The Winnow Wizard

Principles, Techniques, and Operating Instructions

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Acknowledgements

I would like to thank Frank Morton, renowned plant breeder and owner of Wild Garden Seed (and my boss), for believing in me, trusting me with engineering projects at the edge of my expertise, and giving me the freedom to tinker with innovations on company time. Hank Keogh, Wild Garden Seed manager, first taught me how to winnow and provided numerous design suggestions and proposed improvements from the first prototype. Thanks to the rest of the Wild Garden crew – Karen Morton, Helen Dziuba, Victor Sauvie, and James Young – for support and enthusiasm along the way.

Thanks to my wife, Elizabeth Records, for her excitement with my tinkerings even when it meant less time for hiking and gardening together.

Finally, a special thanks to Petra Page-Mann of Fruition Seeds, who convinced me – with tears of joy at the Organic Seed Growers conference – that this was an invention worthy of sharing.

The Story

When I arrived at Wild Garden Seed, we cleaned our seed from threshing to final product using hand screens, hand winnowing, and (for round brassica seeds) a spiral separator lovingly named "the roundy-round." We owned a few small cleaning machines, but they seldom saw use. The problem was that seeds got stuck in machines, and to use them with our small and diverse seed lots we would either need to spend more time cleaning them out than using them or else deal with an unacceptable level of cross-contamination.

Most people winnow in front of fans, where the turbulent airflow makes any degree of accuracy impossible. This is fine for getting out dust and leafy chaff, but not for separating light seed and sticks. Long before I arrived, Frank improved this method, building wind tunnels behind fans, then winnowing in the more even airflow entering the tunnel. This is many times more accurate than working in front of a fan, but I found it stressful. After a few months of trying to shake a pouring dish in exactly the right spot and realizing that even behind a fan the airflow is not perfectly even, I decided I would try to design a more accurate winnower.

The first design, in December 2014, was a bit wild – two air tunnels stacked on top of each other, with a catching tray in between, designed to winnow seed twice while the operator stood on a ladder and poured at the top. Seeds bounced too much for that to work, but it worked well as a single level. Accuracy was improved, but it didn't really save time as an operator had to pour into the feed slot. The art of winnowing had been reduced to the tedium of slow dumping.

Manager Hank Keogh suggested a hopper, and I added one in September 2015, along with a vibrating feed tray. In that configuration, the first prototype Winnow Wizard saw nearly continuous use during the fall seed cleaning season – to the point that we needed a second one.

We listed all of the aspects that could be improved, and I set about building a second prototype with even steadier adjustable airflow, a better feed system, and the ability to divide seed into three bins rather than just two. The project was finished a few days before the 8th Organic Seed Growers Conference in Corvallis. Petra Page-Mann, who was running an equipment seminar, saw it on a tour of our farm and insisted on setting up a demonstration at the conference. I quickly figured out the right settings for quinoa and set the Winnow Wizard to work on 70 pounds of our Brightest Brilliant mix. From a number of conversations at the conference, I came to realize that this was truly a novel design, with some advantages over existing technology in terms of ease of cleaning and precision of separation.

Principles of precision winnowing

Winnowing separates material based on what I will call "aerodynamic density," the ratio of mass to cross-sectional area. Accuracy is determined primarily by five factors, namely:

1. Stability of airflow
2. Speed of airflow
3. Length of drop
4. Nature of feed
5. Shape of seed

Airflow stability

Airflow stability is the most challenging factor to address. Any low-viscosity fluid moving quickly will naturally develop turbulence – this is the reason strong winds are gustier than light breezes. Fans and blowers add to this by chopping the air with whirling blades, sending little packets of air spinning off in different directions. The airflow behind a fan is much smoother, but it is still slightly turbulent and uneven.

During my years in a microbiology lab, I spent many tedious days working in laminar flow hoods – partially enclosed workspaces kept sterile by a continuous laminar (non-turbulent) flow of filtered air. These devices create laminar flow by creating a pressure differential across a filter or grate. Driven by the difference in pressure, air rushes equally through all of the tiny holes in the grate, averaging out to a steady, even flow.

I thought to apply this technique to winnowing. The first prototype used a 40% open screen in front of a box fan and produced a partially-even airflow about on par with our old method of winnowing behind a fan. For the new design, I decided to use two separate 25% open screens for maximum effect, but this required a much greater pressure than a fan could deliver. I swapped out the fan for a ½ hp, three-speed furnace blower that would be capable of creating a pressure differential across two screens in sequence. The result was a very even, adjustable airflow.

Due to friction, airflow near the edges of a tunnel is slower than airflow in the middle. To avoid this effect, winnowing should occur in the central part of the flow.

Airflow speed

The airflow speed required for maximum accuracy varies, not surprisingly, with the aerodynamic density of the seed – strongest for brassicas and spinach and softest for lettuce, carrots, and marigolds. Ideally the good seed should be deflected at least 2-3" by the airflow (enough that lighter seeds can be separated) but not so far that it blows into the turbulent region where the air stream begins interacting with ambient air. In practice this means that for a diverse array of seeds, airflow must be adjustable.

This can be achieved by using a multi-speed blower, adding more screens, or swapping out screens for more or less open versions.

Length of drop

For a given wind speed, the longer the fall through the wind, the greater the horizontal separation will be at the bottom. Furthermore, the longer the fall, the less of an effect random spread (from the feed tray) will have on accuracy. From a design perspective, there is a trade-off between length of drop and wind speed. If a blower can produce a 5 mph wind in a tunnel 20 inches high, that same blower can produce a 10 mph wind in a tunnel 10 inches high. However, turbulence increases as wind speed increases (even with screens in place), so it is better to design for a longer drop in a softer breeze. Once sufficient height is achieved for good separation, further increasing height leads to diminishing returns along with increased lateral spread of the seed stream, increased seed bounce at the bottom, and increased overall height making it more difficult to pour into the hopper. I have found 18-20" to be a good length of drop.

Nature of feed

For maximum accuracy, every particle should fall straight down into the airflow from the same starting position, far enough from other particles that it experiences the wind as if it is falling alone. When winnowing by hand, we shake the pouring tray to reduce the angle of repose, allowing seeds to fall straight down from the edge rather than flowing outward over the edge like a waterfall. In a machine, the same effect can be achieved by vibrating the feed tray. A vibrating tray pouring against a vertical plate through a slot just wider than the seed will produce an even, single-layer-thick feed for optimum winnowing. Even with this setup, there is a tradeoff between throughput and accuracy. A slower feed will increase distance between falling particles, reducing interference with the airflow.

Shape of seed

Round balls (like brassica seeds) will fall identically according to their mass and diameter, generating a very thin stream that is easily separated from lighter and heavier material. The further seed shape deviates from a round ball, the more randomness is introduced. Flat seeds falling face-on to the wind fly further than the same seeds falling edge-on. While the first four factors can be addressed by design, seed shape must be addressed by technique.

Building a Winnow Wizard

Plans are available at www.luterra.com/winnow-wizard. Assembly requires a basic collection of hand and power tools and a solid knowledge of woodcraft, metal cutting/bending/drilling, and electrical wiring. Material cost is around $400-$500, and fabrication time is on the order of 30-40 hours.

If you decide you would rather purchase a Winnow Wizard pre-built, I am able to build them on a limited scale. Cost is $1875-$1925 (depending on blower HP) plus freight shipping from Corvallis, OR. Send an email to mark@luterra.com if you are interested.

Precautions and Maintenance

- Plug the Winnow Wizard into a properly grounded electrical outlet, ideally with GFCI protection.
- Do not store or operate in wet or damp conditions.
- Do not operate without blower intake screens in place.
- Keep hair, loose clothing, and necklaces away from blower intakes.
- Keep blower intake screens clean
- Annually, or more often in dusty locations, remove blower screens and feed tray motor cover. Clean blower motor, shaker motor, and blower blades with compressed air. Dust buildup reduces efficiency and is a possible overheating/fire hazard.

Operating Instructions

Siting

The Winnow Wizard needs to be level and located away from ambient winds. Dust and chaff will land 10-20 feet in front of the machine, so this area should be open and ideally covered with a tarp.

Seed preparation

Seed needs to be field-cleaned before running through the Winnow Wizard. Too much fine chaff will prevent seed from flowing out of the hopper, and large debris will clog the hopper outlet and feed slot. In general, it is sufficient to do one field winnow followed by one screening using a screen no larger than twice the diameter of the seed.

Sizing

If we assume that all good seeds in a population have the same mass density of "stuff" (embryo, endosperm, seed coat) inside, then seed mass will be proportional to seed volume. For a spherical seed, volume is given by $(4/3)\pi R^3$, where R is the seed radius. Cross sectional area is given by πR^2. Aerodynamic density (mass divided by cross sectional area) will then be $[(4/3)\pi R^3]/[\pi R^2] = (4/3)R$. All other things being equal, larger seeds will have a higher aerodynamic density and will be deflected less than smaller seeds. If the smaller seeds have acceptable germination, it can be helpful to split the lot into two or more sizes with screens before fine winnowing. If the seed is not sized, it can be difficult to set the divider such that all chaff is removed without also removing the smaller seed.

Air speed

Most of the good seed should be deflected somewhere between 3" and 8". Blower speed setting is less important than restrictor screen selection/placement. Some screen combinations create more even airflow than others; the table below is based on a season of experimenting to find the best placement.

Blower speed: H (high), M (medium), L (low)

Restrictor screens: O (open – no screen in slot), L (1/8" holes), S (1/16" holes)

R1 (1/16" holes, 50% obstructed), R2 (1/16" holes, 75% obstructed)

Screen slots: 1 (closest to exit), 2 (middle), 3 (closest to blower)

Settings are for a 3/4 HP blower; move one step higher for a particular seed class in a 1/3 HP model.

Setting	Slot 1	Slot 2	Slot 3	Blower speed	Applications
Very high	L	O	O	H	Beans? (some turbulence)
High	S	O	O	H	Corn, heavy seeds, overwinnowing seed from rocks
Standard	S	O	S	H, M, L	Most seeds – quinoa, grains, brassicas, amaranth, beets, overwinnowing seed from dirt. Select blower speed as appropriate.
Low	S	R1	S	L	Flat, light seeds, e.g. lettuce
Very Low	S	R2	R1	L	Tiny flower seeds, e.g. snapdragon, yarrow

Slot width

The feed slot width needs to be wide enough to pass the largest chaff in the lot, but in general should be made as small as possible. The smaller the slot width, the more uniform and vertical the trajectory of the seed falling into the airflow. The slot width needs to be matched to the feed rate from the hopper to avoid filling up the feed tray.

Feed tray angle

Seeds should move down the feed tray toward the slot when vibration is turned on. The slower their horizontal motion, the less they will bounce off the vertical feed plate and the less random spread will be introduced. In general, flat seeds like peppers and lettuce require a steeper feed tray angle while round seeds like brassicas need a lower angle.

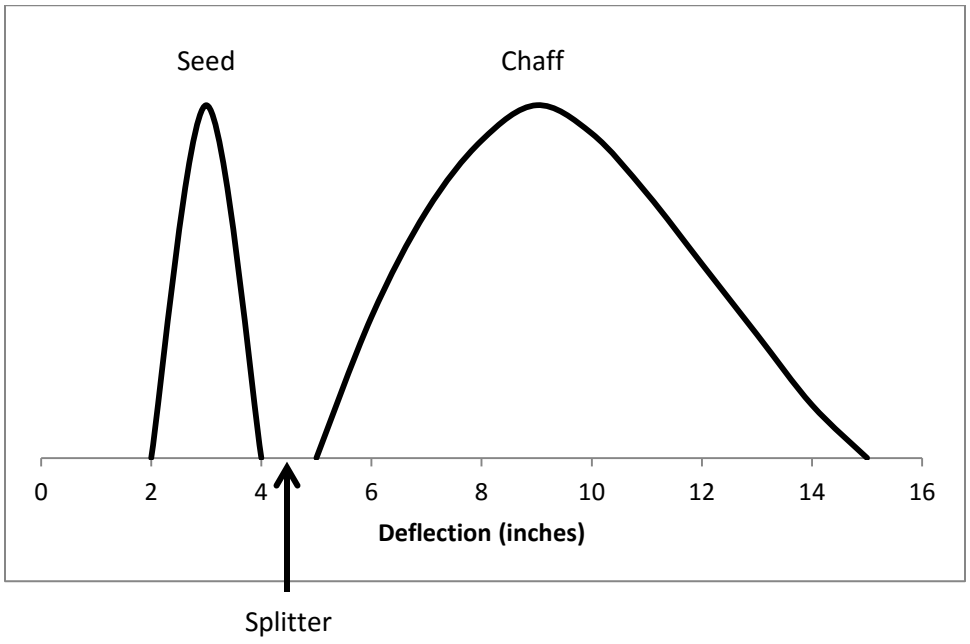
Feed rate

To a point, the slower the throughput, the more accurate separation will be. With fewer seeds dropping, there is less scatter from collisions in the feed slot and less wind interference from nearby falling seeds. For maximum accuracy, select the smallest hopper opening that maintains a steady flow across the full width of the feed tray. With dirty seed, it is often useful to start with a fast-feed, wide-slot "rough winnow" to remove 90% of the chaff, then do a final winnow with a slower feed, narrower slot, and shorter splitter setting.

Winnowing Techniques

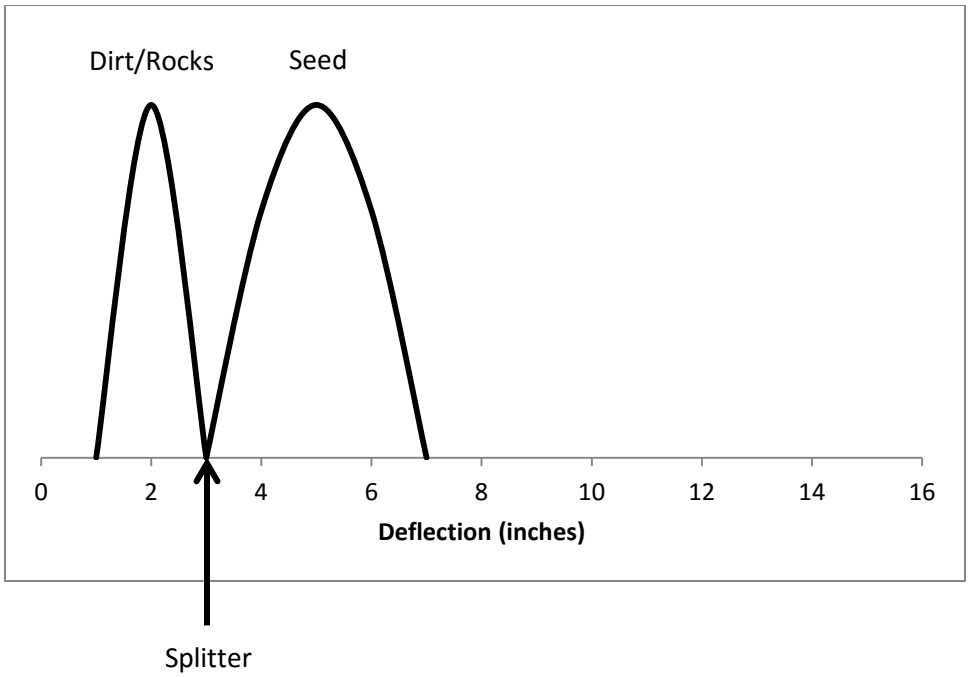
Single-pass split

For heavy round seeds – including most brassicas – it is possible to set a division point that retains 99% of the good seed while removing 99% of the chaff. Fill the hopper, watch it run, pack up the clean seed, pat yourself on the back for growing easily-cleaned seeds, and grab a beer…



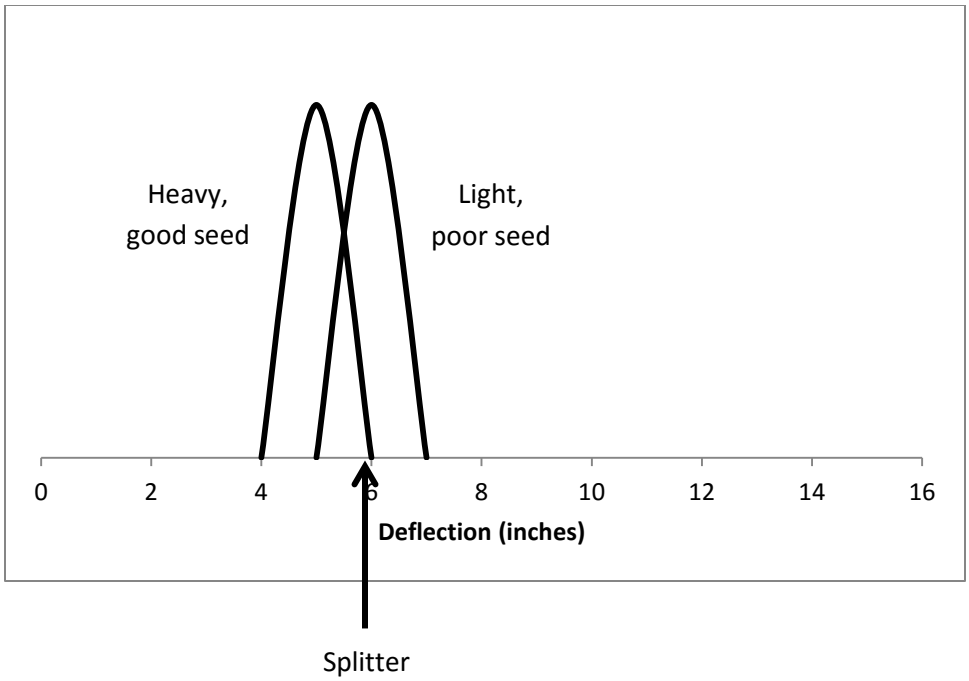
Overwinnowing

If your seed contains heavy debris (usually dirt clods and rocks), it is often possible to blow the seed away from the dirt with maximum airflow. I have done this often to get chunks of dirt out of beet seed. Set the splitter in a location such that ~99% of the seed lands beyond it, then re-winnow the dirt fraction at the same setting to recapture that 1% of seed.



"Shaving" to increase germination

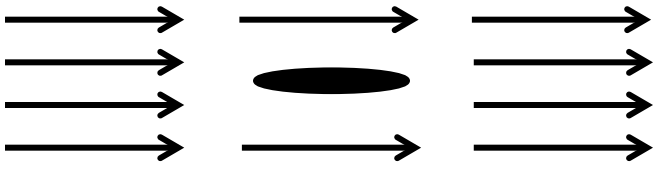
In general, lighter seeds are less viable than heavier seeds, so it is usually possible to increase germination by winnowing away the lightest seed. At Wild Garden Seed we have had great success using the Winnow Wizard to raise germination from 50-70% up to 85% or higher. The trick is to winnow away the correct proportion. If a seed lot tests at 66% germination, aim to shave away 1/3 of the seed. Because there is always some random spread, it is best in this example to set the splitter to remove about 20% of the seed, then re-run the heavy fraction once or twice until about 1/3 of the seed has been winnowed out. If possible, run a germ test on both the heavy and light fractions to confirm success before throwing away the light seed.



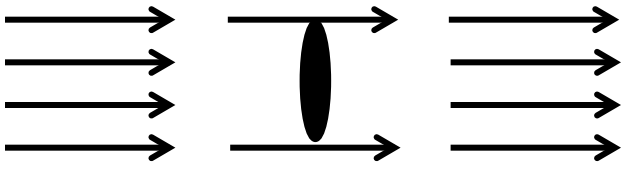
Winnowing flat seeds: the shrinking middle

Winnowing is a probability game. Let us assume that we have a perfectly uniform population of round seeds, all the same size and density. For these seeds, all spread will be due to the machine itself: slight bounces off of the feed plate, slight turbulence in the airflow, and airflow interference caused by seeds falling close together. Under ideal circumstances, this random spread should be less than 2" horizontal at a 6" deflection, which is to say that 99% of our theoretical identical seeds would land between 5" and 7".

If we take our uniform collection of round seeds and smash them to form an equally uniform collection of flat seeds, then run them through the Wizard, we will find that the horizontal spread increases substantially. This occurs because a seed falling edge-on to the wind will be deflected less than a seed falling face-on to the wind; in effect aerodynamic density is now dependent on orientation.

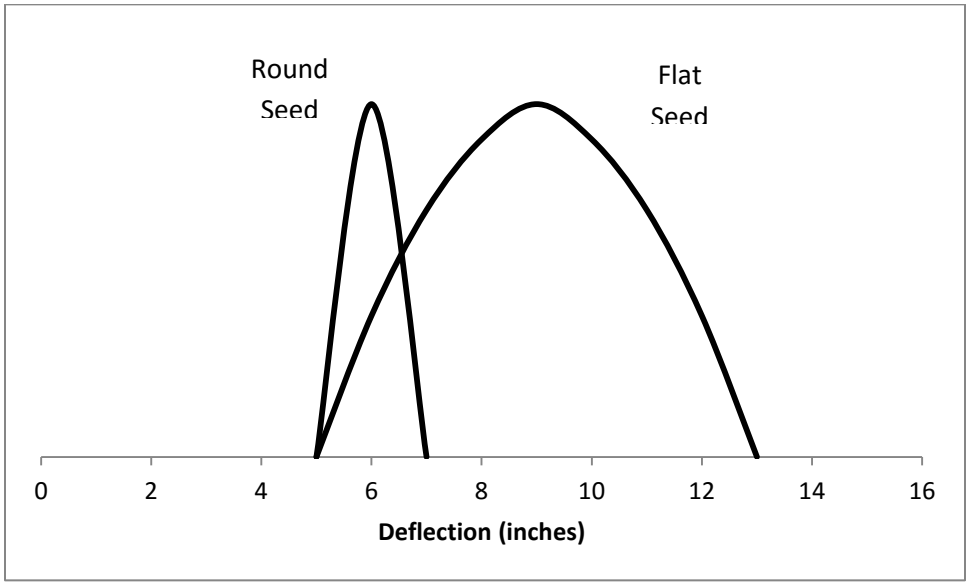


Flat seed falling edge-on



Flat seed falling flat-side-on

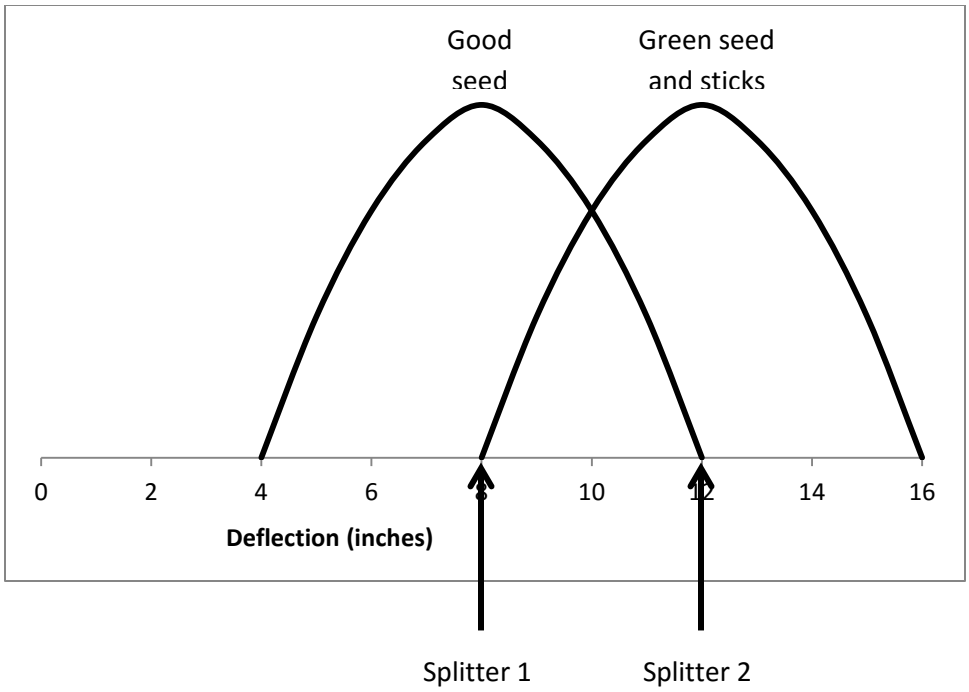
If we graph the spread curves of our round and flattened seeds, they will look something like this:



The important thing to note is that this spread is entirely random, as all of our flat seeds are identical. One particular flat seed may land at 6" in one pass, 12" in the next, and 9" in a third, depending on how it is oriented as it falls. The spread curve can be viewed equally as the positions at which 1000 identical seeds will fall, or the positions at which one single seed will fall if it is dropped 1000 times.

The challenge with winnowing flat seed is that the tail end of the spread – the seed that happens to fall face-on to the wind – overlaps with chaff, small sticks, and light seed. The solution is to take advantage of the fact that with enough passes, any given good seed will eventually fall edge-on and land closer in, while sticks and light seed will always be deflected past a certain point. This is the theoretical basis for our lettuce seed winnowing strategy, which has dramatically reduced the time required to clean lettuce – less screening – while also producing a cleaner finished seed.

In our Wizard, the curves look something like this:



Using a narrow central bin and two splitters set at 8" and 12", we split the stream into three fractions. The close fraction is almost 100% good seed with no sticks. The farthest fraction is almost 100% light seed and sticks with no good seed. The middle fraction is a mix. The middle fraction is then re-winnowed, and the stream fractionates a second time along the same probability curves. With each pass, the volume of the middle shrinks by about 50%, and about 50% of the good seed in the middle falls in front of the first divider and is recovered. If we continue to re-winnow the middle five times, we can recover over 98% of the good seed while removing nearly all of the sticks and light seed.

# of passes	% of good seed recovered
1	50%
2	75%
3	87.5%
4	93.8%
5	96.9%
6	98.4%

In reality, there is usually less overlap than in the example, and it is sufficient to re-winnow the middle fraction 3-4 times. When the volume of the middle fraction is small and it appears to be mostly green seed and chaff, then we add it to the chaff bin and call it done.

Winnowing flat seeds with one splitter

One problem with using a two splitter system is that a few seeds (less than 1%) are unlucky enough to bounce off the top of the first splitter, over the second, and into the trash bin. To avoid this, or to winnow lots that are too large for the narrow bin, we have sometimes adopted a different strategy.

1. Set the splitter at position 1 in the above diagram (at which 50-70% of the good seed stays in and all of the sticks/light seed winnow out). Winnow the whole lot, then re-run the light fraction, collecting the heavies in the same bin as before. Set these heavies aside as Lot 1 – this should be around 75-85% of the total seed.
2. Set the splitter at position 2 in the diagram (at which everything that winnows out is trash) and winnow the "2x light" fraction. Discard the trash. Continue to the next step with the heavier fraction.
3. Set the splitter back at position 1, or a little back from position 1 if you want to save lighter-or-smaller-but-still good seed. Winnow the seed from Step 2, then re-winnow the light fraction 2-6 times until you are content to discard the remaining light fraction. The combined heavies from this step – usually 15-25% of the total seed – are Lot 2.
4. If necessary, perform additional screening/cleaning steps on Lot 2 until it is clean enough to combine with Lot 1.