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Agricultural Development and Diversification Grant Program
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Commercial Production and Field Processing of New carrot cultivars for the Specialty Juice Industry

Combining new processing methods with new carrot cultivars to create new high value, fortified products

EXECUTIVE SUMMARY

Up into the 1970's central Wisconsin produced a large portion of the US carrot supply. Wisconsin is an ideal location for growing high quality carrots, but since that time lost nearly all of its juice and fresh carrot production to higher yielding locations in California.

In this project, our vision is to bring back carrot production into central Wisconsin by exploiting newly emerging cultivars with a demanding nutraceutical and functional food industry. There is increasing demand for healthier, more fortified products, and the nutraceutical/functional food industry has emerged from this demand.

The scope of our project included both discoveries of new specialty carrot cultivars as well as unique processing methods for these carrots. Our first overall objective was to find and collect new carrot cultivars that have highly desirable nutritional properties. This was quite a difficult task because carrot-breeding companies were not staffed to produce specialty cultivars, and academic universities were not in the business of building up seed stock. We soon discovered that there is not much specialty carrot seed grown anymore, but there is a lot contained in breeding programs around the United States. Our closest carrot-breeding program is housed in the Department of Horticulture at the University of Wisconsin-Madison. For years this team, led by Dr. Philipp Simon, has been studying the functionality of carrots, and breeding for a healthier carrot.

In this study we were successful at finding one particular red carrot called Nutri-Red, which is rich in lycopene, a phytonutrient with anti-cancer and heart disease preventative properties. Our marketing calls indicated that lycopene-based carrots are highly desirable for the nutraceutical and functional food industry, including juice beverages.

Though this grant we were able to attend marketing meeting across the United States to determine potential for a new product. We were also able to open doors with the University of Washington in testing their new dehydrating equipment at MCD technologies on our red carrots.

We still face the challenges of improving the quality of a red carrot for commercial production. There is very little seed remaining from the only lycopene based carrot currently released. Additionally, the Nutri-Red cultivar is highly variable with different levels of lycopene, terpenoids, and other poor attributes that need to be improved or removed. Luckily, this can easily be accomplished with traditional plant breeding over a short period of time.

INTRODUCTION

This report is written for those who have a working knowledge of vegetable crop production. For additional information on carrot production and breeding, I advise you to read the following papers and websites listed at the back of this report.

Specialty carrots are defined as those that are physically unusual, or a different color than orange. When we first started this project and looked for commercial volumes of seed, we essentially found none. The carrot breeding industry has focused its efforts on the large processors, and left specialty cultivars to the research team as side projects. If there was time and resources, a large seed company might develop a few hundred pounds of a specialty seed, sell it within 2-3 years to home gardeners, and then discontinue the cultivar.

Carrots naturally come in a variety of colors, but they have been selected out over the centuries. The pigment colors are also phytonutrients, so color type and intensity are very important parameters for a nutraceutical product. There are five different colors of carrots. White carrots lack pigmentation and have no carotenoids. Yellow Carrots get their color from the phytonutrient complex called xanthophylls. Orange carrots get their color from the well-known phytonutrient beta-carotene. Red Carrots get their unique color from the phytonutrient lycopene, which is also found in tomatoes. Purple (or sometimes called black) carrots get their color from a class of phytonutrients called anthocyanins, similar to those found in blueberries, cranberries, and other red fruit.

STATE OF THE CARROT SEED INDUSTRY

The carrot seed industry is going through an intense consolidation, with buyouts and mergers of large carrot seed producing companies. Seminis has recently purchased both Peto and Asgrow, but the company is now in financial trouble and nearing chapter 11 bankruptcy. The reduction of workforce to ensure profitability as caused these new companies to focus their efforts on large-volume cultivars, as opposed to new specialty cultivars. A majority of the carrot seeds are grown and developed for just a few large companies, and the rest of the industry now must select from these cultivars.

After combing the entire United States and conferring with carrot breeders we came to the conclusion that there is not a lot of specialty carrot seed on the market, nor will there be anytime in the near future. We designed our first project to look at all available specialty carrots cultivars, as well as some typical orange carrots that are not currently grown in Wisconsin.

SPECIALTY SEEDS

There are several specialty seed companies that handle carrot seed. Most of them have the same cultivars since very few retail seed companies actually have their own breeding grounds. These are the companies we contacted to find our seed supplies:
www.eburgess.com; www.burpee.com; www.cooksgarden.com; www.farmerseed.com; www.gardencityseed.com; www.gurneys.com; www.harrisseeds.com; www.henryfields.com; www.jungseed.com; www.johnnyseeds.com; www.neseed.com; www.parkseed.com; www.superseeds.com; www.seedsofchange.com; www.shepherdseeds.com; www.rhshumway.com; www.southernexposure.com; www.territorial-seed.com; www.vermontbean.com; www.bejo.com; www.siegers.com; www.peto.com; www.seedway.com; www.stokeseeds.com; www.asgrow.com;

CARROT COLORS

There are five different colors of carrots, each with a different pigment. Orange carrots get their color from beta-carotene, a pigment that the human body converts to vitamin A. Orange carrots provide 30% of the vitamin A in the U.S. diet. Red carrots get their color from lycopene, another carotenoid that holds significant phytonutrient profile in preventing cancers and heart disease. Yellow carrots contain xanthophylls, which help develop healthy eyes and prevent lung and other cancers. Purple types of carrots contain anthocyanins, pigments that act as powerful antioxidants, tying up harmful free radicals in the body. White carrots lack carotenoid pigments and therefore also the health benefits associated with colored carrots.

In the industry, we have found that there is quite a bit of confusion with the term red carrot, since the "red" color can come from two different phytonutrient sources. Lycopene, as stated above is a red carotenoid, while the anthocyanins (or purple carrots) are in an entirely different family or class of pigments. True red carrots are in fact almost entirely lycopene and have a color very much like the flesh of a red watermelon. The anthocyanin carrots are decidedly purple, but have been marketed as "black or red carrots".
Anthocyanins are found in many fruit crops, including red cranberries. However, lycopene is in relatively few crops, but predominantly tomatoes. The USDA-NCC carotenoid database states that tomatoes have the highest concentration of lycopene with averages from 93-156 ppm. Recently Campbell's food has been advertising the healthful anti-cancer and heart disease prevention of lycopene on their tomato soup cans. This is evidence that lycopene is soon to be a well-recognized phytonutrient in the nutritional dialogue.

2001 SPRING PLANTING

In the 2001 planting we selected as many interesting cultivars as possible for evaluation. We had yet to do any marketing effort, so we focused on planting a variety of all kinds of carrots that are not typically grown in Wisconsin.

Yellow Carrots

Yellowstone (Seedway). This is a new yellow carrot that has just been introduced into commercial production and is being evaluated for its use in the Wisconsin canning industry as a substitute for yellow sweet corn. We feel it has potential as a source for natural xanthophylls.

Lubiana (Irish Eyes). This is a new release of a yellow carrot that also has specialty potential for a niche market. Supply for this seed is very limited at this point (2 grams).

Red Carrots with Lycopene.

Nutri-Red (Irish Eyes). This new red carrot was introduced last year into home garden production and limited seed supply is available. This cultivar was developed by one of the researchers at Seminis as a side project. NutriRed is the first specialty carrot marketed to home gardeners for it potential nutraceutical benefit. NutriRed contains the phytonutrient lycopene, which has recently gained notoriety in tomatoes as a cancer fighter.
Red Carrots with Anthocyanins.

Dragon (Irish Eyes). This is a new release of a red carrot. This carrot is red on the outside and orange in the middle. The red color (phloem tissue) is derived from anthocyanins while the orange color (xylem) is from beta-carotene.

Orange Carrots.

Sunrise (Peto). This is a deep orange carrot with high beta-carotene concentrations and is highly desired for the baby food industry as a puree.

Red-Core Chantanney (Irish Eyes). This is an old cultivar that gets its name from the fact that it is deep orange to the core of the carrot, as opposed to turning whitish in the middle. Despite its name, it has no lycopene content.

Cheyenne, Choctaw, Apache, Triple Play 58, Sugar Snax 54, Prime Cut (Sun Seeds). These cultivars are fresh carrot 'cut and peels'. They are grown specifically for the fresh market and not grown extensively in Wisconsin.

SCX0654, CXC 2670, Royal Chantenay, Red Chantenay (Alf Christensen). These four cultivars are mainstays in the cut and peel line.

Magno RZ (Reich Zuann). This is a German orange cultivar.

Bolero (Vil Morin). This cultivar is grown extensively in Wisconsin and serves as our control for comparison purposes.

TWO LOCATIONS

We elected to plant our commercial sized carrot plots in the central sands region of Wisconsin. Miller Farms, Hancock, Wisconsin, rotates carrots on a five-year cycle with potatoes, beans, peas, and sweet corn. Miller Farms generally harvests between 25-40 tons carrots per acre. We also conducted some small-scale plantings at Shiprock Farms where the Seedway sales rep conducts trials of new cultivars. Shiprock Farms is located in the muck soils of central Wisconsin. Each grower agreed to plant our carrots within their existing carrot fields. Thus, our carrots received the exact same fertilizer, herbicide, pesticide, and irrigation regime that is typical for commercial carrot production in central Wisconsin.

PLANTING DATE

Small-scale plantings of double 20' rows were done on May 15, 2001 on both the Miller and Shiprock Farms. Dragon, Lubiana and Nutri-Red were planted.

Large-scale plantings of 1/3-acre size per cultivar was conducted on Miller Farms on June 15, 2001.

Seed spacing was determined by the recommendations that came with the seed. Seed spacing was as follows:

12-15 seeds/ft: Red-core Chantanay, Royal Chantanay, Red Chantanay, and Bolero.

17-20 seeds/ft.: Yellowstone, MagnoRZ, SCX0654, CXC2670,

26 seeds/ft: Sunrise, NutriRed, Cheyenne, Choctaw, Apache, TriplePlay SugarSnax Prime Cut, Dragon, Lubiana.

HARVEST RESULTS

Growth and productivity. Based on visual observation, it was apparent that some of the larger cultivars of carrots might have needed more fertilizer than others, but overall the cultural practices of each grower provided an adequate growing environment for our specialty carrots.

We harvested the plots on October 5, 2001 to get yield and growth estimates. See Table 1. We then mechanically harvested the entire field of carrots on October 19, 2002, which is as late as possible in the season.

We noted earlier in the season that color development in the yellow and red carrots was affected by maturity. Older carrots had a deeper red color, which is indicative of more lycopene (red) or xanthophylls (yellow). We kept the carrots in the field as long as possible to maximize this color development.

The results of our yield and production are outlined in Table 1. Yields ranged from 14 to 34 tons per acre. Yields were lower than average due to the late planting date, but with the wet spring and extremely hot August, good yields across the state were variable.

We conducted typical assessments for strength of tops, amount of verticillium wilt disease, and degree of bolting. Weak tops can result in poor harvest ability using a top harvester. Verticillium wilt disease causes roots to have numerous root hairs and decreased yields, and bolting cause the plant to flower instead of produce root.

LOSS OF SMALL CARROTS

Top strength is very important for the FMC top picking harvesters. Without a strong top, a bottom draw harvester must be used. I feel that the top-picking harvester may miss a number of the smaller carrots and select for larger carrots. This harvest, the NutriRed were very small carrots, and we feel that, looking at the bed after harvest, we lost about 50% due to small size. These small carrots appear to be our most nutritious carrot (because they had better color than the larger carrots) and ones we want to capture for processing.

TASTE TESTING.

We conducted a taste test on the specialty carrots to compare them to the orange carrot cultivars. The easiest "taste" to decipher from all carrot juices is the amount of terpenoids that gives the juice a bitter taste. The red carrots, including Dragon and Nutri-Red were very high in terpenoids and the juice was barely drinkable. The yellow cultivars were very sweet with almost no detectable terpenoids. Many of the orange carrots had acceptable flavors and were not detrimental to taste.

TABLE 1.

ADD-Carrot Grant

Tops 0 = weak 6= strong
wilt 0=none 6= complete
Bolt 0=none 6= complete

Cultivar	**Tops**	**Wilt**	**Bolt**	**lb. Per acre**	**tons/acre**
Bolero	2	3	1	35700	17.9
Red Chantanney	4	2	1	28613	14.3
Royal Chantanney	5	1	3	32813	16.4
CXC2670	2	1	1	47775	23.9
Magno RZ	2	3	0	49613	24.8
SCX0654	2	2	2	48563	24.3
Prime Cut	3	1	0	28875	14.4
Sugar Snax 54	2	2	0	43575	21.8
Triple Play 58	3	1	0	57225	28.6
Apache	3	1	1	48825	24.4
Choctaw	3	1	3	38063	19.0
Cheyenne	3	1	0	50663	25.3
Red Core Chantanney	5	2	2	46988	23.5
Nutri-Red	3	4	2	42000	21.0
Sunrise	4	1	0	68250	34.1

Yellowstone	6	2	0	59588	29.8

POST HARVEST STORAGE

We stored carrots in an insulated 48' trailer, rented from Moodie Trucking. A 1000 lb. tote of each cultivar, along with 5 totes of NutriRed, was placed into the van immediately after harvest. The exercise was not entirely successful. We attempted to maintain proper carrot storage and conditions: 31F with 98% humidity. November and December were the warmest on record and we had problems slowing down respiration and deterioration of the roots. By the end of December, many of the cultivars had decomposed so significantly, they were only 75% of their original weight, with massive moisture loss. The best cultivar was Royal Chantanney, which only lost about 10% of its mass in moisture loss. We realize that, if we wish to hold our product in storage, we'll have to build or contract out with carrot storage facilities, the closest one I found, being in Minnesota.

COMMENTS ON STORING SPECIALTY CARROTS

At this point in the research project, I'm not sure that we want to attempt to store specialty carrots in Wisconsin. In growing areas toward the southern US, carrots can be stored in the ground until needed. However in Wisconsin, carrots must be out of the ground by early November to avoid the threat of permanent frost through winter.

Although conditions were far from optimal in the fall 2001, the carrots we grew this season did not store well. This leads me to believe that we should process our crop as quickly as possible, or store it in the freezer until it can be dehydrated. We don't yet know if lycopene levels are maintained, elevated, or reduced when carrots are stored fresh for long periods of time. In speaking with carrot breeders, none of the specialty cultivars have been bred for storage quality, so it would be best to harvest and process or freeze immediately.

DEHYDRATION EQUIPMENT

MCD technology has new drying equipment that was developed in conjunction with Washington State University and is now in commercial use. The technique uses a combination of vacuum and low temperatures to dry the product on the belt. As a result, temperatures are kept very low (<140F) during the drying process. The trick with this machinery is the time vs. temperature relationship. Temperatures must be high enough to dry the product in a reasonable amount of time, yet too high a temperature can degrade the product. Depending on the material, long durations of low temperature can be worse than a short burst of high temperature during drying. Based on our experiences with driers, we felt that this technology would be best suited for our lycopene based red carrots.

We collected about 400 lb. of NutriRed carrots for processing on the MCD technology in Washington. We did not have enough anthocyanins red carrot to conduct a study specifically on carrots so we substituted cranberries for this study. The red carrots were cleaned manually and then run through a Fitzmill to make a puree. This puree was frozen until thawed and placed on the special drying equipment. Bernie Lager, from Northern Lights Food Processing flew out to conduct the study of drying technology on red carrots in Washington. The entire lot of NutriRed carrot puree was run on the machine at different temperature and timings.

The results of that study showed that red carrots can be processed and dried to yield a reddish powder. However the intensity of red color was diminished the longer the product remained in the drier. The drier worked on a low temperature and vacuum principle, with temperatures typically below 140F. Lycopene levels were sampled by the owners of the MCD equipment. We were told that lycopene levels in the original fruit was 120ppm, but final dried tissue yielded less than 21 ppm. It appeared that both high temperature as well as duration in the drier played a large role in the loss of lycopene during drying. Upon further research we learned that the juice/puree contains active enzymes that we failed to kill prior to freezing the macerated carrots. The enzymes remained active after the puree was thawed and during the heat process, broke down the lycopene. We discovered that inactivating the enzyme with a short burst of heat above 160F just prior to freezing or low-temperature drying, and our lycopene would probably have been fine.

Our research on the cranberry puree was extremely important in verifying the quality of the MCD machine. Cranberry puree was dried at low temperature. Bernie Lager was director of Manufacturing at Northland Cranberries for seven years, and is a master at manufacturing high quality puree and powder. His observations concluded that the MCD technology created a very, very high quality powder with very little browning. The low temperature vacuum technology worked well to preserve the anthocyanins. As temperatures exceed a critical point, anthocyanins break down and the product turns brown. The red:brown ratio was exceptionally high with the dried cranberry product, yielding a product that could exceed qualities of other manufacturers.

From this experiment, we determined that the MCD technology can be used on carrots as well as cranberries! Anthocyanins will not degrade in the equipment but lycopene enzymes must be inactivated with a short burst of heat prior to drying. A second year of testing may be necessary to document success with this equipment.

FUTURE BREEDING EFFORTS

In our 2001 carrot harvest we encountered a large degree of color variability in the specialty seeds, especially Nutri-Red. Some roots were a very light shade of pink while others were deep red. This variability is a trait that can be selected for, in an attempt to get more uniform color.

We have found that the yellow cultivar Yellowstone is going to be commercially available in 2002. Lubiana, another yellow cultivar will not be available for many years due to a low seed volume. Of the red carrots, Nutri-Red seed is nearly gone. Seminis only has 230lb. of seed remaining in inventory, and after that is exhausted they will not make any more. Likewise, if germination levels fall below 80%, they will discard any remaining seed. Seminis has no need for specialty seed, but other small breeders can build up the seed reserves if they wish, since it’s an open pollinate variety.

IMPROVING THE NUTRI-RED CULTIVAR

There is potential to significantly increase lycopene levels in carrots using traditional breeding techniques. It would be conducted similar to what Dr. Phil Simon has done with beta-carotene in orange carrots. The same degree of variation for lycopene seems to exist in red carrots. This suggests that red pigment levels are conferred by additive genes that can be “stacked” to increase levels in subsequent generations through plant breeding.

It is going to be very important to reduce the concentration of terpenoids in the Nutri-Red. The juice was very bitter, and at this time would not be palatable in a juice product. At this time w don't know how the drying process affects terpenoid levels, but we assume that terpenoids would be stable during dehydration.

Bolting was not much of a problem except for one orange cultivar: Choctaw. Bolting is the process of a carrot producing a seed stalk instead of a fully developed tuber. None of our specialty carrots were specifically developed for growing in Wisconsin climate. When talking to the carrot breeders we discovered that most of the carrots we were testing would probably "bolt" if planted too early in the growing season. Bolting occurs when the new shoot achieves a minimum number of "chill hours" and begins to flower instead of produce a root. We found, for example, that NutriRed would probably bolt if it accumulates more than 50 hours of temperatures below 50F. With this information and the need to produce a viable root, we pushed our planting date to the end of the planting cycle in mid-May.

Verticillium wilt impacts the top strength as well as the quality of the tuber in storage. NutriRed was one of the poorest carrots, with high levels of wilt. Improvement in this arena needs to be done too.

DEVELOPING A PROCESSING FACILITY

Based on our current knowledge we now realize that we must deactivate the enzymes that degrade the precious phytonutrients. Heat is the only means for deactivation, so we must be able to quickly increase temperature to deactivate the enzymes, then cool the product to minimize degradation of the phytonutrients. We feel that slicing or macerating the carrots, followed by a quick heat/cool cycle through a pasteurizer, would stabilize the phytonutrients.

At Northern Lights, we evaluated a number of machines and found that the most popular machine for powdering dry materials as well as slicing and macerating wet product is a Fitzmill. Temperatures on the blades were minimal, ensuring no product degradation during the grinding and macerating process. We purchased a Fitzmill from the Fitzpatrick Company in Chicago, Illinois. The $25K unit can macerate up to 5000 lb. of raw carrots per hour through a 0.065" screen.

MARKETING COLORED CARROTS

After our first successful harvest and pre-processing of carrots, samples of our products were taken to the Supply Side West trade shows as well as the Natural Food Products show. Our feedback from product distributors was very positive for lycopene red carrot powder, as expected. With the thrust of tomato promoting lycopene for anti-cancer as well as healthy heart, red carrot supplements could become a demand product. Fuji Chemical, the third largest marketer of nutraceutical ingredients saw great opportunity to market a carrot-based lycopene, especially to the Japanese food industry. Japan views colors as vitally important in their diet, and red products are derived as being 'healthy'. A red carrot ingredient would be an important export material for this country.

Artemis International is a manufacturer, researcher, and marketer of anthocyanins based colorants for the juice and nutraceutical industry. Meetings with Jan Mills, CEO, indicated a sincere willingness to promote and sell any product that could be developed from red carrots. She offered to jointly fund and conduct research on carrot products to gather more information for consumers.

There was very little enthusiasm for the yellow carrots because of the lack of research and information on xanthophylls. Likewise, the antioxidant capacity of anthocyanins in red carrots is diminished by the fact that other red fruits and vegetables have already been marketed using this approach. Except for some interest in anthocyanins for use as a natural food or clothing dye, lycopene based red carrots appears to be the next hot functional food ingredient. Orange carrots with high beta-carotene levels are sometimes used as supplements, but none of our material appeared to have very high beta-carotene levels, so excitement for regular dried orange carrots was minimal.

In our conclusion we found that red carrots containing lycopene are highly marketable. We must be able to powder the carrots into a finished product for sale to the nutraceutical and functional food industry. We know that Nutri-Red can grow under Wisconsin conditions but there is lack of an adequate supply of seed. Nutri-Red also has less than favorable characteristics that should be bred out of succeeding generations. We determined that, during pre-processing, it is important to kill the enzymes that can degrade the phytonutrients in the carrot, leading to a maximum concentration of phytonutrients. From this research we now have the basic knowledge we need to advance quicker towards our goal of establishing a new specialty crop for the Wisconsin carrot industry.

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www.freshcut.com is a monthly newsletter on carrot issues.
www.edis.ifas.ufl.edu is an excellent extension article on common diseases of carrots.
www.newcrop.hort.purdue.edu/rhodev/hort410/carrot contains production statistics for all US processing carrot production
www.arec.umd.edu/policy/carroll/budgets/vegetables/carrots.htm is a spreadsheet on the costs of carrot production in the US.