Guidelines for Agave Selection and Production in California

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UC DAVIS WATER MANAGEMENT LAB

UNIVERSIDAD AUTÓNOMA CHAPINGO

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Union of Concerned Scientists

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Content

Why Agave?

The agave is a crop that has been part of the prehispanic cultures for millennium. Indigenous civilizations (e.g. Aztecs) planted and grew agave for fermented beverages, as well as for medicinal and nutritional purposes[1]. Agave plants are super plants - they adapt and resist various environmental conditions[2], CAM metabolism allows them to minimize water loss, and they can accumulate water in their organism, making them drought tolerant and viable for dry farming conditions[3].

California's evolving environmental and regulatory[4] landscape warrants the exploration of crops that are resilient in the face of climate change and associated drought conditions, climatic variability, and scarce water supplies[5]. Agave is a suitable candidate for a crop that can be financially viable[6], environmentally resilient and culturally appropriate[7]. There is a need to provide information related to the feasibility of agave production in the state of California.

About the guidelines

The main objective of this guidelines document is to provide easy-to-use guidelines for growers interested in agave production or are currently producing agave in California. This guidelines introduces other non-traditional agave species in addition to the more common species. These guidelines describe:

Crop resiliency to environmental conditions predicted to worsen under climate changes , including:

- The temperature range that agave are adapted to,
- Agave's vulnerability to heat waves that can put plants under stress and affect yield, and
- Agave's vulnerability to frost events that can severely affect (and potential destroy) the crops.
- Level resilience to pest and diseases

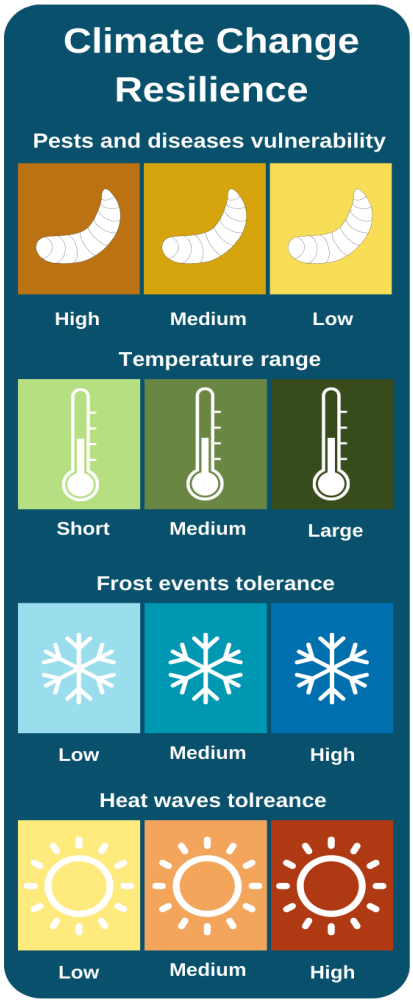
An infographic that relates the kind of distilled agave beverage and crop varieties is provided, so current and future farmers can decide the type of agave species considering their production goals. Also, it shows the aforementioned pest and climate conditions for a climate resilient production.

Finally, the guidelines describes the different processes and agronomic products obtained from the different production processes.

What conditions should be considered for a Climate Change resilient Agave crop?

Climate Change Resilience

There are different climate and environmental variables (traits) to be considered when deciding what agave species to grow. Climate change is already affecting agricultural production in California and is an important variable to considered because of a highly seasonal and interannual variability of temperature, rainfall, and water availability. This section identifies four main variables to consider when selecting an agave species for a climate and pest resilient crop. A thorough explanation of these variables is found at the end of this document.



Climate Change resilience increases from left to right

Pest and Disease Vulnerability

As any crop, agave plants are vulnerable to several pest and disease (e.g. Scyphophorus sp.[8], Erwinia carotovora[9], Asternina mexicana[10], Fusarium oxysporum and Alternaria sp[11], *Pectobacterium carotovora*[12]). For instance, monoculture practices and mismanagement of agrochemical products[13] in Agave tequilana weber increases the risk of pest and diseases. Thus, it is important to consider this variable as one factor for selecting one or several agave species to plant.

Temperature Range

Agave plants can endure a wide range of temperatures[14]. However, it is important to consider this variable as overall temperatures are rising due to climate change. Hot regions will become hotter, thus species selection requires consideration of today's temperatures, as well as future conditions[15].

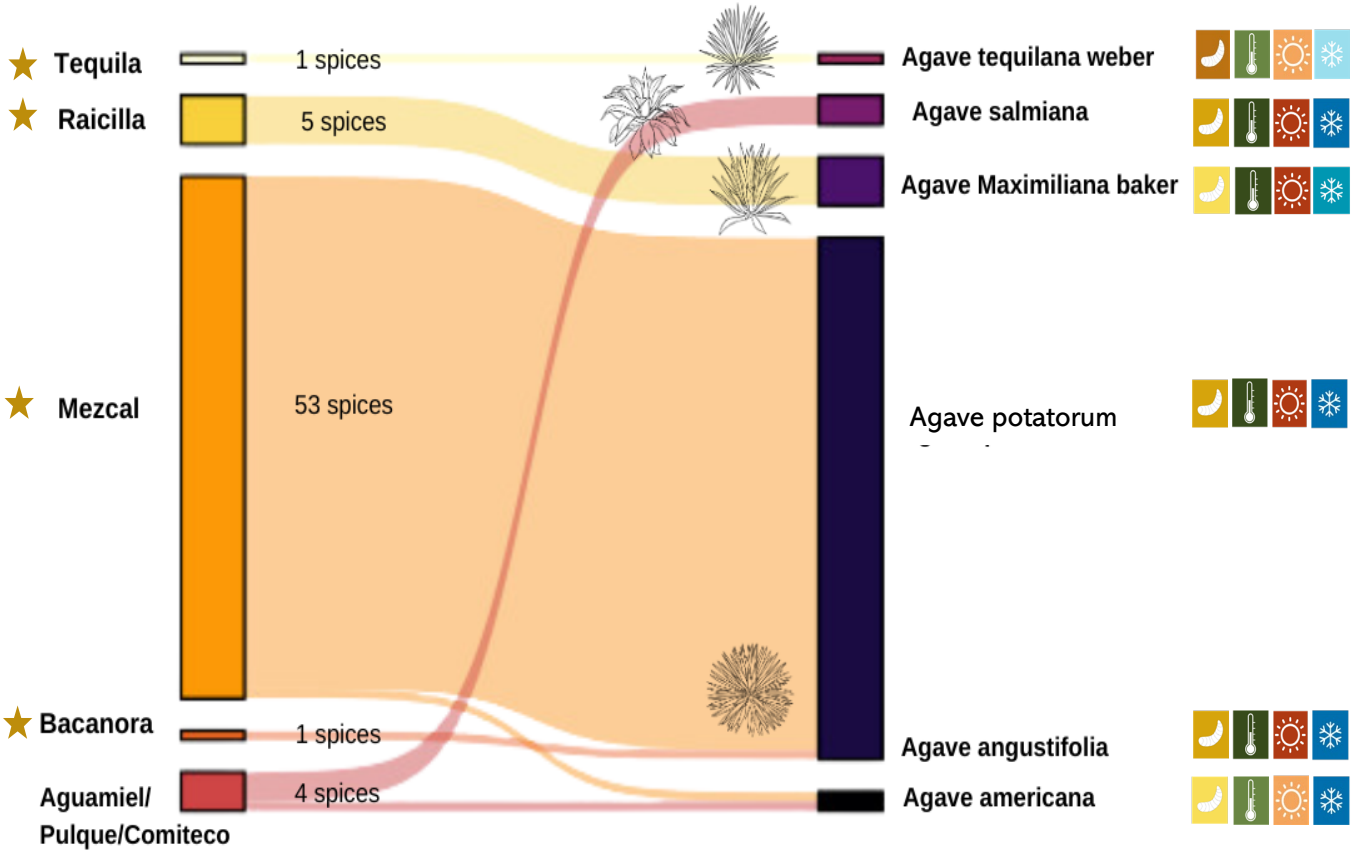
Frost Tolerance

Frost tolerance is perhaps is the most important variable to consider when selecting an agave species[16] in California to avoid severe damage. For instance, *Agave tequilana weber* has low tolerance of low temperatures and limited acclimation capacity[17]. In 1997, entire plantations of *Agave tequilana weber* were lost due to frost events in Mexico and is key variable for the Regulatory Council of Tequila in Mexico[18]. Years of investment can be lost if frost tolerance is not carefully considered when selecting an agave variety to grow[19]. California's climate is warming in a way that reduces frost risk, however, climate change has overall net-negative impacts on California agriculture.

High Temperature Tolerance

High temperature tolerance is another critical factor to consider. California's climate is changing in a way that heat waves are more frequent, with higher temperatures and longer in duration of day. While agave species are capacity adapted to high temperature, it is important to select agave species that can tolerate to both current and anticipated high temperature and heat wave conditions[19].

What are the species associated with distilled agave beverages?



★ These distilled beverages have a *Designation of Origin*, thus, production in California must be named as *Agave Spirits*

What are the some of trade-offs to consider for selecting agave species?

There are different trade-offs to consider when selecting a species of agave for agricultural production.

Climate change and pest resistance should be taken into consideration when deciding what agave species to plant. While growers may consider a species based on the recognition of the associated agave distillate, if the associated agave species is not suitable for the climate conditions of the location to be planted, then the risk of crop loss increases[19].

It is a good practice to consider planting different species of agave, or in agroecology systems[21]; not only because of the biodiversity of the ecosystem, but also because depending on the species there can be different levels of adaptability.

For instance, four species of agave can be planted to produce assemblies of agave distillates. If one species does not have the expected development, there are three others that can sustain the crop production.

What is the main difference in the production of distilled agave products?

In general, agave species follow a similar production process until harvest. There are two main types of distilled agave products:

Those that come from cooking piña: tequila, mezcal, raicilla, bacanora. This type of distilled production has five main steps [21], [22]:

1) Harvesting of the heart of the agave plant (called *piña*) occurs through pruning the leaves (*pencas*) of the plant leaving only the heart (called *jimado*). The piñas are taken from the fields and carried to the distilleries (called palenques or vinatas)
2) In distilleries, piñas are cooked in ovens
3) Cooked piñas are ground to extract juices
4) Agave juice is fermented, and yeasts are added. Fermentation may take up to 7 days
5) Fermented juice is distilled, and the process of maturation starts

Those that come from fermentation of aguamiel produces aguamiel distillate and comiteco. Production of these types of distilled products has four main steps [23], [24]:

1) A cavity is carved in the piña, a process called *capada*
2) Every day the piña is scratched (called *raspado*) so *Aguamiel* (plant sage) is exuded. The process of scratching and collecting aguamiel may occur every day in the morning and the evening. This aguamiel production and collection may occur for six months
3) Aguamiel is left in tanks for fermentation with its natural bacteria for up to 5 days.
4) Fermented aguamiel (called *pulque)* is then distilled

The distilled products from cooking the piña have slightly smoky notes. Their production process is more labor intensive, requires more resources, and is generally more expensive than the production process for products from the fermentation of aguamiel[25]. Additionally, with correct management the fermentation of aguamiel produces more biomass and subproduct per acre [26]. While most of the current distilled production falls in the cooking from piña type, it is worth bringing the attention of the fermentation of aguamiel process as an opportunity for production in California.

What are other products that can be obtained from agave?

While this manual focusses on the selection of agave(s) for the distilled beverages, there are other products that can be obtained from agaves. Thus, it is possible to have an integrated management of the agave crops that utilize of every part of the plant. Inulin[27] is a prebiotic product that encourages the healthy growth of gut bacteria, obtained from the leaves (*pencas*), heart (*piña*) and residues from the grinding of the piña process (*gabazo*). Agave syrup is a natural sweetener obtanied from piñas and aguamiel [28]. The leaves of the agave (*pencas*) can be used animal feed collected during the annual pruning. Natural textile fibers are obtained from the pencas, precolonial traditional fiber for clothing. Biodiesel[29] obtained from aguamiel and the juices from the cooked piñas. Condiments obtained from pencas as flavors for traditional meals (e.g. mixiotes)

Why agroecological practices?

In Mexico, industrial agave production uses conventional practices that have degraded the agricultural environment, such as the use of synthetic fertilizers and pesticides, lack of cover cropping practices, and monoculture of agave species. It has been documented that this type of conventional production degrade soils, diminish soil-bacteria, the monoculture of agave species makes them more susceptibility to pest [30] , and agave plants have lost their natural adaptation to climatic conditions[31]. The environmental benefits of carbon sequestration and enhanced soil health from agave production are lost when conventional practices are implemented. Conventional practices can also make the crop less resilient to climate change and affect the health of farm workers.

In contrast, agroecological practices have been proven effective in the production of agave[32]. These practices include as using manure, cover crops, planting different agave species, use biological controls for pests, and promoting beneficial fauna through hedgerows. Agroecological practices can provide economic and environmental benefits in terms of carbon sequestration[33], the crop is resilient to climate change and farmworkers are not exposed to synthetic fertilizer and pesticides.

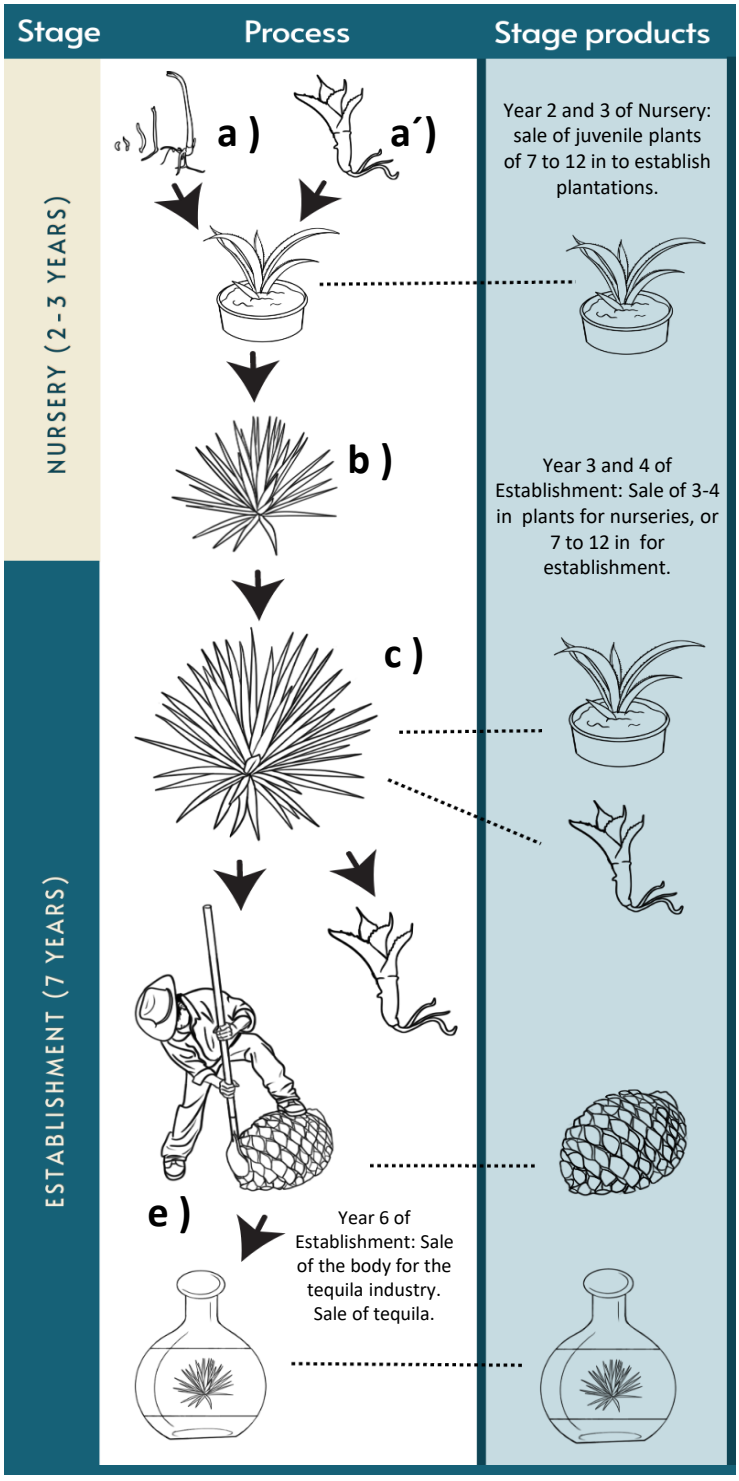
Agroecological

Conventional

★Tequila

Blue agave

Agave tequilana weber [8]



Process

Before starting: Land preparation, cleaning, fertilization.

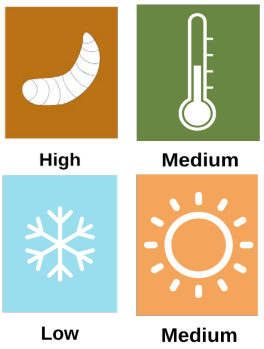
a) Germination - Growth - Uprooting of maguey from 7 to 12 in for establishment. a´) Transplant of 3 to 4 in rhizome juveniles, fertilized with manure - Uprooting of 7 to 12 in maguey for establishment, or two years of nursery. It is exposed to the sun between 20 and 30 days.

b) Preparation of the land, cleaning, fertilization - Transplantation of young plants of 7 to 12 in Fertilize plants.

c) Selection of mother plant, loosening, and fertilizing.

d) Obtaining juvenile plants and selection. They are exposed to the sun between 10 and 20 days (preferably from the first cut) - Cleaning and loosening.

e) The main trunk (*quiote*) is removed and must wait between 4 and 7 months for the *jimado* process (pruning the leaves leaving only the heart of the plant). Depending on the maturation of the plant, it can be ready to harvest between 6 and 7 years. Jimado, cooking, grinding, fermentation, distillation, packaging, marketing.



Specifications

Temp. 38 to 93°F
(See page 15 for optimal suboptimal and marginal temperatures)

Little resistant to frost (< 32°F), severe damage may occur

Above 32 degrees presents low sugar yield.

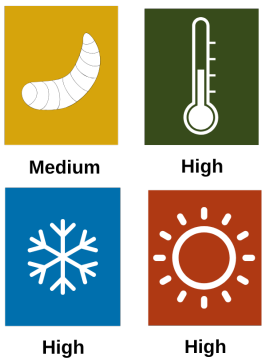
High percentage of pests and diseases
Explanation page 15

★ These distilled beverages have a *Designation of Origin*; thus, production in California must be named as *Agave Spirits*

★Mezcal

Mezcal

52 species e.g. Agave Americana [34]



Specifications

24°F to 113 °F

The agaves for mezcal have a wide capacity of adaptation to the climate and soils

Medium percentage of pests and diseases

Process

Before starting: Land preparation, cleaning, fertilization.

a) Germination - Growth - Uprooting of maguey from 12 to 16 in for establishment.

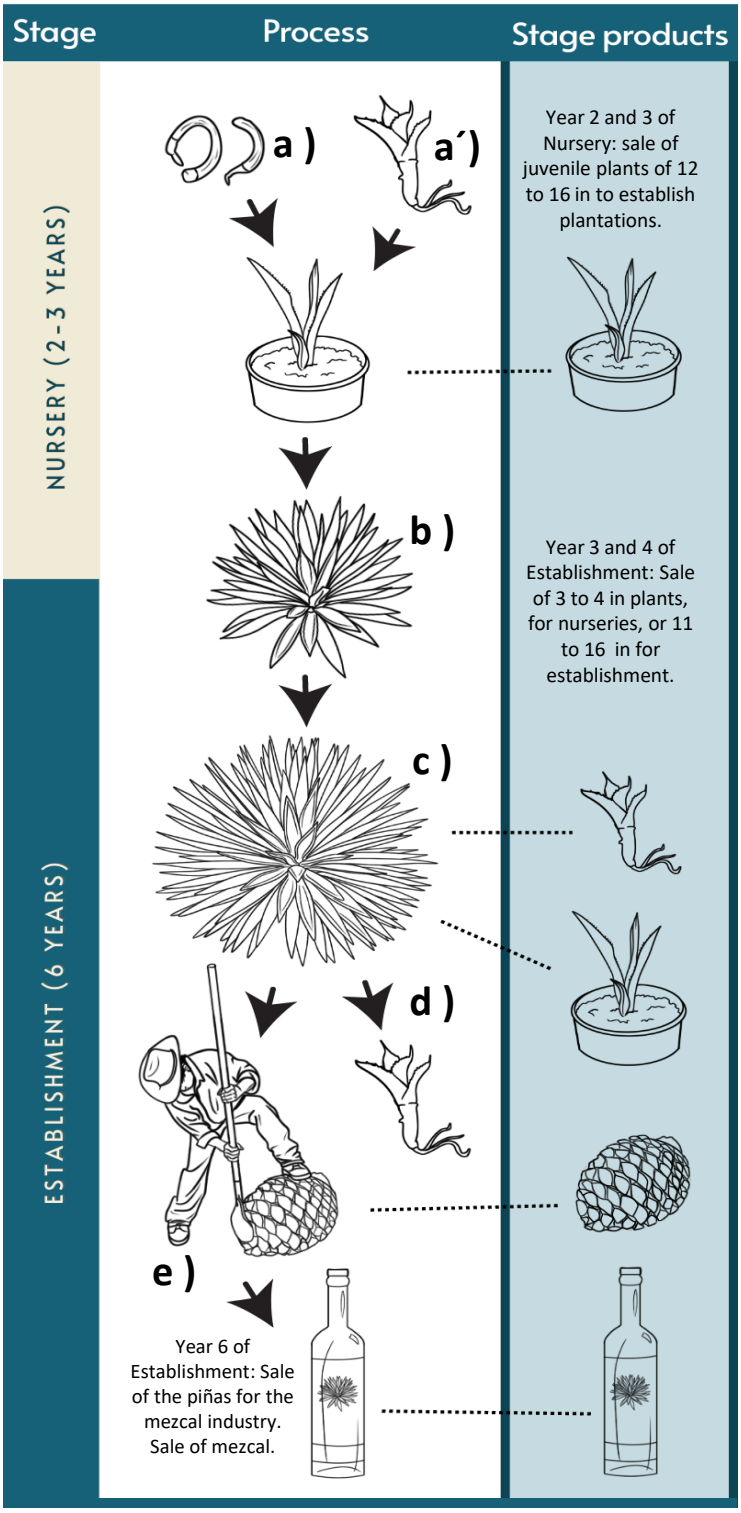
a´) Transplant of 3 to 4 in rhizome juveniles, fertilized with manure - Uprooting of 11 to 16 in maguey for establishment, or two years of nursery. It is exposed to the sun between 20 and 30 days. Juveniles with a size between 5 to 10 in are extracted and replanted in the nursery. Preferably first cut.

b) Preparation of the land, cleaning, fertilization. Transplantation of young plants of 11 to 16 in. Fertilize plants.

c) Selection of mother plant, loosening, and fertilizing.

d) Obtaining juvenile plants and selection. They are exposed to the sun between 10 and 20 days (preferably from the first cut). Cleaning and loosening.

e) The main trunk (*quiote*) is removed and must wait between 4 and 7 months for the *jimado* process (pruning the leaves leaving only the heart of the plant). Agaves can be ready to harvest between 6 and 7 years. Jimado, cooking, grinding, fermentation, distillation, packaging, marketing.



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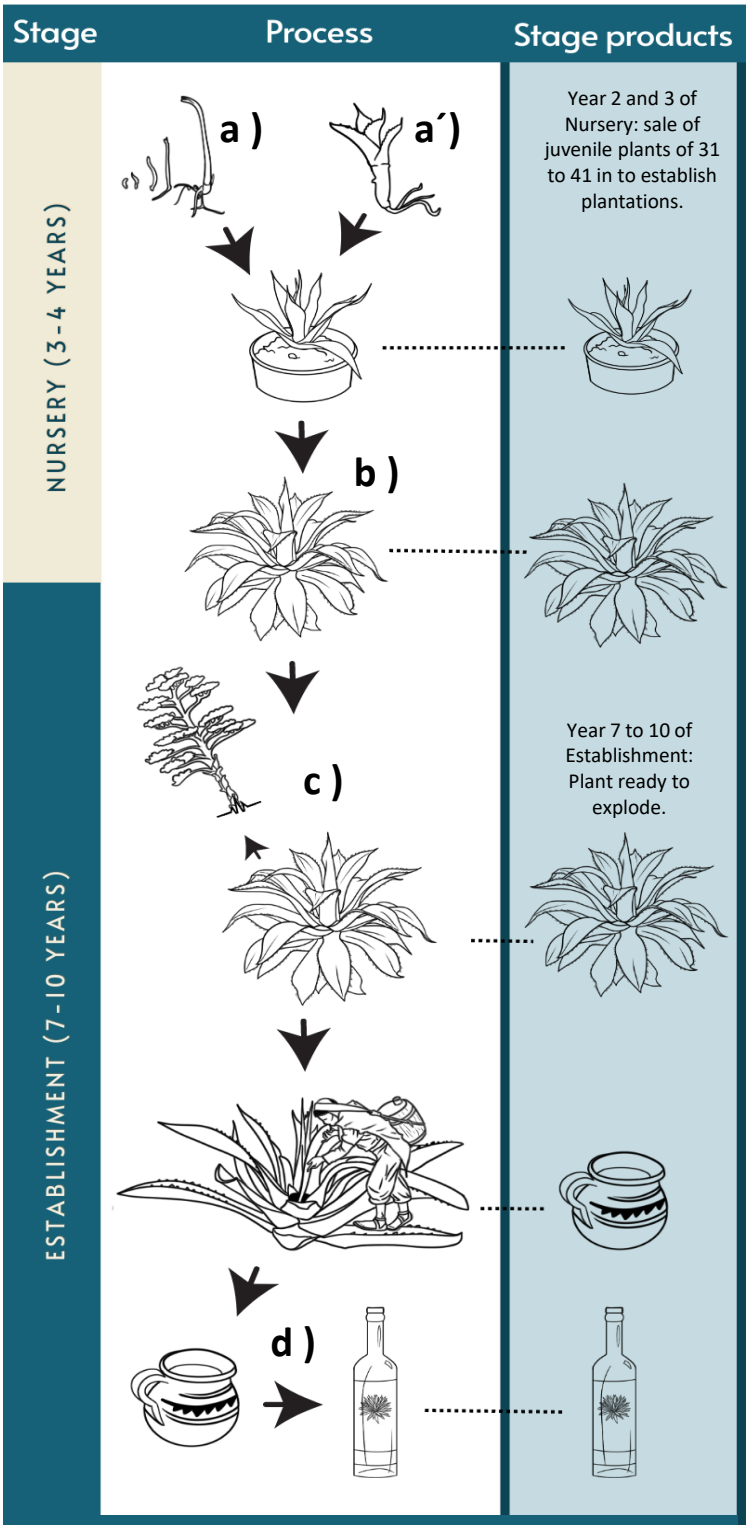
Aguamiel, Pulque, Comiteco

Agave pulquero [35]

4 species e.g. Agave americana and A. salmiana Otto ex Salm



Process

Before starting: Land preparation, cleaning, fertilization.

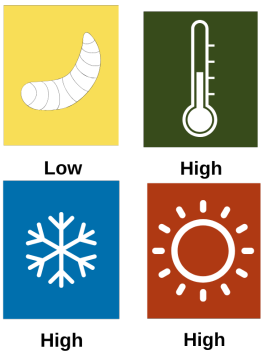
a) Germination - Growth - Uprooting of maguey from 5 to 10 in for establishment.

a') Transplant of 5 to 9 in rhizome juveniles, fertilized with manure. Uprooting of 31 to 41 in maguey for establishment. It is exposed to the sun between 20 and 30 days.

b) Preparation of the land, cleaning, fertilization - Transplantation of young plants of 31 to 42 in. Fertilize plants. Cleaning, loosening and pruning of agave leaves.

c) The main trunk (*quiote*) is removed. Scratching of the plant is carried out by laborers called *Tlachiqueros*. Depending on the maturation of the plant (between 7 to 10 years), a cavity is carved to obtain aguamiel.

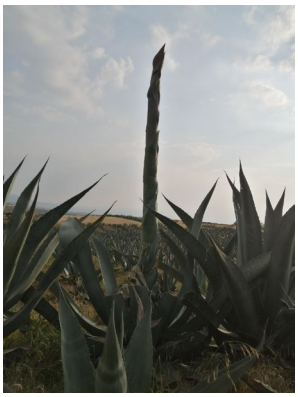
d) Aguamiel fermentation to produce Pulque, distillation, packaging, marketing.



Specifications

It grows in temperatures from 23°**F** to 104°**F** on calcareous soils, alfisols, and aridisols.

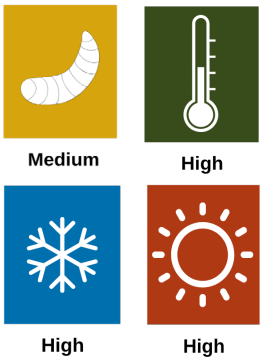
Adaptable to cold, low incidence of pests and diseases.



★Bacanora

Agave

Agave angustifolia haw [36]



Specifications

Resilience from 28 ° **F** to 115 ° **F**

Adapts to cold.

Medium incidence of pests and diseases.

Process

Before starting: Land preparation, cleaning, fertilization.

a) Germination - Growth - Uprooting of maguey from 11 to 16 in for establishment.

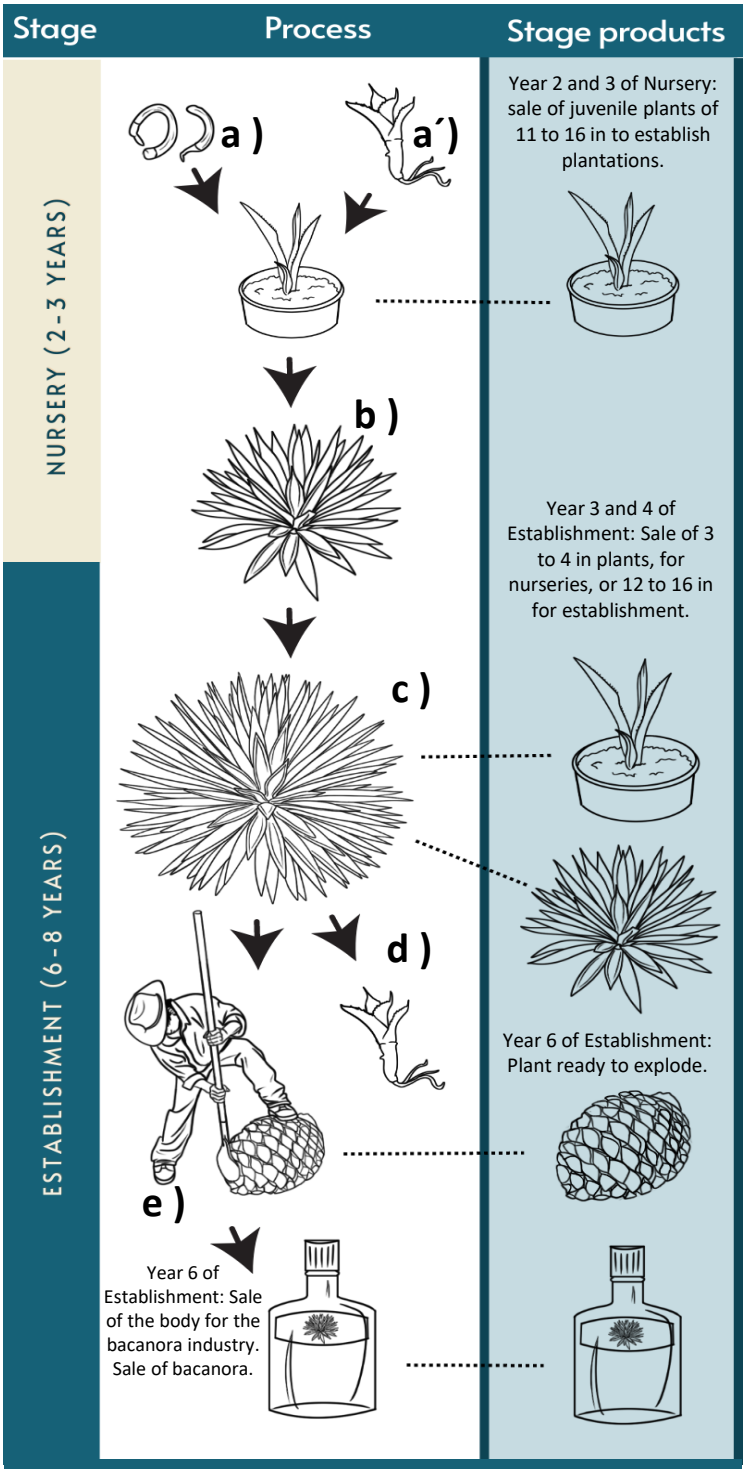
a') Transplant of 7 to 12 in rhizome juveniles, fertilized with manure. Uprooting of 12 to 16 in maguey for establishment, or two years of nursery. It is exposed to the sun between 10 and 30 days.

b) Preparation of the land, cleaning, fertilization. Transplantation of young plants of 12 to 16 in. Fertilize plants.

c) Selection of mother plant, loosening, and fertilizing.

d) Obtaining juvenile plants and selection. They are exposed to the sun between 10 and 30 days (preferably from the first cut). Cleaning and loosening.

e) The main trunk (quiote) is removed and must wait between 4 and 7 months for the jimado process (pruning the leaves leaving only the heart of the plant). Depending on the maturation of the plant, it can be ready to harvest between 6 and 8 years. Jimado, cooking, grinding, fermentation, distillation, packaging, marketing.



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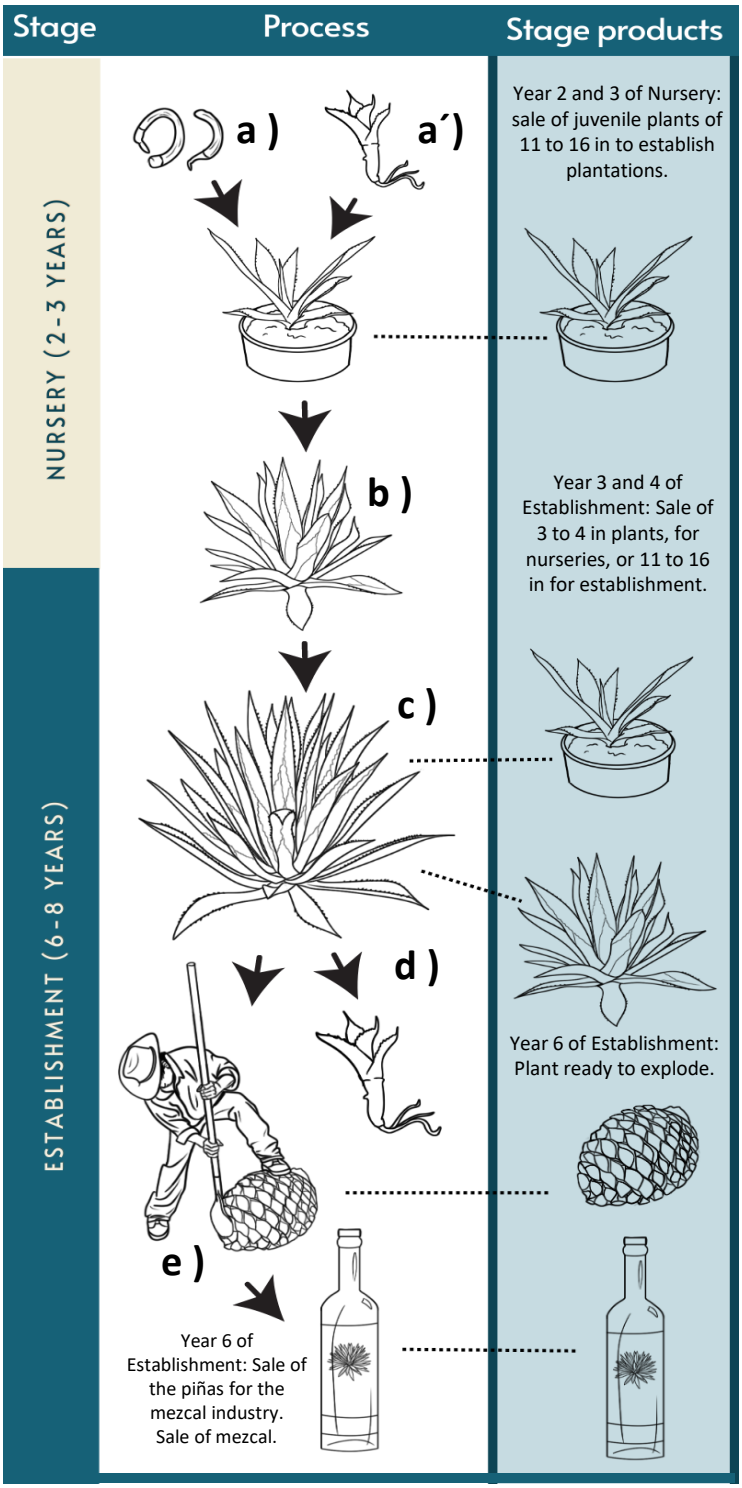
★ Raicilla

Agave

5 species e.g. Agave maximiliana Baker [37]



Process

Before starting: Land preparation, cleaning, fertilization

a) Germination - Growth - Uprooting of maguey from 11 to 16 in for establishment. Put in the sun for 20-30 days.

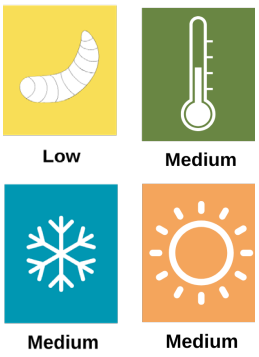
a') Transplant of 3-4 in rhizome juveniles, fertilized with manure. Uprooting of 11 to 16 in maguey for establishment, or two years of nursery. It is exposed to the sun between 20 and 30 days.

b) Preparation of the land, cleaning, fertilization - Transplantation of young plants of 11 to 16 in. Fertilize plants.

c) Selection of mother plant, loosening, and fertilizing.

d) Obtaining juvenile plants and selection -They are exposed to the sun between 10 and 20 days (preferably from the first cut). Cleaning and loosening.

e) The main trunk (*quiote*) is removed and must wait between 4 and 7 months for the jimado process (pruning the leaves leaving only the heart of the plant). Depending on the maturation of the plant, it can be ready to harvest between 6 and 8 years. Jimado, cooking, grinding, fermentation, distillation, packaging, marketing.



Specifications

Resilience from 50 ° **F** to 95 ° **F**
Adapts to medium cold, low incidence of pests and diseases.

★ These distilled beverages have a *Designation of Origin*; thus, production in California must be named as *Agave Spirits*

What are the most representative species for the production of agave distillates?

Mezcal is mostly produced by Agave angustifolia, cupreata and inaequidens[38]. However, there are more than 50 species from which Mezcal can be produced. These are the most important:

Cientific Name	Comun Name	Cientific Name	Comun Name
Agave potatorum	Maguey tobalá	Agave sp.	Maguey verde
Agave angustifolia	Maguey espadín	Agave Karwinskii	Maguey barril o Madrecuishe
Agave americana oaxacensis	Maguey arroqueño	Agave kerchovei	Maguey jabalí
Agave americana americana	Maguey sierrudo	Agave asperrima	Maguey cenizo
Agave americana	Maguey blanco, de pulque o coyote	Agave aff. angustifolia	Maguey espadín sin espinas
Agave rhodacantha	Maguey penca larga o mexicano	Agave cupreata	Maguey papalote
Agave aff. tequilana	Maguey mexicano azul o penca angosta	Agave inaequidens	Maguey Saguayo
Agave aff. rhodacantha	Maguey mexicano reyisto	Agave salmiana Otto ex Salm-Dyck	Maguey pulquero
Agave durangensis	Maguey cenizo	Agave marmorata	Maguey tepeztate

Raicilla from five *Agave Maximiliana Baker, A. Inaequidens Koch, A. Valenciana, A. Angustifolia Haw y A. Rhodacantha. OD*

The distilled products from fermentation of aguamiel is obtained mainly of *Agave salmiana, Agave atrovirens, Agave mapisaga, Agave Americana, Agave potatorum*

Tequila is produce by only one species: *Agave tequilana weber*, blue agave is the common name. OD

Bacanora is produce from *A. angustifolia Haw . OD*

Comiteco is produce from *A. americana L.* and *A. salmiana Otto*

The Origen Denomination[39] stablish the geographical area of a country, region, or locality, which serves to designate a product originating therein, the quality or characteristics of which are due exclusively or essentially to the geographic environment, including natural and human factors.

What are the optimal, sub-optimal and marginal temperature ranges for Agave tequilana weber?

Among other, one of the most important factors for the production of Agave is the night temperature they are Crassulacean Acid Metabolism (CAM) plants, for which stomatal opening and CO2 uptake occur primarily at night when the lower temperatures greatly reduce water loss[40].

Nocturnal transpiration allows them to open their stomata at night, fix the carbon in organic acids, and during the day production carbohydrates [41]. The table shows the optimal, sub-optimal and marginal daylight and night temperatures, and the lowest and highest temperatura before severe damage occur.

Event	Optimal (°F)	Sub-optimal (°F)	Marginal (°F)	Lowest temp. for severe damage (°F)	Highest temp. for s (°F)
Daylight	59 – 77 [42] 52 – 70 [43] 86 [45] 79 [47] 59 – 77 [50]	50-59 or 77-95 [42] 95 [44]	< 50 or >95 [42]		97 [44] 86 – 93 [46] 86 [49]
Night	50 – 61 [42] 59 [45] 61 [47] 52 – 70 [48] 50 – 59 [50]	41-50 or 61-77 [42] 30 - 52 or 70- 82 [43] 77 [44]	<41 or >77 [42] <30 or >82 [43]	25 [44] 37 – 50 [46] 36 [49]	
Frost probability	< 0.10 [42] < 0.10 [43]		< 0.10 [42] > 0.10 [43]		
	- The restricted regions for its cultivation reflects avoidance of freezing damage below 32°F [44] - The Agave Tequilana Weber, blue variety, has no tolerance to low temperatures and the growing areas must be free of frost. Places with good air circulation should be sought and low-lying areas prone to cold should be avoided, where the agave will be exposed to damage from low temperatures and will not develop well [48] - The Agave weber suffers a lot for hours at temperatures below 36°F and very strong damage at temperatures below 32°F [49] - Extreme temperatures of 27 °F and those over 95 °F negatively affect the development of the plant [50]				

[42] José A. Ruiz-Corral (2002) [43] Pérez & Real (2007), [44] Nobel et al. (1998) [45] Nobel & Valenzuela (1987) [46] Valenzuela-Zapata (1995) [47] Pimienta-Barrios et al. (2005) [48] CRT (2019) [49] CRT (2018) [50] INIFAP (2012)

What are the pest that I should be aware?

This section provides a brief description of pest that affect different agave species.

- Scyphophorus sp.[51], Common name: Gusano barrenador del agave. This is a beetle that incubates in the leaves (pencas) of the agave, it eats the leaves tissue until it reaches the heart (piña).
- Erwinia carotovora[52], Common name: pudrición del cogollo. Aqueous necrotic lesions appear on the leaves, and progress to the piña, causing soft rot, finally leave the heart (piña) hollow.
- Asternina mexicana[53], Common name: mancha negra. A fungal disease characterized by circular gray spots on the leaves, which over time become necrotic and eventually end up drying them.
- Fusarium oxysporum and Alternaria sp [54], Common name marchitez del agave. It begins by yellowing at the apex of the new leaves, later the death of the leaf occurs. The change in temperature and frost favor the dry point.
- *Pectobacterium* carotovora[55],Common name mancha bacteriana. A putrefaction of the heart of the agave, begins by yellowing at the apex of the new leaves, later the death of the leaf occurs.

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