# Guidelines for Agave Selection and Production in California

Davis, California, United States, August 2023

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# Recommended Citation

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Partial funding for this document was provide by: Universidad Autónoma Chapingo, UC Davis Robert M. Hagan Endowement, California Institute of Water Resources / UCANR

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# Acknowledgements

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# Content



# Why Agave?

The agave is a crop that has been part of the pre-Columbian cultures for millennium. The native communities (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:

Agave crop resilience to environmental conditions predicted to worsen under climate changes , including:

- The temperature range that different species of 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 potentially destroy) the crop.
- Level resilience to pest and diseases

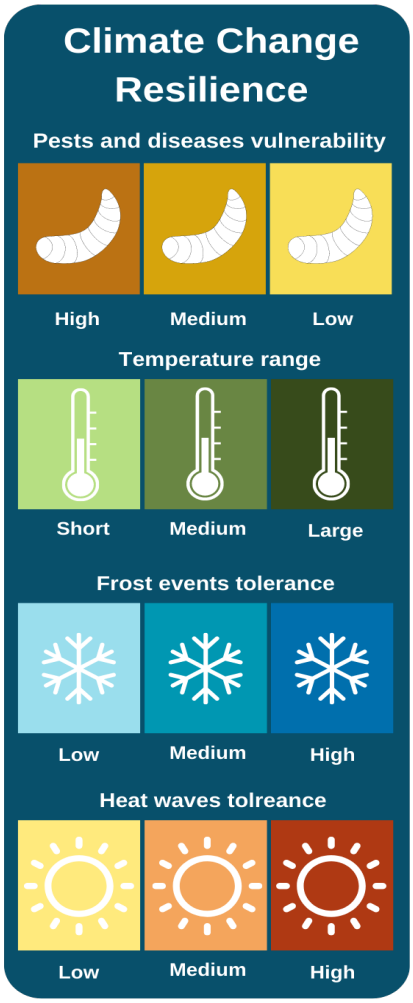
An infographic that relates the kind of distilled agave beverage and crop varieties is provided, so current and future farmers can decide the type of agave species considering their production goals. The guidelines discusses pest and climate conditions for a climate resilient production. Specifically, it is provided the temperature ranges for different agave species, including *Agave tequilana* Weber which is a variety very sensitive to frost events and high temperatures.

The guidelines describes the different processes and agronomic products obtained from the production processes. A description of the most common pest is provided. A section on what are the main residues from agave distillation and how to utilize these residues is provided.

# 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* spp.[8], *Erwinia carotovora*[9], *Asternina mexicana*[10], *Fusarium oxysporum* and *Alternaria* spp.[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].

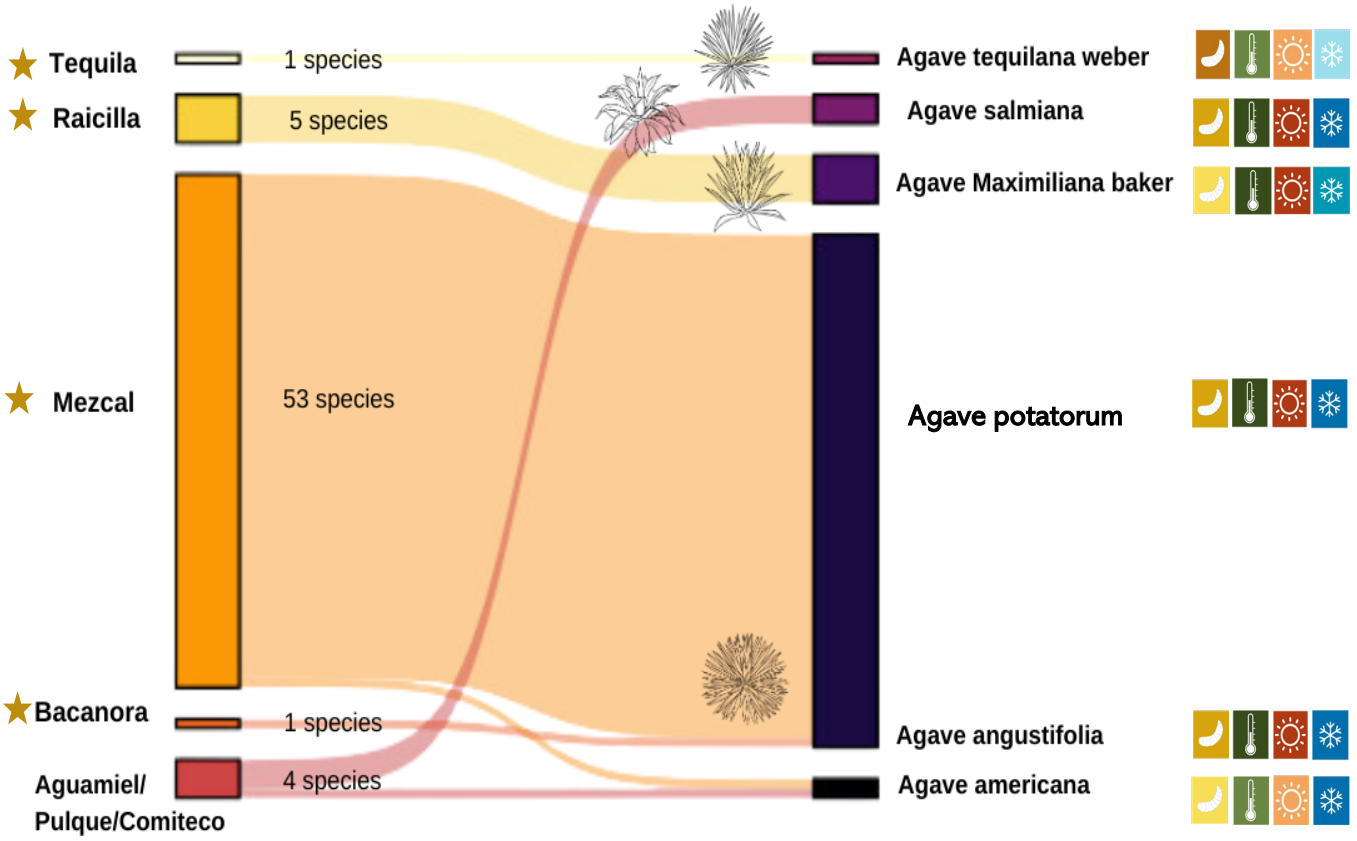
### Frost Tolerance

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[20].

# What are the species associated with distilled agave beverages?




Distilated Beverages

Example of species

★ 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 six 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
6) The distillation process residues (bagasse and vinasses) are disposed accordingly (see page 16).

**Those that come from fermentation of aguamiel** produces aguamiel distillate and comiteco. Production of these types of distilled products has Five 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.
5) The distillation process residue (only vinasse) is disposed accordingly (see page 16).

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 degrades 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 health risks due to application of synthetic fertilizer and pesticides.

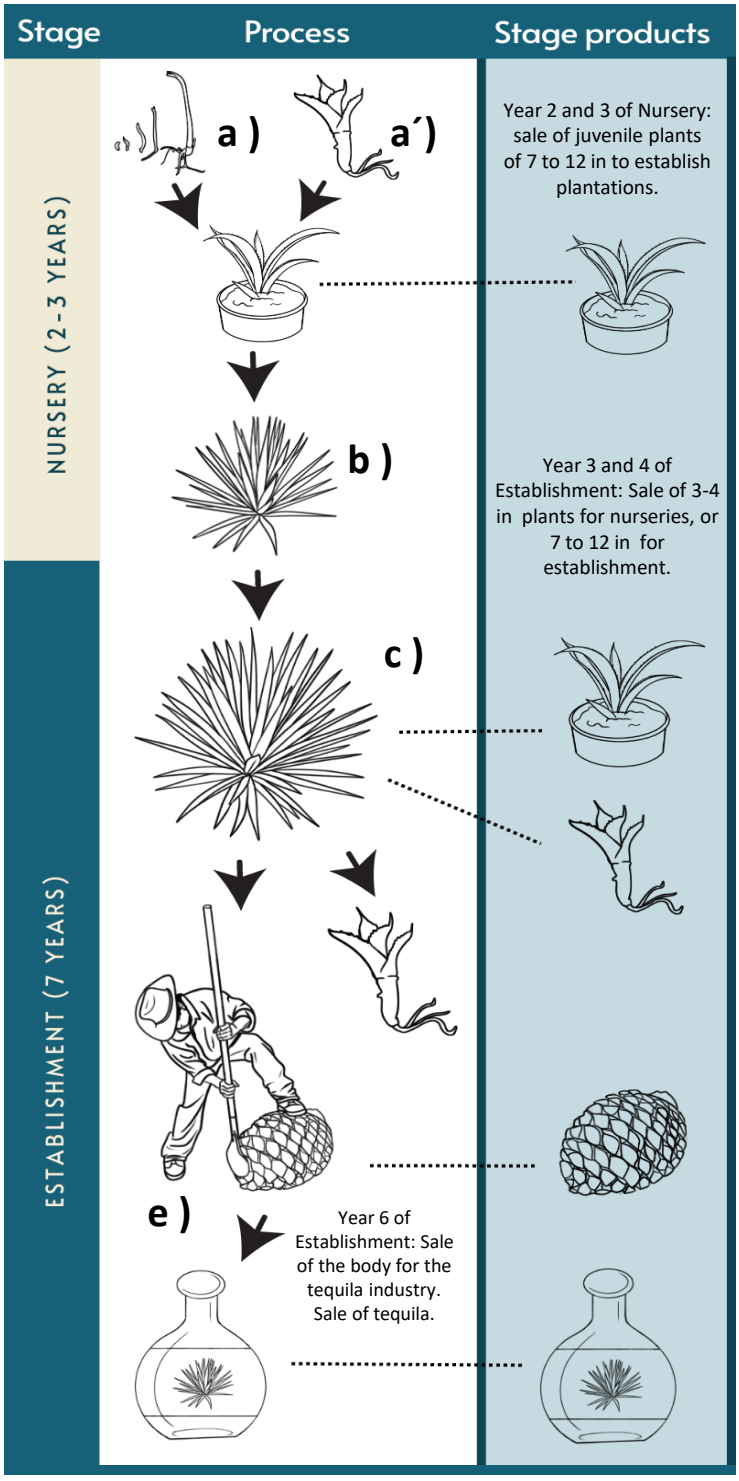
Agroecological

Conventional

# ★ Tequila

## Blue agave

## *Agave tequilana* Weber var. azul [8]




### Process

Before starting: Land preparation, cleaning, fertilization.

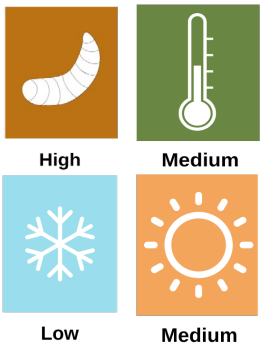
a) Germination - Growth - Uprooting of maguey from 7 to 12 in for establishment. a´) Transplant of 3 to 4 in rhizome juveniles, fertilized with manure - Uprooting of 7 to 12 in maguey for establishment, or two years of nursery. It is exposed to the sun between 20 and 30 days.

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

*>50 species and sub-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.

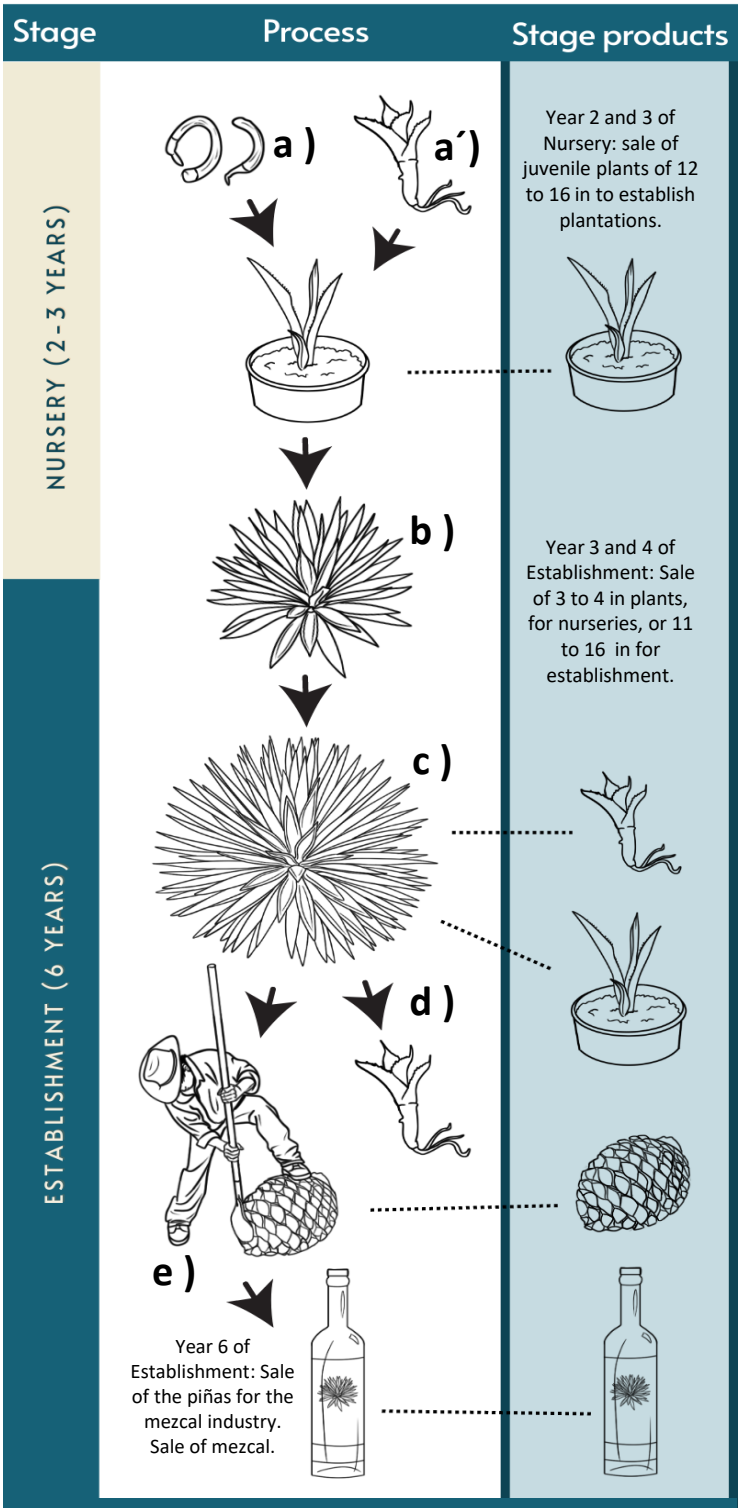
a´) Transplant of 3 to 4 in rhizome juveniles, fertilized with manure - Uprooting of 11 to 16 in maguey for establishment, or two years of nursery. It is exposed to the sun between 20 and 30 days. Juveniles with a size between 5 to 10 in are extracted and replanted in the nursery. Preferably first cut.

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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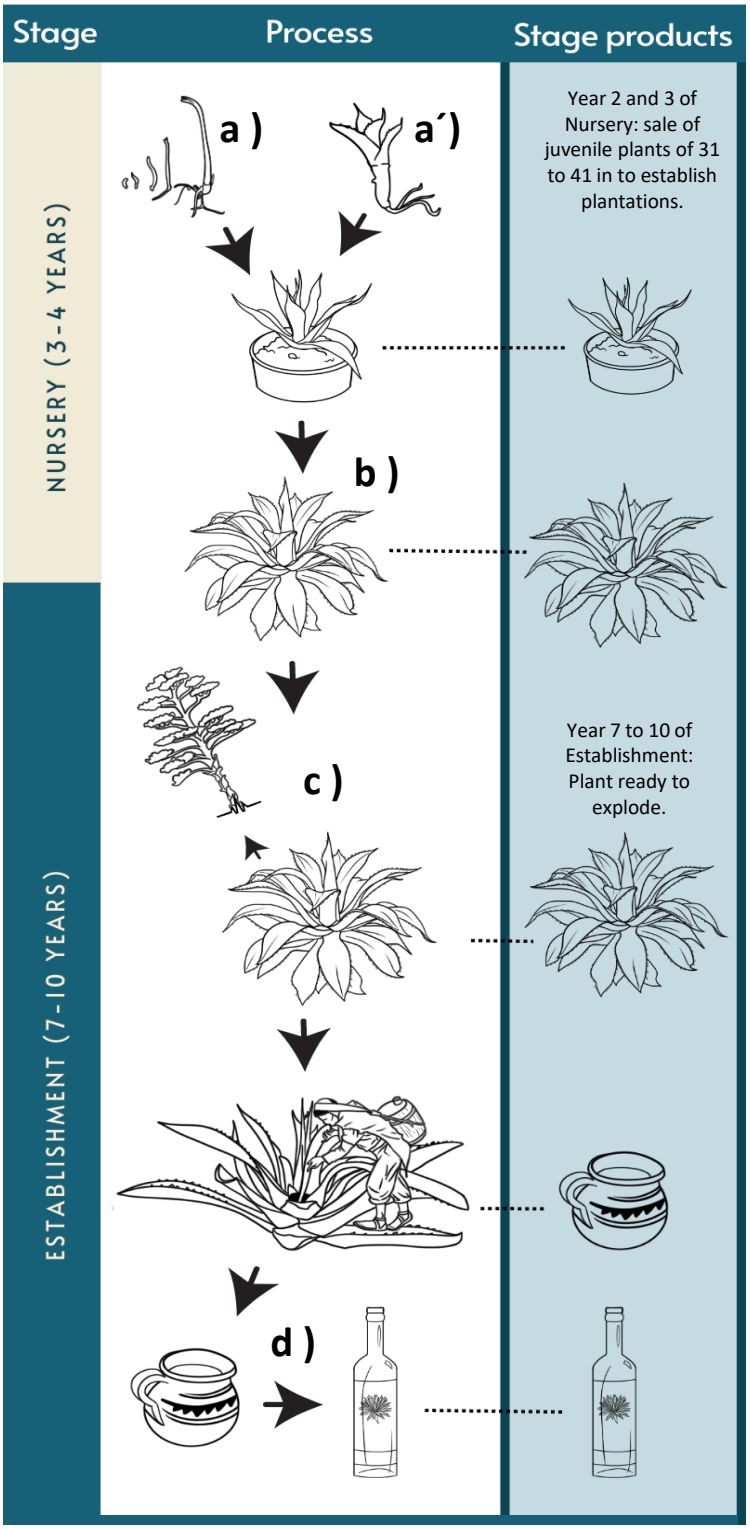
# Aguamiel, Pulque, Comiteco

## Agave pulquero [35]

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




### Process

Before starting: Land preparation, cleaning, fertilization.

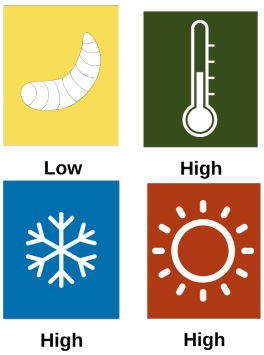
a) Germination - Growth - Uprooting of maguey from 5 to 10 in for establishment.

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.

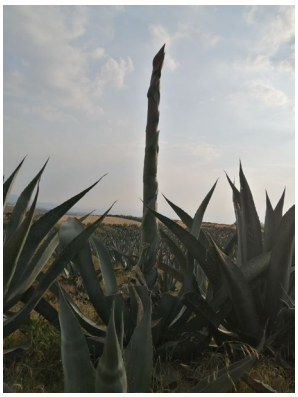
d) Aguamiel fermentation to produce Pulque, distillation, packaging, marketing.




### Specifications

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

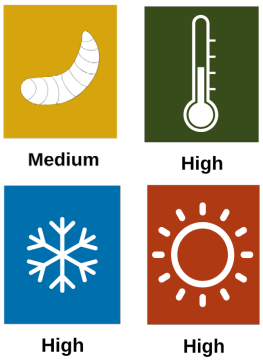
Adaptable to cold, low incidence of pests and diseases.



# ★Bacanora

## Agave

## *Agave angustifolia* Haw var. *pacifica*[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.

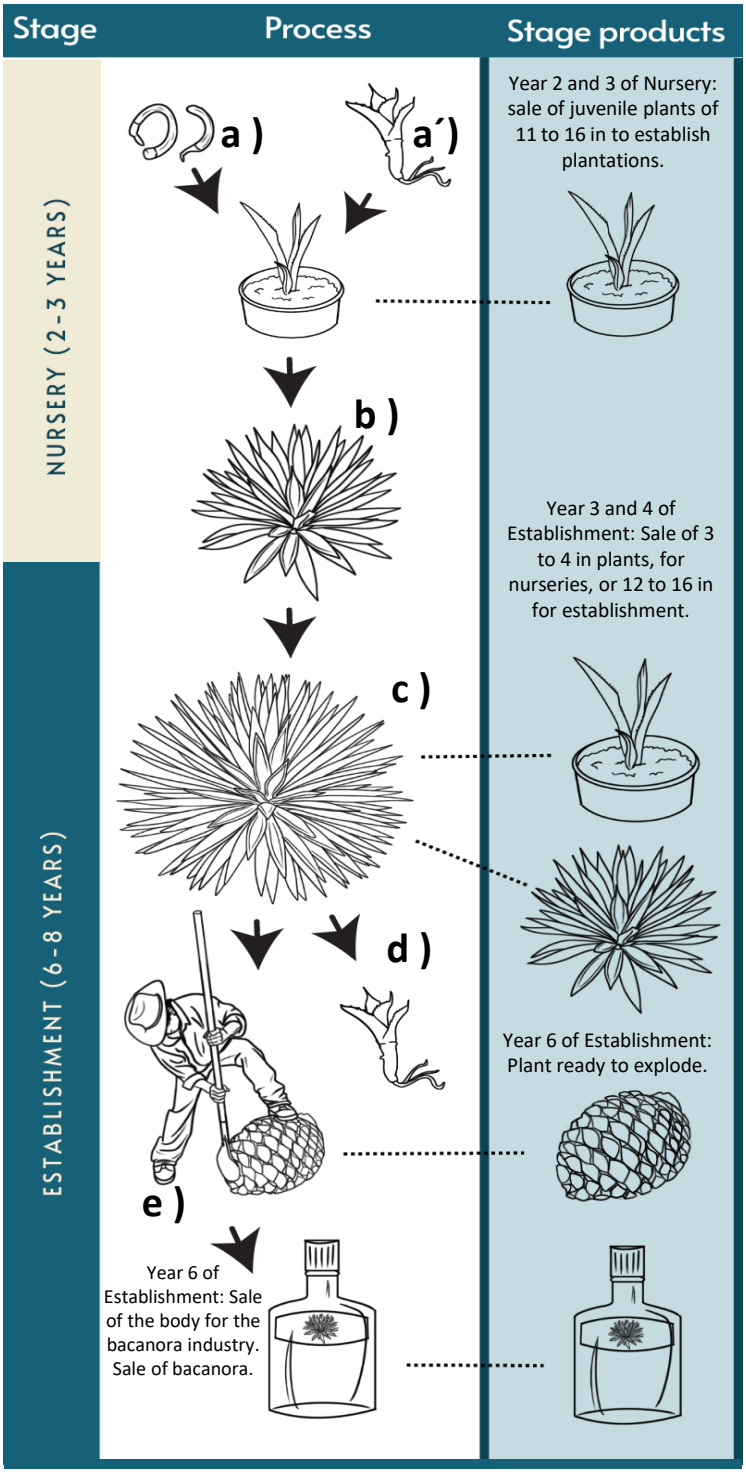
a') Transplant of 7 to 12 in rhizome juveniles, fertilized with manure. Uprooting of 12 to 16 in maguey for establishment, or two years of nursery. It is exposed to the sun between 10 and 30 days.

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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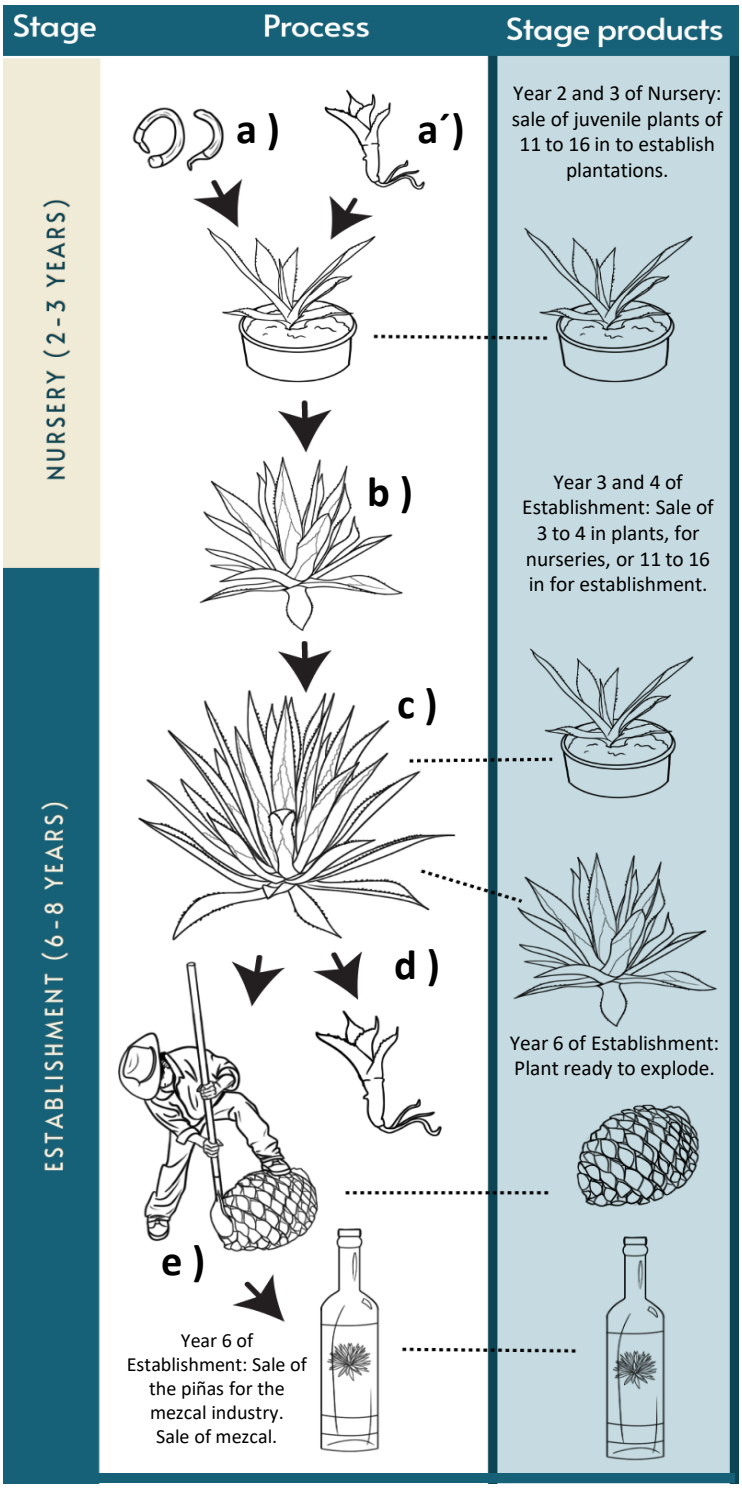
# ★ Raicilla

## Agave

*5 species e.g. Agave maximiliana* [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.

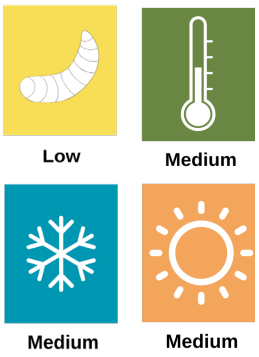
a') Transplant of 3-4 in rhizome juveniles, fertilized with manure. Uprooting of 11 to 16 in maguey for establishment, or two years of nursery. It is exposed to the sun between 20 and 30 days.

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*, *A. cupreata* and *A. inaequidens*[38]. However, there are more than 50 species and sub-species from which Mezcal can be produced. These are the most important:

| Scientific Name | Common Name | Scientific Name | Common Name |
|---|---|---|---|
| ***Agave potatorum*** | Maguey tobalá | ***Agave* spp.** | Maguey verde |
| ***Agave angustifolia*** | Maguey espadín | ***Agave karwinskii*** | Maguey barril o Madrecuishe |
| ***Agave americana* var. *oaxacensis*** | Maguey arroqueño | ***Agave kerchovei*** | Maguey jabalí |
| ***Agave americana* var. *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 is produced from five species: *Agave maximiliana, A. inaequidens, A. valenciana, A. angustifolia* Haw var. *pacifica* and *A. rhodacantha.* DO.

The distilled products from fermentation of aguamiel are obtained mainly from *Agave salmiana, A. atrovirens, A. mapisaga, A. americana* and *A. potatorum.*

Tequila is produced by only one species: *Agave tequilana* Weber var. azul; blue agave is the common name. DO.

Bacanora is produced from *Agave angustifolia* Haw var. *pacifica.* DO.

Comiteco is produced from *Agave americana* and *A. salmiana*.

The Denomination of Origin [39] (DO) established 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. Agave is Crassulacean Acid Metabolism (CAM) plant, 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 below shows the optimal, sub-optimal and marginal daylight and night temperatures, and the lowest and highest temperatura before severe damage occur. A. Tequilana Weber can be produced under low or high temperatures, but destillates products will be of poor quality and will require several agro-chemicals.

| Event | Optimal (°F) | Sub-optimal (°F) | Marginal (°F) | Lowest temp. for severe damage (°F) | Highest temp. for severe damage (°F) |
|---|---|---|---|---|---|
| Daylight | 59 – 77 [42]<br>52 – 70 [43]<br>86 [45]<br>79 [47]<br>59 – 77 [50] | 50-59 or<br>77-95 [42]<br>95 [44] | < 50 or<br>>95 [42] | | 97 [44]<br>86 – 93 [46]<br>86 [49] |
| Night | 50 – 61 [42]<br>59 [45]<br>61 [47]<br>52 – 70 [48]<br>50 – 59 [50] | 41-50 or<br>61-77 [42]<br>30 - 52 or<br>70- 82 [43]<br>77 [44] | <41 or<br>>77 [42]<br><30 or<br>>82 [43] | 25 [44]<br>37 – 50 [46]<br>36 [49] | |
| Frost probability | < 0.10 [42]<br>< 0.10 [43] | | < 0.10 [42]<br>> 0.10 [43] | | |
| | - The restricted regions for its cultivation reflects avoidance of freezing damage below 32°F [44]<br>- The *Agave tequilana* Weber var. azul 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]<br>- The *Agave tequilana* Weber var. azul suffers a lot for hours at temperatures below 36°F and very strong damage at temperatures below 32°F [49]<br>- 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)

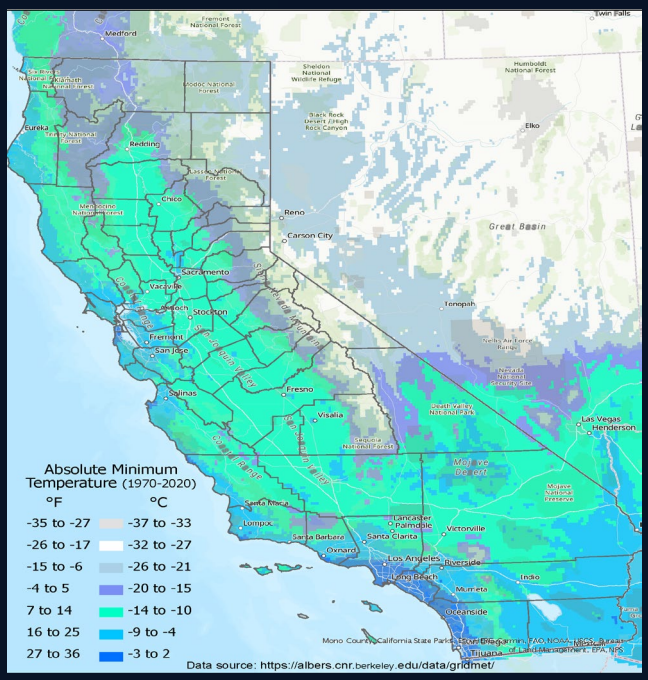
# What are the pest that I should be aware of?

- *Scyphophorus* spp.[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* spp. [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.

# Night and daylight temperature maps of California

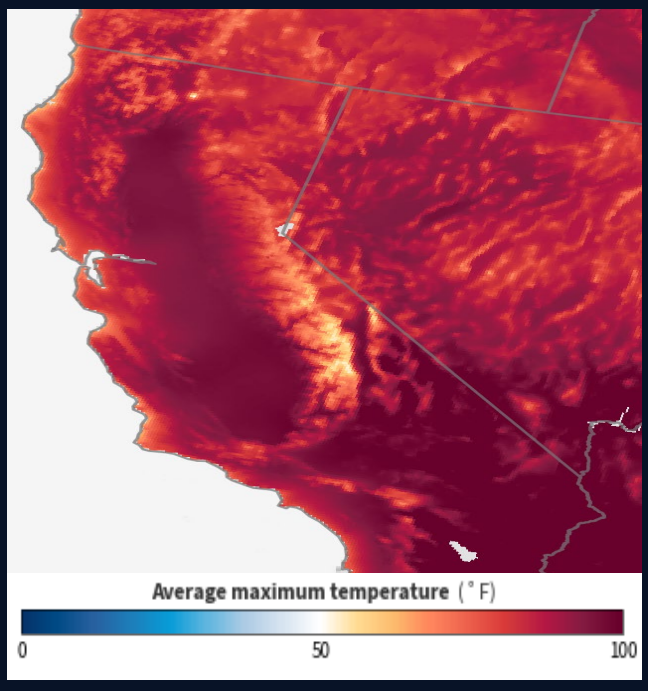
## Night Temperatures

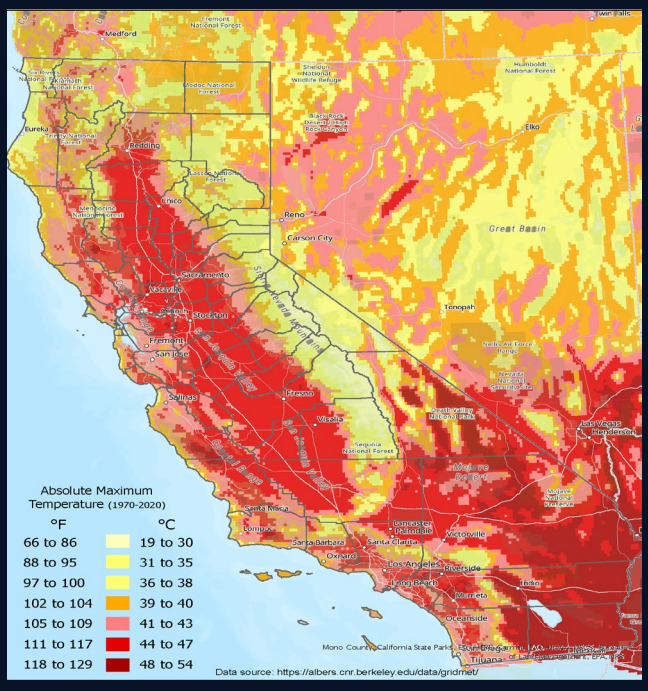
The average minimum temperature (left) also referred as the Plant Hardiness from USDA (1976-2005) and the absolute minimum temperature (right) (1970-2020) used by growers to determine which plants are most likely to thrive at a given location.


## Daylight Temperatures

The average maximum temperature (left) for July from NOAA (1991-2020) and the absolute maximum temperature (right) used by growers to determine which plants are most likely to survive high temperatures and heat waves at a given location. Climate Change is expected to increase this maximum temperature values in the near future.



# What are the residues generated by agave distillate industry?

The production of agave distillates generates two residues: bagasse and vinasse. Distillates that come from cooking piña (e.g. Tequila or Mezcal) produces both residues and distillates that come from fermentation of aguamiel (e.g. Aguamiel distillate or Comiteco) only produce vinasse residues (see page 7).

**Bagasse**

Bagasse is a solid residue generated during the grinding of the piña to extract the juice[56] for the production of agave distillates that come from cooking piña. Bagasse is composed of cellulose (43%), lignin (15%), hemicellulose (19%), reduced sugars (5%), nitrogen (3%), pectin (1%), fats (1%) and others (13%)[57]. The decomposition of bagasse produces leaching that contaminate soils and water resources (rivers and aquifers)[58].

On average, for each liter of agave distillate, 1.4 kg (3 pounds) of bagasse is produced, but this amount of residue can increase depending on the equipment to grind the piñas[59]. One sustainable option for disposing bagasse is to turn it into compost (See page 18).

**Vinasse**

Vinasse is the liquid residue that is generated after the distillation of the agave juices. Vinasse is produced in the distillation that come from cooking piña and from fermentation of aguamiel. Vinasses are dark brown in color, because it contains phenolics (tannic and humic acids), melanoidins that are low and high molecular weight polymers[60].

Vinasses can significantly contaminate the environment if they are untraded and disposed in the soil or in water bodies due to their high concentrations of total solids (> 21,000 mg per liter)[61]. On average, for each liter of agave distillate, approximately 10 to 12 liters of vinasse is generated[62]. One sustainable option is the biologic treatment of vinasse using anaerobic-anoxic-aerobic treatment systems[63] (See page 18).

In Mexico, there are severe environmental problems related to the poor disposal of large quantities of vinasse as a result of the increase in the production and consumption of agave distillates. In California there are regulations that describe the requirements for adequate disposal of liquid residues to prevent the contamination of rivers and aquifers[64]. Currently there is a regulation for wineries and other similar facilities for general waste discharge requirements for process water[65].

# How can I utilize the by-products of the distillation process?

We should stop to consider residues as waste and start managing them as by-products, since with an adequate treatment, these residues can be reused, providing added value to the production.

| Use of Agave Bagasse | Type of Process |
|---|---|
| Production of paper and cardboard | Pulping and paper manufacturing process |
| Generation of biogas or biomass energy | Anaerobic digestion or combustion process |
| Manufacture of construction materials | Mixing and molding process |
| Production of compost and organic fertilizers | Composting process |
| Manufacturing of textiles and crafts | Fiber extraction and weaving process |
| Use as animal feed | Drying and grinding process |
| Production of bioethanol and chemicals | Fermentation and distillation process |
| Utilization in the cosmetics and personal care industry | Active ingredient extraction process |

| Use of Agave Vinasse | Type of Process |
|---|---|
| Agricultural fertilizer | Application in agricultural fields after treatment |
| Biogas production | Anaerobic digestion process |
| Wastewater treatment | Biological treatment process |
| Thermal energy generation | Direct combustion in boilers |
| Biofertilizer production | Fermentation process and nutrient extraction |
| Use in distillery processes | Recirculation and treatment for reuse |
| Utilization in the food industry | Flavoring or ingredient in certain products |
| Phytoremediation processes | Utilization of vinasse to remove contaminants from soil |
| Production of natural extracts | Extraction and concentration process of bioactive compounds |

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