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ENGINEERING AND GINNING

Fiber Properties of Saw and Roller Ginned Naturally Colored Cottons

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ABSTRACT

Naturally colored cottons have economic and environmental appeal because they do not require dyeing. Naturally colored cottons do not have the same fiber length and strength as white cotton cultivars. To determine the optimal ginning process for colored fiber two Upland (*G. hirsutum*) varieties were roller and saw ginned following a complete block experimental design. HVI and AFIS analysis favored roller ginning. It resulted in 0.7 mm (1/32 in) greater HVI fiber lengths and 33% fewer AFIS fiber neps compared to saw ginning. This increase in fiber value may justify the higher cost of roller ginning.

Naturally colored cottons have a long history, dating from 3400 to 2300 BC in Mexico, 3100 BC in Peru (with fibers from 12 to 43 mm (0.5 to 1.7 in) length), 2250 BC in Egypt (19 to 22 mm (0.75 to 0.87 in) and sometime before 1200 AD in China. Russian brown cottons from the past century had good strength but lint length averaged only 19.8 mm (0.78 in), with short fiber index a low 31.1%. Colored cottons also have a history of commerce; Peru exported twelve colors from 1865 to 1937, to English manufacturers, who blended them with wool. Russia offered for sale some 700 Mg (770 ton) naturally pigmented fiber in 1945 (Vreeland, 1993).

Fiber quality and spinning tests of colored cottons enjoy a bit of history as well, with tests in the 1960s confirming data from the 1940s (Ware and Bennedict, 1962); that naturally colored cotton fibers ranged in length from 15.9 to 26.2 mm (0.63 to 1.03 in). Relative to white cottons, colored cottons were found to be weaker and shorter. Despite greater disease resistance and salt tolerance in some colored varieties, yield and lint content were lower (Conrad and Neely, 1943; Price et al., 2001). Although yields tend to be 50 to 70 percent lower than yields of conventionally grown white cotton, prices for organically grown naturally colored cotton have been higher. In 1996, organic, naturally colored brown commanded \$4.06 to 7.39 kg^{-1} (\$1.84 to 3.35 lb^{-1}) and green cotton ranged from \$8.36 to 11.02 kg^{-1} (\$3.79 to 5.00 lb^{-1}) (Katz et al., 1997). At that time base grade conventional white cottons were selling for \$1.48 to 1.74 kg^{-1} (\$0.67 to 0.79 lb^{-1}).

There has been a recent resurgence of commercial interest in naturally colored cotton since it can be made into textiles without dyeing the yarn. Consumers wishing to reduce the environmental impact of clothing are attracted by this feature. Manufacturers are attracted by the savings since dyeing can represent about 15% of the cost of an apparel item (Nimon and Beghin, 1999). To improve colored cotton fiber properties for machine processing, breeding projects are in progress in Brazil, Greece, Israel, Peru, Turkey and the former Soviet Union (Matusiak et al., 2007). Research on spinning colored cottons is being conducted in Poland (Matusiak et al., 2007).

This resurgence has, however, been a bumpy road. The production of naturally colored cottons in the United States was an estimated 1575 ha (4,000 acres) in 1992. The eco-fashion market for organic, naturally colored cotton peaked in 1993-1994, and by 1995, when world production had peaked at 11,670 Mg (53,600 bales), with 6,736 Mg (30,940 bales) grown in the U.S., many retailers had withdrawn from the market. By 1996 U.S. planting had fallen to approximately 20 hectares (50 acres) (Katz, et al., 1997).

Nonetheless, production of naturally colored cotton that can be machine spun continues. Small quantities are sold to mills in Europe and Japan. The primary difficulty US producers face today is not marketing, but finding a gin willing to process their crop. States have passed legislation to protect white cotton from contamination (California Code of Regulations, 1997; Arizona Department of Agriculture, 2005). Most gin managers feel that the required notification, separation, cleanup and inspection costs far exceed the potential revenue from ginning a small batch of colored cotton. One solution may be to dedicate a gin to processing

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colored cotton exclusively; this may be feasible now as a number of gins are closing because of consolidations and reduced plantings.

The primary objective of this study is to compare fiber properties resulting from roller and saw ginning modern cultivars of naturally colored Upland (*G. hirsutum*), to help mills and producers decide which process best meets their needs. Additionally, fiber properties for two colors and two sources are compared with published historic data.

MATERIALS AND METHODS

Although naturally colored Pima cottons (*G. barbadense*) also exist, most production today is naturally colored Upland (*G. hirsutum*); only the latter species was tested. Two colors of naturally pigmented seed cotton complying with phytosanitary certification requirements were brought to Mesilla Park, New Mexico in a sealed container. The material was weighed and divided into 100 kg (220 lb) lots, four green and eight a rust or reddish-brown (henceforth called "brown"). After sampling for moisture content, the hand picked seed cotton was pre-cleaned in one 6-cylinder inclined cleaner and one burr-and-stick machine. No drying was used.

Two treatments, saw or roller ginning, were randomly assigned in a complete block design resulting in four replicates for brown and two replicates for the green cotton. The saw gin operated under normal settings. Seed cotton final cleaning and opening occurred in a Galaxy 91 cm (36 in) wide feeder. Fiber-seed separation occurred in a Continental/Murray Double Eagle 40.6 cm (16 in) diameter 46-saw stand with seed tube; saw speed was 656 rev min^{-1}. Lint cleaning took place in a 165 cm (65 in) wide Moss-Gordon lint cleaner, with a feed roller speed of 82 rev min^{-1} and the lint cleaner saw drum turning at 1031 rev min^{-1} past five grid bars.

During roller ginning the Consolidated HGM feeder operated slowly, at 29% of normal speed. This slower speed was required for continuous smooth operation; at higher speeds seedcotton tended to choke up the reclaimer (due to its shorter fiber length, there was more carry over). The Consolidated HGM 102 cm (40 in) wide 40 cm (15 in) diameter ginning roller speed was 121 rev min^{-1} and the rotary knife speed 417 rev min^{-1}. Stationary knife air cylinder pressure was 32,000 kg m^{-2} (45.5 lb in^{-2}). Lint cleaning occurred in a 98 cm (38.5 in) wide 40.6 cm (16 in) diameter pin-on-lug-type three lug cleaner turning at 1090 rev min^{-1}. During roller ginning, the battery condenser ran at 36% the speed it did when saw ginning.

The colored cotton came from two sources. The brown and green seed cotton used in the ginning test came from one source, all hand picked. Additional lint samples were obtained for comparison purposes from a second, machine harvested source. Samples from both sources were analyzed to compare fiber properties of modern, naturally colored cotton from two cultivars and two production locations with modern whites and other naturally colored cottons, where published data exists.

Two samples of lint from the first and last minute of ginning were collected at the lint slide over the bale press. Lint samples were divided into analysis samples of the appropriate weight; these were sent to the USDA-Agricultural Marketing Service-Cotton Division Classing Office in Visalia, CA for High Volume Instrument (HVI) analysis, and to the USDA-Agricultural Research Service-Cotton Quality Research Station in Clemson, SC for Advanced Fiber Information System (AFIS) analysis.

RESULTS AND CONCLUSIONS

Despite hand harvest having extended over more than a month, seed cotton moisture content was found to be reasonably uniform from lot to lot, averaging 7.5% for the green and 8.6% for the brown, dry mass basis. Trash content and nep counts were low, another affect attributed to hand harvesting.

Differences by Ginning Treatment. Table 1 compares fiber properties of colored cottons for saw and roller ginning. Results are presented for the two colors combined and separately. When separated by color, HVI staple length increased 0.79 mm (1/32 in) with roller ginning. A similar increase was observed for white upland cotton by Armijo and Gillum (2007), who reported length increasing from 29.5 to 30.5 mm (from 37.2 to 38.3 thirty-seconds) when comparing roller ginning to saw ginning. Length uniformity reported in Table 1 showed a slight improvement, but HVI fiber strength decreased with roller ginning. Again, these results are similar to those obtained from white cotton by Armijo and Gillum (2007), who saw uniformity increase from 81 to 82.8, and strength decreasing from 27.8 to 27.4 g/tex (273 to 269 mN tex^{-1}), though they report no statistical significance for the decrease in strength associated with roller ginning. With saw ginning there are more fibers broken. It is possible that the weaker fibers break preferentially, resulting in a mean increase in strength among the surviving fibers.

Table 1. Impact of roller or saw ginning on fiber properties of colored cotton.

Variable	Average of Both Green and Brown			Green			Brown		
	Saw	Roller	Pr>F*	Saw	Roller	Pr>F*	Saw	Roller	Pr>F*
Observations n	12	12		4	4		8	8	
HVI Measurements									
Staple Length (mm)	25		0.1304	26.2	26.8	0.0240	23.8	24.6	<0.0001
Micronaire	3.39		0.8211	2.79		0.3559	3.69		0.1080
Strength (mN tex^{-1}) [gf tex^{-1}]	241 [24.6]	236 [24.1]	0.0131	238 [24.3]		0.2002	242 [24.7]	236 [24.1]	0.0432
Leaf	1.08		0.1522	1.25		0.1340	1		1
Length (mm)	25		0.1083	26.2	26.9	0.0020	24	24.7	<0.0001
Uniformity (%)	78.7	79.8	<0.0001	78.9		0.1074	78.7	80.1	<0.0001
AFIS Measurements									
Mean Nep Size (µm)	716	769	<0.0001	722	771	0.0008	713	768	0.0003
Total Nep Count (g^{-1})	340	252	0.0005	416	297	0.0059	303	229	<0.0001
Fiber Length (mm, by weight)	22	22.9	0.0137	22.9	24	0.0003	21.5	22.3	<0.0001
Coefficient of Length Variation (% by wt.)	34.3		0.2075	36.3		0.113	33.8	32.8	0.0199
Upper Quartile Length (mm, by wt.)	26.9		0.1258	27.9	28.7	0.0033	25.9	26.4	<0.0001
Short Fiber Content (% by wt.)	11.46	9.43	<0.0001	10.5	8.68	0.0074	11.96	9.81	0.0003
Mean Fiber Length (mm, by no.)	18.2	19.1	0.0012	18.9	19.7	0.0033	17.9	18.8	0.0005
Coefficient of Length Variation (% by no.)	44.8		0.0915	46.5		0.6105	44.8	43.2	0.0125
Short Fiber Content (% by no.)	27.2	23.9	0.0001	25.8	23.2	0.0337	27.9	24.2	0.0008
Length Exceeded by 5% of Fibers (mm)	30.5		0.2174	32	33.3	<0.0001	29.2	29.7	<0.0001
Trash Count (g^{-1})	828	1355	0.0165	1170	2190	0.0005	659	940	0.0027
Mean Size of all Particles (µm)	263	248	0.0253	289	248	<0.0001	249		0.5724
Dust Count (g^{-1})	725	1236	0.0112	1010	2000	0.0003	585	853	0.0022
Trash Count (g^{-1})	111		0.4537	172		0.389	80.2		0.0578
Visible Foreign Matter (% by weight)	2.18		0.0982	2.83	3.8	0.0242	1.36	1.86	0.0239
Mean Seed Coat Nep Size (µm)	1290	1362	0.0229	1290	1410	0.0206	1314		0.2668
Seed Coat Nep Count (g^{-1})	35.1	47.3	0.0037	45.1		0.1304	31.6	46.9	0.0092
Fineness (millitex)	157		0.6660	142		0.8439	166	163	0.0067
Immature Fiber Content (%)	9.63	9.21	0.0078	9.56		0.1268	9.56	9.13	0.0314
Maturity (%)	0.826		0.1101	0.818		0.1135	0.83		0.2328

***Where there is no statistical significance (at the 0.05 level) the mean is presented.**

AFIS properties that were significantly different are numerous. The most important differences were fiber length (both by number and weight basis), short fiber content (again by number and weight) and total nep count, all of which favored roller ginning. Each of these were also found to be significant in the test reported by Armijo and Gillum (2007) where length increased from 26 to 27.3 mm, short fiber content decreased from 10 to 7.83% and total nep count decreased from 316 to 219 per gram, all due to roller ginning. With roller ginning there were fewer total neps, but seed coat neps were higher. This indicates an increase in seed damage from roller ginning. Roller ginning also results in slightly higher turnout (recovered lint as a percent of seed cotton mass); Armijo and Gillum (2007) report upland cotton turnout increasing from 34.5 to 35.8%. Combining that with improved grades, value of a 218 kg (480 lb) bale of white cotton increases $3.29 by roller ginning. It would be inappropriate to estimate the change in price for a bale of colored cotton the same way, since organic naturally pigmented lint does not trade based on the USDA-CCC loan value. It is up to individual spinning mills to estimate the increase in value based on their processing experience.

Differences between two colors and white. While these specialty cottons are not traded based on USDA-AMS Classing Office (HVI) grades, it is interesting to observe the differences between them and "typical" upland cottons. Table 2 shows HVI and AFIS fiber properties for hand picked roller ginned green and brown colored cotton, and the range of values for typical machine harvested saw ginned upland white cottons found in recent publications. While different, the harvest and ginning histories are typical for each respective type of cotton.

Table 2. HVI and AFIS fiber properties of green and brown specialty cottons with range of values of typical white cottons provided for comparison.

Variable	Green	Brown	Pr > F*	White	
Observations n	8	16		(typical)	Ref
HVI Measurements					
Staple Length (mm)	26.5	24.2	<0.0001	26.7 - 31.2	2
Micronaire	2.79	3.69	<0.0001	3.90 - 4.89	1
Strength (mN tex^{-1}) [gf tex^{-1}]	239 [24.4]		0.6924	235 – 324 [24.0 - 33.0]	1,4
Leaf	1.25	1.00	0.0377	2.93 - 3.80	1
Upper Half Mean Length (mm)	26.4	24.4	<0.0001	26.5 – 29.7	3
Uniformity, %	79.2		0.0984	80.7 - 84.6	3,4
AFIS Measurements					
Mean Nep Size (µm)	743		0.6853	697 - 743	2
Total Nep Count (g^{-1})	357	266	0.0008	164 - 278	1,2
Average Fiber Length (mm, by weight)	23.5	21.9	<0.0001	23.0 - 31.0	2,4
Coefficient of Length Variation (% by wt)	36.3	33.3	<0.0001	30.9 - 35.7	1
Upper Quartile Length (mm, by weight)	28.2	26.2	<0.0001	27.4 - 32.3	2
Short Fiber Content (% by weight)	9.56	10.89	0.0308	6.33 - 10.6	1,4
Mean Fiber Length (mm, by number)	19.3	18.4	0.0010	17.3 - 20.5	1,3
Coefficient of Length Variation (% by no.)	46.5	44.0	<0.0001	44.7 - 63.4	1,3
Short Fiber Content (% by number)	25.5		0.1382	21.7 - 35.8	1,3
Length Exceeded by 5% of Fibers (mm)	32.8	29.5	<0.0001	32.1 – 33.6	1
Total Trash Count (g^{-1})	1677	799	<0.0001	53 - 266	2
Mean Size of all Particles (µm)	269	249	0.0071	250 - 306	4
Dust Count (g^{-1})	1505	719	<0.0001	310 - 654	1
Trash Count (g^{-1})	171.5	80.2	<0.0001	67 - 111	1
Visible Foreign Matter (% by weight)	3.31	1.61	<0.0001	1.29 - 6.10	1,2
Mean Seed Coat Nep Size (µm)	1330		0.3040	689 - 1190	1,2
Seed Coat Nep Count (g^{-1})	41.2		0.2243	9.11 - 40.2	1,2
Fineness (millitex)	142	164	<0.0001	165 - 188	1
Immature Fiber Content, %	9.42		0.2159	2.84 - 4.61	1
Maturity Ratio, %	0.818	0.830	0.0023	0.832 - 0.905	1

***Where there is no statistical significance (at the 0.05 level) the mean is presented.**

References: [1] Boykin (2005), [2] Holt (2004), [3] Bednarz et al. (2002), [4] McAlister (2001)

Micronaire is strongly affected by climate and can vary from year to year. Seventy-five percent of US cotton falls between 3.5 and 4.9 (the base range) (USDA, 2001). The brown cotton micronaire of 3.7 was in the premium range, the green, at 2.8, would receive a discount if it were priced using the same criteria as white cottons.

Fiber length is the property that has the greatest influence on lint value. From these comparisons the brown was 80 to 90% of the average length of white cottons, the green was comparable to the lower end of the whites. From the standpoint of machine spinning, naturally colored fibers, often blended with organic Pima Extra Long Staple (ELS) to make finer yarns, are approaching a more respectable quality.

Source differences. Fiber properties of roller ginned colored cotton from two sources (Table 3) shows differences in fiber properties both from genetics and from growing location. For the green colored cotton from source "A" HVI staple and AFIS upper quartile length was less yet AFIS mean and average fiber length was more. Though both ranked low in HVI uniformity, the "A" source was slightly more consistent in fiber length. The "B" source appeared to be a different variety, possibly a recent hybrid. For the brown cotton, source "A" enjoyed a consistent

Table 3. Fiber properties of roller ginned colored cotton from two sources.

Color	Green (n=10)			Brown (n=14)		
Source (Harvest Method)	A (Hand)	B (Machine)	Pr>F*	A (Hand)	B (Machine)	Pr>F*
HVI Measurements						
Staple Length (mm)	33.8	35.2	0.0011	31.0	28.7	<.0001
Micronaire	2.8	2.7	<.0001	3.82		0.1724
Strength (mN tex-1) [gf tex-1]	238 [24.3]		0.5621	236 [24.1]	222 [22.6]	0.0008
Leaf	1	3	<.0001	1.00		0.0000
Length (mm)	1.06	1.10	0.0006	0.97	0.900	<.0001
Uniformity (%)	79.2	77.4	0.0002	80.1	76.4	<.0001
AFIS Measurements						
Mean Nep Size (µm)	771	714	<.0001	768		0.9621
Total Nep Count (g-1)	297	613	<.0001	229	523	0.0013
Average Fiber Length (mm, by weight)	0.95	0.93	0.0169	0.88	0.75	<.0001
Coefficient of Length Variation (% by weight)	36.0	42.1	<.0001	32.8	39.0	<.0001
Upper Quartile Length (mm, by weight)	1.13	1.17	0.0004	1.04	0.93	<.0001
Short Fiber Content (% by weight)	8.68	14.1	<.0001	9.81	20.2	<.0001
Mean Fiber Length (mm, by number)	0.78	0.7	<.0001	0.740	0.59	<.0001
Coefficient of Length Variation (% by number)	46.3	56.8	<.0001	43.2	51.6	<.0001
Short Fiber Content (% by number)	23.2	35.3	<.0001	24.2	40.9	<.0001
Length Exceeded by 5% of Fibers (mm)	1.31	1.36	<.0001	1.17	1.06	<.0001
Total Trash Count (g-1)	2190	3280	0.0013	917		0.8008
Mean Size of all Particles (µm)	248	286	0.0004	248	308	0.0005
Dust Count (g-1)	2000	2870	0.0031	807		0.5473
Trash Count (g-1)	181	408	<.0001	110		0.1590
Visible Foreign Matter (% by weight)	3.80	7.30	<.0001	2.22		0.2552
Mean Seed Coat Nep Size (µm)	1410	1180	0.0147	1350		0.3680
Seed Coat Nep Count (g-1)	48.3	32.7	0.0012	59.4		0.0744
Fineness (millitex)	142	124	<.0001	164		0.2619
Immature Fiber Content (%)	9.38	11.2	<.0001	9.13	11.2	0.0067
Maturity Ratio (%)	0.82	0.78	<.0001	0.83	0.8	0.0111

***Where there is no statistical significance (at the 0.05 level) the mean is presented.**

length advantage. Since most elongation occurs when the boll is between 5 and 15 days old (Smith and Cothren, 1999), length is less dependent on climate and more a function of genetics than other fiber properties. Therefore, with the limited information available from fiber properties, it appeared that both sets were from different seed lines even though both brown and green lint colors were strikingly similar.

Fiber strength, also largely determined by variety (USDA, 2001), was only conclusive in establishing genetic differences in the case of the reddish-brown cottons. However, the fact that length was significantly different for both colors and the fact that length was independent of location lends credence to the assumption that for both colors the two sources were of unique parentage.

Growing conditions appeared to be more favorable where source "A" was produced, as for both colors the immature fiber content was less and the maturity ratio was higher. HVI leaf (for the green cottons) and AFIS trash, dust and visible foreign matter for both colors were significantly different because source "A" was hand picked while source "B" was machine harvested. This also explains the significant difference in total neps, source "B" being much higher (even though source "A" green had more seed coat neps).

Comparison to Other Naturally Colored Cottons. Lint lengths of pre-Columbian Peruvian cottons marketed today range from 12 to 43 mm (Vreeland, 1996). Lint lengths of Nankeen brown and Arkansas green, naturally colored cottons grown in the U.S. during the colonial period, ranged from 15.9 to 26.2 mm (Katz et al., 1997). Measuring methodology was not specified for these antique cottons thus comparisons may be unfair. Today lint length (staple) measured by an HVI classing machine is the average length of the longer half of the fibers (upper half mean length), measured by passing a beard of paralleled fibers through a sensing point (USDA, 2001).

Cottons from other studies that were measured in the same manner are presented to compare the fiber qualities of different recent varieties selected for machine spinability. Table 4 compares the two colors ginned in this test; the range of values for four

Table 4. HVI and AFIS fiber properties of the green and brown specialty cottons tested, with range of values of naturally colored antique cottons and averages of modern Delta Pine 458 and modern naturally colored brown cotton of Greek origin provided for comparison.

Variable Observations n	Green 8	Brown 16	Pr > F*	Colored Antique [1] (range)	Modern Varieties (average)
HVI Measurements					**Delta Pine 458 White[2]**
Staple Length (mm)	26.5	24.2	<0.0001	18.5 – 23.4	38.3[2]
Micronaire	2.79	3.69	<0.0001	3.50 – 4.50	
Strength (mN tex^{-1}) [gf tex^{-1}]	239 [24.4]		0.6924	202 – 279 [20.6 – 28.5]	269[2] [27.4]
Upper Half Mean Length (mm)	26.4	24.4	<0.0001	23.9 – 28.5	
Uniformity, %	79.2		0.0984	77.6 – 82.1	82.8[2]
AFIS Measurements					**Brown Greek[3]**
Total Nep Count (g^{-1})	357	266	0.0008		448[3]
Upper Quartile Length (mm, by wt.)	28.2	26.2	<0.0001	25.9 – 30.5	26.7[3]
Short Fiber Content (% by weight)	9.56	10.89	0.0308	6.5 – 9.0	12.0[3]
Average Fiber Length (mm, by wt.)	23.5	21.9	<0.0001		21.9[3]
Coefficient of Length Variation (% by weight)	36.3	33.3	<0.0001		35.4[3]
Mean Fiber Length (mm, by number)	19.3	18.4	0.0010	22.9 – 25.4	
Coefficient of Length Variation (% by number)	46.5	44.0	<0.0001	31.7 – 34.9	
Fineness (millitex)	142	164	<0.0001	146 – 159	162[3]
Immature Fiber Content, %	9.42		0.2159	13.8 – 16.9	7.4[3]
Maturity Ratio, %	0.818	0.830	0.0023	0.74 –0.82	0.84[3]

***Where there is no statistical significance (at the 0.05 level) the mean is presented.**

[1] Price et al., 2001; four naturally colored cottons

[2] Armijo and Gillum (2007); white Delta Pine 458

[3] Matusiak et al. (2007); brown cotton of Greek origin

naturally colored cottons for which published HVI and AFIS data were available (Price et al., 2001); average HVI values of a white Delta Pine 458 (Armijo and Gillum, 2007) and AFIS values of a modern Greek naturally colored brown cotton (Matusiak et al., 2007).

CONCLUSION

Cotton from two different sources, apparently from different seed lines, both showed improvement in HVI staple length over varieties tested about ten years earlier. Despite these gains from selective breeding programs, naturally colored cottons still are not as long or as strong as white cottons grown today.

Roller ginning naturally colored cottons resulted in a 0.7 mm increase in HVI length (approximately one staple) and a 32 to 33% decrease in fiber neps. Roller ginning reduced strength and improved uniformity for one color, and reduced short fiber content for both.

Roller ginning is more expensive than saw ginning. However, improvements in fiber properties and potential increases in gin turnout help to offset the added cost. Roller ginning naturally colored cottons could preserve fiber length, an important consideration when machine spinning lint that is intrinsically shorter than white cottons. Because of the premium market value naturally colored cottons enjoy, it may be worthwhile.

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DISCLAIMER

Names are necessary to report factually on available data; however the USDA neither guarantees nor warrants the standard of the product(s), and the use of the name by the USDA implies no approval of the product to the exclusion of others that may be suitable.

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