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Crambe

A North Dakota Case Study

A report for the Rural Industries Research and Development Corporation

By S E Knights

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Executive Summary

Crambe (*Crambe abyssinica*), an industrial oilseed, has been successfully grown, processed and marketed on a commercial scale in North Dakota, USA, since 1990. A major reason for its success has been a multidisciplinary team involved in the research, development and commercialisation of the species through the auspices of the High Erucic Acid Development Effort (HEADE).

In North Dakota, ecologically, crambe has offered a unique opportunity for farmers to diversify their crop rotations as it shares few pests with more commonly grown crops. It also shows tolerance to a wide range of insects and is produced using standard small grain equipment. However, crambe has one short fall, as due to its low-test weight it is only economic to process it locally.

In recent years, the production of crambe in North Dakota has fluctuated as the commercial players involved in the industry have changed. Its future will depend upon both the future of biorenewable resources together with innovative research to develop additional markets for the crop.

This report combines a short study tour of key research centres involved in crambe research and development in North Dakota undertaken by the author together with documented information on the oilseed for the benefit of Australian growers, processors, marketers and researchers of new crops.

Introduction

Hundreds of crops have been domesticated and cultivated by humankind during the history of agriculture, utilised for food, forage, fibre and medicine. However, only a small number provide the bulk of the raw material necessary for human survival. The limited diversity has increased the vulnerability of crops to adverse climatic conditions and fluctuating markets.

In recent years, particularly in Europe and the USA, there has been growing interest in the use of crops as biorenewable industrial feedstocks, for uses such as fuels, lubricants and bioplastics. *Crambe abyssinica* (crambe) is such a crop that has industrial potential.

The major aim of this small project was to compile a case study of the crambe industry in North Dakota, USA. It involved a brief study tour of key North Dakotan State University Research and Extension Centres involved in crambe research and development by the project leader (Sue Knights) supported by Rural Industry Research and Development Corporation together with the compilation of background information on crambe research, development and production in North Dakota.

Crambe- the plant

The following information is drawn from a Scoping Study titled 'Opportunities for alternative oilseeds in the Southern Region', a report prepared by Dr Sue Knights for the Grains Research and Development Corporation.

Description

Crambe (*Crambe abyssinica*) is a member of the *Brassicaceae* family and is native to the Mediterranean region. It is also known as Ethiopian kale, Abyssinian mustard, Abyssinian kale, Colewart and Katran but is most commonly referred to as crambe. The plants are erect, herbaceous annuals with large, pinnately lobed leaves (Figure 1) (White and Higgins, 1966). It has a straight stem which is moderately branched. The white flowers are clustered in racemes and the fruits are spherical, almost always one-seeded, indehiscent, and remain attached to the plant at maturity, unless heavy rain and wind at maturity cause extensive shedding (Hanzel *et al*., 1993). The silique wall or hull remains attached to the seed during harvest, but it can be removed fairly easily, thus raising the oil content from 35% to 46% (Erickson and Bassin, 1990).

Origin

Crambe belongs to the *Leptocrambe* DC section of the genus, which occurs principally in the Mediterranean region (Leppik, 1975) and it is the only cultivated member of the genus (Weiss, 2000). The centre of origin of the genus appears to be in the Turko-Iranian region, with subsequent migration to the Mediterranean during periods of geological and climatic changes. The occurrence of two species in Ethiopia, *C. abyssinica* and *C. sinualenta* (Weiss, 2000), suggests that these have evolved from the related species, *C. hispanica*, as it migrated down the Nile Valley and the Red Sea in ancient times. An outlying population of another related species, *C. filiformis*, in southern Chile and Patagonia probably was established from Mediterranean material transported by early Spanish or Portuguese explorers and colonists.

Figure 1: Crambe plant, flower and seeds (with husk removed, top) respectively.

Adaptation

Crambe originated in a warm-temperate area of Ethiopia with a moderate rainfall, but it has become adapted to colder and drier regions (Weiss, 2000). It is sensitive to drought, but can escape damage provided the deep root system is able to tap subsoil water. The vegetative plants prefer a temperature range of 15 – 25 C, but will tolerate higher temperatures except at flowering. In warmer regions, crambe is severely damaged by frosts of –1 C, although the seedlings will tolerate –4 to –6 C. Kmec (1998) showed that about 1350 degree-days above 2.5 C are accumulated between sowing and physiological maturity. In North Dakota, the crop takes about 85-100 days from sowing to maturity (Golz, 1993). There, crambe is more resistant than canola to heat and drought at the end of the growing season, and, on average, crambe is the higher yielding crop (McKay, 1992).

Uses

Crambe abyssinica has potential as an industrial fatty acid feedstock as a source of erucic acid. Erucic acid is used mainly as erucamide, an effective non-stick agent in polyolefin films for wrapping food, plastic bags, shrink wraps, etc. It can also be converted to nylon 1313, or hydrogenated to behenic acid, which also has many applications in the manufacture of rubber, pharmaceuticals, cosmetics, fabric softeners, hair conditioners and rinses (Carlson and van Dyne, 1992). High erucic oils are used for the production of lubricants, plasticisers and foam suppressants (Princen, 1983). Crambe oil is a very effective lubricant, and is much more biodegradable than mineral oils, so it may be used alone or as additives for the textile, steel and shipping industries

The 1.89% of unsaponifiable matter in crambe oil is composed primarily of -sitosterol, campesterol, and the long-chain aliphatic alcohols, hexacosanol and docosanol (Lazzeri, 1994). The sterols may be useful as margarine additives for the reduction of blood cholesterol, and the alcohols for esterification to long-chain fatty acids to produce liquid waxes similar to those in jojoba and sperm whale oils.

Table 1: Amino acid composition (g/16g N) of the seed proteins of crambe in comparison with those of other protein-rich meals

Amino acid	Crambe[1]	Canola[2]	Soybean[1]
Asp	6.0-7.6	7.0	11.8
Thr	3.1-4.6	4.4	3.9
Ser	3.5-4.1	4.4	5.5
Glu	14.2-17.0	18.7	18.6
Pro	5.5-6.2	6.1	5.9[4]
Gly	4.7-5.3	5.1	4.3
Ala	3.8-4.2	4.4	4.3
Cys	2.6-2.8	1.2	0.9
Val	4.5-5.6	4.9	4.6
Met	1.6-1.9	1.9	1.1
Ile	3.7-4.1	3.8	4.6
Leu	5.9-6.8	7.0	7.8
Tyr	2.5-3.0	2.3	3.4
Phe	3.4-4.0	3.8	5.0
His	2.2-2.7	2.7	2.6
Lys	4.9-5.7	5.9	6.4
Arg	5.7-7.3	5.6	7.3
Trp	1.0-2.0[3]	1.2	1.3[4]

[1] National Sun Industries, North Dakota, quoted in Carlson *et al*. (1996).
[2] Appelquist and Ohlson (1972).
[3] Carlson and Tookey (1983).
[4] Busson (1965).

The meal remaining after oil extraction can be used as a component of feed for ruminants. The hulls are poorly digested (45%) by rumen liquor from cattle, but the organic matter of the meal remaining after extracting the oil from dehulled seed is 85% digestible (Steg *et al*., 1994). Crambe meal organic matter, crude protein and neutral detergent fibre were digested more rapidly in the rumen of dairy cattle than soybean meal, but heat treatment of the flaked seed prior to oil extraction would decrease meal digestibility substantially (Liu *et al*., 1993b). The whole seed of crambe contains 3-4%, or about 90 mole/g, of glucosinolates, most of which is *epi*-progoitrin [(S)-2-hydroxy-3-butenyl glucosinolate,] (Lazzeri, 1994). This glucosinolate concentration is about twice that in high glucosinolate rapeseed (Carlson, 1985). Glucosinolates are toxic to a wide range of organisms, and reduce rumen microflora activity for six days after cattle are first fed diets containing them (Duncan and Milne, 1991). Stock *et al*. (1993) reported a decrease in the feed intake of cattle for three days after first including crambe meal in their diet, after which intake returned to normal. Crambe has been cleared by the US Food and Drug Administration for use in beef cattle rations to the extent of 4.2%; the experimental evidence used to reach this decision was reviewed by Carlson *et al*. (1996). However, glucosinolates are toxic to monogastric animals (Liu *et al*., 1993a), so crambe meal cannot be included in pig or poultry diets unless the glucosinolates can be removed or inactivated economically. Crambe meal also contains the glucosinolate breakdown product, 1-cyano-2hydroxy-3-butene, which is toxic to both plants (Vaughn and Berhow, 1998) and animals (Carlson, 1985).

The low glucosinolate trait has not yet been discovered in crambe, but Lazzeri (1994) listed the methods by which the glucosinolates could be separated from the meal for the preparation of other chemicals. The remaining meal would have a favourable amino acid composition (Table 1) for animal feeds or possibly for the production of food-grade protein isolates and concentrates. Crambe seed protein is rich in the sulfur-containing amino acids, cystine and methionine, and in lysine and threonine, in which cereal proteins are deficient. The meal from dehulled seeds contains almost 50% crude protein (Steg *et al*., 1994). Massoura *et al*. (1996) extracted proteins efficiently from crambe meal at pH 11 and separated them by isoelectric precipitation and ultrafiltration. At alkaline pH, crambe proteins had good emulsifying properties. The fraction precipitated at pH 5.5 produced a more stable and voluminous foam than hen's egg white. These results suggested that crambe proteins may be valuable in the food industry.

Fatty acid profile and products

Crambe has a higher concentration of the long-chain fatty acid, erucic acid (C22:1), than most other species, including rapeseed (HEAR) and other *Brassica* species (Table 2).

The fatty acid profile of crambe is shown in Table 3. The erucic acid residues are located at the outer positions in the triglyceride molecules, from where the fatty acids can be preferentially removed enzymatically using *Rhizopus javanicus* lipase (Derksen, 1993) to give a mixture containing over 85% erucic acid, from which almost pure erucic acid can be recovered by distillation. Ammonia treatment then gives erucamide, the main use for erucic acid oils (Lazzeri, 1994).

Table 2: Fatty acid composition of oilseeds high in erucic acid

Species	**Oil (%)**	**Fatty acids**								
		C18:0	**C18:1**	**C18:2**	**C18:3**	**C20:1**	**C22:1**	**C22:2**	**C24:1**	**Others**
Crambe[1]	30 - 45[5]	0.9	15.9	8.7	8.7		56.4			9.4
HEAR[2]	40 – 45	2.3	12.0	11.2	12.5	8.0	49.5	-	1.1	3.4
Brassica juncea[3]	37-44	1.1	11.5	17.7	10.2	6.8	47.0	1.33		4.4
B. carinata[3]	40	1.2	10.0	18.3	13.0	8.2	41.6			7.7
B. oleracea	-	0.6	6.5	13.3	10.9	3.9	58.1	-	2.7	4.0
Sinapis alba	30-37[5]									
cv. Gisilba[4]		1.2	31.6	9.5	8.2	11.8	35.1			2.6
cv. Mustang[4]		0.8	18.4	11.1	9.3	4.6	53.4			2.4
Low erucic[4]		1.9	66.2	10.6	11.6	4.1	2.9			2.7
Lunaria annua[5]	30-40		18				48		24	10

[1] Leonard (1993) [2] (Robbelen *et al*., 1989)[3] R. N. Oram (unpub.) [4] Brown *et al*., (1999) [5] Katepa-Mupondwa *et al*., (1999)

Crambe oil has a high smoke point and viscosity, making it potentially useful in the lubricating, emulsifying and refrigeration fields (Lazzeri, 1994). As a lubricant, it has a higher heat removal coefficient than mineral oils at temperatures of 700 C, whereas the better mineral oils reach a maximum rate of heat removal at 500 - 600 C. Crambe oil is highly compatible with mineral oils, and mixtures can be designed with maximal heat removal rates at different temperatures (Lazzeri, 1994). Also, crambe oil containing 3% of a polyphenol antioxidant was stable at 180 C for 240 h., and did not develop any oxidation or polymerisation products such as soluble resins or insoluble gums. Therefore, it is suitable as a chain saw lubricant, especially as it is readily biodegradable.

Table 3: Properties of *Crambe abyssinica* oil (Watkins, 1999)

Characteristic	Value
Free fatty acids	<0.5%
Iodine value	85-90
Insoluble impurities	<0.01%
Sulphur	30-60 ppm
Fatty acids (% of total)	
Oleic (C18:1)	16
Linoleic (C18:2)	8
Linolenic (C18:3)	5
Erucic (C22:1)	>55

History of Crambe in North Dakota

Crambe seed stocks were first introduced into the USA from Europe in the 1940's by the Connecticut Agricultural Experimental Station (Lessman and Anderson, 1981) and commercialised in North Dakota in the early 1990's.

Interest in the crop was first stimulated after the end of WWII in an effort to replace some of the commodity crops produced with specialty food crops or industrial crops to cope with US agricultures over production of commodity crops. A federal program begun in the late 1950s and led by the US Department of Agricultures (USDA) utilisation laboratory at Peoria, Illinois, screened more than 8,000 species, of which crambe was identified as a promising source of high erucic acid (Princen, 1983). This work led to the evaluation of crambe throughout the United States as a potential new crop with much of the initial agronomic research completed by 1966 (White and Higgins, 1966). USDA scientist Ken Carlson in Peoria led the utilisation and processing research necessary as a precursor for commercial development. Koert Lessman at Purdue and later at New Mexico State University maintained the breeding effort throughout the entire development period in conjunction with a federal germplasm effort led by George White and Austin Campbell at USDA facilities in Beltsville, Maryland (Gardner, 1996).

However, attempts to introduce industrial crops, to this point, had been very slow, often haphazard and inefficient (Carlson *et al*., 1996). In fact, the first commercial attempt to produce crambe had failed in western Kentucky, USA during the 1981 season as agronomic test plots failed causing interest in crambe to fail as well (Watkins, 1999). But the situation began to improve when a group of university scientists, private sector representative, and government scientists and managers focussed on rapeseed and crambe.

This came about, when interest was revived in crambe during a meeting, held in Kansas City, Missouri in December 1986 organised by the US Department of Agriculture, through its Cooperative State Research, Education and Extension Services (CSREES) Office of Agricultural Materials and its Agricultural Research Services (ARS) National Agricultural Utilisation Research (NCAUR) and the University of Missouri's Department of Agricultural Economics. Along with Iowa State and Kansas State Universities and the Kansas Board of Agriculture, provided leadership for establishing the initial management structure, setting goals and developing action plans, primarily for commercialising crambe (Carlson *et al*., 1996).

In 1989, the 'crambe project' sponsored a crush of 150 t of crambe seed produced in Iowa and successfully marketed the oil, which immediately increased both public and private sector interest in high erucic oil crops. In 1990, the project was extended to include industrial rapeseed and several additional universities joined the project. Thus the High Erucic Acid Development Effort (HEADE) was initiated (Table 4).

Table 4 : High Erucic Acid Development Effort (HEADE) participants and contributions by discipline or expertise

Institutional partner	Contributions by discipline and acquired knowledge
US Department of Agriculture, Cooperative State Research, Eduction and Extension Service, Office of Industrial Materials	Management, oversight, budgeting
US Department of Agriculture, Agricultural Research Service, National Centre for Agricultural Utilisations Research	Management, chemistry, oil & meal processing, markets
University of Georgia	Rapeseed- breeding, production sciences
University of Idaho	Rapeseed- breeding, plant & animal sciences, crop production, economics
University of Illinois	Animal science, marketing
Iowa State University	Crambe- plant science, processing, economics
Kansas Board of Agriculture	Marketing, economics, management skills
Kansas State University	Plant & animal science, processing
University of Missouri	Management, plant & animal science, economics
University of Nebraska	Plant & animal science, processing engineering
New Mexico State University	Crambe- breeding, plant science, crop production
North Dakota State University	Crambe- breeding, plant & animal science, chemistry, marketing, extension service to growers

(Carlson *et al*., 1996)

A crucial event involved in the commercialisation of crambe eventuated when a group of North Dakotan farmers joined National Sun Industries (NSI) and North Dakota State University (NDSU) and HEADE from 1990 to 1995. In 1990 they produced 900 ha of crambe, and within four years the alliance had 24,000 ha of crambe under cultivation (Carlson *et al*., 1996). At the same time, the HEADE team sponsored and conducted production, breeding, processing, product development and marketing research.

An annual line item appropriating from the Congress provided partial funding for HEADE activities (less than USD $500,000). The funds were administered through the CSREES Office of Agricultural Materials to the participating universities under cooperative agreements. Each member university also provided funds and in-kind support for the research and commercialisation projects. The HEADE management committee established Requests for Proposals and peer review procedures to select 15-20 projects for funding each year.

The line item funding ended in the 1995 financial year, wherein the HEADE management committee completed the remaining funded research projects and encouraged project members to continue their institutional commitments to both crambe and rapeseed commercialisation. Internal funding and development of cooperative interactions with seed, biotech and chemical companies and with grower groups have enabled several universities to continue breeding, agronomic, animal feeding and chemical research on both crops.

For a comprehensive review of the research and development involved in crambe up to 1996 refer to Carlson *et al*., (1996).

In 1995, the commercial development of crambe faltered again when the US Congress discontinued funding to the HEADE consortium and National Sun Industries announced a pending longterm lease of all its processing facilities, as the parent company had shifted its business focus. However, the grower group, now numbering some 540 growers (the American Renewable Oil Association) began shopping around for other processing/marketing partners in their region. The growers found the local oilseed processing industry very helpful, making its facilities available for toll crushing if the growers would shoulder the risk of contracting the production and marketing the oil and meal of the small volume niche oilseed (Gardner, 1996).

The growers decided to establish their own value-added business. This was a concept not entirely new to North Dakotan growers as they had been very successful in establishing value-added industries for durum wheat for pasta, sugar beets and corn for sweeteners and buffalo for low-cholesterol steaks. They established a company called AgGrow Oils LLC which was headed by John Gardner, formerly director/agronomist for the NDSU Carrington Research Extension Center. John Gardner had been involved with the development of crambe right from the start of the venture in North Dakota and is considered by some to be the ‘Father of crambe’.

AgGrow Oils LLC was a fairly ambitious processing and marketing effort that attempted to take advantage of the mega-processing companies' biggest weakness - their inability to react quickly to change, in the market and on the land. They were also involved in other niche crops such as safflower, borage and canola.

Originally crambe had been processed by National Sun Industries at its Enderlin plant in North Dakota and NSI also marketed the oil and meal. In January 1998 a 200t/day oil processing facility for niche specialty oils opened in Carrington, North Dakota, a joint venture between AgGrow Oils LLC and Cenex Harvest States Cooperatives involving some 540 growers (Watkins, 1999). However, this facility is no longer in operation as a specialty oil crushing facility as it was sold to a local company for use as a packaging plant for birdfood and other nonoil seed commodities in 2001.

The AgGrow Oils venture lasted only two years, however, the grower group, American Renewable Oil Association, is still active today.

In 2000 and 2001 the Montola Oilseed crushing facility in Culbertson, Montana was utilised by the crambe grower consortium. This facility has a capacity of 300 t/day. In November, 2001, Harvest States, a division of Cenex Harvest States Cooperative, dropped its plans to buy the crushing facility which had been owned by Sheridan Electric. At this point in time, it is unknown what the status of this facility is.

In February 2000 a new commercial interest moved into the crambe scene in North Dakota, John K King & Sons Limited, an English company owned by Allied Grain (a wholly owned subsidiary of Associated British Foods PLC, one of the UK's leading companies, and the country's largest agri-food business) opened an office in Carrington, North Dakota.

Kings, having worked directly with growers in North Dakota since 1995, recognised the tremendous ability and commitment towards the production of speciality identity preserved crops in this region. The climate, soil type, agricultural environment and expertise of growers in North Dakota gave them the confidence to open their office in Carrington in February 2000.

Kings is a company that operates at the leading edge of innovative crop development. The Company develops crops for the pharmaceutical, oleochemical and cosmetic industries brought to market through the creation of an international network of contract growers of identity preserved crops. A specialist oil extraction plant in Lincoln, UK, was purchased in 1999 to enable onward processing of niche crops and ensure the maintenance of identity preservation in the supply chain.

Kings is a fully intergrated and global company that is a leader in the supply chain management of new and niche plant derived products for the industrial chemical, dietary supplement, pharmaceutical, specialist nutrition and cosmetic markets.

Specialist activities include:

a) The identification, strategic sourcing and identity preserved production of novel and alternative agricultural crops and other specialist plant derived material.
b) The processing (extraction, blending, formulation and standardisation) of such plant derived material.
c) Marketing, supply and distribution of plant and seed derived products, guaranteeing assurity, continuity, quality, traceability and price stability of product through long-term contractual arrangements.
d) Meeting the highest relevant standards (GMP, GLP, ISO, HACCP, MCA) for their production and processing facilities.
e) Supporting commercial activities through innovation, research and development for future growth.

Kings supply a number of speciality oils that have use in a host of different industries. Most are derived from 'Identity Preserved' crops grown on contract throughout the world. This allows Kings to be able to succesfully fulfill key criteria such as continuity of supply, price stability and full traceability - allowing the customer complete peace of mind.

Part of Kings expertise lies in identifying the most suitable plant sources for specific fatty acids. Examples of some specific fatty acids and selected plant sources that they produce are:

- γ-linolenic acid- *Borago officinalis* (Borage or Starflower)
- α-linolenic acid- *Camelina sativa* (Camelina or false flax)
- stearidonic acid- *Echium plantagineum* (Patterson's curse or Salvation Jane)
- Oleic acid- high oleic sunflowers
- Erucic acid- crambe/high erucic rapeseed

In 2000, Kings set a 30,000-acre goal for contracting crambe production in North Dakota, in competition with AgGrow Oils. Kings utilised Archer Daniels Midland plant in Enderlin, North Dakota to crush the seed. In 2001 they contracted 11,000 acres but reportedly will not be offering contracts next year as they are having problems filling their required 20,000 acres (Zwinger, pers com.). Kings now competes with Cenex Harvest States for the current production of the crop in North Dakota.

Crambe breeding

Koert Lessman led the first breeding program for crambe at the USDA in Peoria, Illinois which released three cultivars, 'Prophet', 'Indy', and 'Meyer' in the early 1980s. Campbell *et al*. (1986) then developed and released the cultivars, 'BelAnn' and 'BelEnzian', and the lines C-22, C-29, and C-37, by introgressing genetic material from wild populations into Indy. The five releases performed as good as or better than 'Prophet', 'Indy', and 'Meyer' in several locations.

Lessman continued his breeding effort at New Mexico State University during the 1980s and developed a group of elite lines that approached his earlier releases in performance. With Lessman's retirement in 1991, HEADE arranged to establish a crambe breeding program at North Dakota State University. Crambe germplasm gathered for the NDSU program included previously released cultivars, 103 accessions from the world collection maintained at the North Central Plant Introduction Station at Ames, Iowa, and breeding material from Lessman's Purdue and New Mexico State University programs.

The objectives of the NDSU crambe breeding program included:

1. increase seed yield;
2. increase oil content of the seed to a level near that of rapeseed;
3. lower glucosinolate content to acceptable levels or eliminate them altogether;
4. increase erucic acid content of the oil to its maximum level;
5. and develop cultivars that are resistant/tolerant to potentially harmful diseases, *Alternaria* and *Sclerotinia,* and insects, such as the diamond back moth. Other

characteristics being considered include resistance to lodging and seed shatter, and a short seed dormancy period.

These objectives are being approached in two ways:

a. evaluation of existing germplasm; and
b. selection among and within breeding populations developed through hybridization among existing germplasm and subsequent selfing.

A bulk-pedigree method is being used as inbred lines are originally derived from F_2 plants and seed is bulked in the succeeding generations. By using a two-generation greenhouse season and a winter nursery, $F_{2:5}$ lines are available for evaluation two years after the crosses are made. Preliminary yield evaluations are being initiated in the $F_{2:6}$ generation.

Performance evaluations conducted at numerous locations in North Dakota in the years 1992-94 have indicated that many breeding lines have the potential to perform better than the currently grown cultivars, 'Meyer', 'BelAnn', and 'BelEnzian', in all important characteristics (Hanzel *et al*., 1993). However, no one breeding line contains all traits expressed at the desired levels. Breeding efforts are continuing to combine all desirable traits. Oil content has still averaged well below the desired level, and, of thousands of lines evaluated in the three-year period, only several have possessed glucosinolate levels that approach acceptable levels. Non-conventional breeding techniques are being considered to modify the expression of these traits.

The current NDSU crambe breeder is Dr Jim Hammond whose major research duties is flax improvement.

Current agronomic practices for crambe production in North Dakota

There has been a large amount of research invested in developing agronomic packages for crambe in North Dakota. The following information is from Endres, (1993) a NDSU Extension Service publication which was revised in 1999, much of the information has been retained in imperial units.

Varieties

BelAnn and Meyer are the two crambe cultivars currently available in North Dakota for commercial production.

Seedbed preparation

A critical phase of successful crambe production is stand establishment. A vigorous stand that emerges early will take advantage of cooler temperatures and available soil moisture and be more competitive with weeds. The seedbed for crambe should be firm in order to place seed at a uniform and shallow depth. High-quality (e.g. certified) seed should be sown 3/4-inch deep and no deeper than 1.5 inches. The crop should be seeded in narrow row widths (6 to 10 inches). Small grain seeding equipment, including double disc opener press drills and air seeders, can be used.

Crambe should be sown in late April to early May when soil conditions are suitable for planting. The seedling crop can tolerate temperatures in the low 20's for several hours. If the crop is injured by frost, allow sufficient time (7 to 10 days) to determine if damage warrants destruction of the crop. A significant decrease in seed yield and oil content can be expected if seeding is delayed until late May or June.

A seeding rate of 15 to 20 pounds of pure live seed per acre is recommended. At 60,000 to 80,000 seeds per pound, this seeding rate should provide a targeted stand of 1 million plants per acre or 23 plants per square foot. Seeding rates as low as 8 pounds live seed per acre have resulted in low plant densities (10 to 12 plants per square foot) but good yields due to increased plant branching and an extended flowering period. However, using the recommended seeding rate will result in crambe plants being more competitive with weeds and maturing more uniformly. The recommended seeding rate also is suggested if soil crusting is anticipated. Seeding rates greater than 20 pounds per acre will result in greater seed costs, increased lodging, and probably no improved yield compared to the recommended seeding rates.

The seedling crop can tolerate temperatures in the low 20's for several hours. For example, at the Carrington Research Extension Centre in 1990, temperatures of 22-23 degrees were present for about 5 hr, followed by 35 degrees as the high temperature for the day. These temperatures occurred when crambe was in the cotyledon stage (tips of true leaves just visible). Later, the cotyledons turned completely brown and the tips of the true leaves also were brown. However, the true leaves eventually emerged and the plants developed normally. Also, during the week of May 24, 1992 at the Carrington Centre, low temperatures of 30 degrees for 4 hours were tolerated by crambe in the cotyledon to emerging true-leaf stage. With this data in mind, delay any decisions to destroy a frost-damaged crambe stand until the crop's condition is known. Allow about 7 to 10 days to determine if normal regrowth is occurring.

Fertility management

Crambe's response to soil fertility is similar to that of small grain crops like mustard, and canola. A soil test should be conducted to determine the need for additional nutrients. About 5 pounds of nitrogen is required for each 100 pounds of seed yield per acre. Avoid using more than 10 pounds of actual nitrogen per acre and do not use urea with the seed as germination injury can occur. Crambe is generally responsive to phosphorus fertilization when soil levels are medium or less.

Weed control

Weed control is a critical management factor in crambe production. The crop is not a strong competitor with weeds during early vegetative development. Typically, three to four weeks are required for a crop canopy to be formed after emergence. It is during this period that the biggest challenge for weed control exists.

It is important that crambe be seeded on relatively weed-free fields. Fields that contain perennial weeds such as Canada thistle, perennial sowthistle, and field bindweed should be avoided. Also, avoid fields where crops grown the previous year may produce volunteer plants such as buckwheat and sunflower. A vigorous stand should be established ahead of weed development to provide optimum competition. A 2-year study at Carrington found that weeds emerging at densities up to 76 plants per square yard several weeks after crambe emergence did not adversely affect seed yield.

Seeding early and using recommended seeding techniques will help establish a crambe stand that is competitive with weeds.

A harrow or rotary hoe may be used for control of shallow-emerging weeds three to seven days after crambe planting. However, extreme caution must be exercised with these tillage tools as a high percentage of crambe seedlings may be damaged or destroyed.

A limited number of herbicides are labeled for use in crambe. Trifluralin is labelled for fall or spring application as a pre-plant, soil-incorporated treatment to control certain annual grass and broadleaf weeds. Assure II and Poast are labelled for postemergence control of annual grasses and quackgrass. Crambe is susceptible to certain previously-applied herbicides with long soil residue and to damage from drift of many broadleaf herbicides.

Diseases

Diseases identified in crambe in North Dakota include sclerotinia (white mold) and alternaria black spot, ascochyta blight and aster yellows. Crambe is susceptible to sclerotinia but slightly less so than sunflower and dry bean. Other potential diseases include bacterial blight, blackleg, clubroot, pythium root rot, and turnip yellow mosaic virus.

Crop rotations should be carefully planned to keep disease pressure to a minimum. It is suggested to maintain a four-year rotation with crambe as well as other crops susceptible to sclerotinia including sunflower, dry bean, canola, field pea, and soybean. Certified seed should be planted to avoid alternaria and other seed-borne diseases.

Insects

Insects that have potential for causing damage to crambe include grasshoppers, aphids, flea beetles, imported cabbage moth, diamondback moth, leafhoppers and lygus bugs. Of these, only grasshoppers have caused significant injury to crambe (typically in field margins) in North Dakota. Crambe is most susceptible to grasshopper damage at the seedling stage. Grasshoppers tend to choose other crop foliage as crambe develops.

Harvesting

After flowering, crambe matures rapidly (one to two weeks). Timely harvest is important to avoid high shattering losses. During warm, dry weather the crop should be frequently monitored (daily or every other day) to determine correct harvest stage.

Crambe is physiologically mature when about 50 percent of the seeds have turned brown. At maturity, the appearance of the plant may range from stems and leaves remaining green to leaves turning yellow and dropping. Attention should be directed to the seeds and seed-bearing branches to determine the onset of harvest.

Crambe may be swathed or straight cut. Both harvest methods have been successful, but the choice depends on acreage, harvest equipment, weather conditions, uniformity of maturity, and weed density. Straight combining is recommended for a mature, clean and low moisture crop. If the majority of seed pods are brown, straight combining is recommended as swathing may cause excessive shattering. If approximately 100 crambe seeds per square foot are present on the ground from shattering, a 60 to 70 pound per acre yield loss occurs. Crambe seed moisture should be 14 percent or less for straight combining. Crambe seed containing greater than 14 percent moisture will cause harvest problems due to difficulty moving the green plant material through the combine. At seed moisture less than 12 percent, high shattering potential exists.

Swathing may be necessary if maturity is variable where some plants are beginning to shatter, while others are still slightly green. If a sufficient number of green weeds are present, swathing may be required. Crambe should be swathed when about 50 percent of the seeds have turned brown. If the majority of the seed turns brown before swathing, the swathing and combining operations may cause excessive shattering. When swathing, reel speed should be reduced to one-half to two-thirds of that for small grain. Seed shatter can be minimized by swathing during a time of day when humidity is high. Swathing should be done just below the lowest seed pods, leaving the stubble as high as possible. This will allow the windrow to settle into the stubble and reduce loss from wind. Crambe will dry quickly after a rain (compared to small grain) in a swath or if the crop is standing.

Storage

Crambe seed is small, round, and light weight (25 pounds per bushel). Because crambe has a low test weight and is a relatively bulky crop, transportation costs are greater than for small grain and corn, and similar to sunflower. Equipment for transportation and facilities for storage must be tight to avoid loss of the seed. Before drying and storage, the seed should be passed through a roller screen or scalper to remove excess foreign material.

Crambe seed should be stored and marketed at a moisture content of 10 percent or less. Calibrations to determine crambe seed moisture with the Motomco electronic moisture tester have been developed. If using oil sunflower standard charts when testing crambe seed moisture, the moisture tester reading will be about 1 to 2 percentage points low depending on the brand and moisture range.
If seed is harvested at high moisture, natural air or artificial drying can be used. Do not dry seed with unheated air if seed moisture exceeds 20 percent. To maintain seed quality, a maximum drying temperature of 110 degrees Fahrenheit is recommended. Bin-drying with unheated air requires a minimum airflow of 1 cfm per bushel. During storage, the seed should be checked at regular intervals for heating or other problems. To prevent heating, aerate the seed with a minimum airflow of 0.1 cfm per bushel. Aeration should be continued until seed moisture and temperature equilibrium has been maintained throughout the bin.

Rotations

Rotation of crambe with other crops is recommended to avoid a buildup of pests and diseases. When developing a crop rotation plan, crambe should not precede or follow other broadleaf crops, especially closely-related crops such as canola or mustard.

Crambe should follow small grain, corn, or other grass crops. These crop options provide a break in pest cycles and provide soil conditions that can be easily managed to prepare for crambe production.

Small grain should perform well following crambe. Crambe stubble provides an acceptable cover for trapping snow, controlling erosion and establishing fall-seeded crops in a conservation-till system. When planting fall-seeded crops, care must be taken to minimize stubble disturbance as crambe residue is fragile.

Also, volunteer crambe is easily managed in succeeding crops using tillage or herbicides.

Production

Crambe production in North Dakota has fluctuated from 23,000 ha in 1993 to as low as 500 ha in 1995 (Figure 2). Over production in 1993 and 1994 led to the low production in 1995. This was possibly also linked with the discontinuing of the HEADE investment and the change in nature of National Sun Industries business. There are reports in the literature that the 1995 production was purely to maintain seedstocks (Gardner, 1996).

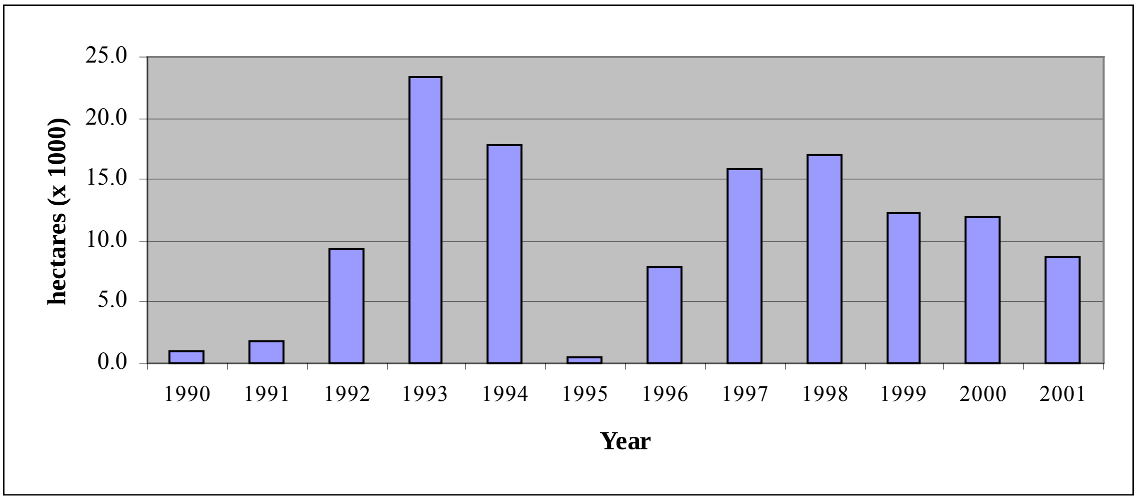

Figure 2: **Crambe production (x 1000 ha) from 1991 to 2001 (figures from North Dakota Agricultural Statistics Service and North Dakota State University Research and Extension Centre)**

The main regions for production are the drier western third of North Dakota. At one time, when crambe production first started, most of the production was in the higher yielding eastern part of the sate but as North Dakota entered a wet cycle the production shifted to the west where disease incidence was lower (Zwinger, pers com.). The growing season in this area is from May to September with on average 320 mm rainfall and around 120 frost free days.

In recent years prices for crambe have been around USD\$135t^{-1} with government subsidies bringing it to around USD \$219t^{-1} .

Figure 3 shows the total production areas for the crops produced in North Dakota over 1999 and 2000. In can be seen that the crop species produced are quite diverse and wheat is the dominant crop, followed by barley, soybeans, sunflower and canola. The dominant oilseeds are soybeans, sunflower (about one quarter of the production is utilised for non-oil purposes) and canola. The production of canola has expanded quite considerably in recent years.

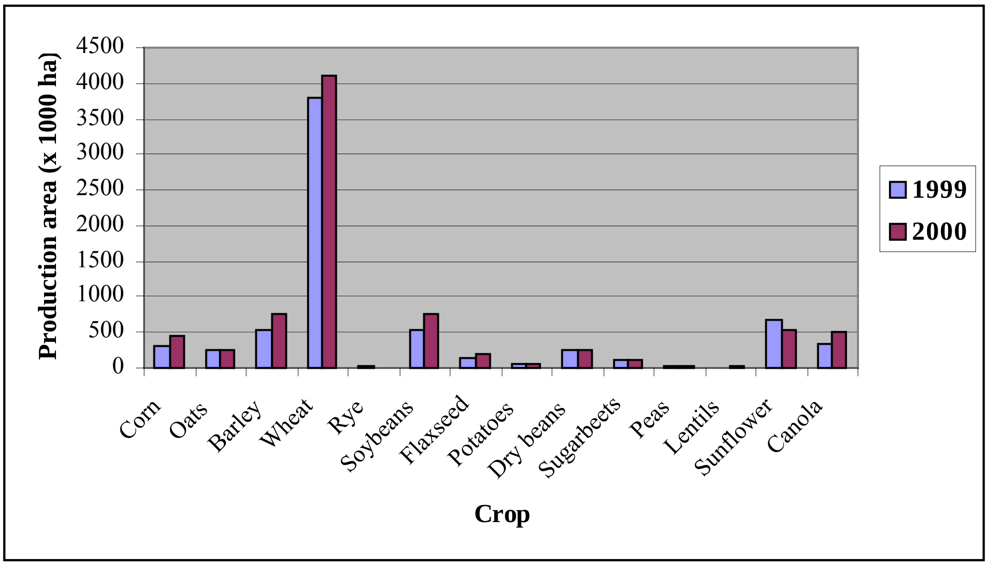

Figure 3: **Division of total crop production area in North Dakota for 1999 and 2000 (North Dakota Statistical Service)**

The production area of crambe in North Dakota is comparable to other niche crops such as rye and lentils.

Study Tour

The brief study tour involved visits to the Research and Extension Centres of North Dakota State University (NDSU), located at Minot, Carrington and Fargo between July 18 and 20, 2001 (Figure 4).

Minot

The North Central Research Extension Centre is located one mile south of Minot on U.S. 83. The 900-acre research Centre was established in 1945 for agricultural field research and pure seed increase. Today, it specializes in crop research and Extension education activities, and in foundation seed production. The surrounding area includes the largest durum wheat producing counties in the state. Forty percent of the nation's durum is produced in counties served by the Centre.

Figure 4: **Map of North Dakota, USA showing key locations visited circled.**

The Centre is located on the border of North Dakota's two most prominent soil and vegetation regions - the dark brown soils of the semi-arid grassland in the west, and the black soils of central North Dakota's subhumid grassland. With gently rolling land and 16.5 inches of annual precipitation, the Centre's main research efforts involve grain variety evaluation, weed control, tillage and fertilizer tests. Research is done on small grains, oilseeds, row crops, legumes, forages and some specialty crops. Production is evaluated for no-till and conventional tillage systems.

Significant new research programs include:

- studying profitability of rotation crops for durum, spring wheat and barley in north-central North Dakota. Included are sunflower, canola, pinto and navy beans, crambe, lentils, dry peas, mustard and lupins.
- sulfur fertility needs of small grains and canola.
- Commercialisation of pea production and harvest.
- row spacing and plant population for oil-and confection-sunflower production.
- the timing of fungicide applications for small-grain disease protection.

More than 1,500 owned, rented and contracted acres are planted for Foundation seed production. This recently increased from 600 acres in response to producer needs. Extension programs were added to the existing research site in 1976 to cover 10 surrounding counties and Fort Berthold. A considerable amount of research and extension educational programs comes from a small number of experts at the North Central Research Extension Centre.

The crambe trials conducted at Minot during the 2001 season were a crambe cultivar evaluation trial (Figure 5) and a windrowing date trial.

Figure 5: **Inspecting the 2001 crambe evaluation trial with Blaine Klein, Ag Research Technician, Minot Research and Extension Centre, NDSU, July 18**

Carrington

The Carrington Research Extension Centre was established as the Carrington Irrigation Branch Station by the state in 1960. The focus of the research effort was to support the Garrison Diversion Project plan to divert water from the Missouri River for irrigation. The Centre's scope has since expanded to include livestock research and the responsibility for dryland crop production research for central North Dakota. The location of the Carrington Centre is important because its research program can address crops and issues representing a significant part of North Dakota agriculture. The research effort at the Carrington Centre focuses on these general program areas:

crop variety evaluation.
crop production and management.
alternative crop development.
cropping systems.
integration of crop and livestock production.
beef cattle feeding and feedlot management.
cow-calf production.
bison nutrition research.
aquaculture.
the development of new agricultural enterprises.

These efforts have given the Carrington Centre a national reputation for its involvement in agriculturally based economic development, and for studying a wide range of crops and cropping systems.

There are 800 acres in the Centre. About 300 acres are irrigated by Centre-pivot systems and 100 acres by surface methods. The remaining acreage is managed as dryland and primarily used for dryland research. Another 320 acres are leased to supplement seed and forage production needs.

Figure 6: **The author inspecting a crambe cultivar evaluation trial with Steve Zwinger, Carrington Research and Extension Centre, NDSU, July 19, 2001**

Carrington Research Extension Centre facilities include the headquarters unit with buildings and equipment for storing and processing Foundation seed, equipment maintenance and storage, laboratories, and a residence. The Headquarters itself has offices and large meeting rooms for university, industry or community meetings. An adjoining building houses aquaculture research and demonstration facilities. An attached site can accommodate about 500 head of beef cattle and 160 head of bison. It includes feed and forage storage, pole barns, equipment storage, a residence, and extensive pens and feedlots.

Crambe trials conducted in 2001 included a cultivar evaluation trial (Figure 6).

Fargo

The Main Station of the North Dakota Agricultural Experiment Station is located in the northwest corner of Fargo, with research land and buildings on the north and west edges of the North Dakota State University campus. Approximately 2,300 acres accommodate 500 employees in the departments of Agricultural Economics, Agricultural and Biological Systems Engineering, Animal and Range Science, Biochemistry, Veterinary and Microbiological Sciences, Cereal Science, Plant Science, Entomology, Plant Pathology and Soil Science, as well as some research positions in the College of Human Development and Education.

The Northern Crops Institute, N.D. State Seed Department, N.D. Agricultural Statistics Service, N.D. Census Centre and USDA's Northern Crop Science and Bioscience Research Laboratories are also located on the NDSU campus. The close affiliation of scientific interests and physical location of these programs provides a solid research nucleus to concentrate on state, regional and national needs in agricultural research.

The NDAES Main Station's program includes research on crop production and management, livestock production and management, agricultural finance, marketing, policy analysis, and the processing and use of agricultural products. Special emphasis is given to several aspects of rural life and North Dakota population changes.

Scientists based at the Main Station do research under local conditions and work with Experiment Station and Extension staff throughout the state. Nearly 400 acres of Main Station land is intensely cultivated and maintained in orderly, research plots. These experiments are carefully designed and replicated to simulate large-scale farming enterprises in order to test new varieties of plants and experimental ways of raising them more efficiently and effectively.

Livestock research is conducted in several groups of buildings on the northwest side of campus, including dairy, beef, swine, and sheep barns. The NDSU Animal Research Facility at the northwestern edge of campus is scheduled for expansion and remodeling pending funding from the 1997 state legislature. This expanded facility will allow Experiment Station scientists to further investigate problems related to livestock growth, reproduction and health.

The main crambe breeding trials for NDSU were run at this location in 2001 and were inspected by the author with Dr Burton Johnson, Head of the New Crop Program, NDSU. Unfortunately they had had problems with the breeding trials due to establishment difficulties and herbicide drift and the trials were not in a good condition.

For further information see www.ag.ndsu.nodak.edu.

Summary

This brief case study of the North Dakotan crambe industry provides many incites into the development of a new crop that Australian growers and researchers could learn from. It’s success was fostered by a crop champion, together with the sharing of risk among producers and processors, each with visions of the potential benefits of commercialising an alternative crop together with the considerable work of a multidisciplinary team.

Although crambe seems to have found a niche in North Dakota, its production is still far from secure and will obviously depend on the future of bio-renewable resources not only in the USA but world-wide. However, in the mean time North Dakota has gained a wealth of experience with the crop in the state, and this would have not been possible without the university, industry, and the creativity that the North Dakotan farmers possess.

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