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Effects of Harvest Aids on Sesame (*Sesamum indicum* L.) Drydown and Maturity

William James Grichar, Peter A. Dotray and
Derald Ray Langham

Abstract

Harvest aids are traditionally used to desiccate weeds to improve crop quality and harvest efficiency. Field studies were conducted in Texas to determine the effect of harvest aids (glyphosate, diquat-dibromide, glufosinate-ammonium, and carfentrazone-ethyl) on sesame drydown and yield. The objective was to identify one or more harvest aids that could (1) accelerate drydown, (2) burn-down green weeds, (3) even up a field with varying levels of drydown, (4) stop regrowth, (5) stop vivipary, and (6) prepare to plant a new crop. Other than diquat-dibromide, the herbicides were chosen based on the effect on weeds in other crops. The plan was to apply the herbicides 1 week before physiological maturity (PM), at PM, and 1 week after PM. However, sesame maturity is very sensitive to ground moisture, ambient temperature, and relative humidity. The weather was different in all trials and some stages could not be completed. In two cases, the trials had to be abandoned; however, certain patterns emerged. All the herbicides accelerated drydown compared to the untreated check. Diquat-dibromide and glufosinate-ammonium dried sesame faster than glyphosate and carfentrazone-ethyl. The higher rates of the herbicide dried down the sesame faster than the low rate. Although there were some differences in yields across the three application periods, there was no consistent pattern.

Keywords: carfentrazone-ethyl, diquat-dibromide, glyphosate, glufosinate-ammonium, and sesame yield

1. Introduction

After a crop has matured and completed seed fill, there is no weather event that can increase yield, but there are many weather events that can decrease yield and crop quality. Getting the crop out of the field as soon as possible is a critical part of recovering what has taken months to nurture and develop. Harvest aids traditionally are used to desiccate weeds to improve crop quality and harvest efficiency [1].

In recent years, the use of harvest aids has become important in production of early maturing soybean (*Glycine max* L.) in the states of Kentucky, Mississippi, Missouri, and Tennessee. Soybean leaf retention and presence of green stems and/or green pods in fields where soybean seed are mature (green plant malady) can delay or prevent harvest [2]. Philbrook and Oplinger [3] reported that soybean seed yield loss increased linearly at a rate of 0.2% per day as harvest was delayed out to

42 days. Therefore, harvest aids play an important role in desiccating the crop and accelerating harvest.

Fromme et al. [4] reported using harvest aids to harvest sorghum [*Sorghum bicolor* (L.) Moench] at or after maturity. Harvest aids provide the following advantages: accelerates harvest minimizing weather related damage; prevents or stops seed sprouting; kills the sorghum plant, which is a perennial; provides more efficient and faster threshing; dries out nonproductive suckers and tillers which can delay harvest; reduces differences in harvest maturity across a field; kills late-season weeds; and reduces weed matter in the grain. The application must wait until physiological maturity (PM) to avoid sacrificing yield and reducing test weight. There are three products labelled for use in sorghum: sodium chlorate, glyphosate, and carfentrazone-ethyl. Sodium chlorate provides leaf desiccation but will not kill the plant. Harvest must be timely to avoid regrowth. Desiccation is slowed with low temperatures. Glyphosate is a systemic that will kill the plant and weeds but not accelerate maturity. Carfentrazone-ethyl kills weeds, particularly *Ipomoea* spp. Trostle and McGinty [5] reported good results with the same harvest aids plus diquat-dibromide, which is used only for seed hybrid grain sorghum. Bean [6] reported sodium chlorate is also used for harvesting seed grain sorghum. In North Texas, frost will kill plants without using a harvest aid.

Armstrong [7] reported metsulfuron, 2,4-D, dicamba, glyphosate, and carfentrazone-ethyl and combinations are used as harvest aids for wheat (*Triticum aestivum* L.) to help reduce the amount of green weeds running through the combine. The application must be done after the wheat is mature and different harvest intervals are necessary to allow some of the seed from the weeds to dry so they can be separated by the combine fan. Johnson et al. [8] reported dicamba, glyphosate, and 2,4-D could be used on wheat; however, dicamba and 2,4-D may affect a subsequent double crop. Glyphosate should not be used for seed wheat.

In peanuts (*Arachis hypogaea* L.), Jordan [9] recommended applying carfentrazone-ethyl within 7 days of optimum pod maturity and digging and vine inversion to control *Ipomoea*, which can be a problem at harvest. Chaudhari and Jordan [10] reported carfentrazone-ethyl and pyraflufen-ethyl applied 2 weeks before digging did not reduce the yield or quality of peanuts and controlled *Ipomoea*. Grichar et al. [11] reported 7–52% injury and 4–26% stunting of peanut when carfentrazone-ethyl and pyraflufen-ethyl were applied 35–56 days after planting. They also reported peanut tolerance to carfentrazone-ethyl and pyraflufen-ethyl was cultivar dependent.

Hardke [12] reported sodium chlorate is used as a harvest aid on rice (*Oryza sativa* L.) to accelerate drying in order to accelerate harvest time. Diquat-dibromide, glyphosate, and saflufenacil are used to desiccate canola (*Brassica napus* L.) in Canada [13]. The crop is swathed or harvested direct by using harvest aids to avoid killing frosts that damage the quality of the canola. As opposed to swathing, the advantages of direct harvest are reduced labor and equipment requirements. Diquat-dibromide is a desiccant that will accelerate drydown (4–7 days) but will not control weeds. Glyphosate can dry down canola in warm, sunny days (1–3 weeks), but the primary function is to control weeds. Saflufenacil has some of the functions of diquat-dibromide and glyphosate in terms of contact and systemic activity but none of the harvest aids will hasten maturity and they need to be applied at or after maturity.

Dodds et al. [14] reported harvest aids are used for cotton (*Gossypium hirsutum* L.) defoliation, weed control, and desiccation. All are dependent on the field conditions, weather conditions, and require multiple applications. Defoliation provides the following benefits: removing leaves; eliminating the main source of stain and trash; better lint grades; preventing boll rot; faster and more efficient picker

operation; managing maturity, allowing earlier harvest; increased air movement through the crop canopy, which facilitates quicker drying to allow picking to begin earlier in the day; reducing moisture; and improving storage in modules. There are many products used for defoliation in cotton including tribufos, carfentrazone-ethyl, carfentrazone-ethyl + fluthiacet-methyl, pyraflufen-ethyl, saflufenacil, thidiazuron, thidiazuron + diuron, and ethephon + cyclanilide. Glyphosate is used for killing weeds in the crop while paraquat-dichloride and sodium chlorate are used for desiccation.

Zotarelli et al. [15] reported carfentrazone-ethyl, diquat-dibromide, glufosinate-ammonium, pyraflufen-ethyl, and pelargonic acid are used for vine killing in potato (*Solanum tuberosum* L.) harvest. Killing the vine can improve the quality of some potatoes, but used incorrectly, the harvest aids may reduce the quality. Fleury [16] reported diquat-dibromide, glyphosate, carfentrazone-ethyl, and carfentrazone-ethyl + glyphosate are used to desiccate chickpeas (*Cicer arietinum* L.) in Canada. Proper size and color are critical for marketing chickpeas; thus, the crop needs to be mature before using harvest aids. Direct harvest is preferred over swathing because the peas will not cure well in the swath. The cooler nights and shorter days increase the number of days to drydown. Frosts may desiccate the crop without the use of harvest aids. Diquat-dibromide and carfentrazone-ethyl will accelerate drydown while glyphosate will not accelerate drydown. Glyphosate and carfentrazone-ethyl should not be used on chickpea that is to be used for planting seed since they will affect the germination.

In reviewing the information on other crops, there are certain points that pertain to using harvest aids or dessicants that have been studied for sesame (*Sesamum indicum* L.): glyphosate, paraquat-dichloride, diquat-dibromide, glufosinate-ammonium, carfentrazone-ethyl, and pyraflufen-ethyl.

- Harvest aids accelerate the harvest of a crop thereby reducing losses from inclement weather.
- Harvest aids should be applied at or after PM to avoid crop and/or quality loss. Harvest aids will not mature immature seed. The authors have observed that the harvest aids stop all growth on the sesame plant and appear to freeze the seed fill; however, this has not been confirmed in controlled experiments. Although the seed will not increase in weight, it is a living organism and may put on seed color and dry the placenta attachment.
- Harvest aids work better in warm, dry weather than in cold, cloudy, rainy weather. Depending on the temperatures and length of time in subfreezing weather, frosts will kill the sesame and not require harvest aids. Frost generally does not harm seed quality; however, hard freezes may affect the quality. M.L. Kinman (personal communication, 1982) related that in Nebraska a hard freeze killed sesame. When the seed was harvested, it appeared normal, but within a few days the free fatty acids increased quickly rendering the crop unmarketable. The effects of the cold are dependent on the length of time with freezing temperatures, the temperature itself, and the moisture in the seed.
- Harvest aids can help kill weeds facilitating combining and producing a drier crop. In the USA, harvesting sesame during 6% moisture is critical for storage in silos. Sesame has approximately 50% oil, and under high moisture, like other oilseeds, can catch fire in silos. Most of the world can harvest sesame at higher moisture levels because the seed is stored in jute bags that breathe. In harvesting sesame seeds that are 6% moisture, if there are moist weed stems,

leaves, and/or seeds in the bin, the moisture will transfer from the weeds to the sesame [17]. Extensive work in Venezuela to dry sesame by passing it through dryers showed that it was too expensive and that if more than 1% of moisture was removed per pass through the machines, the seed quality deteriorated to an unmarketable level (MAVESA representatives, personal communication, 1983).

- Glyphosate, carfentrazone-ethyl, and pyraflufen-ethyl are non-selective herbicides that will kill the sesame and the weeds; however, they are not desiccants. Among these, glyphosate is a better weed killer. Glyphosate should not be used for seed sesame because it can affect the germination.
- Paraquat-dichloride and diquat-dibromide are desiccants and may not kill weeds. They are based on contact with the sesame surface.
- Glufosinate-ammonium is a non-selective herbicide, but also will dry the sesame down at a comparable rate to the desiccants.
- Tolerance to some herbicides is cultivar dependent.

2. Phenology of sesame

Sesame is a survivor crop. For 5500 years it has been planted by subsistence growers in areas that will not support the growth of other crops or under very difficult growing conditions with drought and/or high heat. In some countries, it is grown after the monsoon season on residual moisture with no rains during the production stage while in other areas it is grown during the monsoon season and subject to daily rains during the growing season. In several countries, it is the last crop that can be grown at the edge of deserts where no other crops grow. Very little sesame is grown under high input conditions [18].

There are four phases in the phenology of sesame: vegetative, reproductive, ripening, and drying and there is a tremendous amount of variability in these phases [19]. Sesame is an indeterminate species, and thus, there is an overlap between the reproductive, ripening, and drying phases [18]. Since this chapter deals with sesame desiccation only the ripening and drying phases will be discussed.

Technically, as an indeterminate species, sesame is in the ripening stage from the mid-bloom stage through the full maturity stage. Sesame starts self-defoliation in late bloom stage and leaves have mostly fallen off by the initial drydown stage. As the plant stops flowering and matures, the leaves will drop starting at the bottom of the plant. In some fields, the upper leaves can remain attached providing some photosynthesis for seed fill in the upper capsules. Generally, leaves will turn yellowish green before dropping [18].

The character of leaf drop is very important for mechanical harvest and for using harvest aids. There is world germplasm where the leaves do not drop and can remain green even with a dry, open capsule in the leaf axil. Through plant breeding, the ability to self-defoliate has been incorporated into germplasm in the Americas starting in Venezuela from the mid-1940s [20].

At PM, 75% of the capsules on the main stem have seed with final color (darker than the milky white of the immature seed) as shown in **Figure 1**. Most of the seed grown for edible purposes is a light color, but there are cultivars with brown and black seed. The darker colors at PM are easy to distinguish from the milky white immature seed. Physiological mature seed also will have a brown tip where the



Figure 1.

The capsule on the bottom has seed that is milky white and is not mature. The capsule on the top has seed with final color (Photo: J. Riney).

placenta attachment has dried, and in many varieties, the capsules also may have a dark seed line on one side as shown in **Figure 2**. However, there is world germplasm where the seed line is present but not visible without a magnifying glass.

There are cultivars where the yellowish green color of the capsule will indicate that the seed inside the capsule is at PM. However, there are other cultivars where the capsules are dark green with PM seed inside, and still other cultivars where the capsules are a pale yellow with immature seed inside. Before using capsule color to tell PM, the grower must be familiar with the cultivar.

The concept of PM in sesame was developed in the 1950s (M.L. Kinman, personal communication, 1982) to determine the earliest date that the plants could be cut and still harvest over 95% of the potential yield. When the seed has the final color, the seed can germinate. If the sesame is cut at PM, most of the seed with a greater than 75% darker color will continue maturing sufficiently for germination

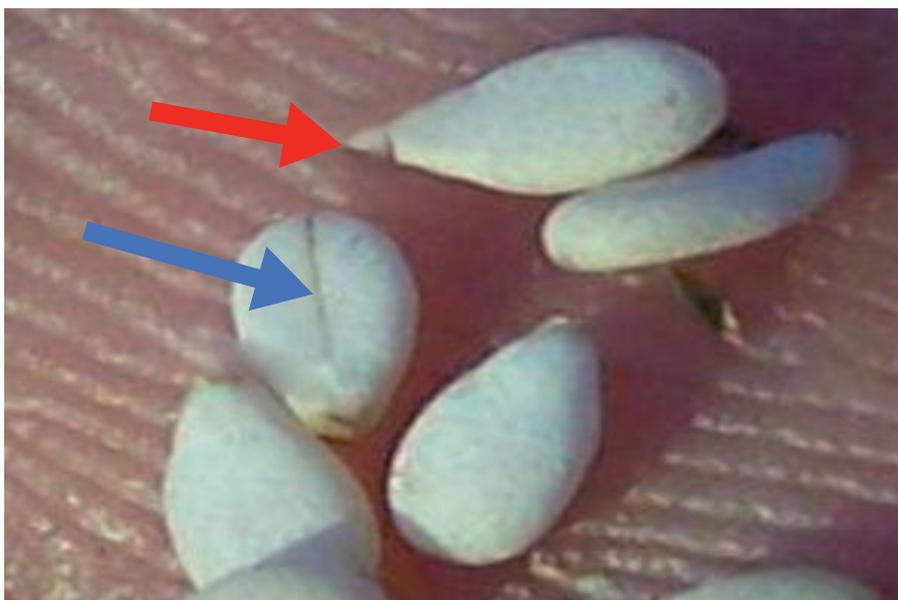


Figure 2.

PM seeds have a brown tip (red arrow) where the placenta attachment has dried and on one side of the seed, a seed line is visible (blue arrow) (Photo: D.R. Langham).

but may be lighter in weight. Even in a fully mature plant, the seed weight produced at the top of the plant is lower; however, this loss of seed weight does not seriously affect the potential seed yield of the plant. Physiological maturity is important in the northern US crop where there is a potential for an early frost or freeze. After PM, most of the potential yield can be harvested, even if the plants were terminated by cold temperatures. In south Texas, the rule of thumb is that PM moves up 6–7 node pairs per week below the 75% PM level, and 4–5 node pairs per week above the 75% level. At higher latitudes where night temperatures are cooler, the progress of PM is 3–4 node pairs per week below the 75% level and 1–2 node pairs above it. The threshold temperature for growing degree days of sesame is 16°C. When night temperatures go below the threshold, it takes longer for the crop to mature. Physiological maturity also delineates the earliest time that harvest aids should be applied; applying them earlier will reduce potential yield.

The drying phase is divided into three stages: full maturity, initial drydown, and late drydown. Full maturity occurs from PM until 90% of the plants have all seeds mature. This stage usually occurs from 107 to 112 days after planting and lasts for approximately 1 week. With direct harvest, without the use of harvest aids, this stage is not important. With harvest aids, the plants will be killed, and the seeds will no longer fill. At the end of this stage, the plants will have the highest potential yield and can be terminated to accelerate drydown. However, since the capsules in the top 2–3 node pairs contribute little seed, the practical time to apply harvest aids may be at some point between PM and when all seeds are mature.

The initial drydown stage occurs from the time all seeds are mature until the sesame plants have one dry capsule. This stage typically occurs 113–126 days after planting and can last for up to 2 weeks. This is a unique stage for most sesame that is grown in the Americas. In the world germplasm, a few cultivars have dry capsules with a green leaf in the same leaf axil, and many cultivars have a dry capsule when the top of the plant is still flowering. As a result, growers cut the plants to prevent seed loss and create a situation where some of the seed is mature and other seed is immature. In the Americas, the capsules do not drydown and open until flowering is complete and the majority of seed fill is complete. This character is described as “delayed shattering” (W. Wongyai, personal communication, 1998). Since sesame is basically indeterminate, the ability to stop flowering is difficult. There is germplasm that will stop flowering based on daylength; others that will stop based on cold nights; but most stop when they run out of moisture and/or fertility. The only problem with the latter germplasm is potential regrowth, which will be discussed later. A potential problem with delayed shattering is vivipary, which also will be discussed later.

The main stem will generally have dry capsules before the branches; however, the branches will generally drydown before the main stem. The lower capsules dry first with the top capsules drying last. There are some cultivars where the bottom capsules at the 2–3 node pairs drydown late even though the seed is at PM. Parts of the stem will dry before all the capsules are dry.

The late dry-down stage occurs from the time of the first capsule drydown until enough dry-down has occurred to produce 6% or less moisture seed. The first capsule drydown usually occurs 127 to 146 days after planting and the late dry-down stage can last up to 3 wks. If the reproductive phase is shorter because of a lack of fertility, the first capsule drydown will occur a shorter time from planting but will not necessarily change the length of time of the late-drydown stage. However, if the reproductive phase is shorter because of a lack of moisture, the first capsule drydown will have a shorter time from planting and a shorter length of time of the late dry-down stage.

Phase	Days from planting		Length of phase, days	
	Range	Mean	Range	Mean
Vegetative	29–59	42	29–59	42
Reproductive	56–116	89	16–70	47
Ripening	77–140	108	(14) ^a –54	11
Drying	102–181	150	11–57	38

^aIn some lines, there are dry capsules above green leaves while the upper part of the plant is still flowering creating a negative range.

Table 1.
 Range of days in phases for world germplasm.

The above paragraphs show nominal days for one cultivar in the USA. There is a range in the world germplasm planted in the USA (**Table 1**).

Generally, if a cultivar starts flowering early, it will also stop flowering, mature, and dry early. The point is that if a crop is left in the field to drydown without harvest aids, it takes about 5–6 weeks to be dry enough for a combine to harvest. If it is in the rainy season, it could take longer.

3. Shattering nature of sesame

Due to the shattering nature of the capsules, in most of the world, the sesame needs to be cut when green and shocked (stacking in bundles) so less seed will fall out as the plants dry (**Figures 3** and **4**).

Growers will cut the plants before the capsules start opening. Over 99% of the sesame harvest in the world involves some or total manual labor to cut the sesame, and no plants are left standing to dry in the field. Therefore, most of the sesame is harvested during or at the end of the ripening phase. Once shocked, the capsules will start drying and opening. Since the sesame is stacked and in a shock, which does not bend in the wind, most of the seed will stay in the capsules with some falling out of the top. In a commercial field in Venezuela, the author examined shocks that



Figure 3.
 The plants are cut before the capsules start drying even though they have leaves and are not completely mature to the top (Photo: D.R. Langham).



Figure 4.
The plants are placed in shocks to dry. The leaves shrivel quickly, but it will take about 2–3 weeks to dry, particularly in center of shock (Photo: D.R. Langham).

were about 75% dry and found that about 10–15% of the seed had fallen out. That evening, it rained about 10 mm, and two days later the outer bundles in the shock had lost 20–40% of the seed, while the inside bundles which had not been wet were still at about 10–15% loss. **Figure 5** shows a similar Mexican commercial variety after a rain. Shattering is necessary for a manual harvest (**Figure 6**) where minimal force is used to get the seed out of the capsules.

Since the 1940s, the goal in Venezuela and the USA has been to completely mechanize the sesame harvest. Leaving a shattering cultivar in the field to harvest



Figure 5.
More seed shattered out than usual with some capsules still green because of rain (Photo: D.R. Langham).



Figure 6.

Shattering is essential to release seed as in this photo. Many growers hold the sesame plant upside down and hit with an implement. Some seed is lost while drying in the shock; other seed is lost in handling the sesame from the shock to the threshing area but upon threshing 95–100% of the remaining seed is collected (Photo: N. Smith).

direct may lead to as much as 90% loss of seed as discovered in 1978–1980 with attempts to harvest shattering varieties left to dry in the field.

In the 1940s, D.G. Langham [20] harvested sesame by using a binder to cut and bind the sesame at maturity. The sesame was manually shocked and when dry, the bundles were thrown into the combine header. Langham [21–23] discussed the history of improving shatter resistance in the USA. Basically by 1982, there was enough shatter resistance to be able to swath sesame into a windrow and leave it on



Figure 7.

Improved non-dehiscent capsule. These capsules hold their seed better and will still release it in the combine. This photo was taken on Dec 17 when the crop could have been combined the first week of Oct. The seed is still in the capsules 76 days after the plants were dry enough for combining (Photo: D.R. Langham).

the ground instead of shocking it manually. The windrows were harvested with a combine equipped with a pickup attachment. By 1988, the shatter resistance had improved to the point where the sesame could be left in the field to dry and then cut. The goal had been to have the seeds stay in the capsules until the combines arrived and then release the seed in the combine with a minimum of force. Improvements continued with the development of non-dehiscent sesame [24, 25] and later improved non-dehiscent sesame [25]. The seed would stay in the capsules through wind and rain even after the plants were dry enough to combine (**Figure 7**).

4. History of sesame harvest aids

Gollifer and Radley [26] studied the use of diquat-dibromide (a desiccant) at 3.5 L ha^{-1} and endothal (a defoliant) at 8.2 L ha^{-1} using the Venezuela 51 sesame variety in Trinidad at 78 and 88 days after planting. These applications reduced yield, moisture, and oil content. For the first application there were reductions in sesame yield (35%), seed weight (12%) and oil content (14%). Also, endothal reduced germination 16%. There were no appreciable differences at the 88 day after planting application between the two herbicides. The diquat-dibromide was a good desiccant while the endothal was not an effective defoliant.

Perez and Gonzalez [27] evaluated 1% paraquat-dichloride as a harvest aid compared to the untreated check using one variety (Morada indehiscente) at three timings in Venezuela. They concluded that there was no difference in yield, but there was in oil content.

Urdaneta and Mazzani [28] studied the effect of diquat-dibromide at 1.5 and 2 L ha^{-1} with different surfactants (JF-4825, JF-4826, and Agral 90) applied 96 and 103 days after emergence (DAE), using one variety (Aceitera R) in Venezuela. They concluded that diquat-dibromide at 1.5 L ha^{-1} resulted in a higher yield than at 2.0 L ha^{-1} ; yield from the 103 DAE application was greater than the 96 DAE application; there were differences in the surfactant used; harvesting plots without a harvest aid at the same time as the application of harvest aids yielded less than the application of the harvest aids; and there were no differences in germination of the seed harvested from treated and untreated plants.

Lee [29] sprayed two concentrations (0.3 and 0.5%, v/v) of diquat-dibromide on one variety in South Korea. Both concentrations reduced sesame moisture content and increased capsule dehiscence. He concluded diquat-dibromide could be used as a harvest aid to accelerate desiccation up to 2 weeks from normal field conditions.

In South Korea, Han et al. [30] applied diquat-dibromide and paraquat-dichloride at 250, 500, and 1000 ppm on sesame 3 days or 3 h before cutting the plants. The moisture content decreased rapidly while yield and germination were not different from untreated check. There were no detectable diquat-dibromide or paraquat-dichloride residues when sprayed at 250 ppm 3 days before cutting but there were higher residues for all other concentrations and for the 3 h before cutting application. There was 25% less labor required in threshing the diquat-dibromide and paraquat-dichloride treated plots as opposed to the untreated and 100% of the seed was recovered in 9 days as opposed to 12 days for the untreated.

In Australia, Bennett [31] studied the effects of diquat-dibromide applied 81, 86, and 89 days after planting (DAP) and rates ($1.2, 2.2, \text{ and } 4.5 \text{ L ha}^{-1}$) in 1992 and 1993 using the sesame variety, Yori 77. He concluded that diquat-dibromide dried the sesame quicker than natural drydown and stem moisture was higher than the seed moisture. The greener stem could be a problem in combining in that the sap from the stems could coat the seeds and give them a bad flavor. There was less sap when the stems reached 10% moisture; however, it could take an additional 7 days

for the stem to reach this moisture level leading to more seed loss in the field. Also, desiccation did not have an effect on defoliation, and the ability to harvest earlier through desiccation increased seed yield. In a grower book, Bennett et al. [32] recommended a diquat-dibromide application of 3 L ha⁻¹. This application rate reduced shattering but seed loss was still evident even while waiting for sufficient drydown to spray (**Figure 8**). Also, there was still more loss when the cutter bar struck the sesame and the sesame was being moved by the auger into the feeder housing of the combine.

Bennett and Routley [33] studied diquat-dibromide at 0, 1.4, 2.6, and 5.3 L ha⁻¹ and time of application (97 DAP with 40% green capsules, 103 DAP with 18% green capsules, 109 DAP with 0% green capsules, and untreated) in the 1993 and 1994 growing season using the sesame variety, Y1:44. Results indicated that application rates of 2.0 L ha⁻¹ were cost effective and that time of application should be between 20 and 40% green capsules. They also concluded that desiccation was a risk management tool. Sesame naturally drying down can be exposed for 30–40 days of various weather conditions, including rains and high winds, while a desiccated crop has a drydown of 7–10 days and, therefore, less of a chance of being exposed to inclement weather conditions. Also, desiccation allows the grower to plan for contract harvesting and trucks.

Mazzani [34] summarizing sesame research in Venezuela stated after almost 30 years of research and grower experience, the recommendations were to use diquat-dibromide at 1 kg ha⁻¹ at normal cutting time, which resulted in only a 15% lower yield over the untreated. Applying diquat-dibromide at 2 kg ha⁻¹ a week earlier than normal cutting time resulted in 97% seed loss due to immature seeds. The desiccation system is 4–8% of the cost of traditional system of cutting, binding, and shocking. Mazzani (personal communication, 1999) said that the timing of the herbicide application required grower experience of the sesame maturity stage based on capsule color and variety instead of number of days from emergence. Also, combining after using diquat-dibromide could be a bit earlier than the traditional method. Using the traditional shocking method, the inner bundles in the shocks take longer to drydown resulting in high risk, since the start of the monsoon season can occur while the sesame is still in shocks. One of the major advantages of using desiccants is that there is less manual labor available at harvest for cutting and shocking. On the negative side, the use of desiccants may produce less yield than the traditional method, particularly if there is a wind during drydown, which may cause



Figure 8.
Sesame on the ground even before combining from using dehiscent varieties (Photo: M. Bennett).



Figure 9.
(a) and (b) Spraying of mature sesame with diquat-dibromide to drydown the sesame for direct harvest (Photos: S. Araujo).



Figure 10.
Combining sesame in various countries. US (Photo: J. Riney), China (Photo: H.Y. Zhang), Brazil (Photo: V. Queroga). (a) USA; (b) China; (c) Brazil.

some seed to shatter or in the case of severe winds most of the seed to shatter. Some growers (L. Jimenez, personal communication, 1998) who have large plantings use both methods since all the fields may be ready for harvest at the same time and there is not enough labor to cut all the sesame at the same time. However, in years when there is asynchronous maturity and labor is available, they prefer cutting instead of applying a harvest aid.

Currently in Venezuela, Araujo [35] reported that two applications of diquat-dibromide at 2 kg ha^{-1} are applied a week apart (**Figure 9a** and **b**).

In the USA, glyphosate has been approved for use as a harvest aid by the Environmental Protection Agency (EPA) and it is used extensively for harvest in the southern USA (**Figure 10a**). In the northern latitudes, glyphosate is not as effective because of possible low temperatures at harvest. In addition, in the northern areas, there are normally frosts or freezes that accelerate drydown.

P. Bazyar (personal communication, 2018) reported diquat-dibromide is currently used as a harvest aid in Iran. Diquat-dibromide is sprayed when 65–75% of the capsules have changed color from dark green to bright green and the crop is harvested with a wheat combine. H.M. Miao (personal communication, 2019) reported either paraquat-dichloride or ethylene (1.5 kg ha^{-1}) are used as a harvest aid in direct harvest sesame in Xinjiang Province in China (**Figure 10b**).

V. Queiroga and N. Arriel (personal communication, 2019) reported paraquat-dichloride or diquat-dibromide are used as a harvest aids in direct harvest sesame in Mato Grosso, Brazil (**Figure 10c**).

5. Rationale for harvest aids in the USA

In the USA, all the sesame is mechanically harvested with a combine and the use of a harvest aid can help facilitate harvest in most cases. In northern latitudes, with

cool evenings, harvest aids are slower acting and a frost or freeze will dry down the sesame just as effectively as a harvest aid. There are six reasons to consider a harvest aid for use in sesame:

- 1. Accelerate drydown.** This is basically using the idea that no weather event can increase yield after the crop is mature, but there are many weather events that can reduce yield. Natural drydown averages 5–6 weeks and inclement weather can prevent a combine from entering a field for as many as 8–9 weeks. With harvest aids, the drydown is 1–2 weeks depending on heat and humidity. In the USA, sesame is grown from the southern-most tip of Texas to the Kansas border. Planting starts in late March in the south and ends in early July in the north while harvest starts in late August in the south and ends in December in the north. Into the fall and early winter, the daylength shortens and temperatures cool with a pattern in most areas of increased rainfall. In south Texas, harvest aids will accelerate the drydown and avoid poor weather (particularly the threat of hurricanes along the Texas coast). In the northern part of Texas, Oklahoma, or Kansas, frost will generally kill sesame without having to use harvest aids. There is a gray zone in between where in some years, harvest aids are used and in other years the growers will wait for the frost, particularly on late planted sesame.
- 2. Burn-down green weeds.** Green weeds can add moisture to the sesame seed in the combine bin. As stated above, moisture needs to be around 6% at harvest. Sesame can be dry and yet in the combine bin and the truck, moisture from the weeds can be absorbed by the sesame seed. The two major weed problems are *Amaranthus* spp. and *Echinochloa crus-galli*. *Amaranthus* spp. has a lot of moisture in the stems while green *E. crus-galli* seeds will not blow out the back of the combine and will go into the bin with a remarkable amount of moisture. Certain weeds can be a serious problem in processing sesame. A large percentage of any weed seed can be a problem when cleaning sesame even though it may be as small as *Amaranthus* spp. or as large as the seed of *Ipomoea* spp. Certain weed seeds such *Sorghum halepense*, *Solanum rostratum*, *Coreopsis* spp., *Salsola tragus*, *Salvia reflexa*, *Chenopodium album*, and *Kochia scoparia* are more of a problem, even in small quantities. No one wants any seed, other than sesame, on top of their hamburger bun. Although much of *Sorghum halepense* seed is a different size compared to sesame, the elongated seeds of *Sorghum halepense* can go through the round holes of the cleaner head first. Once through the cleaner, they have a specific gravity close to sesame seed and cannot be easily separated on the gravity table. Finally, a portion will be close enough in color to sesame that it will not be separated by the color sorter. *Solanum rostratum* is the same size and specific gravity as sesame and the seed may not be cleaned out of the sesame. *Salvia reflexa* is a special problem in that when it contacts water, the seed coat will swell into a sticky gelatinous substance that will clump sesame seeds together. As mentioned by Bennett [31], sap from some weed stems can coat the seeds and give them a bad flavor.
- 3. Even up a field with varying levels of drydown.** Many fields have low spots that can still be green while high spots are drying. The difference between the stage of the driest and the stage of the greenest and the proportion between the dry and the green must be considered. In most cases, the “green portions” are 1–2 weeks behind the ‘dry portions’. In this case, the dry portions should go past PM until the capsules start drying down to allow the green portions to mature further increasing the yield potential. However, if the differences are

more than 2 weeks, the field should be harvested at different times. On the other hand, if the proportion of green is very small, it is not practical to harvest at different times, and the yield loss in the green portion should be acceptable.

There is no set formula to determine the solution. Like most farming decisions, it is up to the judgement of the grower. In some cases, some seed maybe planted in dry soil and only germinate after a rain resulting in two growth stages. The decision to harvest is therefore not clear. A rain 1–2 weeks after planting is different from a rain 4–6 weeks after planting. As stated above, the proportion is also important. If most of the field is of late germination, the early plants should be ignored. In a higher proportion of early germination, the older plants will have a more aggressive root system, shading the younger plants, and therefore the younger plants will act like weeds. The younger plants will not produce a substantial amount of seed and should be ignored in the decision as to when to use harvest aids. Using glyphosate on uneven fields will kill all the sesame and the stage of seed fill will be frozen. Killing sesame while leaves are still attached does cause some problems with dry leaves (particularly the petioles) being broken up and entering the combine bin as foreign matter.

4. Stop regrowth. Certain sesame varieties have a propensity for restarting growth and flowering after the main stem has stopped flowering. Regrowth usually occurs in areas where conditions are such that the plants have run out of moisture and/or fertility. If there is rain, some varieties will form branches at the bottom of the plant and these will flower and set capsules while the main stem and the older branches will not start flowering again (**Figures 11 and 12**). There are three types of regrowth: top (restarts at the tops of the main stems), middle (branches emerge from the middle of the main stem), and bottom (branches start in the axils of other branches or below the branches). There are varieties that show spontaneous branching whereby branches start in the middle of the capsule zone under capsules. However, this is not considered regrowth because spontaneous branches begin during flowering and stop flowering before the top of the main stem stops flowering. In regrowth,



Figure 11.
Bottom regrowth (red arrow) below the lowest capsule (yellow arrow).



Figure 12. Middle regrowth (red arrow) in the middle of the capsule zone. Note: the sesame without regrowth is dry. Both of these are minor regrowth which has already stopped flowering. In some cases, there may be over 20 capsules on each branch.

capsules on the original plant will dry down while it may take another 60 days for the regrowth capsules to mature and dry out. Since most of the yield is in the old growth, it can shatter while waiting for the regrowth to dry to be combined. Combining when the original plant is dry and the regrowth is green is similar to the weed situation in that it will introduce moisture into the combine bin. Using glyphosate as a harvest aid will kill the plant and stop the regrowth.

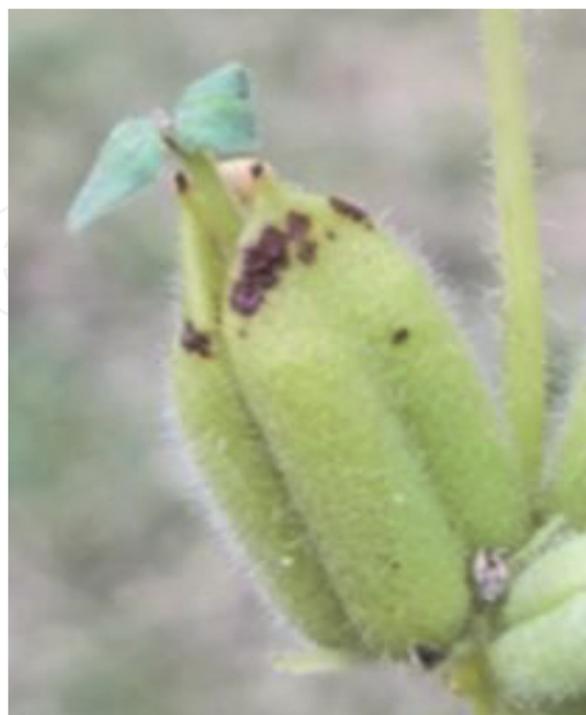


Figure 13. In many areas of the world, seed will germinate inside the green capsule when the temperatures are high. Even if only the top seeds germinate, the roots from the seedlings will trap the seeds below, preventing them from being harvested (Photo: D.R. Langham).

5. Stopping vivipary. Under some conditions, there is vivipary in sesame—the seeds will germinate in the capsules (**Figure 13**). Not only are the germinated seeds lost, but the roots of the seedlings bind the rest of the seed and keep it in the capsule when combined.

Many growers have felt that the opening of the capsules allows water to enter and germinate the seed. The opposite occurs. Seeds in open capsules do not germinate because the moisture will evaporate out of the capsule before the seed can germinate. Vivipary occurs in closed capsules. It is believed that this is a dispersal mechanism to open the capsule and allow the seed to fall out. The exception in dry capsule is if the tip of the capsule has a minimum opening. Not only can there be vivipary, but there is also the danger of mold forming inside the dry capsules. When there is vivipary, the seedlings persist as the capsules continue to dry. Vivipary is controlled genetically through seed dormancy with some varieties having a greater propensity than others. Vivipary is rare in the USA because normally at harvest the night temperatures are below 15°C, the minimum germination temperature. Glyphosate will kill the sesame plants and stop vivipary.

6. Prepare to plant a new crop. In many areas of the USA, wheat and sesame are double cropped. The earlier the sesame is harvested, the earlier the wheat can be planted.

6. Harvest aid research in the USA

The first testing in the USA was done by D.M. Yermanos (personal communication, 1982) in California in the mid-1970s. He used paraquat-dichloride; however, the varieties at the time were shattering and leaving the plants standing even for 2 weeks longer resulted in lower yields than cutting and drying in shocks. In addition, a paraquat-dichloride application at harvest would not be acceptable in the US food market since there would be the potential to get the paraquat-dichloride on the seed in an open capsule. Paraquat-dichloride, a restricted use pesticide, is considered to have oral, dermal, and inhalation toxicity to humans (skull and cross bone symbol) [36]. In 1975, St. Andre et al. [37] reported that diquat-dibromide, either alone or in combination with products called ‘Bolls Eye’ or ‘Dinitro’, had potential to serve as dessicants in sesame.

There was no additional harvest aid research until 2003 after the 2002 harvest season showed that weather had significantly affected sesame yield in some areas. Getting the crop out of the field earlier became a priority. Many felt that sesame should follow the cotton harvest pattern of first defoliating the plants and then drying the sesame down. In 2003, test strips in a nursery were sprayed with paraquat-dichloride, diquat-dibromide, glyphosate, carfentrazone-ethyl, and pyraflufen-ethyl when the plants had stopped flowering but still had their leaves. Paraquat-dichloride and diquat-dibromide caused spotting on the leaves where the drops contacted the plants; however, this did not kill the sesame. The amount of spotting was greater at the top of the plant than at the bottom. Glyphosate killed the sesame but retained its leaves and did not mature the seed in the upper capsules. Carfentrazone-ethyl and pyraflufen-ethyl produced no visible effect.

At this point in time, it was thought that the sesame plant had to have the leaves to allow the herbicide (particularly glyphosate) to be absorbed and translocated to the roots. However, sesame is different from cotton in that there is sesame germplasm that will allow plants to self-defoliate as the capsules mature. Parallel to this, a

grower sprayed glyphosate on a sesame crop with no leaves to eliminate volunteer sorghum and weeds within the crop and the glyphosate also killed the sesame without leaves. It was postulated that the capsules and stems absorbed the glyphosate and it translocated to the roots. In addition, the lack of leaves allowed the glyphosate to reach the lower stem and capsules. Subsequent testing was done at PM when the leaves had dropped naturally.

With the above field observations, research was conducted to answer some questions. Previous experience, when sesame was swathed at maturity, had shown that if the sesame was cut earlier than PM, yield and quality of the seed would be reduced. Other experience had shown that even though sesame had been bred with improved non-dehiscence, weather could reduce the yield. Therefore, the objective of this research was to identify herbicides that may help promote desiccation of sesame and the effect of these herbicides on sesame development and also determine the optimum application timing to determine the amount of loss if the harvest aid was applied too early or too late.

7. Field studies

The weather was variable and it was very difficult to predict when PM would occur to schedule the sprayings. As mentioned previously, PM proceeds between 1 and 7 node pairs per week depending on the weather. The variability can be exacerbated when planting sesame under pivots. In several years of successive droughts, the moisture below 30 cm was depleted and the soil was very dry; therefore, no roots could penetrate the soil. Water in Texas can be scarce and when irrigating with an overhead irrigation system pivot, the minimum amount necessary is used. The results are roots that are often in the top 20–30 cm of soil. Irrigation is terminated when the crop stops flowering. If there is hot weather with low humidity, the sesame can go to drydown in less than 2 weeks instead of the normal 5–6 weeks. One harvest aid experiment in Uvalde was cancelled because the plants were in the late drydown stage at the predicted 1 week before PM. In another study, near Lorenzo, Texas, the crop was sprayed at least 2 weeks before PM because a cold front had delayed PM and the plants still had their leaves.

7.1 Materials and methods

7.1.1 Research sites

Field studies were conducted from 2006 through 2008 near Uvalde (29.468° N, 99.7061° W) in the south Texas sesame growing region and near Lorenzo (33.6684° N, 101.5354° W) in the Texas High Plains sesame growing region to evaluate sesame response to harvest aids. Soil type at Uvalde was a Winterhaven silty clay loam (fine-silty, carbonatic, hyperthermic Fluventic Ustochrepts) with less than 1.0% organic matter and pH 7.8. Soil type at Lorenzo was an Amarillo sandy clay loam (fine-loamy, mixed, thermic Aridic Paleustalf) with 0.8% organic matter and pH 7.8.

7.1.2 Herbicides and application

A randomized complete-block experimental design was used, and treatments were replicated three times. Treatments consisted of a factorial arrangement of four herbicide treatments (carfentrazone-ethyl, diquat-dibromide, glufosinate-ammonium, and glyphosate) at two rates. A non-treated control was included for comparison. Herbicides included glyphosate (Durango® Herbicide,

Dow AgroSciences, 9330 Zionsville Rd., Indianapolis, IN 46268 in south Texas and Roundup Weathermax, Bayer CropScience, 800 N. Lindberg Blvd., St. Louis, MO 63167 in the Texas High Plains) at 0.63 and 0.84 kg ae ha⁻¹; diquat-dibromide (Reglone® Herbicide, Syngenta Crop Protection, Inc., P.O. Box 18,300, Greensboro, NC 27409) at 0.28 and 0.56 kg ai ha⁻¹; glufosinate-ammonium (Bayer CropScience) at 0.47 and 0.58 kg ai ha⁻¹; and carfentrazone-ethyl (FMC, 1735 Market St., Philadelphia, PA 19103) at 0.018 and 0.035 kg ai ha⁻¹. Carfentrazone-ethyl was only evaluated in 2006 and 2008 at Lorenzo.

These herbicides were applied prior to physiological maturity (PRE PM), at physiological maturity (PM), or after physiological maturity (POST PM). The PRE PM treatment was not applied in 2006 at Lorenzo or 2007 at Uvalde due to sesame development that was farther along than anticipated. At Lorenzo, the PRE PM treatments were applied 99 and 103 DAP in 2007 and 2008, respectively; PM treatments applied 97, 105, and 112 DAP in 2006, 2007, and 2008, respectively; and POST PM treatments applied 113, 112, and 121 DAP in 2006, 2007, and 2008, respectively. At Uvalde, the 2006 treatments were cancelled because drydown developed much faster than anticipated. The PRE PM treatments in 2008 were applied 104 DAP; PM treatments were applied 102 and 110 DAP in 2007 and 2008, respectively; and POST PM treatments were applied 114 and 119 DAP in 2007 and 2008, respectively.

In the original concept in designing the experiment, herbicide sprays would be done within 2 weeks: the PRE PM followed by PM a week later followed by POST PM a week later. However, scheduling and weather problems prevented the exact 1 week intervals. Sprayings were postponed when the sesame was wet or rains were imminent.

Plot size was five rows (76 cm apart) by 9.1 m in south Texas (Uvalde) and four rows (101 cm apart) by 7.3 m in the Texas High Plains (Lorenzo). Only the two middle rows were sprayed and the other rows were untreated and served as buffers.

Herbicides were applied in water using a CO₂-pressurized backpack sprayer with either Teejet 11002 DG, TeeJet® 11002DG, or Turbotee 110015 flat fan spray tips (Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) nozzles calibrated to deliver 190 L/ha at 180 kPa at Uvalde and Turbotee 110015 calibrated to deliver 140 L/ha at 207 kPa at Lorenzo.

7.1.3 Sesame plantings, observations, and harvest

The sesame variety 'S29' was planted at Lorenzo in 2006; however, in 2007 and 2008 at both locations 'S32' was grown since it was the main variety used in all sesame growing areas of the US at that time [17]. Planting dates at the Uvalde location were June 2 in 2007 and May 30 in 2008 while at the Lubbock location, sesame was planted May 26 in 2006, June 18 in 2007 and June 26 in 2008. Each sesame cultivar was seeded approximately 2.0 cm deep at 9 kg/ha at both locations.

Sesame drydown was evaluated 7–14 days after herbicide application based on a scale of 0 (no drydown, plants still green) to 100 (complete drydown, no green tissue). Due to the extremely dry conditions at Uvalde in 2008, an accurate assessment of drydown could not be obtained. Plants in each plot were hand-cut, bagged, and threshed with a harvester to obtain sesame yield. Sesame yields were not obtained from the PRE PM and PM diquat-dibromide and glufosinate-ammonium treatments at Uvalde in 2008 because they had been dry long before the other treatments and comparisons were invalid. One of the problems with the methodology was that all plots were harvested at the same time regardless of treatment drydown (other than 2008 as stated above).

7.1.4 Data analysis

Data for percentage of sesame drydown were transformed to the arcsine square root prior to analysis; however, non-transformed means are presented because arcsine transformation did not affect interpretation of the data. Data were subjected to analysis of variance (ANOVA) and analyzed using SAS PROC MIXED with locations and years designated as random effects in the model. A mixed model was chosen because the actual environments experienced at both locations in Texas where the experiments were conducted are unlikely to occur again in the future. Allowing the four environments to be random allows estimates of treatment responses to be made over a range of environments. Treatment means were separated using Fisher's Protected LSD at $P \leq 0.05$. The untreated check was used for yield comparison and a visual comparison for sesame drydown and was included in the drydown and yield data analysis.

8. Results

Since weather conditions and sesame development varied from year-to-year and across locations no attempt was made to combine data across years or locations. Also, in some years (2006 at Lorenzo, 2007 at Uvalde), the PRE PM stage occurred sooner than anticipated and a timely herbicide application was not made. Since drydown in 2008 at Uvalde occurred so quickly due to the extreme drought conditions, an accurate assessment of sesame drydown could not be obtained. An herbicide treatment by application timing interaction was noted in each year for drydown and sesame yield; therefore, data are presented separately for herbicide treatment and application timing.

8.1 Sesame drydown

8.1.1 Lorenzo

In 2006, when the PM applications were compared, diquat-dibromide and glufosinate-ammonium accelerated drydown more than glyphosate or carfentrazone-ethyl (**Table 2**). With the POST PM timing, a rate effect was noted with carfentrazone-ethyl, diquat-dibromide, and glyphosate but not glufosinate-ammonium. The high rates of glyphosate and diquat-dibromide improved drydown 44–54% while the high rate of carfentrazone-ethyl improved drydown 29% when compared with the lower rates while virtually no difference was noted between glufosinate-ammonium rates. The high rate of glyphosate resulted in the greater drydown than other herbicides. All treatments improved drydown over the untreated check. In 2007 at the PRE PM and PM stage, diquat-dibromide at 0.28 and 0.56 kg ai ha⁻¹ accelerated sesame drydown greater than glufosinate-ammonium at 0.47 and 0.58 kg ai ha⁻¹, which was greater than glyphosate at 0.63 and 0.84 kg ae ha⁻¹; however, the high rate of glyphosate and both rates of glufosinate-ammonium performed similarly at the POST PM stage (**Table 2**). Diquat-dibromide at either rate applied POST PM provided $\geq 87\%$ sesame drydown. Sesame drydown with the untreated check was $\leq 39\%$ at all application stages.

In 2008 at the PRE PM stage, diquat-dibromide at 0.28 and 0.56 kg ai ha⁻¹ and glufosinate-ammonium at 0.47 kg ha⁻¹ produced 63–80% drydown while both rates of glyphosate and the untreated check resulted in $< 10\%$ drydown (**Table 2**). Carfentrazone-ethyl at 0.018 and 0.035 kg ai ha⁻¹ was intermediate in sesame

	Carfentrazone-ethyl (kg ai ha ⁻¹)		Diquat-dibromide (kg ai ha ⁻¹)		Glufosinate-ammonium (kg ai ha ⁻¹)		Glyphosate (kg ae ha ⁻¹)		
Stage ^a	0.018	0.035	0.28	0.56	0.47	0.58	0.63	0.84	Check
	%								
Lorenzo									
2006									
PRE PM	—	—	—	—	—	—	—	—	—
PM	12	12	24	28	26	26	15	15	0
POST PM	28	36	26	40	44	46	36	52	16
LSD (0.05)	6								
2007									
PRE PM	—	—	78	84	65	73	12	7	4
PM	—	—	67	74	62	66	13	13	11
POST PM	—	—	87	93	60	59	38	56	39
LSD (0.05)	8								
2008									
PRE PM	14	18	67	80	63	57	4	7	1
PM	18	16	63	70	45	48	14	16	10
POST PM	88	94	97	98	96	98	86	94	28
LSD (0.05)	6								
Uvalde									
2007									
PRE PM	—	—	—	—	—	—	—	—	—
PM	—	—	67	67	70	73	53	57	50
POST PM	—	—	80	80	80	77	67	70	73
LSD (0.05)	7								

^aPRE PM, prior to physiological maturity; PM, physiological maturity; POST PM, after physiological maturity.

Table 2. Sesame drydown (7–14 d after treatment) at Lorenzo and Uvalde as influenced by herbicides.

drydown. At the PM stage, diquat-dibromide at either rate produced the greatest drydown (63–70%), glufosinate-ammonium was intermediate (45–48%) and carfentrazone-ethyl and glyphosate resulted in $\leq 18\%$ drydown. At the POST PM stage, the high rates of carfentrazone-ethyl and glyphosate and both rates of diquat-dibromide and glufosinate-ammonium resulted in $\geq 94\%$ drydown while the untreated check showed only 28% drydown.

8.1.2 Uvalde

At the PM stage, diquat-dibromide and glufosinate-ammonium resulted in 67–73% sesame drydown while glyphosate drydown was no more than 57% and no better than the untreated check (**Table 2**). At POST PM no herbicide treatment was better than the untreated check.

8.2 Sesame yield

8.2.1 Lorenzo

In 2006 at the PM stage, diquat-dibromide at 0.28 kg ai ha⁻¹ and glufosinate-ammonium at 0.58 kg ai ha⁻¹ produced yields that were lower than the untreated check (**Table 3**). None of the other herbicide treatments produced yields that were different from the untreated check. At POST PM, all sesame yields were lower than the untreated check and no differences were noted between herbicide treatments.

Stage ^a	Carfentrazone-ethyl (kg ai ha ⁻¹)		Diquat- dibromide (kg ai ha ⁻¹)		Glufosinate- ammonium (kg ai ha ⁻¹)		Glyphosate (kg ae ha ⁻¹)		Check
	0.018	0.035	0.28	0.56	0.47	0.58	0.63	0.84	
Lorenzo									
(kg ha ⁻¹)									
2006									
PRE PM	—	—	—	—	—	—	—	—	—
PM	650	583	466	525	554	408	670	637	
POST PM	451	412	247	448	448	417	433	327	717
LSD (0.05)					250				
2007									
PRE PM	—	—	1282	1345	1364	1298	1058	1132	
PM	—	—	1357	1383	1409	1361	1245	1139	
POST PM	—	—	1195	1325	1151	1158	1280	1049	1091
LSD (0.05)					191				
2008									
PRE PM	785	890	818	890	946	773	670	818	
PM	753	795	998	964	773	868	762	841	
POST PM	863	829	751	1002	860	836	874	778	851
LSD (0.05)					197				
Uvalde									
2007									
PRE PM	—	—	—	—	—	—	—	—	—
PM	—	—	1535	1657	1562	1602	1645	1444	
POST PM	—	—	1473	1506	1585	1475	1547	1506	1645
LSD (0.05)					NS				
2008									
PRE PM	—	—	—	—	—	—	1344	1330	
PM	—	—	—	—	—	—	1406	1352	
POST PM	—	—	1310	1304	1350	1390	1432	1562	1430
LSD (0.05)					217				

^aPRE PM, prior to physiological maturity; PM, physiological maturity; POST PM, after physiological maturity.

Table 3.
 Sesame yield at Lorenzo and Uvalde as influenced by drydown herbicides.

In 2007 at the PRE PM stage, diquat-dibromide at 0.56 kg ha⁻¹ and both rates of glufosinate-ammonium produced yields that were greater than the untreated check (**Table 3**). At the PM stage, both diquat-dibromide and glufosinate-ammonium increased yield over the untreated check while glyphosate was not different than the untreated check. At the POST PM stage, only diquat-dibromide at 0.56 kg ha⁻¹ increased yield over the untreated check.

In 2008 at any sesame development stage, none of the herbicides improved yields over the untreated check. However, at the POST PM stage, diquat-dibromide at 0.56 kg ha⁻¹ improved sesame yield 29–34% over diquat-dibromide at 0.28 kg ha⁻¹ and glyphosate at 0.84 kg ha⁻¹ (**Table 3**).

8.2.2 Uvalde

In 2007 or 2008 no differences in sesame yield was noted between the untreated check and any herbicide treatment (**Table 3**). In 2008, glyphosate at 0.84 kg ae ha⁻¹ applied POST PM did result in greater yield than glyphosate at either rate applied PRE PM or diquat-dibromide at both rates applied POST PM.

9. Discussion

Since the 1950s study by M. Kinman (personal communication, 1982), there have been no studies to try to define PM. Those studies were based on cultivars that had dry, open capsules at the bottom of the plant while the top was not mature. His criterion was to find the point of maximum yield knowing there is an offset of the weight gained by more seed fill versus the weight loss by shattering. Current cultivars do not have dry, open capsules until after the tops of the plants have completed seed fill. Testing should show the amount of yield lost by spraying 1, 2, 3, and 4 weeks ahead of PM. There is no credible way to show the loss by spraying 1, 2, 3, and 4 weeks after PM because the weather cannot be controlled. Rain, fog, dews, temperature, relative humidity, and wind affect the amount of shattering and lodging. In doing this type of study it is important to test all the phenotypes. Sesame phenotypes can be classified by the amount of branching (no branching, few branches, or many branches) and the number of capsules per leaf axil (single or triple capsule). Over 30 lines were segmented into lower main stem, middle main stem, upper main stem, lower branches, and upper branches with the percentage of seed weight in each of the segments depending on phenotype (**Table 4**). The branches complete flowering and seed fill before the main stem [18]. If one phenotype is chosen for the study and the phenotype does not have branches, there will

Branch	Caps	LMS ¹	MMS	UMS	MS	LBR	UBR	BR
%								
None	1	31.2	37.1	31.7	100.0			
Few	1	27.1	28.8	23.7	79.6	9.9	10.5	20.4
Many	1	22.4	23.5	17.7	63.6	15.9	20.5	36.4
None	3	25.5	41.8	32.7	100.0			
Few	3	19.1	32.5	26.9	78.5	10.6	10.9	21.5

¹Abbreviations: BR, branches; LMS, lower main stem; MMS, middle main stem, UMS, upper middle stem; MS, main stem; LBR, lower branches; UBR, upper branches.

Table 4.
Percentage of seed weight in segments of the plants.

Reasons for harvest aid	Glyphosate (GLY)	Glufosinate-ammonium (GLU)	Carfentrazone-ethyl (CAR)	Diquat-dibromide (DIQ)	Untreated (UNT)
Accelerate drydown	DIQ > GLU > GLY > CAR				No
Burn-down green weeds ^a	GLY > GLU > CAR			No	No
Evening up a field with varying levels of drydown	Yes	Not tested, probably yes	Needs to be tested	No	No
Stopping regrowth	Yes	Not tested			No
Stopping vivipary	Yes	Not tested			No
Preparing to plant a new crop	Yes	Yes	Not sure	Yes	No

^aThere is an exception with herbicide tolerant weeds. There are also some weeds that are killed more effectively by one herbicide, e.g. Ipomoea spp. with carfentrazone-ethyl.

Table 5.
 Performance of herbicides on sesame harvest aids requirements.

probably be a shorter cutting window before there is substantial yield loss by cutting early as opposed to a phenotype with many branches.

These studies led to the US EPA approval of glyphosate as a harvest aid. As a result, glyphosate has been used as a harvest aid on hundreds of thousands of hectares in the last 10 years. Past experience plus these experiments provide an idea of how these herbicides satisfy the requirements for harvest aids for sesame (**Table 5**).

10. Conclusions

The use of herbicides in sesame did accelerate drydown although this did not always result in an increase in yield over the untreated check. However, there was no weather event such as rain, fog, dews, or strong winds during the experiment which would have an impact on the results. Diquat-dibromide and glufosinate-ammonium dried the sesame faster than glyphosate and carfentrazone-ethyl.

With all herbicides, the higher rate dried the sesame down faster.

Efforts should be continued to try to persuade manufacturers to support for registration of diquat-dibromide and glufosinate-ammonium. Even though carfentrazone-ethyl is not as effective as glyphosate, with the present legal battles with glyphosate as a carcinogen, efforts should be made to register carfentrazone-ethyl. Stopping regrowth and vivipary is not an experiment that can be set up because they do not occur in most of the fields or nurseries. However, when a field is found with regrowth and/or vivipary, glufosinate-ammonium, carfentrazone-ethyl, and diquat-dibromide should be tested and glyphosate should be added for comparison purposes.

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Conflict of interest

There is no conflict of interest with any of the authors.

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Author details

William James Grichar^{1*}, Peter A. Dotray² and Derald Ray Langham³

1 Texas A&M AgriLife Research, Corpus Christi, TX, USA

2 Texas A&M AgriLife Research, Lubbock, TX, USA

3 Sesame Research LLC, San Antonio, TX, USA

*Address all correspondence to: w-grichar@tamu.edu

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