



Evaluation of safflower seed size, length (shape), and density in relation to seed vigor and oil content
by David Michael Wichman

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Agronomy

Montana State University

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Abstract:

Stand establishment and weed control are two major problems in dryland safflower production in the Northern Great Plains. Improving stand establishment would improve weed control through competition. Selecting seed that is large and has high density could improve seedling vigor thus improve stand establishment. However, selecting large, high density seed would be selecting lower oil type seed for reproduction.

The purpose of these studies is to evaluate the use of seed size, length (shape), and density of a safflower bulk population in improving seedling vigor while maintaining or improving oil content of the population. To investigate this problem, safflower seed of the 1981 Sidney bulk population, its 1982 progeny grown at Havre, and the cultivars Hartman, S-208, and S-541 grown at several locations, were classified by size, length, density, and evaluated for oil content and seedling vigor. Seed size was based on seed diameter as determined by slotted screens. A laboratory indent cylinder was used to classify seed by length. Seed density classes were obtained using water-alcohol solutions, Caldwell forced air fan, and an Oregon continuous seed blower. Seed oil content was determined by wide-line nuclear magnetic resonance. Emerged seedling weights were used to evaluate seed vigor in field and greenhouse studies.

The large, high density or longer seed, within each seed lot, was found to have more seedling vigor and lower oil content than the small, low density or short seed. Sidney bulk seed in the short class appeared to be more oval in shape and to have less hull in the basal area than the unseparated seed.

The relationship of oil content to seed size, length (shape) and density, when compared across cultivars Hartman, S-208, and S-541, did not follow the same pattern as was found within seed lots. S-541 seed had the highest oil content but it also had the highest seed density and was intermediate to Hartman and S-208 seed in size and length.

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A thesis submitted in partial fulfillment
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APPROVAL

of a thesis submitted by

David Michael Wichman

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for admission to the College of Graduate Studies.

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ABSTRACT

Stand establishment and weed control are two major problems in dryland safflower production in the Northern Great Plains. Improving stand establishment would improve weed control through competition. Selecting seed that is large and has high density could improve seedling vigor thus improve stand establishment. However, selecting large, high density seed would be selecting lower oil type seed for reproduction.

The purpose of these studies is to evaluate the use of seed size, length (shape), and density of a safflower bulk population in improving seedling vigor while maintaining or improving oil content of the population. To investigate this problem, safflower seed of the 1981 Sidney bulk population, its 1982 progeny grown at Havre, and the cultivars Hartman, S-208, and S-541 grown at several locations, were classified by size, length, density, and evaluated for oil content and seedling vigor. Seed size was based on seed diameter as determined by slotted screens. A laboratory indent cylinder was used to classify seed by length. Seed density classes were obtained using water-alcohol solutions, Caldwell forced air fan, and an Oregon continuous seed blower. Seed oil content was determined by wide-line nuclear magnetic resonance. Emerged seedling weights were used to evaluate seed vigor in field and greenhouse studies.

The large, high density or longer seed, within each seed lot, was found to have more seedling vigor and lower oil content than the small, low density or short seed. Sidney bulk seed in the short class appeared to be more oval in shape and to have less hull in the basal area than the unseparated seed.

The relationship of oil content to seed size, length (shape) and density, when compared across cultivars Hartman, S-208, and S-541, did not follow the same pattern as was found within seed lots. S-541 seed had the highest oil content but it also had the highest seed density and was intermediate to Hartman and S-208 seed in size and length.

CHAPTER I

INTRODUCTION

Safflower (*Carthamus tinctorius*), an oilseed crop, is well adapted to dryland production in the Northern Great Plains. Its deep-rooting and soil water depletion characteristics make it an ideal crop for use in crop rotations to control saline seep. Research has shown there is little yield benefit when growing safflower on land that was previously fallowed as compared to recropping [9]. Safflower's adaptation to recropping further increases its effectiveness as a tool in saline seep control.

Stand establishment and weed control are two agronomic problems in dryland safflower production in the Northern Great Plains. These problems are interrelated in that the incorporation of pre-plant herbicides loosens the soil which allows the top 5-10 centimeters (cm) to dry. The loose soil and often dry, windy spring conditions at planting time, April 15-May 15, result in a seedbed unsuited for good germination and stand establishment. The weed problem may be enhanced through lack of crop competition.

Safflower cultivars, capable of emerging from deeper planting depth, which are tolerant of nonincorporated herbicides, would improve stand establishment and weed control.

The objective of these studies is to determine if safflower seed (achene) size, specific density and length can be used as selection tools to maintain or improve oil content while selecting for improved seedling emergence.

CHAPTER II

LITERATURE REVIEW

A seed is the product of its genotype and the environment in which it develops. Kidd and West [30] concluded that the external conditions of one generation may influence the performance of the subsequent generation through its effect on the seed.

Halstead [26] postulated that soybean (*Glycine max* L.) seed size is partially determined by the number of seeds in a pod and its position within the pod. Seeds at the top of the soybean pod have higher oil and lower protein content than the other seeds. [16]. Soybean seeds from the bottom of the plant have higher oil and lower protein content than those from the top of the plant [16].

Similar positions effects and seed size relationship occur in safflower. Seed from the primary head (capitulum) are larger and have lower oil content than seeds from secondary and tertiary heads [8,37,52,54]. Mehta et al. [35] concurred with these findings except they reported seed from primary heads had a higher oil content than seed from secondary heads. Reducing the plant population increases the number of secondary and tertiary heads, but lowered the oil content of seed from each position [8,52].

Variations in plant available moisture and soil fertility have a large influence on heads per area and seeds per head while having a minimal influence on seed weight [1,2,6,25,29,37,41]. Seed size variation within a heterogeneous population is primarily due to genotypes [1,2,5,29]. Mature safflower seed from world-wide origins ranged in weight from 0.03-0.09 grams per seed [51].

Seed Hull

Safflower seed is composed of hull and embryo [46]. The hull component contains 1-2% oil, and is 32-65% of the total weight [15]. Four hull types have been identified based on the development of the inner and outer schlerenchyma cells; normal-hull, partial-hull, thin-hull and striped hull [19,52,45,49]. Sixty percent of the hull in the normal-hull is composed of the highly lignified inner and outer schlerenchymas. The partial-hull, which is recessive to normal-hull, thin-hull, and striped hull are independently inherited hull types in which reduced development of the schlerenchymas occur [18,19,33,45,46,49,50].

The expression of some hull types is influenced by the plants' genotype and environment and the seeds' position on the plant. A positive relationship exists between seed size and hull content [8,15,54].

Seed Density

Seed density has long been used as an indicator of seed quality [7]. Test weight has been the primary method of determining seed density.

The oil content of four safflower cultivars was found to be negatively correlated with test weight [38]. A similar association has been observed in the species flax (*Linum asitativissimum* L.), rapeseed (*Brassica* spp.) and soybeans which are capsule, silique, and pod seed types respectively. Seed density has been evaluated as a selection technique for improving oil and protein content in soybeans and safflower [21,22,27,47]. A water-glycerol solution was used to determine soybean seed densities. Selecting plants from low density seed increased the frequency of high oil types while selecting plants from high density seed increased the frequency of high protein types. It was found that seeds with cracked seed coats floated regardless of chemical composition and large seeds had a higher

frequency of cracked seed coats [22]. Eslick [21] selected high density safflower seed with forced air and shifted the population toward lower oil and higher protein.

Changes in safflower seed density are associated with other changes in the seed [38]. As seed density increased, air space within the hull decreased, embryo oil content decreased, and hull content usually increased. Seed density increases as hull content increases because the density of the hull is always greater than that of the whole seed. Pawloski [38] also observed that the density of the radicle and the hypocotyl was greater than that of the cotyledons. Sudan IV staining showed the cotyledons had larger fat globules than the radicle.

Several researchers have noted an inverse relationship between oil content and protein content [12,15,17,23,37]. Classen et al. [15] concluded that safflower with 35-40% oil content and 40% or more hull would probably have less than 3.0% nitrogen. The relationship between oil and protein content is not 1:1; therefore, protein can be improved while selecting for higher oil content.

Seedling Vigor

Seed size affects speed of emergence and seedling growth of many species, including monocots, dicots, perennials and annuals. Seedlings from large seeds usually emerge quicker and are more vigorous than those of small seeds [11,13,20,24,31,38,48]. Larger seeds are associated with larger embryo axis, leaf primordia, and cotyledon area [24]. The tendency for large seeds to produce quicker emerging and more vigorous seedlings holds true for the oil seed crops safflower, soybeans and sunflowers [20,28,40,44,48]. Seedlings of large soybean seeds have superior emergence, cotyledon area and more unifoliate leaf area but the seedlings from small seeds have a higher rate of photosynthesis. Further, mixing large and small sized soybeans in a row produced less yield than planting non-mixed lots of large or small seeds [48]. The effect of seed size on seedling vigor may vary by cultivar within a species [3,34].

Researchers have shown that planting large seeds does not always result in quicker or higher percent emergence and can result in decreased speed and percent emergence as compared to an intermediate sized seed [4,10,36,42]. The F4 lines, of a *Vicia sativa* L. X *V. angustifolia* cross, with intermediate seed size were found to be faster emerging and had a higher emergence percentage than the large seeded F4's [4]. The large seeds of alfalfa (*Medicago sativa* L.) and crimson clover (*Trifolium incarnatum*) seed usually produce more vigorous seedlings but sometimes have a lower emergence percentage than intermediate sized seed. It is hypothesized that the cotyledon of some large seeds are over sized [36]. Seed of small and medium sized soybeans cultivars imbibe water and emerge quicker than large seeded cultivars, thus escape soil crusting which can reduce emergence percentage [42]. The pod of sanfoin (*Onobrychis viciifolia* Scop.) delayed water imbibition by 4-5 hours, thus delayed germination in laboratory studies. However, no discernible effect was observed in field emergence between shelled and unshelled seed [14]. The benefits of seed vigor may not persist through to yield; however, vigor levels are often reflected in yield of short season annuals [53].

CHAPTER III

MATERIALS AND METHODS

General Procedures

Several seed sources were used in these studies. The 1981 seed production from the world collection of safflower (SB), which has been replanted continuously since 1961 on an irrigated site at the Eastern Montana Research Center, Sidney, Montana, and its 1982 progeny (SB82) grown at the Northern Montana Research Center (NARC), Havre, Montana, are the two bulk populations used in these experiments. Seed of the cultivars Hartman, S-208, and S-541 grown in replicated dryland trials at Huntley, Fort Benton, Havre, and Froid were used in the seed size distribution experiment, the water-alcohol density experiment and the seed size effect on seedling vigor studies. Seed of these three cultivars used in other density experiments and the seed length studies was produced on the Gary Meland farm north of Havre in 1981.

Oil content was determined with a wide-line nuclear magnetic resonance spectrometer [43]. Forty milliliter (ml) seed samples replicated five times in a completely random design were used for oil determination, except for the water-alcohol density separations, where 2 ml samples with six replications were used. Oil content is reported in percent oil content on a dry weight basis.

Seedling vigor was determined by harvesting the above soil portion of the seedling. The seedlings were dried for 24 hour (h) at 60°C then weighed. Weights are reported mg/seedling.

Hull content was determined using 40 seeds with five replications. The seed was dried for 24h at 40°C, weighed, then germinated for 48h at 20°C. The germination percentage was determined, hulls removed, dried for 24h at 40°C and weighed. Hull content is reported in percent hull content of the whole seed on a dry weight basis.

Seed weight was determined by drying four replications of 100 seeds for 24h at 60°C and weighing. Seed weight is reported as mg/40 seed weight to have uniformity with embryo weights.

Field experiments were conducted on a dryland Joplin clay loam site at NARC. The site was fallow for 2 years. The 1982 growing season precipitation was 17.5 centimeters (cm). Nitrogen at 78.5 kilogram (kg)/hectare (ha) and P_2O_5 at 33.5 kg/ha of P_2O_5 were preplant dual injected in the forms of anhydrous ammonium and liquid ammoniated polyphosphate respectively. Trifluralin was preplant incorporated to a depth of 5 cm at a rate of 1.12 kg active ingredient/acre. The seed was treated with the fungicide, zinc ion and manganese ethylene bisdithiocarbamate powder at a rate of 0.8 grams (g)/liter of seed.

The field experiments were planted May 7, 1982, with 19.8 seeds/meter (m) row seeding rate, with 0.3 m row spacing. Seedling vigor evaluations were made 15 and 36 days (d) after planting by harvesting 1.2 m of row from single row plots arranged in a completely random design. The number of replications varied with each experiment. Seed yield samples were harvested 131 d after planting, from 3 row plots, 3.6 m long, in a randomized complete block design with 6 replications.

Greenhouse seedling vigor experiments were grown at 20°C in 25 × 50 × 7.5 cm flats with one replication/flat. Seed was planted 2.0 cm deep and all seedlings were harvested 21 days after planting. A randomized complete block design was used with 12 seeds/replication and 5 replications/experiment.

Seed Size

Seed size distribution of Hartman, S-208, S-541 and SB was determined by sieving 0.9 liters of seed through a series of slotted screens in the following order 4.0, 3.6, 3.2, 2.8, and 2.4 mm size. Seeds which did not pass through a particular screen were classified as that screen size. Seed smaller than 2.4 mm was discarded. The seed size distribution of the cultivars Hartman, S-208, and S-541 was replicated five times with seed source locations serving as replications. Seed size distribution of the SB82 seed lots was divided into three classes; greater than 3.2, 2.8, and less than 2.8 mm. Seed size distribution and oil content of progeny of SB 2.8, 3.2 mm, and unsized parents was determined on seed produced in single row plots, which were planted 2.5 cm deep, in a completely random design with six replications. The effect of SB seed size class on seedling vigor was evaluated in two separate experiments, one planted 2.5 cm deep and the other 6.25 cm deep. The seed was planted in single row plots in a completely random design with six replications. Field experiments to evaluate seed size effect on seedling vigor of Hartman, S-208, and S-541 were planted 6.25 cm deep in single row plots with 10 replications (5 seed source locations).

Seed Density

Seed density classifications in these experiments is based on relative seed density. Three seed density classification methods were evaluated; water-isopropyl alcohol solution (W-A), forced air from a 23 cm Caldwell fan CFA, and forced air in an Oregon continuous seed blower (OCSB).

Water-alcohol solutions with alcohol concentrations ranging from 65, 45, 25 and 0 percent by volume were used to divide SB 2.8 (7/64) and 3.2 mm (8/64) sized seed into five density classes. The density separations were designated as light, mid light, mid, mid heavy, and heavy. The seed was first exposed to the high alcohol concentrations. Seed

which sank was then exposed to solution lower alcohol concentrations. Therefore, high density seed was exposed to all four W-A density solutions. SB 2.4 (6/64), 3.6 (9/64), and 4.0 mm (10/64) sized seed was split into high and low density classes with 45 percent W-A. The alcohol concentration for density classifications of Hartman, S-208, and S-541 was that which gave a 50-50 split into high and low density by volume of the seed produced at Fort Benton (Table 1). The seed density classes obtained were used to determine the effect of seed density on oil content and seedling vigor. Seedling vigor was evaluated by field planting seed density classes 6.25 cm deep in single row plots in a completely random design. Seed density studies using the SB seed sources had 6 replications (2 sizes) and the studies using cultivars had 10 replications (5 seed source locations).

Table 1. Isopropyl Alcohol Percentage in Water-Alcohol Solution Used to Determine Seed Density Classes of Three Safflower Cultivars.

Cultivar	Alcohol Concentration %
Hartman	62
S-208	54
S-541	45

Forced air from a 23 cm Caldwell fan (CFA) was used to separate SB unsized, SB long, and SB mid length seed into four density classes. The seed was poured through the CFA air stream and caught in 4 (60 cm × 60 cm × 30 cm) boxes placed under the flow of air. The first box was placed against the base of the fan to insure all seed was caught. Seed falling in the box closest to the fan was classified as high density, followed mid high, mid low, and low density seed. CFA separated seed was used to evaluate the relationship of seed density and oil content.

The Oregon continuous seed blower model CS-1 (OCSB) was used to separate SB, unsized, SB 3.2 mm, SB82, Hartman, and S-208 seed into five density classes: low, mid low, mid, mid high and high by opening the intake aperture; 7.5 8.0, 8.5, and 9.0 cm

respectively. The effect of seed density, as determined by OCSB, on seedling vigor was evaluated in greenhouse studies.

Seed Length

The Seed Master laboratory cleaner-indent cylinder was used to make length separations on seed of SB, SB82, Hartman, S-208 and S-541. Two kg of seed were first processed using the No. 20½ indent cylinder (indents 8 mm in diam). Seed that was not picked up was classified as "long." The seed picked up by the No. 20½ indent cylinder was reprocessed using the No. 11 indent cylinder (indents 5 mm diam). The seed which was picked up by this indent cylinder was classified as "short" and seed not picked up was classified "mid." SB82 had an additional length class, "mid short," which was seed that remained in the indent cylinder. Two hundred seeds of each length separation were measured using a binocular microscope at 15X to determine seed length in millimeters. Field experiments to evaluate the effect of seed length on seedling vigor were planted 2.5 cm deep in single row plots with six replications. Seedling vigor was determined by harvesting seedlings from 1.2 m of row, 36d after planting.

The effect of seed length on seed yield was evaluated by planting seed 2.5 cm deep in three row plots arranged in a randomized complete block design and harvesting 3.6 m of all three rows.

CHAPTER IV

RESULTS AND DISCUSSION

Seed Size Distribution

Most seed of the S-208 and S-541 cultivars was of the 2.8 and 3.2 mm size as compared to Hartman which had smaller seed and the majority of it was in the 2.4 to 2.8 mm size classes (Table 2). The 1981 Sidney bulk population (SB) seed size distribution is similar to S-208 and S-541 cultivars, with 84.1% of its seed in the 2.8 to 3.2 mm size (Table 3).

Table 2. Average Seed Size Distribution of Three Safflower Cultivars Grown at Five Locations.

Cultivar	Screen Size (mm)			
	2.4 %	2.8 %	3.2 %	3.6 %
Hartman	25.9 a [†]	64.2 a	9.6 a	0.3 a
S-208	3.1 b	43.4 b	49.9 b	3.5 b
S-541	7.1 b	54.3 a	37.3 c	1.3 a

[†]Means in the same column followed by a common letter are not significantly different based on Newman-Keul test of significance at the .05 probability level (P = .05 N.K. test).

Table 3. 1981 Sidney Bulk Safflower Population Seed Size Distribution and Oil Content of Each Size.

Seed Character	Screen Size (mm)				
	2.4	2.8	3.2	3.6	4.0
Percentage of pop. (%)	3.7	35.3	48.8	10.9	1.3
Oil content (%)	31.2 a [†]	28.9 b	27.8 b	25.7 c	24.4 c

[†]Means in same row followed by a common letter are not significantly different (P = .05 N.K. test).

Seed size distribution of the SB progeny is influenced by the seed size of the parents. Progeny of the SB 3.2 mm seed had 8.6% more seed larger than 2.8 mm size and 5.6% less seed of the 2.8 mm size than did the progeny of the 2.8 parent (Table 4).

Table 4. Average Seed Size Distribution of Progeny of 1981 Sidney Bulk Safflower (SB) Seed Length and Size Classes Grown at Havre in 1982.

Parent Screen Size	Screen Size (mm)		
	< 2.8 %	2.8 %	≥ 3.2 %
SB 2.8 mm	11.5 a [†]	64.5 a	23.8 a
SB 3.2 mm	8.3 b	58.9 b	32.4 b
SB unseparated [‡]	12.5	63.7	26.7

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

[‡]Not included in statistical comparison.

Further, the seed distribution of the progeny of SB unsized parent is similar to that of progeny of the SB 2.8 mm seed (Tables 4 and 31). The effect of environment on seed size distribution is demonstrated by comparing the seed size distribution of SB, which was grown under irrigation to that of SB82, which was grown under dryland conditions. The majority of the SB seed was of the 3.2 mm or larger size while the majority of the SB82 seed is of the 2.8 mm size (Table 5).

Table 5. Seed Size Distribution of 1981 Sidney Bulk Population (SB) and Its 1982 Progeny (SB82).

Seed Source	Screen Size (mm)		
	< 2.8 %	2.8 %	≥ 3.2 %
SB	3.7	35.3	61.0
SB82	12.5	63.7	26.7

*No statistical comparison.

Oil Content

The trend for lower oil content with increasing seed size occurred in all safflower evaluated. There was a 6.8% decrease in oil content from the 2.4 mm seed size to the 4.0 mm seed, of Hartman, S-208, and S-541, which was grown at five locations, had a higher oil content than the 3.2 mm seed 13 out of 15 times (Tables 28, 29, and 30).

Seed sizing as a selection technique to improve oil content has limitations. These limitations become obvious when seed size and oil content of Hartman, S-208, and S-541 are compared. Hartman has the smallest seed yet has the lowest oil content (Tables 2 and 6). Whereas, S-541 has the highest oil content and is intermediate in size. Further, the oil contents of progeny of SB 2.8, SB 3.2 mm and SB unsized were 28.2, 28.2 and 28.4 percent respectively, which was not significantly different ($P = .05$ N.K. test).

Table 6. Average Oil Content of Three Cultivars Grown at Five Locations in 1981.

Cultivar	Hartman	S-208	S-541
Oil content [†]	41.5	43.7	45.7

[†]Mean oil content value obtained from size and density separations, Tables 28, 29, and 30.

Seedling Vigor

Larger safflower seeds produced more vigorous seedlings which concurs with previous research [20]. In field studies at Havre, SB 3.2 mm seed planted 6.25 cm deep, produced heavier seedlings than SB 2.8 mm seed 36 days after planting (Table 7). Similar results were obtained at the 2.5 cm planting depth (Table 8). SB 3.2 and 3.6 mm seed, planted 2.5 cm deep produced significantly heavier seedlings 36 days after planting than the SB 2.8 mm seed. However, there was no difference in the number of seedlings per 1.2 meters of row. The reduced seedling vigor due to small seed size did not result in reduced yield (Table 9). These results are similar to those obtained with sunflowers [40].

Table 7. Field Performance of Seedlings of 1981 Sidney Bulk Safflower Seed Size Classes Planted 6.25 cm Deep at Havre in 1982.

Seed Size	Days After Planting			
	15		36	
	plts/1.2 m	mg/plt	plts/1.2 m	mg/plt
SB 2.8 mm	22.3 a [†]	18. a	23.7 a	171 a
SB 3.2 mm	21.7 a	17. a	23.2 a	240 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 8. Field Performance of Seedlings of 1981 Sidney Bulk Safflower Seed Size Classes Planted 2.5 cm Deep at Havre in 1982.

Seed Size	Days After Planting	
	36	
	plts/1.2 m	mg/plt
SB 2.8 mm	19.5 a [†]	290 a
SB 3.2 mm	19.3 a	347 bc
SB 3.6 mm	22.2 a	404 c
SB unseparated	19.5 a	339 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 9. Seed Yield of 1981 Sidney Bulk Safflower Population Planted 2.5 cm Deep and Thinned to 39 Plants per Square Meter at Havre in 1982.

Seed Size	kg/ha
SB 2.8 mm	1517
SB 3.2 mm	1538
SB 3.6 mm	1544
SB unseparated	1550

No significant differences (P = .05 N.K. test).

Larger seed of Hartman, S-208, and S-541 also produced heavier seedlings, though the difference due to seed size was not significant (Table 10). Low plant number, which may be due to reduced viability from exposure to the water-alcohol solution could have caused enough variability to render the difference nonsignificant.

Table 10. Average Seedling Weight Produced at Havre in 1982 by Sized Seed of Three Cultivars Grown at Five Locations.

Cultivar	Days After Planting			
	15		36	
	2.8 mm mg	3.2 mm mg	2.8 mm mg	3.2 mm mg
Hartman	.013 a [†]	.014 a	.056 a	.062 a
S-208	.016 a	.015 a	.076 a	.083 a
S-541	.013 a	.018 a	.048 a	.067 b

[†]Means within the same row and harvest date followed by a common letter are not significantly different (P = .05 N.K. test).

These data show that selection of large seed for planting will improve seedling vigor thus should be beneficial in stand establishment. The selection of larger seeds for planting should improve the oil content of the seed lot from which the large seed were removed, thus improving the quality of seed to be processed. Seed sizing should not be done for too many generations, especially on cultivars which are composites of several lines or early generation releases, because the genetic character of the cultivar could be altered.

In a breeding program, the selection of large seeded safflower to improve seedling vigor should have to be combined with other selection criteria to prevent simultaneous selection toward lower oil content.

Seed Density

Evaluation of Methods

The three methods of making density separations, water-alcohol solution (W-A), Caldwell forced air fan (CFA), and Oregon continuous seed blower (OCSB), are all effective in grouping safflower seed into density classes (Table 11). However, the three methods are not equal in their ease of use or precision.

Table 11. Forty Seed weight in Grams of the 1981 Sidney Bulk Safflower Population and Its 1982 Progeny Separated Into Density Classes by Three Methods.

Density Class	W-A		CFA			OCSB	
	SB	SB	SB	SB	SB	SB	SB82
	2.8 mm	3.2 mm		Long	Mid		
	g	g	g	g	g	g	g
Low	1.00 a [†]	1.23 a	1.210 a	1.576 a	1.204 a	.885 a	.908 a
Mid Low	1.30 b	1.55 b	1.388 b	1.654 ab	1.360 b	1.410 b	1.322 b
Mid High	1.47 c	1.86 c	1.672 c	1.738 bc	1.548 c	1.807 c	1.404 c
High	1.53 d	1.96 d	1.720 c	1.828 c	1.590 c	1.938 d	1.504 d
Unseparated	1.28 b	1.59 b	1.520 b	1.668 a	1.374 b	1.520 b	1.570 b

[†]Means not in the same column followed by a common letter are not significantly different at .05 probability level (N.K. test).

The W-A method is accurate because the concentrations of water and alcohol can be precisely reconstituted. However, it has several weaknesses, those being: handling wet seed, repulsive fumes, misplacement of seed due to physical damage [22], and it can damage seed viability. The average stand counts for W-A separated density classes of SB 3.2 mm seed was 8.1 seedlings per 1.2 meters of row, 15 days after planting, compared to 21.7 seedlings per 1.2 meters of row for SB 3.2 mm not exposed to W-A solution (Tables 32 and 33).

CFA density separations were easy to conduct and had minimal equipment requirement. However, the inability of the CFA method to repeat its results was a definite weakness. Seed of one density class, when reprocessed, would fall into all four density classes. The CFA method could be improved by more uniform rate of seed feed and by channeling the air flow.

The OCSB method is superior to the other two methods because; it is easy to operate, there is minimal chance of seed damage, and the seed density classifications were repeatable.

Oil Content

Intermediate density classes had higher oil contents than either the high or low density seed (Fig. 1, and Table 34). Further, the mid-low density seed in 5 of 6 OCSB density

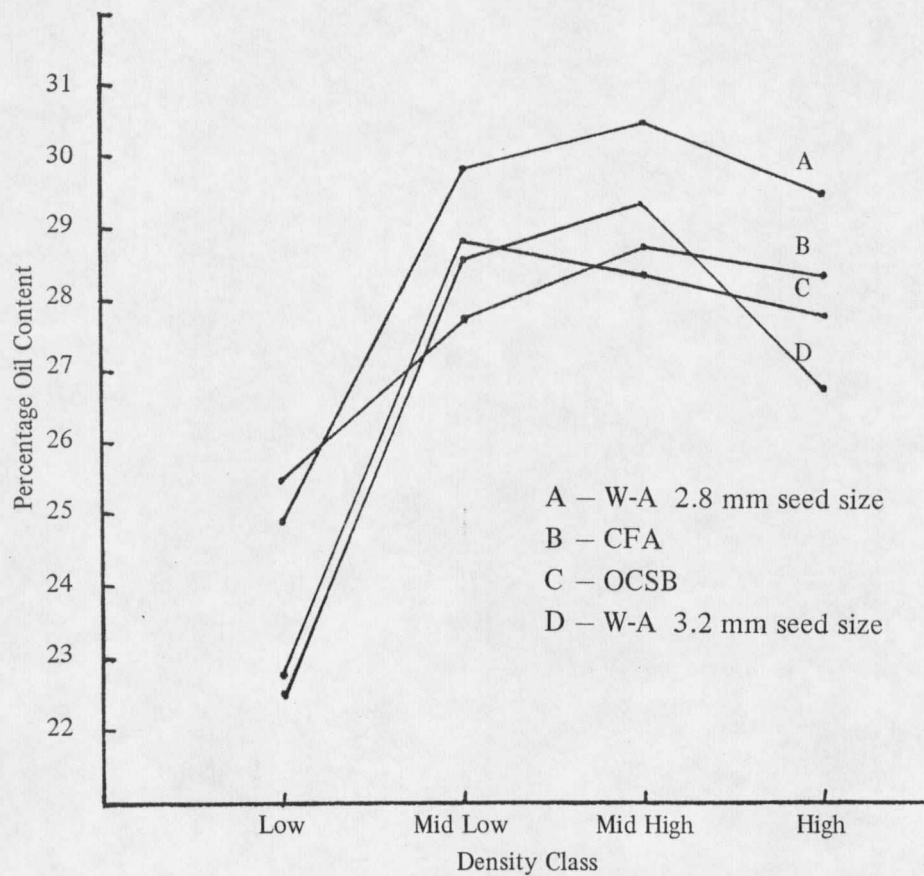


Figure 1. Percentage oil content of seed density classes, as determined by water-alcohol solution (W-A), Caldwell forced air fan (CFA), and Oregon continuous seed blower (OCSB), of 1981 Sidney bulk safflower population.

separation, had the highest oil content (Table 12). The low density seed had the lowest oil content because of the presence of immature hollow seed as indicated by high hull content and low germination (Tables 13, 35, 36, and 37). Excluding the low density classes, oil content decreases as seed density increases due to increased hull content [15,39].

When divided into two density classes, the low density seed of both the 2.8 and 3.2 mm sizes, of the cultivars Hartman, S-208, and S-541, had the highest oil content when averaged across five locations (Table 14). However, the pattern for the low density seed to have the highest oil content did not apply for all locations (Tables 28, 29, and 30).

The relationship between oil content and seed density across the cultivars is the inverse of the relationship found within seed lots of bulk populations and the cultivars. S-541 has both the highest oil content and the highest density seed (Tables 1 and 6). S-208 was intermediate for both characters and Hartman had both the lowest oil content and the lowest seed density. This conflicts with previous research which found cultivars with lower density seed had higher oil contents [38]. Apparently seed of the cultivars S-208, and Hartman have more air space inside the hull or within the hull itself which cause them to have a lower oil content as well as lower seed density than S-541.

Table 12. Percentage Oil Content of Seed Density Class as Determined by OCSB of 1981 Sidney Bulk Safflower, Progeny of SB Size and Length Classes and Two Cultivars.

Density Class	Seed Type					
	SB82 Parent Size and Length				Hartman	S-208
	SB %	Unseparated %	2.8 mm Long %	2.8 mm Short %		
Low	22.7 a [†]	24.5 a	24.9 a	24.9 a	39.9 [‡]	39.6 [‡]
Mid Low	28.9 c	29.3 c	29.0 c	29.6 d	42.0 b	42.1 a
Mid	28.4 bc	29.0 bc	28.7 c	29.5 d	41.9 b	42.6 b
Mid High	27.8 b	28.7 b	28.1 b	28.9 c	41.0 a	42.5 ab
High	27.9 b	28.4 b	27.9 b	28.2 b	No seed	42.2 ab
Unseparated	28.3 bc	28.8 b	28.3 bc	28.9 c	41.6 ab	42.4 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

[‡]Insufficient replications to be included in statistical comparisons.

Table 13. Percentage Hull Content of Seed Density Classes Sidney Bulk Safflower Unsize (SB), 3.2 mm Size (SB 3.2 mm) and Progeny of the Unsize (SB82).

Density Class	SB %	SB 3.2 mm %	SB82 %
Low	57.04 a [†]	59.48 a	51.66 a
Mid Low	47.96 b	48.34 c	46.34 b
Mid	50.24 b	49.60 bc	46.80 c
Mid High	51.78 c	51.42 b	47.12 d
High	51.78 c	51.60 b	48.66 e

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 14. The Percentage Oil Content of the High and Low Density Sized Seed of Three Cultivars Grown at Five Locations.

Cultivar	Screen Size			
	2.8 mm		3.2 mm	
	Low	High	Low	High
Hartman	42.0 [†]	42.0	41.4	40.5
S-208	44.4	43.4	43.7	43.4
S-541	46.3	46.1	45.5	44.8

[†]Means of oil content data presented in Tables 28, 29, and 30.

Seedling Vigor

Seedling weight increased as seed density increased for SB seed in field studies at Havre (Table 15). The average difference in seedling weight between low and mid high classes increased from 5 mg at 15 days after planting to 120 mg at 36 days after planting. Similar results were found for the cultivars Hartman, S-208, and S-541 but the differences were not as distinct (Table 16). The trend for seedling weight to increase with increasing seed density was also observed in the greenhouse (Table 17). However, the difference in seedling weight due to seed density did not appear to be as pronounced in the greenhouse. The shallower planting depth and the more ideal growing conditions in the greenhouse reduced the need for increased seedling vigor. The W-A solution did effect emergence as indicated in Table 15 by increased number of seedling/1.2 m of row for the seed not exposed to W-A solution.

Table 15. Field Performance of Seedlings of W-A Seed Density Classes of Sidney Bulk Safflower Averaged Across 2.8 and 3.2 mm Seed Sizes at Havre.

Density Class	Plts/1.2 m	mg/plt	Plts/1.2 m	mg/plt
SB Low	2.3 a [†]	11 a	4.0 a	83 a
SB Mid Low	5.5 a	14 b	9.0 ab	162 b
SB Mid High	11.3 b	17 c	15.0 b	203 c
SB Unseparated [‡]	22.0 c	18 c	23.4 c	205 c

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

[‡]Seed not exposed to water-alcohol solution.

Table 16. Field Performance of Seedlings of High and Low Density, as Determined by W-A Solution, Averaged Across 2.8 and 3.2 mm Sizes, of Three Cultivars at Havre.

Cultivar	Days After Planting			
	15		36	
	Low (mg/plt)	High (mg/plt)	Low (mg/plt)	High (mg/plt)
Hartman	14	25	53	67
S-208	14	17	78	81
S-541	14	17	54	57

No significant difference between density classes within a cultivar within a harvest date (P = .05 N.K. test).

Table 17. Greenhouse Performance of Seedlings of Oregon Continuous Seed Blower Separation Seed Density Classes of Three Bulk Populations and Two Cultivars.

Density Class	1981 Sidney Bulk Safflower			Cultivars	
	SB mg/plt	SB 3.2 mm mg/plt	SB82 mg/plt	Hartman mg/plt	S-208 mg/plt
Low	17 a [†]	15 a	20 a	14	19 a
Mid Low	17 a	22 a	22 ab	14	20 a
Mid High	20 a	24 b	23 ab	15	23 b
High	21 a	24 b	24 b	16	23 b
Unseparated	18 a	23 b	—	15	21 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Increased embryo size appears to be the reason for increased seedling weight of higher density seed (Table 18).

Table 18. Forty Seed Embryo Weights of Oregon Continuous Seed Blower Separation Density Classes of 1981 Sidney Bulk Safflower Unsized (SB), 3.2 mm Size (SB 3.2 mm), and Progeny of the Unsized Seed.

Density Class	SB mg	SB 3.2 mm mg	SB82 mg
Low	505 a [†]	387 a	441 a
Mid Low	676 b	756 b	708 b
Mid High	930 c	859 c	797 c
High	1,000 d	898 c	803 c

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

These investigations indicate seed density separations within a bulk population could be used as a selection technique for improving oil content in safflower. However, comparisons of commonly grown cultivars indicate there are limitations. If selecting for low density seed is used as a selection technique to select for higher oil content, the seed should be planted deep enough to prevent reproduction of plants from immature seed or inferior seedlings. At the grower level the greatest benefit to use of density separation would probably be to remove immature seed, foreign matter and increase seedling vigor.

Safflower Seed Length

Length and Oil

The indent cylinder was an effective means of separating safflower seed into length classes. There was an average length difference of 0.04 mm between the long and mid long classes and a 0.33 mm difference between the mid and short classes when measured across two bulk populations and 3 cultivars (Table 19). Average seed length varied significantly within a length class between seed types. Hartman had the longest seed in all three length classes. The variation in seed length, within a length class, indicates that there are other factors in addition to seed length which influence the indent cylinder separation. Seed shape and weight distribution within the seed could influence indent cylinder separations. Environmental conditions can influence average seed length. The SB, grown

under irrigation at Sidney, had significantly longer seed in the mid and long classes than its progeny, SB82, which was grown on dryland at Havre (Table 19). Regardless of the environmental effects on seed length, the average seed length of progeny of SB 2.8 mm short parent remained shorter than progeny SB 2.8 mm long and SB unsized parents (Table 20). Further, the oil content of the progeny of SB 2.8 mm short parent was significantly higher than that of the progeny of SB 2.8 mm long parent. However, the hull content and 40 seed weight of the progeny of the SB 2.8 mm short parent were not significantly different from those of the SB 2.8 mm long parent (Table 20). Further, the oil content of the parents was not significantly different (Table 23). Other progeny of the 2.8 mm short and SB 2.8 mm long seed, grown in unthinned single row plots in a completely random design, had equal oil contents (Table 45). Oil content also decreased significantly as SB and SB82 seed length increased (Table 21), while the hull content of SB and SB82 was found to increase significantly as seed length increased (Fig. 2 and Table 22). These data concur with previous research, in that oil content tends to decrease as hull content increases [15]. No discernible relationship was found between seed length and oil content within the cultivars Hartman, S-208, and S-541 (Tables 40, 41, and 42).

Table 19. Seed Length in mm of Safflower Seed Length Classes of Two Bulk Populations and 3 Cultivars as Determined by an Indent Cylinder.

Seed Type	Length Class		
	Short mm	Mid mm	Long mm
1981 Sidney Bulk	7.09 a [†] 2 [‡]	7.70 b 3	8.17 c 4
1982 SB Progeny	7.04 a 2	7.29 b 1	7.78 c 2
Hartman	7.67 a 4	7.81 b 3	8.11 c 4
S-208	6.91 a 1	7.28 b 1	7.68 c 1
S-541	7.29 a 3	7.59 b 2	7.93 c 3
Means	7.20	7.53	7.93

[†]Means in the same row followed by a common letter are not significantly different (P = .05 N.K. test).

[‡]Means in the same column followed by a common number are not significantly different (P = .05 N.K. test).

Table 20. Seed Characters of Progeny of Sidney Bulk Safflower 2.8 mm Short, 2.8 mm Long, and Unseparated Seed.

Parent	Seed Length mm	40 Seed wt g	Hull Content %	Oil Content %
SB Short 2.8 mm	7.09 a [†]	1.325 a	45.6 a	28.9 b
SB Long 2.8 mm	7.29 b	1.365 a	45.7 a	28.3 a
SB Unseparated	7.23 b	1.383 a	46.6 a	28.6 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

This indicates that the difference in oil content between length classes of the bulk population could be due to genetics as well as environment.

Length separation could possibly be used on a heterogeneous population to improve oil content by selecting for a short seed type. However, when comparing seed length and oil content of three cultivars, the S-208 seed is the shortest but its oil content is intermediate to that of Hartman and S-541 seed (Tables 6 and 19). This indicates other seed characteristics, in addition to seed length, have to be considered in selecting for higher oil content.

Table 21. Percentage Oil Content of Length Classes of 1981 Sidney Bulk Safflower Population and Its 1982 Progeny.

Length Class	Seed Source	
	SB (%)	SB82 (%)
SB Short	28.4 a [†]	30.0 a
SB Mid	28.2 ab	28.5 b
SB Long	27.9 b	27.4 c
SB Unseparated	28.3 ab	28.6 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

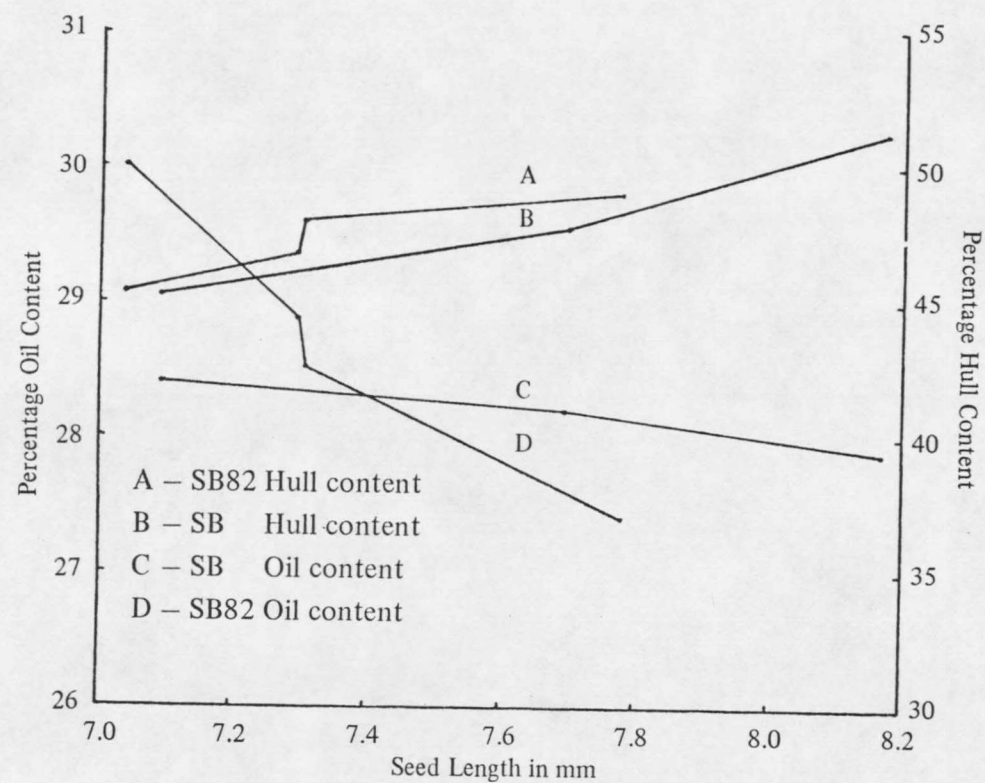


Figure 2. The relationship between seed length, seed oil content, and seed hull content of Sidney bulk safflower and its 1982 progeny.

Table 22. Percentage Hull Content of Length Classes of 1981 Sidney Bulk Safflower and Its Progeny.

	SB % Hull	SB82 % Hull
SB Short	45.3 a [†]	45.3 a
SB Mid	47.7 b	48.0 bc
SB Long	51.3 c	49.0 c
SB Unseparated	47.1 b	46.6 ab

[†]Means within the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 23. Percentage Oil Content of Parent and Progeny of Length and Seed Size Classes of 1981 Sidney Bulk Safflower Grown at Havre in Three Row Plots with Six Replications in Randomized Complete Block Design.

Length and Size	SB % Oil	SB82 % Oil
SB Short 2.8 mm	28.3 a [†]	28.9 a
SB Mid 2.8 mm	28.1 ab	28.6 ab
SB Long 2.8 mm	27.5 ab	28.3 b
SB Mid 3.2 mm	28.1 ab	28.6 ab
SB Long 3.2 mm	27.2 b	28.7 ab
SB Unseparated	27.8 ab	28.6 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Seedling Vigor

Seed of the short length class consistently produced significantly lighter seedlings than the mid, long bulk seed in both the field and the greenhouse experiments (Tables 24 and 25). The increased seedling vigor with increased length could be due to embryo weight increasing as seed length increases (Table 26). The reduced seedling vigor of short seed did not result in significantly lower yield, however there may be a trend toward lower seed yield with reduced seedling vigor (Table 27).

Table 24. Field Seedling Performance of 1981 Sidney Bulk Safflower Length Classes Grown at Havre in 1982.

Seed Length	36 Days after Planting	
	Plts/1.2 m	mg/plt
SB Short	18.7 a [†]	269 a
SB Mid	19.2 a	345 b
SB Long	21.1 a	353 b
SB Unseparated	19.5 a	339 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 25. Greenhouse Seedling Performance of Seed Length Classes of Three Cultivars and Progeny of 1981 Sidney Bulk Safflower.

Seed Length	21 Days after Planting			
	SB82 mg/plt	Hartman mg/plt	S-208 mg/plt	S-541 mg/plt
SB Short	17.1 a [†]	11.2 a	17.2 a	25.3 a
SB Mid	21.7 ab	12.6 ab	19.9 b	29.6 b
SB Long	22.3 b	13.9 b	20.8 b	29.0 ab
SB Unseparated	21.7	12.9 ab	20.8	26.0 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 26. The Forty Embryo Weight of Seed Length Classes of Sidney Bulk Safflower, Its Progeny and Three Cultivars.

Length	Seed Source				
	SB mg	SB82 mg	Hartman mg	S-208 mg	S-541 mg
SB Short	655 a [†]	700 a	561 a	768 a	848 a
SB Mid	790 b	755 ab	639 b	829 b	921 b
SB Long	851 c	773 b	683 b	914 c	943 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 27. Seed Yield of 1981 Sidney Bulk Safflower Length and Size Classes Grown at Havre in 1982.

Length and Class		kg/ha
SB Short	2.8 mm	1417
SB Mid	2.8 mm	1501
SB Long	2.8 mm	1533
SB Mid	3.2 mm	1518
SB Long	3.2 mm	1558
SB Unseparated	—	1550

Seed length, as determined by an indent cylinder, has potential as a selection technique to select for higher oil content without a significant reduction in seedling vigor. Mid length seed had higher oil content than long seed and its seedling vigor was significantly greater than that of short seed. Further, there was not a significant difference in oil content between length classes in the cultivars Hartman, S-208, and S-541. This indicates that long seed of a cultivar could be selected for planting without changing the oil production. Selecting of long seed for planting should improve stand establishment due to more seedling vigor and removal of the long seed should improve the oil content of the seed lot left for oil processing.

General Discussion

Many seeds of the Sidney bulk safflower population, when evaluated ocularly, were found to have excess hull in the basal area, below and opposite the hilum. Based on this observation and previous research, which indicate; (1) that larger seeds produce more vigorous seedlings [20], (2) that less dense seeds tend to have higher oil content [21,38, 39], (3) that reducing the hull portion of the seed increases the oil content [15], we can hypothesize that: seedling vigor of the Sidney bulk safflower population could be improved and the oil content maintained or improved by selecting seed which has low density, is large, and has an oval shape with an acute base.

Within the bulk populations, larger seeds produced more vigorous seedlings, oil content increased as seed density decreased except that the lowest density seed contained more immature hollow seeds, and the short seeds had a higher oil content than the mid and long seeds. Also the large seed in the short class of SB appeared to be more oval in shape and have less hull in the basal area. Further, the oil content differences between length classes of the cultivars Hartman, S-208, and S-541 were nonsignificant, indicating that oil content differences between length classes of the SB are due in part to genotype. However, progeny tests to determine if parent seed length would influence progeny oil content were inconclusive. Changing environments from Sidney irrigated, where the parent was grown, to Havre dryland, where the progeny was grown, may have nullified the selection pressure for higher oil content.

The relationships of oil content to seed size, density, and length among cultivars Hartman, S-208, and S-541 often conflict with those found within the seed lots of the bulk populations. S-541, which had the highest oil content, also had the highest seed density, and was intermediate to Hartman and S-208 in seed length and seed size. Hartman, which had the lowest oil content, also had the lowest in seed density, the smallest seed, and the longest seed. S-208, which had the largest and shortest seed, was intermediate to Hartman and S-541 in oil content and seed density. When comparing seed shape, Hartman and S-541 seed are cylindrical, while S-208 seed has an oval shape. The Hartman and S-541 seed do differ in that S-541 seed has a larger diameter in proportion to its length.

CHAPTER V

SUMMARY AND CONCLUSIONS

Based on these studies we conclude that selection of large, high density, or long seed from a seed lot for planting will improve seedling vigor, thus improve stand establishment. Furthermore, removing these seeds for planting purposes will improve the oil content of the remaining seed for oil processing. The increased seedling vigor and reduced oil content with increasing size, density or length is due to increased embryo size and increased hull content respectively. Selecting for more vigorous planting seed should be done with caution, especially in cultivars which are a composite of lines or an early generation release. Repeated selection of the same seed type for planting could cause a change in genotype.

These studies also indicate that safflower seed size, length (shape), and density can potentially be used in selection techniques to improve seedling vigor while maintaining or improving the oil content of the Sidney bulk safflower population.

Mature mid to low density seed within size classes and length classes had higher oil contents than the high density or bulk seed. Thus, the selection of low density seed from the large short seed of a bulk population is a selection criteria that should be pursued farther as a means of maintaining or improving oil content while improving seedling vigor. Other suggested research: determine if there is a relationship between seed diameter, length and seed oil content, determine if seed length within a size class influences seedling vigor and hypocotyl length, and determine if the difference in seed density between Hartman, a mid oil type, and S-541, a high oil type, is due to density differences in embryos or the hulls.

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APPENDIX

TABLES

Table 28. Percentage Oil Content in Hartman Safflower Grown at Five Locations. The Seed was Sized, and Then Separated Into Density Classes by Water-Alcohol Solution.

Location	Seed Size			
	2.8 mm		3.2 mm	
	Low density	High density	Low density	High density
Huntley I	42.2 a [†]	41.4 a	41.3 a	40.6 a
Huntley II	42.2 a	41.1 a	40.0 a	39.4 a
Ft. Benton	42.9 a	43.5	44.9 b	43.1 a
Havre	40.4 b	40.1 b	38.7 a	39.2 a
Froid	42.1 b	43.7 c	42.0 b	40.3 a
Mean	42.0 a	42.0 a	41.4 a	40.5 a

[†]Means in a row followed by a common letter are not significantly different (P = 0.5 N.K. test).

Table 29. Percentage Oil Content in S-208 Safflower Grown at Five Locations. The Seed was Sized, and Then Separated Into Density Classes by Water-Alcohol Solution.

Location	Seed Size			
	2.8 mm		3.2 mm	
	Low density	High density	Low density	High density
Huntley I	43.8 b [†]	42.8 ab	41.6	42.6 a
Huntley II	43.7 ab	43.0 a	44.7	43.6 ab
Ft. Benton	45.8 b	44.8 ab	45.5	44.2 a
Havre	43.1 a	42.4 a	42.5	42.5 a
Froid	45.4 b	43.8 a	44.3	44.1 a
Mean	44.36 a	42.36 a	43.72 a	43.4 a

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 30. Percentage Oil Content in S-541 Safflower Grown at Five Locations. The Seed was Sized, Then Separated Into Density Classes by Water-Alcohol Solution.

Location	Seed Size			
	2.8 mm		3.2 mm	
	Low density	High density	Low density	High density
Huntley I	46.4 c [†]	45.2 b	45.3 b	44.2 a
Huntley II	45.0 b	45.5 b	44.3 a	44.0 a
Ft. Benton	47.7 b	47.7 ab	46.6 ab	45.8 a
Havre	45.9 ab	46.5 b	45.6 ab	44.9 a
Froid	46.3 b	46.0 b	45.9 ab	44.9 a
Mean	46.28 a	46.18 a	45.54 a	44.76 a

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 31. Percentage Seed Size Distribution of Progeny of 1981 Sidney Bulk Safflower Length and Size Classes.

Parent Length and Size	Seed Size		
	< 2.8 mm %	2.8 mm %	≥ 3.2 mm %
SB Short 2.8 mm	10.0 a [†]	62.5 a	25.4 ab
SB Mid 2.8 mm	10.3 a	63.9 a	25.3 ab
SB Long 2.8 mm	12.7 a	65.0 a	22.2 a
SB Mid 3.2 mm	8.3 a	60.4 ab	31.3 bc
SB Long 3.2 mm	8.2 a	57.4 b	33.4 c
SB Unseparated	12.5 a	63.4 a	26.7 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 32. Percentage Seed Distribution, 1981 Sidney Safflower Bulk Population Sieve Sized and Then Separated by Water and Isopropyl Alcohol Into Density Classes.

Sieve Size	Density	% by wt
2.4 mm	Light	2.5
	Heavy	1.2
		<u>3.7</u>
2.8 mm	Light	1.7
	Mid Light	8.6
	Mid Heavy	10.1
	Heavy	14.9
		<u>35.3</u>
3.2 mm	Light	7.7
	Mid Light	15.1
	Mid Heavy	21.9
	Heavy	4.1
		<u>48.8</u>
3.6 mm	Light	2.6
	Heavy	8.3
		<u>10.9</u>
4.0 mm	Light	0.5
	Heavy	0.8
		<u>1.3</u>

Table 33. Progeny Field Performance of 1982 Progeny of the 1981 Sidney Bulk Safflower Size and Density Classes at Havre.

Size and Density		Days After Planting				Oil Content %
		15		36		
		Plts/1.2 m	mg/plt	Plts/1.2 m	mg/plt	
SB 2.8 mm	Low	0.31 a [†]	10 a	2.6 a	77 a	26.9 a
SB 2.8 mm	Mid Low	6.3 ab	14 ab	11.4 abc	151 ab	27.5 a
SB 2.8 mm	Mid High	13.7 bc	15 ab	13.4 abc	154 ab	27.4 a
SB 2.8 mm	Unseparated [‡]	22.3 c	17 bc	23.4 c	171 ab	28.2 a
SB 3.2 mm	Low	4.3 ab	13 ab	5.4 a	90 a	27.7 a
SB 3.2 mm	Mid Low	5.0 ab	14 ab	6.6 ab	173 ab	27.8 a
SB 3.2 mm	Mid High	9.0 ab	18 bcd	16.6 abc	253 b	27.8 a
SB 3.2 mm	Unseparated [‡]	21.7 c	19 bcd	23.4 c	240 b	28.2 a
SB 3.6 mm	Low	6.0 ab	22 cd	13.4 abc	180 ab	28.0 a
SB 3.6 mm	High	14.3 bc	23 d	22.0 bc	242 b	28.5 a

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

[‡]Seed not exposed to water-alcohol solution.

Table 34. Percentage Oil Content of Seed Density Classes, as Determined by W-A, CFA, and AAC Methods, of the Sidney Bulk Safflower and Its Progeny.

Density Classes	Density Determination Method						
	W-A		CFA			AAC	
	SB 2.8 mm	SB 3.2 mm	SB	SB Long	SB Mid	SB Bulk	SB82
Low	24.9 a [†]	22.5 a	25.5	27.5 a	27.7 a	22.7 a	24.5 a
Mid Low	29.9 c	28.6 c	27.8 a	28.1 ab	28.6 b	28.9 d	29.3 c
Mid High	30.5 c	29.3 c	28.8 a	28.3 b	29.0 b	28.4 cd	29.0 bc
High	29.5 bc	26.8 b	28.4 a	28.6 b	28.7 b	27.8 bc	28.7 bc
Unseparated	28.5 b	28.1 c	28.3 a	27.9 ab	28.2 ab	27.9 b	28.4 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 35. Seed Characters of 1981 Sidney Bulk Safflower Population Seed Separated by Oregon Continuous Seed Blower Into Density Classes.

Density Class	40		Hull %	Germ %	Oil Content %
	Seed wt g	Embryo wt g			
Low	.885 a [†]	.505 a	57.04 a	66.5	22.7 a
Mid Low	1.410 b	.676 b	47.96 b	94.0 a	28.9 d
Mid	1.619 c	.813 c	50.24 b	92.0 a	28.4 cd
Mid High	1.807 d	.930 d	51.78 c	90.0 a	27.8 bc
High	1.938 e	1.002 e	51.78 c	93.0 a	27.9 b

[†]Means in the same column followed by the same letter are not significantly different (P = .05 N.K. test).

Table 36. Seed Characters of 1981 Sidney Bulk Safflower Population: 3.2 mm Sieve Size Seed Separated by Oregon Continuous Seed Blower Into Density Classes.

Density Class	40		Hull %	Germ %
	Seed wt g	Embryo wt g		
Low	.955 a [†]	.387 a	59.48 a	62.0 a
Mid Low	1.528 b	.765 b	48.34 c	96.0 b
Mid	1.692 c	.853 c	49.60 bc	92.4 b
Mid High	1.766 c	.859 c	51.42 b	93.0 b
High	1.884 c	.898 c	51.60 b	92.5 b
Unseparated	1.586 b	.788 b	48.48 c	92.5 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 37. Seed Characters of 1982 Progeny of 1981 Sidney Bulk Safflower Population Seed Separated by Oregon Continuous Air Blower Into Density Classes.

Density Class	40		Hull %	Germ %	Oil Content %
	Seed wt g	Embryo wt g			
Low	.908 a [†]	.441 a	51.66 a	55.5 a	24.5 a
Mid Low	1.322 b	.708 b	46.34	90.5 b	29.3 d
Mid	1.404 c	.748 b	46.80	88.0 b	29.0 d
Mid High	1.504 d	.797 c	47.12	89.0 b	28.7 c
High	1.570 e	.803 c	48.66	88.5 b	28.4 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 38. Seed Characters of S-208 Safflower Seed Separated by Oregon Continuous Seed Blower Into Density Classes.

Density Class	40		Hull %	Oil Content %
	Seed wt g	Embryo wt g		
Low				39.6 [‡]
Mid Low	1.104 a [†]	.6690 a	39.32 a	42.1 a
Mid	1.197 a	.735 b	38.60 a	42.6 b
Mid High	1.327 b	.811 c	38.86 a	42.5 ab
High	1.420 c	.858 d	39.32 a	42.2 ab
Unseparated	1.268 b	.773 bc	38.92 a	42.4 ab

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

[‡]Insufficient number of replications to include in statistical comparisons.

Table 39. Seed Characters of Hartman Safflower Seed Separated by Oregon Continuous Seed Blower Into Density Classes.

Density Class	40		Hull %	Oil Content %
	Seed wt g	Embryo wt g		
Low	—	—	—	42.9
Mid Low	.846 a [†]	.516	39.0 b	45.0 a
Mid	1.050 b	.637	39.3 b	44.9 a
Mid High	1.1126	.673	39.5 b	44.0 b
High	No seed	—	—	—

[†]Means in the same column followed by a common letter are not significantly different (P = .05, NK test).

Table 40. The Seed Characteristics of Length Classes of Hartman.

Class	% of pop.	Seed length (mm)	40 Seed wt (g)	40 Embryo wt (g)	Hull %	Germ %	Oil content %
Short	5.2	7.67 a [†]	.950 a	.561	40.8 a	82.5 a	41.2 a
Mid	79.1	7.81 b	1.042 b	.639 a	40.4 a	78.0 a	41.6 a
Long	15.7	8.11 c	1.140 c	.683 a	40.1 a	81.6 a	41.9 a

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 41. Seed Characteristics of Length Classes of S-208.

Class	% of pop.	Seed length (mm)	40 Seed wt (g)	40 Embryo wt (g)	Hull %	Germ %	Oil content %
Short	35.3	6.91 a [†]	1.169 a	.768 a	34.3 a	93.5 a	41.2 a
Mid	61.7	7.28 b	1.386 b	.829 b	35.6 b	93.0 a	42.3 a
Long	3.0	7.68 c	1.450 c	.914 b	36.4 c	93.5 a	41.8 a

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 42. Seed Characteristics of Seed Length Classes of S-541.

Class	% of pop.	Seed length (mm)	40 Seed wt (g)	40 Embryo wt (g)	Hull %	Germ %	Oil content %
Short	6.1	7.29 a [†]	1.232 a	.848	31.1 a	67.6 a	45.6 a
Mid	71.3	7.61 b	1.344 b	.921 a	31.4 a	72.5 a	45.6 a
Long	22.6	7.93 c	1.393 c	.943 a	32.3	79.0 a	44.5 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 43. Seed Characteristics of Seed Length Classes of 1981 Sidney Bulk Safflower Populations.

Class	% of pop.	Seed length (mm)	40 Seed wt (g)	40 Embryo wt (g)	Hull %	Germ %	Oil content %
Short	1.1	7.09 a [†]	1.198 a	.655 a	45.3 a	94.0 a	28.4 a
Mid	82.6	7.70 b	1.511 b	.790 b	47.7 b	93.6 a	28.2 ab
Long	16.3	8.17 c	1.750 c	.851 c	51.3 c	94.0 a	27.9 b
Unseparated	—	7.77 b	1.566 b	.829 bc	47.1 b	92.5 a	28.3 a

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 44. The Seed Characteristics of Length Classes of 1982 Progeny of 1981 Sidney Bulk Safflower Population.

Class	% of pop.	Seed length (mm)	40 Seed wt (g)	40 Embryo wt (g)	Hull %	Germ %	Oil content %
Short	.8	7.04 a [†]	1.278 a	.700 a	45.3 a	76.0 a	30.0 a
Mid Short	6.7	7.27 b	1.380 b	.717 ab	46.7 abc	85.0 b	28.9 b
Mid	76.7	7.29 b	1.417 b	.755 ab	48.0 bc	85.5 b	28.5 b
Long	15.8	7.78 c	1.532 c	.773 b	49.0 c	79.5 ab	27.5 c
Unseparated	—	7.21 b	1.393 b	.743 ab	45.6 abc	94.5 c	28.6 b

[†]Means in the same column followed by a common letter are not significantly different (P = .05 N.K. test).

Table 45. Seedling Performance of 1981 Sidney Safflower Bulk Population Planted 2.5 cm Deep in Single Rows in a Completely Random Design at Havre.

Parent		# Observations	Oil content	36 Days After Planting	
Length Class	Size		%	Plts/1.2 m	mg/plt
Short	2.4 mm	2	28.4 [†]	12.0	209.
Mid	2.4 mm	2	28.6	17.5	241.
Long	2.4 mm	3	29.9	17.7	211.
Short	2.8 mm	5	28.7	18.6	254.
Mid	2.8 mm	5	29.0	18.8	313.
Long	2.8 mm	5	28.7	21.6	320.
Short	3.2 mm	2	29.2	18.5	285.
Mid	3.2 mm	5	28.8	20.3	373.
Long	3.2 mm	5	28.3	18.3	384.
Mid	3.6 mm	3	28.2	22.3	401.
Long	3.6 mm	5	28.7	22.4	411.
Bulk	—	6	28.8	18.8	341.

[†]No significant oil content difference.

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