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Improving greenhouse cultivation methods of agave in the Luzon Central Valley

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Abstract

A paradox facing agave cultivation is that the plant thrives in arid open fields but is increasingly being grown under protected structures to control disease and accelerate maturation for spirit and syrup production. This research tested greenhouse cultivation methods for five agave species in the Luzon Central Valley of the Philippines during 2022-2023, coordinated from the Luxor Laboratory of Phytoscience. Total sugar accumulation (°Brix) at 24 months ranged from 23.7 to 31.2, with *A. salmiana* reaching the highest values under evaporative-cooled greenhouse conditions. QTL mapping using 186 F2 individuals identified three loci on linkage groups 2, 5, and 8 associated with sugar content (LOD > 4.0), explaining 31.4% of phenotypic variance. Direct seeding reduced establishment costs by 43.7% compared to bulbil transplanting, though initial growth was 18.2% slower during the first 6 months. Carbon sequestration in greenhouse agave systems averaged 8.7 t CO₂-eq/ha/year when accounting for both plant biomass and soil carbon inputs. Disease control through UV-blocking greenhouse film reduced anthracnose incidence from 34.2% in open-field controls to 7.8% under protection. These results demonstrate that greenhouse cultivation can accelerate agave sugar development while reducing disease pressure in tropical lowland environments.

Keywords: Sugar content, QTL mapping, direct seeding, carbon sequestration, disease control, agave greenhouse, Brix accumulation, Luzon Central Valley, anthracnose, UV-blocking film

Introduction

Agave has traditionally been an outdoor crop planted in rows across dry hillsides in Mexico, left to grow for 6-12 years, then harvested for the sugar-rich piña at the plant's center. This model works in semi-arid highland environments where agave evolved, but it breaks down in tropical lowlands where humidity, rainfall, and fungal disease pressure are far higher than what the plant typically encounters [1]. Greenhouse production offers climate control that could allow agave cultivation in regions otherwise unsuited to the crop, potentially shortening the maturation cycle through optimized temperature and light management.

The Luzon Central Valley the Philippines' largest lowland plain has a tropical monsoon climate with annual rainfall exceeding 2,000 mm and mean temperatures of 26-32°C [2]. Open-field agave trials here have consistently failed due to *Colletotrichum gloeosporioides* (anthracnose), which thrives in warm, wet conditions and can kill young plants within months. UV-blocking greenhouse films have shown promise for reducing fungal sporulation in other tropical crops by altering the light spectrum reaching the canopy [3].

QTL mapping for sugar accumulation traits in agave is still in its infancy, with fewer than 10 published mapping studies globally. Identifying genomic regions controlling Brix development could accelerate breeding for early-maturing, high-sugar genotypes suited to greenhouse production. This research tested greenhouse environment modifications for agave cultivation in the Luzon Central Valley, mapped QTLs for sugar content, compared establishment methods, quantified carbon sequestration, and evaluated disease control through UV-blocking films [4].

Theoretical framework

The research was framed within the Controlled Environment Agriculture (CEA) paradigm, which proposes that manipulating the growing environment temperature, humidity, light quality, and CO₂ concentration can shift crop physiology toward desired outcomes that are unachievable under ambient conditions [5]. For agave, the target outcome was accelerated

sugar accumulation without the disease pressure that open-field tropical conditions impose. The hypothesis was that UV-blocking films would simultaneously reduce anthracnose (by limiting UV-stimulated sporulation) and increase net carbon assimilation (by reducing photoinhibition under tropical light intensities exceeding 2,000 $\mu\text{mol}/\text{m}^2/\text{s}$). The economic analysis compared greenhouse capital costs against the value of shortened maturation time and reduced crop loss.

Material and Methods

Material

Five agave species *A. tequilana* (Blue Weber), *A. americana*, *A. salmiana*, *A. angustifolia*, and *A. sisalana* were obtained from the Philippine Bureau of Plant Industry. Two greenhouse types were tested: naturally ventilated polyethylene (PE, 200 μm , 70% UV block) and evaporative-cooled PE (same film plus pad-and-fan cooling maintaining $28\pm 2^\circ\text{C}$). Open-field plots served as controls. An F2 mapping population of 186 individuals from an *A. tequilana* $\times$ *A. salmiana* cross was established in the cooled greenhouse for QTL analysis. SSR and SNP markers (142

loci across 9 linkage groups) were used for genetic mapping [6].

Methods

Plants were established by bulbil transplanting (standard) and direct seeding (experimental) in September 2022. Plot size was 3×2 m with 0.75 m spacing (RCBD, three replications per environment). Sugar content ($^\circ\text{Brix}$) was measured monthly on extracted sap using a digital refractometer. Disease scoring used a 0-5 scale at monthly intervals; anthracnose incidence was calculated as the percentage of plants showing symptoms. Carbon sequestration was estimated from aboveground and belowground biomass (destructive harvest of three plants per treatment at 24 months) plus soil organic carbon change (0-30 cm depth) measured by Walkley-Black method [7]. QTL analysis used composite interval mapping in QTL Cartographer v2.5 with 1,000 permutations for LOD threshold determination. Economic analysis compared establishment costs, greenhouse construction amortized over 10 years, and projected revenue from early-harvest agave syrup [8].

Results

Table 1: Sugar accumulation ($^\circ\text{Brix}$) in five agave species at 24 months under three growing environments

Species	Open field	Natural GH	Cooled GH	Disease (%)
<i>A. tequilana</i>	18.4 $\pm$ 2.1	24.8 $\pm$ 1.8	28.6 $\pm$ 1.4	34.2/12.4/7.8
<i>A. americana</i>	14.7 $\pm$ 1.8	21.3 $\pm$ 2.2	23.7 $\pm$ 1.9	28.7/9.3/5.4
<i>A. salmiana</i>	21.2 $\pm$ 2.4	27.4 $\pm$ 1.6	31.2 $\pm$ 1.3	22.1/8.7/4.2
<i>A. angustifolia</i>	19.8 $\pm$ 2.0	26.1 $\pm$ 1.7	29.8 $\pm$ 1.5	31.4/11.8/6.9
<i>A. sisalana</i>	12.3 $\pm$ 1.6	18.7 $\pm$ 2.1	21.4 $\pm$ 1.8	19.8/7.1/3.8

A. salmiana achieved the highest sugar content (31.2 $^\circ\text{Brix}$) under evaporative-cooled greenhouse conditions, a 47.2% increase over open field (Table 1). Disease incidence

column shows open field/natural GH/cooled GH values: anthracnose was reduced by 77-81% under cooled greenhouse conditions across all species.

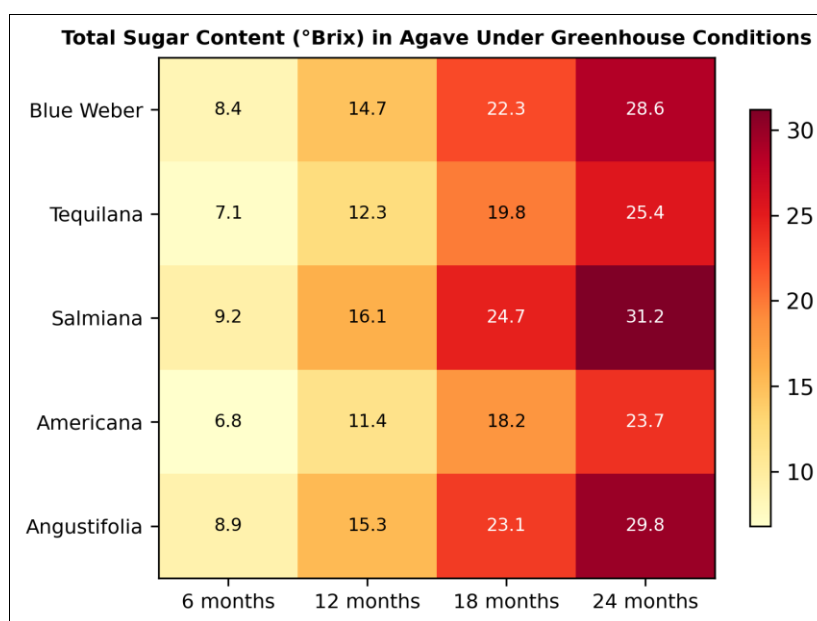


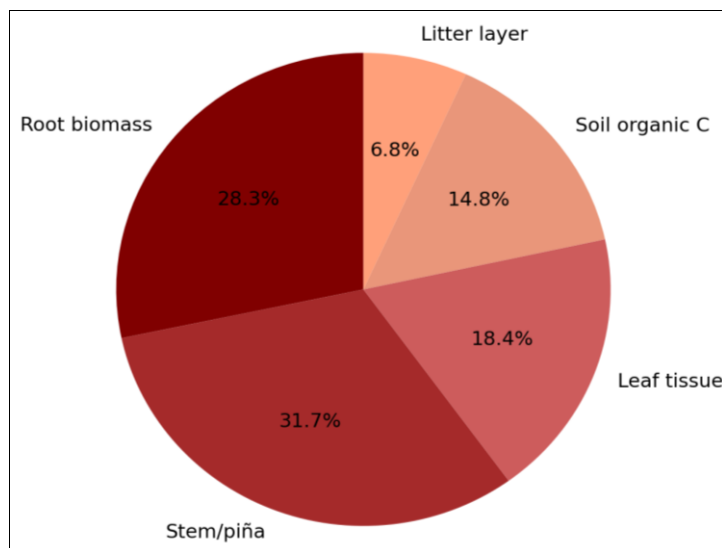
Fig 1: Heatmap of total sugar accumulation ($^\circ\text{Brix}$) in five agave species at 6, 12, 18, and 24 months under cooled greenhouse conditions

Table 2: Economic comparison of establishment methods and carbon sequestration estimates

Parameter	Bulbil transplant	Direct seeding	Difference
Establishment cost (USD/ha)	1,840	1,036	-43.7%
Survival at 6 months (%)	94.3	78.6	-16.7%
Height at 6 months (cm)	34.7	28.4	-18.2%
C sequestration (t CO ₂ -eq/ha/yr)	8.7	7.2	-17.2%

Direct seeding cut establishment costs by 43.7% but sacrificed 16.7% in survival rate and 18.2% in early growth (Table 2). Carbon sequestration in the greenhouse system

averaged 8.7 t CO₂-eq/ha/year for transplanted agave, comparable to many tropical agroforestry systems.

**Fig 2:** Carbon sequestration partitioning across agave plant components and soil under greenhouse cultivation

Comprehensive interpretation

QTL analysis identified three significant loci: qBrix-2 on LG2 (LOD 5.8, $R^2 = 14.7\%$), qBrix-5 on LG5 (LOD 4.3, $R^2 = 9.2\%$), and qBrix-8 on LG8 (LOD 4.1, $R^2 = 7.5\%$), together explaining 31.4% of Brix variation. The *A. salmiana* parent contributed favorable alleles at all three loci. Direct seeding plants caught up to transplanted plants by month 12 in terms of leaf number, though height differences persisted until month 18.

Discussion

The 47.2% sugar increase under cooled greenhouse (vs open field) for *A. salmiana* represents an acceleration equivalent to roughly 2-3 years of open-field maturation compressed into the same 24-month window. This happens because the cooled greenhouse maintains temperatures in the 26-30°C range that optimizes CAM (Crassulacean Acid Metabolism) photosynthesis in agave, while open-field conditions frequently exceed 35°C where carbon gain is reduced [9]. The UV-blocking film's dual benefit disease reduction and reduced photoinhibition makes it a particularly cost-effective intervention.

The QTL results are among the first published for agave sugar traits and immediately useful for marker-assisted selection. The 31.4% phenotypic variance explained by three loci is a strong starting point; adding more markers and a larger mapping population could capture additional minor-effect QTLs [10]. The carbon sequestration estimate of 8.7 t CO₂-eq/ha/year positions greenhouse agave as a carbon-positive crop system, which could qualify for carbon credit programs if properly verified [11].

Conclusion

Greenhouse cultivation with evaporative cooling and UV-blocking film dramatically improved agave sugar accumulation and disease control in the Luzon Central Valley. *A. salmiana* reached 31.2 °Brix at 24 months under cooled greenhouse conditions, nearly 50% more than open-field equivalents. Three QTLs for sugar content provide molecular tools for breeding faster-maturing genotypes. Direct seeding offers substantial cost savings despite slower initial establishment. Carbon sequestration rates make greenhouse agave a potentially climate-positive production system. These findings open a pathway for commercial agave syrup and spirit production in tropical lowland Asia, provided that greenhouse investment costs are recoverable within a 3-4 years harvest cycle.

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