopathic medicine by the general population for both food and medicinal purposes. Its leaves contain vitamins, minerals, enzymes, amino acids, natural sugars, and other bioactive compounds with emollient, purgative, antimicrobial, anti-inflammatory, antioxidant, aphrodisiac, anthelmintic, antifungal, antiseptic, and cosmetic properties. This plant has demonstrated the potential to treat sunburn, minor cuts, and skin cancer (Sahu et al. 2013). Additionally, *A. vera* derivatives remain valuable in various industrial and biotechnological applications, including as growth enhancers (El Sherif 2017), in nanobiotechnology (Song et al. 2022), as a germination accelerator and root development stimulant (Tucuch-Haas et al. 2022), and for maintaining the quality and bioactive compounds in refrigerated fruits through post-harvest coating treatments (Ozturk et al. 2019; Farina et al. 2020).

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Aloe arborescens Mill. (1768) is also a significant source of nutraceutical substances and has been used for centuries in traditional medicine across various African and Asian countries (Beppu et al. 2004). It gained global attention after the Second World War when the therapeutic value of a gel derived from its leaves was demonstrated following its application to victims of nuclear bomb explosions. It is cultivated in tropical and subtropical regions, is a popular garden plant in the Mediterranean, and is commercially grown in Italy, Israel, and China for its medicinal and cosmetic applications (Smith et al. 2012). Various pharmacological and therapeutic properties of *A. arborescens* have been investigated, with numerous reports on its anti-inflammatory (Fujita et al. 1976) and purgative effects (Akao et al. 1996), as well as its potential for treating diabetes, gastric ulcers, and fungal conditions affecting the skin and scalp (Beppu et al. 2006).

More recently, *A. arborescens* has been identified as a potential inhibitor of α-glucosidase, supporting type 2 diabetes therapy, and as an inhibitor of acetylcholinesterase and butyrylcholinesterase activity, which may contribute to the treatment of Alzheimer's disease (Pawłowicz et al. 2022). In veterinary applications, supplementation with lyophilised *A. arborescens* during the dry phase of dairy cows has been shown to reduce inflammatory responses postcalving and enhance milk production in subsequent lactation cycles (Cattaneo et al. 2022). Additional benefits include positive effects on liver function and the modulation of ruminal fermentation (Cattaneo et al. 2023), as well as favourable impacts on both rectal and milk microbiomes. These effects involve microorganisms that contribute to improved energy metabolism or provide protective benefits against enteric dysbiosis and diseases (Cremonesi et al. 2024).

Given their differing geographical origins – *A. vera* from the Arabian Peninsula (Grace et al. 2015) and *A. arborescens* from South Africa (Smith et al. 2012) – these species must coexist in botanical gardens, nurseries, or germplasm banks for hybridisation to occur. Considering the necessity of generating genetic diversity for plant breeding and the economic significance of these succulent species, we conducted manual interspecific crosses to develop hybrids with botanical traits of potential ornamental or agro-industrial value. The objective of this study was to obtain hybrid seeds (*A. arborescens* var. *frutescens* × *A. vera*), promote the growth and development of the offspring, and evaluate their agronomic characteristics under highland conditions with a temperate climate in the Venezuelan coastal mountain range.

MATERIAL AND METHODS

Plant material. Initial hybridisation was conducted using adult plants of *A. arborescens* and *A. vera* located at coordinates 10°23'43''N latitude, 66°58'31''W longitude, at an altitude of 1 620 m a.s.l. These plants had been extensively cultivated in this location as part of the garden ornamentation of the Venezuelan Institute of Scientific Research (IVIC, official acronym). Thirty plants of each species were selected for hybridisation studies and identified as *Aloe arborescens* var. *frutescens* (Salm-Dyck) Link and *Aloe vera* (L.) Burm. f. (=*A. barbadensis* Mill.), following the taxonomic criteria of Lindinger (1926), Carter (1994), and Smith et al. (2012). Flowers about to open were selected from each species, separated from the inflorescence and placed in Petri dishes until anthesis. A total of 200 reciprocal crosses were performed manually using these pollen sources on previously emasculated flowers, which were then labelled and protected to prevent uncontrolled pollination or pollen removal by entomophilous activity.

Six hundred F_1 seeds were soaked for 24 h in 0.1% hydrogen peroxide and subsequently sown in trays filled with washed coarse sand. The trays were watered with tap water every five days using a fine mist spray and maintained in a greenhouse at a controlled temperature of 20–23 °C. After six months, each hybrid was transplanted into a plastic pot containing 450 mL of a substrate composed of equal parts expanded perlite, worm castings, and coarse sand. Both these sexually derived specimens and a sample of 150 vegetative shoots from each parental species were maintained under the same greenhouse conditions until they reached a similar size (25–33 cm).

Thirty plants from each genotype (*A. arborescens*, *A. vera*, and the experimental hybrids) were transplanted under open-air conditions at coordinates 10°23'42''N latitude, 66°59'07''W longitude, at an altitude of 1 727 m a.s.l. This area is classified as a mountain savannah with a temperate and dry climate, featuring temperatures of 13–17.9 °C and annual precipitation of 700–1 199 mm (Silva 2010). These plants were cultivated under dryland conditions for four years to conduct the corresponding agronomic evaluations. Five leaf and inflorescence samples were dissected and deposited in the IRBR

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herbarium, while additional living specimens were preserved in the germplasm bank of our department.

Morphological evaluation. Ten randomly selected adult plants from each genotype were characterised. The following traits were assessed in both the progeny and parental specimens: leaf tip shape, colour, number, weight, length, width, thickness, and volume; number and length of marginal teeth; number of stem branches and basal suckers; flowering period; raceme type; flower colour and number; number of ovules per ovary; and dimensions of the perianth, pedicel, ovary, and exposed stamens-style. Morphological characterisation was conducted following the methodology of Ozols-Narbona and Imery-Buiza (2022).

Leaf processing, juice extraction, and acemannan analysis. In each of the ten previously selected plants, one mature leaf, positioned closest to the ground and of average size, was collected. These ten leaves were washed, and the hydro-parenchyma was manually extracted using a ceramic knife. The tissue was thoroughly washed to remove all traces of hydroxyanthracene-rich latex. The pulp was homogenised using a Lacor 61673 blender (Bamix, Switzerland) for five min, left to rest for ten min, and then vacuum-filtered using a Büchner funnel with Whatman Grade 54 filter paper (particle retention: 22 µm). Three independent samples of the filtered juice from each genotype were analysed to determine acemannan content, following the method described by Jiao et al. (2010). Additionally, a fraction of the leaf material was oven-dried at 85 °C for 96 h to determine humidity percentage (HP) using the following formula:

$$HP = 100 \times \frac{\text{fresh weight} - \text{weight after drying}}{\text{fresh weight}}$$

Cytogenetic evaluation. Five morphologically characterised specimens were selected for karyotypic analysis. Mitotic chromosomes were examined using temporary slide preparations obtained from root tips pre-treated with colchicine, fixed in Carnoy II solution, stained with orcein, and gently squashed, following the methodology of Fukui and Nakayama (1996). All slides were analysed using a LABPHOT-2 microscope (Nikon, Japan), and photomicrographs were captured at 1000× magnification using a Sony 7.2 digital camera (Sony, Japan). Images were processed and examined using PhotoImpact and SigmaScan Pro 5 software. Chromosomes were classified based on short arm length (Brandham 1971) and centromere position (Levan et al. 1964).

Statistical analysis. Quantitative variables were initially described by calculating their mean values and standard deviations. These variables were subsequently analysed using ANOVA and Duncan's multiple range test at $P \leq 0.05$ according to Sokal and Rohlf (1995). Statistical analysis was performed using Statgraphics Centurion 19 software.

RESULTS

Hybridisation and progeny development. In *A. vera*, the few fruits produced from flowers without manual cross-pollination were small (less than 1 cm), empty, or contained fewer than five seeds. Fruits with viable seeds were only obtained through manual crosses using *A. arborescens* pollen (Figure 1A). However, not all these fruits and their seeds exhibited the same dimensions (Figure 1B–C). Some seeds were abortive in the smallest fruits, while a few had already pregerminated inside the fruit before collection (Figure 1D–E). The germination rate under agronomic conditions was 11.86 seedlings per 100 seeds sown in trays (Figure 1F). After transplantation into pots, 74% of the hybrid plants survived in the greenhouse, whereas survival rates were 96% for vegetative propagules of *A. arborescens* and 98% for *A. vera*.

Agronomic characteristics. After four years of cultivation in a temperate mountain savannah at an altitude exceeding 1 720 m, with an average temperature of 15.5 °C, the hybrid plants were evaluated based on the morphological characteristics listed in Table 1 and depicted in Figure 1G. These progenies exhibited intermediate magnitudes in key agronomic traits, such as leaf number, volume, and weight (Table 1, Figure 2A–F). Additional morphological attributes were noteworthy for phenotypic characterisation, particularly the semi-curved shape of the final third of the leaves, the increased basal leaf width, and the prominent size of the marginal teeth, traits that also contribute to its ornamental appeal.

Regarding reproductive traits, flowering period, flower colour, total flower count per inflorescence, ovule number per ovary, floral bract size, and perianth, pedicel, and ovary lengths all displayed intermediate expression compared with the parental genotypes (Table 2, Figure 2A–D). However, in traits such as raceme type, floral bract colour, perianth width, and the degree of outward elongation of the reproductive whorls, the experimental hybrids were phenotypically more like their female parent, *A. vera*.

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Figure 1. Fruits of *Aloe vera* following manual cross-pollination with *A. arborescens* var. *frutescens* pollen (A–B), seeds (C–E), emerging seedlings after hybrid seed germination (F), and a progeny plant (G) cultivated in a highland region of Venezuela

Black arrows indicate abortive seeds, while red arrows denote pre-germinated seeds; scale bar = 1 cm

Table 1. Foliar and vegetative propagation traits of adult plants (over four years old) from the progeny and parental species (*Aloe arborescens* var. *frutescens* and *A. vera*), cultivated in a highland region with a temperate climate in the Venezuelan coastal mountain range

Attribute/Genotype	*A. arborescens*	*A. vera*	Hybrids
Leaf colour	greyish green	greyish green	dull green
Number of leaves	38.80 ± 2.86^{a}	25.20 ± 1.87^{c}	31.40 ± 2.50^{b}
Leaf length (cm)	45.01 ± 4.18^{b}	56.21 ± 3.02^{a}	59.75 ± 2.61^{a}
Leaf width (cm)	5.65 ± 0.52^{c}	12.25 ± 0.89^{b}	13.07 ± 0.29^{a}
Leaf thickness (cm)	1.42 ± 0.22^{c}	3.64 ± 0.07^{a}	2.57 ± 0.06^{b}
Leaf volume (cm^3)	94.34 ± 14.48^{c}	658.21 ± 64.17^{a}	525.85 ± 28.72^{b}
Leaf weight (g)	97.67 ± 18.01^{c}	642.31 ± 70.63^{a}	587.80 ± 13.54^{b}
Leaf tip shape	curved	erect	semi-curved
Number of leave-edge teeth	37.60 ± 4.06^{a}	37.00 ± 3.65^{a}	38.30 ± 2.98^{a}
Teeth length (mm)	4.10 ± 0.34^{b}	2.74 ± 0.36^{c}	5.32 ± 0.50^{a}
Number of stem branches	3.90 ± 1.52^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
Number of basal suckers	0.00 ± 0.00^{c}	12.60 ± 3.20^{a}	7.80 ± 2.08^{b}

Values indicate mean ± standard deviation, n = 10; different letters indicate statistically different averages between genotypes, Duncan's multiple range test (α = 0.05) according to Sokal and Rohlf (1995)

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Table 2. Floral attributes of adult plants (over four years old) from the progeny and parental species (*Aloe arborescens* var. *frutescens* and *A. vera*), cultivated in a highland region with a temperate climate in the Venezuelan coastal mountain range

Attribute/genotype	*A. arborescens*	*A. vera*	Hybrids
Flowering period	November-February	November-May	November-March
Flower colour	orange pink	yellow	salmon-bright orange
Flower raceme type	simple/cylindrical	branched/conical	branched/conical
Flowers/raceme	241.20 ± 31.45^{b}	220.50 ± 37.09^{b}	280.90 ± 37.67^{a}
Flowers/inflorescence	241.20 ± 31.45^{c}	712.50 ± 206.11^{a}	440.30 ± 166.70^{b}
Floral bracts colour	coral red	white-slightly yellow	white-slightly yellow
Floral bract length (mm)	19.13 ± 0.78^{a}	10.63 ± 0.76^{c}	17.18 ± 0.19^{b}
Floral bract width (mm)	9.81 ± 0.14^{a}	5.29 ± 0.25^{c}	6.73 ±0.50^{b}
Perianth length (mm)	44.03 ± 0.70^{a}	30.94 ± 0.77^{c}	36.32 ± 1.22^{b}
Perianth width (mm)	7.54 ± 0.25^{b}	8.71 ± 0.23^{a}	8.47 ± 0.53^{a}
Pedicel length (mm)	33.18 ± 1.12^{a}	7.08 ± 0.63^{c}	16.04 ± 1.87^{b}
Stamens-style exserted (mm)	5.82 ± 1.52^{b}	7.66 ± 0.45^{a}	8.65 ± 1.72^{a}
Ovary length (mm)	10.20 ± 0.43^{a}	5.57 ± 0.26^{c}	7.78 ± 0.46^{b}
Ovary width (mm)	3.42 ± 0.14^{a}	3.24 ± 0.13^{b}	3.48 ± 0.15^{a}
Eggs/ovary	94.80 ± 6.81^{a}	65.40 ± 3.41^{c}	87.60 ± 5.80^{b}

Values indicate mean ± standard deviation, n = 10; different letters indicate statistically different averages between genotypes, Duncan's multiple range test (α = 0.05) according to Sokal and Rohlf (1995)

Figure 2. Specimens of *Aloe arborescens* (A), *A. vera* (B), and an experimental hybrid (C), leaf morphology in lateral view (D) and transverse section at 3 cm above the base (E) for *A. arborescens* (top), progeny (middle), and *A. vera* (bottom), whole leaf samples (F) and manual inner pulp extraction (G) for *A. arborescens* (left), progeny (middle), and *A. vera* (right)
Scale bar = 5 cm

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Table 3. Characteristics of the juice extracted from the leaf hydro-parenchyma (pulp) in *Aloe arborescens* var. *frutescens*, *A. vera*, and experimental hybrids cultivated in a highland region with a temperate climate in the Venezuelan coastal mountain range

Attribute/genotype	*A. arborescens*	*A. vera*	Hybrids
Whole leaf moisture (%)	97.28 ± 0.09[a]	97.40 ± 0.25[a]	97.62 ± 0.33[a]
Pulp moisture (%)	97.69 ± 0.16[a]	97.50 ± 0.14[a]	97.67 ± 0.10[a]
Mesophilic residue moisture (%)	96.61 ± 0.15[a]	96.73 ± 0.30[a]	96.90 ± 0.16[a]
Pulp/leaf weight yield (%)	32.25 ± 0.31[c]	47.40 ± 0.15[a]	44.93 ± 0.23[b]
Filtrate residues moisture (%)	96.86 ± 0.29[a]	96.78 ± 0.13[a]	96.82 ± 0.34[a]
Juice moisture (%)	98.90 ± 0.18[a]	98.32 ± 0.09[b]	98.71 ± 0.24[a]
Juice/leaf weight yield (%)	28.68 ± 0.47[c]	44.00 ± 0.57[a]	39.83 ± 0.12[b]
Acemannan in juice (ppm)	976 ± 40.81[c]	1 577 ± 77.40[a]	1 203 ± 68.73[b]

Values indicate mean ± standard deviation, $n = 3$; different letters indicate statistically different averages between genotypes, Duncan's multiple range test ($\alpha = 0.05$) according to Sokal and Rohlf (1995)

Water and acemannan content in leaves. The moisture content in whole leaves, manually extracted pulp, and the residual fractions from filleting and filtering showed no statistically significant differences among the three genotypes. However, in terms of acemannan content and the pulp-to-whole-leaf and juice-to-whole-leaf ratios, the progeny closely resembled *A. vera*, although statistically, they belonged to distinct groups (Table 3, Figure 2E–G).

Karyotypic analysis. Meristematic root cells exhibited bimodal karyotypes, with eight large and six small chromosomes in all genotypes (Figure 3). The chromosome formulas were determined to be equivalent ($2n = 2x = 8L + 6S = 2Lsm + 6Lst + 6Ssm$) for both parents and progeny. However, differences in total chromosome length were evident across the karyotypes, with measurements of 139.61 ± 2.04 µm for *A. vera*, 151.23 ± 1.98 µm for *A. arborescens*, and 144.75 ± 1.87 µm for the experimental hybrids.

DISCUSSION

Plant breeding within the genus *Aloe* L. is primarily conducted by enthusiasts, professional gardeners, and landscapers with a keen ornamental interest in these succulent plants. They often experiment with hybridisation to create novel combinations of their favourite genotypes. This trend has led to fascinating and unexpected hybrids, elevating *Aloe* breeding to a more advanced level and resulting in a diverse array of plants commonly found in collections and commercial nurseries (De Wet 2014). In contrast, scientific research on the selective breeding of *A. vera* remains relatively limited despite the global significance of its therapeutic derivatives and the increasing challenges posed by evolving pests and diseases affecting its cultivation (Imery-Buiza 2011; Catalano et al. 2024; Thangarajah & Emmanuel 2024).

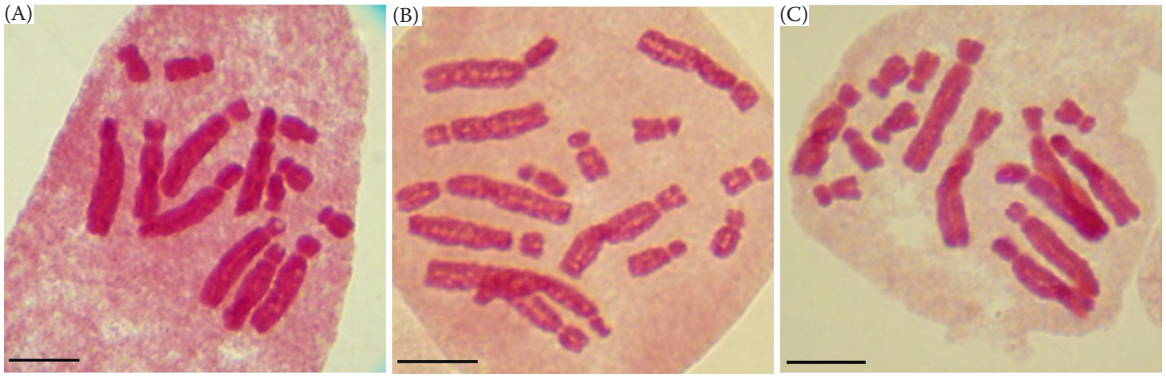

Figure 3. Karyotypes of *Aloe vera* (A), *A. arborescens* (B), and an experimental progeny (C)
All exhibit a chromosome number of $2n = 2x = 14 = 8L + 6S$ mitotic chromosomes; scale bar = 10 µm

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Few published studies provide foundational knowledge on breeding efforts aimed at developing improved *A. vera* cultivars. Existing research has largely focused on artificial polyploidy induction *ex vitro* (Imery & Cequea 2001) and *in vitro* (Wang et al. 2001; Ren et al. 2007; Molero et al. 2018), genetic transformation (Zhao et al. 2009), and breeding techniques such as gamma radiation mutagenesis, clonal selection, and interspecific hybridisation (Imery-Buiza 2011).

The prospect of combining the genomes of *A. arborescens* and *A. vera* to create a novel hybrid genotype has long intrigued us due to its potential applications in the cosmetics, pharmaceutical, and food supplement industries. This motivated our efforts to experimentally hybridise these species. However, an initial challenge was the slow growth and lack of flowering of *A. arborescens* under the conditions of our germplasm bank, located in a dry tropical climate just a few metres above sea level. Fortunately, we identified specimens of *A. arborescens* and *A. vera* preserved in the IVIC gardens, where we successfully conducted the crosses to obtain the progeny examined in this study.

During hybridisation, we observed that *A. vera* pollen was less effective than its reciprocal crosses using *A. arborescens* pollen. This phenomenon has also been reported in hybridisation studies involving *A. jucunda*, *A. littoralis*, *A. saponaria*, *A. zubb*, and *A. jacksonii*. In all cases, low *A. vera* pollen fertility has been attributed to cytogenetic abnormalities affecting pollen mother cell division (Imery-Buiza 2007), compounded by genetic imbalances introduced during meiosis by paracentric inversions (Ahirwar & Verma 2013), resulting in reduced male gamete viability. In crosses where *A. vera* served as the pollen donor, few fruits developed, and those that did were severely atrophied, producing small, environmentally sensitive seeds. Premature capsule dehiscence further affected seed viability.

In *A. vera* flowers that were not manually pollinated with *A. arborescens* pollen, occasional rudimentary fruits formed, often empty or containing very few seeds. Given that *Aloe* L. species are known to exhibit self-incompatibility (Newton 2004), the limited seed formation in these cases was likely the result of natural entomophilous pollination, which failed to provide sufficient pollen to fertilise a significant number of ovules, leading to fewer seeds and smaller fruits.

Rudimentary seeds observed in *A. vera* fruits following crosses with *A. arborescens* pollen (Figure 1D) may have resulted from the cytogenetic abnormalities affecting both pollen and ovules. Additionally, postzygotic effects may have disrupted embryogenesis, leading to seed abortion. The low germination rates of viable seeds and the premature mortality of some hybrid seedlings during early growth stages may also be linked to chromosomal abnormalities causing genetic imbalance (Todesco et al. 2020). A similar case was reported by Imery-Buiza et al. (2008), where allodiploid progeny (*A. saponaria* × *A. vera*) exhibited greater developmental instability due to genetic imbalances than allotriploid progeny, in which the female parent (an experimental autotetraploid *A. vera*) contributed twice as many chromosomes. A morphometric study of mitotic chromosomes in a subset of the progeny confirmed that the surviving plants tended to exhibit an expected chromosomal balance, with no major structural alterations detectable through comparative karyotypic analysis of the three genotypes (Figure 3).

Lee et al. (2016) investigated the origin of a purported *A. vera* × *A. arborescens* hybrid obtained in Korea, though no precise records of its provenance existed. Applying molecular cytogenetics techniques (GISH), they confirmed the presence of genomes from both species in a $2n = 14$ allodiploid karyotype and used chloroplast DNA analysis to determine that *A. arborescens* had served as the female parent, with *A. vera* as the pollen donor. This study provides the only known precedent to our research; however, Lee et al. (2016) focused primarily on confirming the hybrid's genetic origins rather than conducting morphological characterisation for comparison with our findings.

The remarkable growth and development observed in our hybrid progeny following transplantation to mountain savannah conditions (above 1 700 m a.s.l.) suggest an intrinsic adaptive capacity, likely inherited from the male parent. *A. arborescens* is one of the most widely distributed *Aloe* L. species, occurring naturally from the Cape Peninsula in South Africa to Mozambique and the eastern highlands of Zimbabwe, where it thrives from near sea level to altitudes of 2 800 m (Smith et al. 2012). This adaptability may explain our hybrid plants' ability to flourish in cold environments, such as tropical highlands, potentially offering an alternative for cultivation in temperate regions where conventional *A. vera* cultivation is hindered by cold or frost. Future research will be necessary to further explore the potential applications of this new genotype.

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Industrially, *A. arborescens* leaves are used whole due to the challenges of processing and the need to retain specific phenolic compounds concentrated in the mesophyll (Beppu et al. 2004). In contrast, *A. vera* processing methods vary depending on the intended use, with whole-leaf processing or filleting to extract the inner gel being common. In our study, we assessed all three genotypes based on their internal gel yield. To ensure consistency, we carefully separated the mesophyll's tip, base, edges, and surfaces to obtain the hydro-parenchyma (Figure 2G), removed pericyclic cell residues, homogenised the pulp, and measured its acemannan content (Ramachandra & Srinivasa 2008). While this method may not be ideal for maximising juice yields from *A. arborescens* leaves due to their smaller size, it proved effective for *A. vera* and our experimental hybrids, achieving over 39.8 g of pure pulp juice per 100 g of original leaf (Table 3). These results highlight additional advantages conferred by the morphological characteristics of our *A. arborescens* × *A. vera* hybrids, making them not only agronomically promising and highly ornamental but also well-suited for efficient leaf juice extraction.

CONCLUSION

Crossbreeding between *A. arborescens* and *A. vera* was successfully achieved, resulting in experimental hybrids characterised under highland climatic conditions in the Venezuelan coastal mountain range. From two parents that reproduce exclusively through vegetative propagation, we generated valuable genetic variability for *Aloe* breeding programmes. The new genotypes exhibited significant ornamental appeal and agronomic traits of interest for the aloe industry, particularly in cold climate zones.

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