SEED MORPHOLOGY OF NATIVE PERENNIAL GRASSES WITH RELEVANCE TO THE ARBUCKLE NATIVE SEEDSTER

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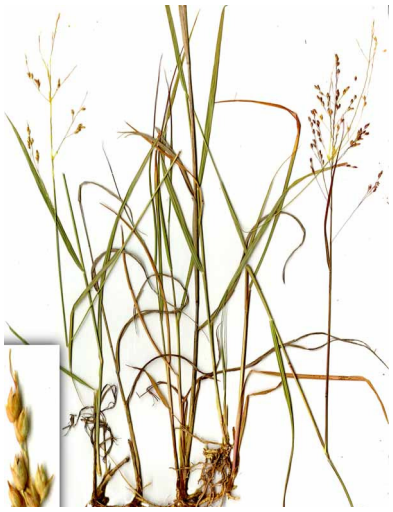
Little bluestem



Images by Montana Prairie Products

Switchgrass

Needleandthread

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Abstract

The scarcity of seed of many native grasses is often the result of low harvest efficiency and difficulty in gleaning and conditioning the seed using standard harvest and cleaning equipment. Arbuckle Ranch Inc. with support from the Montana Board of Research and Commercialization Technology undertook an independent study to examine the key morphological characteristics of plant inflorescences and seeds and how they influence seed harvestability, which consequently affects their market availability and price. A dichotomous key was developed to categorize 999 native species (continental US), subspecies and varieties based on plant height, inflorescence type, point of seed disarticulation, awn length, seed size, seed shape and seed hairiness. A detailed database was created of 197 native grass species with commercial importance, exhibiting morphological characteristics, ecological profiles, and seed availability. The 'seed' unit, as referred to in this study, may be the naked caryopsis, the caryopsis enclosed in the lemma and palea (floret), or the caryopsis enclosed in the lemma, palea, and glumes (spikelet).

Microsoft Access was used to query the database of 197 commercially important grasses finding that 86.8% had panicle inflorescences, while the remaining 13.2% had spikes or racemes. In 69.5% of the grasses the seed unit disarticulated above the glumes, while 30.5% disarticulated below the glumes. Other characteristics that affect harvestability are medium and long awns (25.3%), hairy seed or appendages (45.6%) and small or very small seed (56.8%). Indeterminacy and seed shatter also impact harvest efficiency, but are morphological characteristics that are understood primarily through practical experience of seed growers and researchers.

The Arbuckle Native ***Seedster*** is designed to harvest seeds of difficult-to-harvest grasses, forbs and shrubs. The innovative design utilizes a combination of counter-rotating combs and a brush to pluck the seed from the inflorescence. Grasses with paniculate inflorescences and/or with divergent or twisted awns, and hairy lemmas or appendages are generally difficult to harvest with the standard combine. Rather than a hindrance to harvesting, the awns and hairy appendages actually contribute to the effectiveness of the Native ***Seedster*** harvester. The results of this study can be used by the seed industry to predetermine the relative harvestability of a crop and its potential for harvest with a Native ***Seedster***.

Introduction

One of the principal means of restoring native plant communities is planting of adapted native grass, forb, and shrub species. Major barriers to this effort are the high costs of seeds adapted to planting sites and limited availability of many desirable species. The

high market value of some native seed is a result of one or more of the following factors; scarcity of the plant (either small component of native communities or relatively few commercial production acres), low inherent productivity, low seed harvest efficiency, and difficulty in harvesting and conditioning. The demand for native seed often exceeds available supply. For example, a single Bureau of Land Management seed procurement order in August, 2000, required 5 million pounds of seed, primarily native grass, forb, and shrub species (Commerce Business Daily 2000), yet most was unavailable in the amounts requested. Consequently use of many native species has been limited for government agencies involved in conservation as well as for private organizations and individuals interested in restoration ecology and agricultural production. Improved seed harvesting methods are needed to expand the number of species used in restoration of native plant communities and to lower the cost of seed through increased harvest volumes (Lochner 1997). More recently, demand has dramatically increased for seed of a native grass (switchgrass-*Panicum virgatum*) used as a feedstock in cellulosic ethanol production (Teel, Barnhart, and Miller, 2003). Planted acreage of switchgrass is expected to expand rapidly.

Seeds of commercially desirable native grass species come in a wide variety of sizes and shapes and have a variety of appendages and surface features (attached sterile or staminate florets, attached rachis, awns on lemmas and paleas, hairs/wool/bristles on lemma surface and calluses) that influence harvest efficiency. The unique morphology of each caryopsis, floret or spikelet and the circumstances of their attachment to the parent plant has long posed problems and obstacles in efficient seed harvest. Some unique seeds, such as needleandthread (*Hesperostipa comata* previously *Stipa comata)*, have sharp calluses and 3-5 inch long twisted awns. They are so difficult to harvest that despite huge amounts of needleandthread seed being produced on Western native rangeland, very little is harvested. As a result, needleandthread seed sometimes sells for over $65/lb. Some native grass seeds are extremely small, with over six million seeds per pound. These are necessarily difficult to harvest and their seed may retail for over $100/lb. Other seed shatters so readily, as in the case of bottlebrush squirreltail (*Elymus elymoides* previously *Sitanion hystrix*), that the harvest period is usually severely limited.

Development of a harvester that can successfully capture a range of difficult-to-harvest native grass seeds must consider the physical characteristics of both the seed and the parent plant. These characteristics can be identified as follow:

- **Plant** characteristics:
  - size
  - height
  - shape
  - form (upright, decumbent, spreading)

- **Inflorescence** characteristics:

- type, (panicle, spike, spicate raceme, raceme)
- size
- shape
- position in relation to foliage
- location of seed within the inflorescence (e.g. inside sheath, exposed)

- **Seed attachment** characteristics:
  - location of seed or spikelet disarticulation, (above or below the glumes)
  - strength of attachment (shattering)
  - indeterminacy (ripens progressively)

- **Seed** characteristics (i.e. morphology):
  - size (e.g. number per unit of weight)
  - density
  - shape (regular vs. irregular, elongate, round, etc.)
  - awns, callus characteristics (barbs)
  - pubescence, hairs, appendages

Until recently a grass seed harvester with the capability of addressing this multitude of seed and plant morphologies has not been available. But Lee Arbuckle, a Montana rancher, discovered harvest technology for difficult-to-harvest native grass and forb species with patent awards in 2003 and 2004. The resultant "***Seedster***" is designed especially for difficult-to-harvest native plants, including species with open panicles, indeterminate ripening, fluffy or bulky seeds and seeds that are shatter-prone. The technology creates a new design paradigm for seed harvest that will transform the economics of the native seed industry. The basic technology of counter-rotating brush and combs dislodges seed and minimal chaff and simultaneously generates airflow that transports the seed directly to a hopper or to be engaged by a pneumatic conveyance system to a following trailer-hopper system. Speeds of the hydraulically powered brush and combing drum and their position and spacing are independently controlled for optimum harvest efficiency. Brush filaments and comb shapes can be selected for specific applications.

Because independent operational settings of the ***Seedster*** can be adapted to specific native grass seed crops, morphological characteristics of target species must be known. These characteristics include seed size, shape, presence of awns, bristles, sharp calluses (barbs), hairs, and other unique features, as well as plant size, type of inflorescence, nature of seed disarticulation and seed shatter. Dislodgment and conveyance of seeds is strongly affected by grass seed morphology. For example, small hairy seeds such as little bluestem (*Schizachyrium scoparium* previously *Andropogon scoparius*) shatter readily and require moderate airflow for transport through the harvester. Needleandthread seeds have long awns and a sharp barbed callus that can cause masses of seed to coagulate and clog transport mechanisms. Each species can be effectively harvested by the ***Seedster*** if

brush speeds, comb speeds, and comb shapes are configured or calibrated for the species' particular morphology.

Our literature reviews and consultations with agrostologists and plant materials specialists have not found a compendium of native grass seed morphological characteristics. Consequently Arbuckle Ranch, Inc. undertook an independent study to construct a dichotomous key for categorizing native perennial grasses based on plant and especially seed morphologies as they affect harvestability. The study was jointly funded by the Montana Board of Research and Commercialization Technology and Arbuckle Ranch, Inc. The study compiled a comprehensive database for a majority of native perennial grasses with commercial value that occur in the continental United States. In addition to morphological information, the database includes summaries of plant distribution, ecological settings, associated plant communities, uses, seed availability, and harvest features. Among the study objectives was to identify 'harvest categories' for native perennial grasses of the continental United States. These would be used to define the harvest potential of the ***Seedster***.

The morphological component of the seed key and database was created to:

- identify morphological characteristics of native grasses and their seeds that affect harvestability
- construct an extensive dichotomous grass seed/harvestability key based on these morphologies
- group the grasses according to morphological similarities of the plants and particularly of their seeds
- describe the morphologies of perennial native grasses that have current commercial value
- identify species that have difficult-to-harvest seeds

Questions addressed by the grass seed morphological key and species database include:

- What are the major distinguishing morphological characteristics of native grass seeds?
- What are the major morphological categories of grass seeds?
- Which morphological characteristics of grass seeds tend to limit their harvestability, and why?
- How can a difficult-to-harvest grass seeds be best defined or characterized?
- How many U.S. native grass species have difficult-to-harvest seed?
- How are the difficult-to-harvest native grass species distributed in the U.S.?
- Which difficult-to-harvest native grass species have commercial value?
- Does the database characterize the relative economic and ecological value of each hard-to-harvest U.S. native grass species?

Methods and Procedures

In the grass family (***Poaceae***) the inflorescence is the flowering portion of the plant. The inflorescence is made up of spikelets and their arrangement is classified as a spike (un-branched with spikelets directly attached to rachis), panicle (has main axis with spikelets on subdivided branches) or raceme (spikelets are on pedicels branching from a main rachis). These spikelets, for the majority of grasses, consist of two glumes (bract-like structures) that enclose one or more florets. The floret consists of a lemma and a palea, which cover or enclose the caryopsis. The hairs, awns, sharp calluses, and bristles usually occur as attachments to the lemma and/or glumes and are not attached to the actual seed (caryopsis). In some grass species the caryopsis will drop out of the floret when it matures, however there are species (e.g. ***Paniceae*** tribe) where the seed remains tightly enclosed within the floret. Throughout this report, the dichotomous key and the database the term 'seed' is used to describe the harvested 'seed unit' which may consist of only the naked caryopsis, the caryopsis enclosed in the lemma and palea (floret), or the seed enclosed in the lemma/paleas, as well as the glumes (spikelet). This was done to make this report, dichotomous key, database and other information easier to use and relevant to harvesting. It should be noted however that using these terms interchangeably is not morphologically correct.

With the use of regional floras and broader based floras, a list of perennial native grasses occurring in the continental United Sates was created (999 species, subspecies and varieties) (Appendix A). Plant and seed morphological characteristics, features, and innovations were studied and grouped. The dichotomous grass seed/harvestability key (Appendix B) was constructed based on grass plant, inflorescence and seed morphology with relevance to harvestability. This allowed grouping of plants with similar characteristics, especially those that affect harvestability. In the dichotomous key plant height, type of inflorescence, and point of disarticulation were used to create 12 major groups. Within each group, awn presence, awn length, seed size, seed shape, and floret hairiness were utilized to further categorize the individual species.

The database (Appendix D) consists of only native grasses having economic value. Morphological and ecological profiles were created for 197 native grasses using a variety of information sources. Information included plant and seed morphology, ecological setting, associated plant communities, uses, seed availability and harvest notes. Appendix C summarizes the key morphological characteristics and seed availability of the 197 species included in the database.

Personnel conducting the study included former Montana State University Range Science professor, Dr. Brian Sindelar, Drew King, MSU student Leslie Eddington, Texas A & M agrostologist Dr. Stephan Hatch, plant materials specialist Mark Majerus and Lee Arbuckle, Project Director.

Results and Discussion

We found that 86.8% of the native perennial grasses in the continental United States have panicle inflorescences that tend to be difficult to harvest with conventional methods (e.g. traditional combining). Native grass seeds of plants having spike/spike-like inflorescences tend to be easier to harvest using standard techniques and thus have greater availability and lower cost per pound. This, in turn, has resulted in an imbalance between use of seeds of spike/spike-like inflorescence grasses and paniculate native grasses for conservation and reclamation purposes throughout the U.S. The *Seedster* is specifically designed to harvest seed of native grass species of all heights, with panicle inflorescences, with awns and sharp calluses, with hairy seeds, species that ripen indeterminately and seed that readily shatters. The *Seedster* is intended to address this historic imbalance between spike/spike-like and panicle inflorescence grasses by making more seeds of paniculate grasses available. By adjusting the operating mechanisms of the *Seedster* to address specific grass plant and seed morphological characteristics, we believe that seeds of a majority of these "difficult-to-harvest" grasses can be successfully harvested with this innovative new harvester.

The dichotomous key for grass seeds/harvestability is applicable to all North American grasses. The comprehensive database was created for 197 native perennial grasses of the continental United States that have current commercial value. This value is based on native grass seed demand for a variety of applications such as mined land reclamation, roadside revegetation, biofuel production, forage production, wildlife habitat improvement and other resource conservation practices. The database will aid Arbuckle Ranch Inc. and others in determining potential capabilities and uses of the ***Seedster***. It will help to determine how this revolutionary harvester can facilitate and support the American native grass seed industry.

While 999 native perennial grasses were included in the dichotomous seed morphology key, the comprehensive database currently includes 197 species of particular interest. Database information was necessarily gleaned from many sources, including plant keys and floras, the USDA PLANTS website, technical reports, journal articles, and private sector websites. Obviously time-consuming, the task also revealed that some required information was obscure or lacking, leaving some portions of the data forms incomplete. Information on plant characteristics such as uniformity of ripening (indeterminacy) and tendency to shatter can only be acquired through practical experience of growers and researchers. It was not in the capabilities of this study to get such detailed information on all of the 197 commercially important species. We expect to continue to build the database with additional data as more information is discovered.

The dichotomous morphological key includes characteristics hierarchically ordered by characteristics potentially affecting harvestability of grass seeds in general, but in particular, harvestability by the ***Seedster***. Key morphological features included:

Plant height (3 criteria)
Inflorescence (2 criteria)
Disarticulation (2 criteria)
Awn length (4 criteria)
Seed size (4 criteria)
Seed shape (3 criteria)
Seed hairs (2 criteria)

Morphologies were further refined and grouped by specific criteria. This led to a total of 1152 groups that the native grasses can be classified within. Criteria for the characteristics are shown in Tables 1-3.

Using the morphological order, queries were conducted in Microsoft Access to determine how the grasses would sort and which groups they fell within. The first two morphologies (plant height and inflorescence) were initially sorted to create six main groups. These groups are summarized in Tables 1 and 2. The final classifications with the other five morphological criteria incorporated were then categorized and placed into tables.

The final morphological characterizations included criteria specifically related to seed harvestability for select species. To refine the classifications for the key, those species of economic importance were divided into 12 main groups using plant height, type of inflorescence, and location of disarticulation. These species categories are summarized in Table 3.

The largest category of native grasses of economic interest is panicle inflorescences of medium height (Table 1, Group IV). Over 86.8% of the grasses have panicle inflorescences and 54.3% are of medium height.

Table 2 displays the very small proportion (13.3%) of native perennial grasses of economic importance in the continental United States that have spike/spike-like inflorescences. While conventional harvesters can effectively harvest some panicle type species, many of these species fall into the difficult-to-harvest category. Table 3 shows that the largest category of economic grasses has panicle inflorescences and seeds that disarticulate above the glumes (37%). It is generally assumed that disarticulation above the glumes contributes to a higher level of seed shatter and consequent seed loss prior to and during conventional harvesting.

Using this improved understanding of the role of grass plant and seed morphologies has facilitated design of the ***Seedster*** with features that allow variable settings to accommodate harvest of particular grass seeds.

Table 1: Initial morphological classification of perennial native grasses of economic interest into six groups.

Group	Characteristics	Number of Species	Percent of Total
I	Short plant, spike/spicate raceme inflorescence	3	1.5
II	Short plant, panicle/raceme inflorescence	12	6.1
III	Medium plant, spike/spicate raceme inflorescence	13	6.6
IV	**Medium plant, panicle/raceme inflorescence**	**94**	**47.7**
V	Tall plant, spike/spicate raceme inflorescence	10	5.1
VI	Tall plant, panicle/raceme inflorescence	65	33.0
Total		197	100

Table 2: Native grass plant heights and inflorescence types of economic importance in the continental U.S.

Height	Spike/Spicate raceme Inflorescence Species	Panicle/Raceme Inflorescence Species	Total
Short	3	12	15
Medium	13	94	107
Tall	10	65	75
Total	**26 (13.2%)**	**171 (86.8%)**	197 (100%)

Table 3: Morphological classification of perennial native grasses of economic importance into 12 groups based on height, type of inflorescence, and location of disarticulation.

Group	Plant Height	Inflorescence Type	Disarticulation Location re. Glumes	Number of Species
I	Short	Spike/Spicate raceme	Above	0
II	Short	Spike/Spicate raceme	Below	3
III	**Short**	**Panicle/Raceme**	**Above**	**9**
IV	Short	Panicle/Raceme	Below	3
V	Medium	Spike/Spicate raceme	Above	9
VI	Medium	Spike/Spicate raceme	Below	4
VII	**Medium**	**Panicle/Raceme**	**Above**	**73**
VIII	Medium	Panicle/Raceme	Below	21
IX	Tall	Spike/Spicate raceme	Above	7
X	Tall	Spike/Spicate raceme	Below	3
XI	**Tall**	**Panicle/Raceme**	**Above**	**39**
XII	Tall	Panicle/Raceme	Below	26

Extensive replicated field research trials in Montana, North Dakota, and Minnesota since 2002 have proven the ***Seedster*** highly effective in harvesting seed of seven difficult-to-harvest grass species that fall within the most important of the 12 morphological groups (Table 3). These include Canada wildrye (*Elymus canadensis*) (Group V), little bluestem (Group VI), needleandthread, green needlegrass (*Nassella viridula* previously *Stipa viridula*) (Group VII), switchgrass (Group XI), and indiangrass (*Sorghastrum nutans*) and big bluestem (*Andropogon gerardii*) (Group XII).

Several morphological characteristics contribute to poor gleaning of seed through the sieves or screens of a standard combine and influence the flow of harvested seed through the combine and the unloading of 'in-the-dirt' seed from the hopper. Awns can cause seed to adhere to straw and chaff, preventing them from being efficiently screened through the sieves. Long awns, particularly those that are curved and/or twisted can be problematic. Also the hairiness of the lemma, attached rachis, attached sterile florets and the callus can also contribute to poor gleaning and poor seed flow. The ***Seedster*** is

capable of harvesting this type of seed with minimal amount of trash intake (leaves, stems, chaff). Rather than a hindrance to harvesting, the awns and hairs actually contribute to the effectiveness of the ***Seedster***, as the comb and brush more easily pluck awned and hairy seed from the inflorescence, regardless of whether it is a spike, panicle, or raceme. Small seed can also be hard to harvest with standard equipment. Again, the ***Seedster*** is designed to handle all sizes of seed, with limited loss or leakage from the system. The native grass seeds with awns, hairiness and small seed size are summarized in Table 4.

Table 4. Comparison of panicle/raceme and spike/spicate raceme grass traits which can make standard seed harvest difficult.

Inflorescence Type	Spike and spike-like	Panicle and raceme
Total number of current economically important species for each inflorescence type	26	171
Grass with seed that disarticulates above the glume	16	121
Seeds or florets with hairs	11	79
Seeds or florets with medium to long[1] awns	16	34
Small or extra small seed size[2]	5	107

1. Awns greater than 10 millimeters
2. 250,000 or more seeds per pound

Microsoft Access can query the database to find out how many species have long and medium length awns (50) (25.3%), have hairy seeds or appendages (90) (45.6%), or have small or very small seeds (112) (56.8%) (Table 4). This information can be especially useful in targeting high value species for harvest while anticipating which morphological characteristics typically limit harvest success with standard harvesting equipment.

Summary

This study, jointly sponsored by the Montana Board of Research and Commercialization Technology and Arbuckle Ranch, Inc., produced a dichotomous key for native grass plant, inflorescence and seed morphologies and a comprehensive database of 197 native grasses of economic interest in the continental United States. Morphological features of these grasses affect their seed harvestability and consequently their market availability and seed prices. A great majority of the native grasses in the continental United States have panicle inflorescences and tend to be more difficult to harvest by conventional means. Most seed appendages and hairs decrease the harvestability of seed because of poor gleaning and flow through standard harvesting equipment. The Arbuckle Native ***Seedster*** is specifically designed to harvest these difficult-to-harvest species by addressing morphological features that affect harvestability and handling. Findings of this in-depth study will facilitate harvest and market availability of difficult-to-harvest native grass species throughout the United States.

The following products resulted from this study:

- A list of native perennial grasses of the continental U.S**.** (Appendix A)
- A dichotomous key based on seed and plant morphological characteristics affecting seed harvest of native perennial grasses of the continental U.S**.** (Appendix B)
- A morphology and harvesting database of economically important native perennial grasses of the continental U.S. (Appendices C and D)
- A Microsoft access database containing morphological information, seed availability, official releases--cultivars/germplasm, and ecological information on native perennial grasses of the continental U.S.

Credits

Images compliments of Virtual Herbarium CD, Montana Prairie Products, Plevna, MT. Contact Carol Sparks at 406-778-2320 or sparks@wb.midrivers.com. Images and information on over 140 Montana range plants.

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Appendices

- Appendix A: List of Native Perennial grasses of the Continental U.S. (pages A-1 to A-30)
- Appendix B: Dichotomous Key Based on Morphological Seed Characteristics Affecting Harvesting of Native Perennial Grasses of the Continental U.S. (pages B-1 to B-23)
- Appendix C Table of Native Perennial Grasses of Economic importance of the U.S. (pages C-1 to C-21)
- Appendix D Morphology and Harvesting Data Base for Native Perennial Grasses of Economic Importance in the U.S. (pages D-1 to D-201)