Basic hop breeding for growers

Charlie Rohwer, University of Minnesota rohw0009@umn.edu

Plant breeding is used to make new plants, with novel combinations of genetics that have never existed before. Genes from a female plant and a male plant are combined to make seeds, and all of the seeds from a cross are unique, but all of them have genes only from the mother and the father.

Consider your family. Your mother and your father made you. You have characteristics of both your mother and your father. You and your siblings represent different ways that your parents' genes combined, and each of you is unique. This is the goal of plant breeding: to make a collection of individuals with unique combinations of genes from their mother and father.

Once we have a group of unique individuals, we can test them in any way we want and pick the best ones. In the case of hops, we test how well the individuals grow, if they tend to get diseases, if they are easy to pick, if they mature at an appropriate time, and if they make good beer, for example. We then *select* the individuals that we like the best, and we discard the rest. Breeding is half the process--making new babies. *Selection* of which babies we want to keep, though it sounds morbid, is the other half. Plant breeders must ruthlessly discard underperforming individuals, based on whatever criteria are selected.

The advantage *you* have in breeding hops, compared to breeders in Germany, Oregon, Washington, New Zealand, Australia, Minnesota, and everywhere else is that *you* select individual plants based on your own breeding goals and performance in your own environment and production systems. For example, a breeder in Oregon can't select plants that grow well on *your* trellis in *your* climate, only *you* can do that, and *you* get to define what 'growing well' really means.

Breeding hops is a long-term process. It should take at least 8-10 years from the initial cross to a variety release. The danger in trying to shorten that time is that you might make a substantial investment in planting a very large amount of an experimental variety, not knowing that a very undesirable trait has not yet revealed itself. For example, a plant that is 6 years old may not have experienced a year of heavy downy mildew pressure, or a hop selected for high alpha acid content might show a precipitous alpha dropoff after year 8. Ensuring that the selection you make is a good selection saves headache and trouble in the long run. (Here is a general timeline: https://www.usahops.org/resources/hop-breeding.html).

An important part of making good babies to work with in the first place is selecting the right parents. The point of breeding and selection is to generate a completely novel variety that is better than existing varieties in some way. A long-term breeding program might not find a potential variety, or might not even *plan* to find one, from the first round of crosses. The first group of seedlings might be intended for generating a good parent for the *next* round of crosses.

Selecting Parents

The simplest rule for selecting parents, if you have no other reason to choose one parent over another and you do not have a well-funded breeding program, is to *choose parents that are not closely related*. Mating with your brother, sister, or cousin might give interesting results, but probably not in a good way. One resource that may be helpful in determining relatedness of existing cultivars is a hop pedigree poster (z.umn.edu/hopposter).

Another generally good idea is to consider what has been successful in the past. Hops that tend to grow well in much of the US and tend to have decent brewing qualities are generally a mix of European and North American genetics. Cascade, Brewer's Gold, and Chinook are 3 examples of hops that blend European and North American genetics successfully. If there is too much 'North American' genetics, the hops may taste rough or

harsh, or be susceptible to some diseases, or flower very late. If there is too much 'European' genetics, the hops might not grow well in the photoperiod or hot summers of the continental US.

Hops are dioecious (*dī-'ē-shəs*), meaning male and female flowers are found on separate plants. Females are used in brewing, and males are only used for breeding. To cross two plants, you need both a male and a female.

Female: Choose a variety (or a wild plant) that seems to grow fairly well where you are, but has some characteristic you would like to improve upon. Choose something that is relatively easy to pick, unless that's a trait you would like to improve upon. Some downy mildew tolerance would be preferable.

Magnum, Mt. Rainier, Newport, Orion, Perle, Sorachi Ace, Spalter Select, Teamaker, Tradition, Viking, and Yeoman are some examples of downy mildew-resistant or -tolerant varieties. Other possibilities which may have some tolerance include Brewers Gold, Cascade, Chinook, Northdown, and Omega.

Varieties that are especially susceptible to diseases include Cluster, Columbus, Comet, Galena, Glacier, Goldings, and Zeus.

Some females can NOT be used for breeding. There are 'triploid' varieties that are genetically sterile; they were bred specifically to ***not*** make seeds. The 6 publically-available triploids are Crystal, Liberty, Mt. Hood, Ultra, Willamette, and Triple Pearl; don't even try breeding with these. You should also not use patented cultivars for breeding (if you had to sign a license to grow or market it, don't collect seed from it).

Male: Ideally, the male you choose should tolerate downy mildew as well. And it should grow well where you are. Flowering time is less important for males, although it must obviously flower before or during flowering of the female you're interested in crossing it with. You'll need pollen from the male before or during the time the female is ready to be pollinated. If your male is flowering before the female is ready to pollinate, put the stem of some male sidearms or flower clusters in a glass of water (as you would a bouquet of cut flowers), and put the 'arrangement' on top of wax paper in a draft-free location. Give the stems an occasional 'tap' to release pollen. The pollen will fall onto the wax paper, and you can collect it in a small container and store it in a cool, dry place until the female is ready to pollinate. If the male you have chosen flowers *after* the female you'd like to pollinate, you'll have to collect the pollen and save it until the following year. Store the pollen in refrigerator in a container with a desiccant, like the silica gel packs found in clothing or food products.

If you have more than one male and no reason to choose one over the other, it's OK to mix pollen together. Some breeders choose males that are collected in the wild. Some choose males that have been used by other breeding programs. Again, in general, you will create more interesting and useful seedlings if the parents are more distantly related.

One way to find males for breeding is to search for males growing near open fields. They are typically found near the edges of wooded ditches, where they have ready access to water and some shrubbery or trees to climb up. Another place to get males is to select your own. Some commercial growers or gardeners may notice seeds in their cones, meaning there is obviously a male in the area. Procure these seeds (they are often available through ebay.com too) and germinate them. Roughly 1/3 to ½ of the plants that grow will be male, identified by their flowers. Choose the best one to use for your breeding, and if you know what variety the seeds came from, you know half the pedigree of your male.

You can also find males by germinating seeds collected from plants that you are growing, but did not pollinate yourself—these are called 'open pollinated'. Perhaps you've noticed some seeds collecting around your picker. That indicates your females were pollinated somehow; a nearby male must have been the pollen source for these crosses. Some successful varieties had unknown fathers (Cascade, Brewer's Gold, Palisade, Sovereign, Boadicea, Smoothcone, and WGV, for example) or grandfathers (Mt. Hood, Super Galena, Willamette, Horizon, Vanguard, Liberty, Newport, Boadicea, Progress, Vojvodina, and Bramling Cross, for example).

Pollen from female plants that occasionally generate male flowers should not be used for breeding. The pollen is likely to be not viable, and you will be disappointed with the amount of viable seeds generated (likely to be zero).

Making Crosses

To make seeds, you need to put pollen from a male plant on the newly-forming cones of a female plant. Sperm DNA in the pollen will combine with the egg in the female flowers (yes, plants have their own version of 'sperm' and 'egg'), and a seed will grow in the cone (the new baby plant, or embryo, develops in the seed). In nature, hop pollen spreads with the aid of wind; males shed pollen, which wind carries and deposits on female flowers. The same can happen in your hopyard if male plants are nearby. But hand-pollinating ensures more seeds will form in each cone, and is necessary for crossing a *specific* male with a female.

Male inflorescence

Female inflorescence

The female is ready to pollinate when the flowers look like a paintbrush, and before the tips of the 'bristles' turn brown. The 'bristles' of the brush are the pistils, the parts of the flower that will transfer the sperm (inside the pollen) to where the egg is (inside the developing hop cone). For comparison, the pistils on an ear of corn are the silks. In hops, each pistil is connected to an egg, just like each silk on an ear of corn is connected to a kernel. That means every pistil you successfully pollinate has the potential to produce 1 seed. If you want to create 100 seeds, you need to get pollen on *at least* 100 pistils.

To get the pollen on the pistil, you can dab it on with a finger, paint it on with a brush, or blow a pile of pollen at the female flowers. If you're using your own male plant as a pollen source, you can simply cut an entire flowering branch off the male (carefully) when pollen is being shed, and shake it around on the female flowers if they are ready to be pollinated.

If you have other males around and you want to make a very specific cross that does not include those males, or if you are using separate males to make different crosses, you'll have to protect the female flowers from being pollinated by those other males. One way to do this is to wrap a heavy white 'row cover' around a section of the plant as the sidearms are forming (*before* the pistils appear!). Row covers (aka 'remay') are typically used to cover fruit and vegetables to protect them from insects and frost, and remay is available in different thickness. For hop breeding, the heavier the better. The row cover will allow air and light in and let moisture out as the sidearms grow and develop, but it will not let pollen in. When the flowers are ready to pollinate, open or cut a small slit in the row cover, tap or blow some pollen in through the slit, staple or tie the hole closed, and shake the enclosure to distribute the pollen all over. It may be useful to repeat this every couple of days for a week. Another way, though less successful, is to get a wax bag from a bakery (the kind that French bread comes in). Remove the leaves from a sidearm, and put the bag over the entire sidearm and tie it closed at the base to keep it secure (don't damage the plant though). When the flowers are ready to pollinate, add pollen inside the bag and shake. After about 3 weeks, remove the row cover or bag and mark the area of each plant where seed should be collected and what cross was made there.

Hop flowers can be protected from unwanted pollination with a heavy woven row cover, available from garden centers or catalogs.

When the cones are mature, but before the seeds start to 'shatter' (fall out on their own), gently harvest the fertilized cones. Let them air-dry to make seed collection easier. Roll the cones between your fingers, and pick the seeds out. If you were making multiple crosses between specific parents, be sure to keep the seed from each cross separate. However, if you've got no reason to favor one cross over another, or you're not interested in keeping track of the pedigree of the seeds, it is OK to mix seeds from separate crosses together.

Germinating Seed

Freshly-harvested hop seeds are dormant. Seed dormancy is a mechanism in some plants to protect seedlings from winter. In nature, if fresh hop seed germinated in the fall, they would likely be killed in the cold of winter. The seeds need to experience something akin to winter *before* they will germinate. Even then, germination will not be 100%.

The dormancy-breaking treatment, called stratification, needs to occur in moist, cold conditions. A general, brief tutorial on stratification can be found here: http://www.prairiemoon.com/catalogs/starting-from-seed.pdf. From these instructions, treat hop seeds as category C60 (cold, moist treatment for 2 months). You may also pre-stratify the seeds by keeping them in moist conditions at room temperature for 1-2 days before the cold treatment. If any fungal growth develops during stratification, try to remove the infected seeds and return the rest to the refrigerator.

After stratification, put seeds in seedling trays in a greenhouse or a warm space with plenty of light. Treat them as you would seeds for your garden.

A larger number of seeds may be germinated using methods described here: http://www.ars.usda.gov/News/docs.htm?docid=11069#propagation.

Growing Seedlings

Once seeds have germinated and are growing, treat them like you would other garden plants. Give them plenty of light, water, and appropriate soil volume in a protected environment. Harden them off before transplanting to the field (after danger of hard frosts). For first-year plants, they can be planted fairly close together (1 ft) and on a very short trellis (6 ft) if they are small. Larger plants, started earlier in the spring, will need more space. You can gather basic information on disease susceptibility and sex in the first year of growth, if they are large enough when transplanted (about ⅓ to ½ of the plants will be male). In addition, other traits can be selected if you choose to (internode length, or leaf color, for example). Transplant desirable seedlings to a larger trellis and discard the remaining.

More Selection

The next couple of years should be spent evaluating plants based on the traits you are interested in: yield, disease response, vigor, height, flowering time, etc. Remove undesirable plants and propagate desirable individuals so that you have at least 2 of each plant you want to test further. You can start to get an idea of cone chemistry and validate other traits you are selecting for (growth, yield, etc), and you should have advanced selections tested for the presence of viruses. Ultimately, about 4 to 7 years after the cross is made, you can plant advanced selections in larger blocks on multiple farms, coordinate pilot brewing with the hops, and evaluate brewer / customer acceptability. Continue to propagate the best materials so there will be enough to satisfy demand.

UMN Hop breeding update, spring 2017

To date, all selections have only been harvested from a single string on a single hill in a single location. No fungicides have been applied.

HRC-01M is a male found growing by UMN grape research plots in Excelsior, MN. It is extremely vigorous and has been used in a number of crosses.

2012 selections

- **UMN 1202-001** (Nugget × UMN HRC-01M)
  - The goal of this cross was a female, vigorous and moderate to high alpha, but with more interesting aroma than Nugget.
  - A very small batch of beer was made with this selection in 2015, with favorable opinions from a handful of craft brewers.
  - ~1.1 lb / string, 5.0-5.7% α, ~45% CoH, 1.5 ml oil / 100 g, extremely vigorous, perhaps some disease issues? Berry-like aroma?
    - Being trialed on commercial farms in 2017.

2014 selections

- **UMN 1401-056** (Brewer's Gold × USDA 19173M)
  - 19173M is USDA Strisselspalter × Cluster seedling, and hasn't been used in any commercial hop varieties
  - The goals were 1) a vigorous female like Brewer's Gold but easier to pick and earlier harvest, and 2) a vigorous male to use for breeding mid- to high-alpha hops.
    - We have a male but haven't made crosses with it yet.
    - Matures mid-August, 0.93 lbs / string, 9.8% α, 28% CoH, smells interesting. But still perhaps difficult to pick.
- **UMN 1402-008** and **1402-028** (Sterling × UMN 1204-001M)
  - 1204-001M is an extremely vigorous, disease-resistant male (Spalter Select × HRC-01M)
  - The goal was a female with a clean aroma and moderate alpha, like Sterling, but with more vigor, higher yield, and earlier maturity.
    - Respectively, 1.5 & 1.15 lbs / string, late- & mid-August maturity, 5.3 & 7.7% α, 33 & 25% CoH, clean & OK aroma. Dwarf traits?
- **UMN 1403-005** and **1403-023** (Sterling × USDA 19058M)
  - 19058M is a USDA male known for creating progeny with good vigor and alpha acids. It is the father of Super Galena, Lemon Drop, and Mt. Hood, and the grandfather of Nugget, Horizon, Apollo, Bravo, Calypso, Delta, Summit, Denali, and Millennium.
  - The goals were 1) a female with moderate- to high-alpha acids, more vigorous than Sterling, with interesting flavor. And 2) a male to use for higher-alpha breeding.
    - 1 male was saved but we haven't made crosses with it yet.
    - Respectively, 1.26 & 0.95 lbs / string, mid- & late August maturity, 5.5 & 9.7% α, 35 & 24% CoH, light & interesting aroma.
    - Some downy symptoms later in the season, but cones looked OK. They were inoculated with downy at the beginning of the year and not sprayed all year.

2015 female selections (no harvest yet): 4 putative triploid selections from USDA 21003 (tetraploid Fuggle) × OP, these are half-sisters of Willamette.

2016 seeds (currently in greenhouse): 1) Sorachi Ace × Chinook-derived male, 2) Southern Brewer × 1204-001M, and 3) Chinook × 1204-001M.