Common Milkweed as an Alternative Cellulose Fiber Source for Making Paper with Strength and Moisture Resistance

Hans Kellogg[1], Heather Hendrixson[1],and Renmei Xu[1];
Maruthi Srivatsan Mogundan[2], Matt Stoops[2], and Paul D. Fleming, III[2]

Keywords: cellulous, papermaking, monarch, sustainability, milkweek, ecology, paper

Introduction

The pulp and paper industries are global commerce giants. These products in countless varieties are used each day by billions of people the world over. While there is a prevailing attitude that paper is a dying industry, it is in fact rapidly growing. In 2010, global paper consumption was estimated at approximately 400 million tons, and this figure is expected to increase by up to 25% by 2020 (van Hoeven, 2012). Additionally, the demand for packaging continues to soar due to our modern shift towards an ecommerce business model. Despite the fact that the pulp and paper industry has rebuilt their production process to include comprehensive sustainability and recycling methods, the public perceptions of systematic deforestation prevail. With the increased purchasing power of eco-friendly millennials, the interest in alternative-fiber has gained momentum. According to California Green Solutions (Smith, 2010), Millennials care about the environment; and as a result, most Millennials possess positive attitudes toward green products and are willing to pay more for green services, products, or brands. This market trend has pushed greater research into paper and packaging products utilizing alternative (also called tree-free) fibers, like hemp, kenaf, bamboo, and jute. A quick Internet search yields a number of small start-up specialty paper product companies who are looking to appeal to this niche market and follow its growth.

A fiber with similar properties as the tree-free fibers listed above but with an additional eco-friendly element that moves past the goal of sustainability is Milkweed. Extremely prolific, milkweed grows in varied climates from far south to the northern plains, flourishing in both wet and dry climates (Taylor, 2018). Currently the plant is considered a noxious weed, and farmers work to eliminate it from their fields as it competes with plants grown for commercial value. However,

[1]Ball State University; [2]Western Michigan University

there is interest to the use of the common milkweed because of the concern for the dwindling population of Monarch butterflies. The Monarch larva use only milkweed as their source of sustenance (Deucy, 2018). While this study does not deal directly with the declining Monarch populations, interest in planting milkweed would increase the viability of using this plant for making paper. Research has shown that milkweed is easily cultivated and can be commercially grown with the intent to maximize the output of cellulose (Reddy and Yang, 2009).

The objective of this work is to discover if Milkweed might be a high quality alternative fiber for papermaking and utilize specific properties making its use attractive to both industry and consumers.

History

American Native Indian tribes implemented milkweed for a wide array of uses. Clothing artifacts comprised of the floss have been discovered at ancient burial grounds dating back a millennium (Whitford, 1941). Other tribes were known to use it as a key component in medicine and food recipes. With the advances in science and industry at the beginning of the twentieth century, milkweed was discovered to be a versatile material that could be used to create floss, synthetic fibers, oil, wax, rubber and plastics (Berkman, 1949). During the middle of the second world war, milkweed was again looked upon as a possible avenue to obtain critical supplies. In Canada, a source for producing highly essential rubber was developed using milkweed. Over 500 acres of land in Peterborough County and Ottawa were seeded as part of a subsidized venture by the Canadian government designed to feed a pilot plant designed to extract large amount of resin rubber gum from the plants (Grace, 1944). Milkweed floss became a literal lifesaver for American troops as it became the filler for military grade life preservers when the Japanese cut off supply lines to the West Coast. In 1942 the Federal Government appropriated over $230,000 to build the Milkweed Floss Corporation of America in Petoskey, MI where men, women, and children helped gather and process milkweed floss for the war effort. Over four years, this community generated 2.5 million bags of this lifesaving floss (Berkman, 1949).

During the war years, the future of milkweed use was becoming a raw material of great value, but with the advances in chemistry post-war, it gradually became ignored for industrial use. As it grows in a wide variety of soil types heartily pulling water and nutrients from the soil, it has long been known as nuisance to farmers. With the development of herbicide-tolerant crops in 1994, milkweed plants have rapidly begun to disappear. The area of land where Monarch were formerly able to spawn and feed has dropped 73%. As milkweed is the only form of sustenance for Monarch larva, this reduction has been devastating. The U.S. Fish and Wildlife service is currently petitioning for federal protection for the Monarchs under the Endangered Species Act. Meanwhile, the global industrial packaging industry market is expected to surpass 97.2 billion by 2025 (Shah, 2019).

Consumers shift toward ecommerce continues to grow with no end in sight. Additionally, the packaging of a product has become an integral part of consumer satisfaction. The unboxing phenomenon has become a global sensation. YouTube videos centered around the opening of toys, makeup, and electronics have found a dedicated audience amongst viewers of all ages. While packaging design is integral to this experience, the materials have their part to play as well. 70% of global millennials are willing to pay extra for sustainable offerings up from 50% in 2014 (McCaskill, 2014). A growing market not only enjoys the unboxing experience, but they are willing to pay more for it as well, if it is eco-friendly. If milkweed was used for paper and packaging, it would be particularly noteworthy to consumers as it firstly would be a tree-free material to promote sustainability, and secondly would support the resurgence of an endangered species.

Experimental

Materials

The milkweed gathered for this study is of the common variety, Asclepias syriaca, is a hearty perennial that commonly can be found in open fields, wooded areas, roadsides, and along agricultural boundary lines. Waiting until the plants had died back, the common milkweed was collected for processing. Separating the two portions of the plants, the material was then broken into manageable sized portions and bagged, ready to process. The average length of the cut pieces of the bast fibers measured 3-4 inches and ½ in diameter or less.

Natural cellulose fibers extracted from milkweed stems have been characterized for their composition, structure, and properties. Fibers obtained from milkweed stems have about 75% cellulose, higher than the cellulose in milkweed floss but lower than that in cotton and linen. Milkweed stem fibers have low % crystallinity when compared with cotton and linen but the strength of the fibers is similar to cotton and elongation is higher than that of linen fibers (Reddy & Yang, 2019).

Methods

The following methods were explored to determine a viable option for the creation of a handsheet for testing the strength properties of the paper.

Mechanical Pulping

- A Hammer Mill was used with the largest screen available. 40 grams were taken after fluff was hand sorted. Crushed stems were soaked and stirred in 400 ml of water for about 5 min.
- This was poured into the Mead machine and started with a one- minute cycles.
- A Second attempt with Mead machine was made, which yielded a more fibrous mixture.

- The sieve of 287 microns, 48 mesh and .0117 was chosen for filtering.
- The sheet did not solidify. Microscopic analysis showed the fibers did not adequately disperse.

Chemical Pulping

First Attempt

- Cooking was performed at 150-170º C for 1 hour.
- Processing occurred with various mills but all were clogged.
- The cook did not yield usable material. It was determined that a stronger cook would be required.

Second Attempt

- Milkweed – 220g was and chopped at 3/4 inch.
- White Liquor composition: Sodium Hydroxide – 290.1g Sodium Sulfide – 94.5g
- Total White Liquor Solution – 3L
- Batch Cooking:
    - At 130º C for 20 min, Pressure at the beginning = 40 psi (Gauge Pressure), at the end of 20 min = 55 psi (Gauge Pressure)
    - At 170º C for 1 hour, Pressure at the beginning = 115 psi (Gauge Pressure), at the end of 1 hour

Conclusions

Papermaking

1. Fibers from the stems of milkweed can be processed into pulp, and the pulp can be used to produce paper (non-wood fiber materials).

2. Due to the density and strength of the milkweed stems, a mechanical process is not recommended. A large quantity of fiber clumping occurred. Clumps were so densely compacted they made the mechanical process completely unproductive.

3. A full chemical cook was required to process the raw material into paper. This included Hand chopping stems to 3/4 inch. Producing a White Liquor with the composition of: Sodium Hydroxide – 290.1g Sodium Sulfide – 94.5g. A Total of 3L White Liquor Solution was used. This batch was cooked at 130 º C for 20 min. The pressure at the beginning was 40 psi (Gauge Pressure), and at the end of 20 min it was 55 psi (Gauge Pressure). It was allowed to cook at 170 ºC for 1 hour, Pressure at the beginning was 115 psi (Gauge Pressure), at the end of 1 hour.

4. Paper handsheets were created after the full chemical cook. They showed increases in Burst Strength (negligible), Tensile Strength, and Tear Resistance relative to Bleached Hardwood Kraft paper (control sample).

Unrefined Milkweed

Burst Strength

Sl.No	Burst Resistance		Burst Index (kPa.m^2/g)
	psi	kPa	
1	22.5	155.13075	2.06
	21.5	148.23605	
2	24	165.4728	1.97
	18	124.1046	
3	24	165.4728	2.27
	24.5	168.92015	
4	27	186.1569	2.46
	25.5	175.81485	
5	10	68.947	1.17
	15	103.4205	
		Average	1.99
		STD	0.49

Tensile Strength

Sl.No	Length (mm)	Breadth (mm)	Peak Load (kgf)	Elongation at Break (mm)	TEA (J/m^2)
1	100	15	2.23	1.12	10.26
2	100	15	2.67	1.24	13.20
3	100	15	3.17	1.26	16.25
4	100	15	3.28	1.62	21.68
5	100	15	3.06	1.50	18.40
6	100	15	3.18	1.20	15.51
7	100	15	3.12	1.38	17.45
8	100	15	2.70	1.18	12.50
9	100	15	3.11	1.54	19.95
10	100	15	3.15	1.48	19.12
Mean			2.97	1.35	16.43
Std. Dev.			0.33	0.17	3.61

Tear Resistance

Sl.No	Tear Value	Tearing Force (gf)
Trail I	20.2	64.64
Trail II	20.2	64.64
Trial III	20.4	65.28
	Average	64.85
	STD	0.37

BHKP

Burst Strength

Sl.No	Burst Resistance		Burst Index (kPa.m^2/g)
	psi	kPa	
1	16	110.3152	1.6656
	17	117.2099	
2	19.5	134.4467	1.8423
	17	117.2099	
3	18	124.1046	1.9180
	20	137.894	
4	16	110.3152	1.6152
	16	110.3152	
5	20	137.894	1.9432
	18.5	127.552	
		Average	1.7969

Tensile Strength

Sl.No	Length (mm)	Breadth (mm)	Peak Load (kgf)	Elongation at Break (mm)	TEA (J/m^2)
1	100	15	3.331	1.614	21.437
2	100	15	3.89	1.96	32.625
3	100	15	4.058	2.143	36.336
4	100	15	4.354	2.25	43.127
5	100	15	2.924	1.114	12.57
6	100	15	2.893	1.36	16.243
7	100	15	3.368	1.628	22.368
8	100	15	3.392	1.6	22.888
9	100	15	3.698	1.883	28.766
Mean			3.545	1.728	26.262
Std. Dev.			0.496	0.366	9.813

Tear Resistance

Sl.No	Tear Value	Tearing Force (gf)
Trail I	14	44.8
Trail II	14	44.8
Trial III	15	48
	Average	45.87

5. Additional refining of 500 Rev using the PMI Mill produced increases in these values.

500 REV Milkweed

Burst Strength

Sl.No	Burst Resistance		Burst Index (kPa.m^2/g)
	psi	kPa	
1	29.5	203.39365	2.78
	24	165.4728	
2	33	227.5251	2.93
	23.5	162.02545	
3	31	213.7357	3.40
	34.5	237.86715	
4	33	227.5251	3.30
	30.5	210.28835	
5	30	206.841	3.22
	32	220.6304	
		Average	3.13
		STD	0.26

Tensile Strength

Sl.No	Length (mm)	Breadth (mm)	Peak Load (kgf)	Elongation at Break (mm)	TEA (J/m^2)
1	100	15	3.47	1.20	15.4
2	100	15	3.38	1.32	17.0
3	100	15	4.56	1.73	31.2
4	100	15	4.05	1.34	20.4
5	100	15	4.28	1.48	24.1
6	100	15	4.67	1.55	28.6
7	100	15	4.56	1.62	28.3
8	100	15	4.24	1.47	24.3
9	100	15	4.17	1.75	29.7
10	100	15	3.02	1.06	12.0
Mean			4.04	1.45	23.1
Std. Dev.			0.56	0.22	6.6

Tear Resistance

Sl.No	Tear Value	Tearing Force (gf)
Trail I	17	54.4
Trail II	16.5	52.8
Trial III	17.5	56.0
	Average	54.4
	STD	1.6

6. Further processing of 1000 Rev using the PMI Mill created no appreciable difference, and in some cases, lowered the desired values.

7. However, the Freeness of the pulp, (ability to drain) measured using Canadian Standard Freeness (CSF) was lower with the milkweed fiber. This value went down with the additional processing through the PMI Mill.

MILKWEED PULP

Basis Weight (g/m^2)			
Sl.No	Unrefined	500 Rev.	1000 Rev.
Sample-1	1.48	1.29	1.34
Sample-2	1.46	1.34	1.34
Sample-3	1.48	1.31	1.29
Sample-4	1.49	1.38	1.32
Sample-5	1.45	1.32	1.34
GSM	**73.60**	**66.40**	**66.30**
STD	**0.16**	**0.34**	**0.22**

Freeness of Pulp (CSF) ml			
Sl.No	Unrefined	500 Rev.	1000 Rev.
1	**461**	**331**	**292**

BHKP

Basis Weight (g/m^2)	
Sl.No	Hardwood
Sample-1	1.38
Sample-2	1.38
Sample-3	1.37
Sample-4	1.36
Sample-5	1.34
GSM	**68.30**

Freeness of Pulp (CSF) ml	
Sl.No	Hardwood Pulp
1	**500**

CALIPER (1/1000 inches)				
Sl. No.	Harwood	Milkweed		
	Sample	Unrefined	500 revs.	1000 revs.
Sample-1	4.2	6.17	4.13	4.48
Sample-2	4.25	6.1	4.1	4.5
Sample-3	4.175	6.18	5.01	4.4
Sample-4	3.925	5.95	4.3	4.63
Sample-5	4	5.2	4.325	4.43
Average	4.11	5.92	4.373	4.488

8. Further testing of milkweed fiber is encouraged as an alternative to wood fiber in the production of paper for packaging.

Exploration into Milkweed Floss

- Highly water resistant
- Petroleum industry deploys floss as highly effective material to absorb spilled oil over the ocean.
- The plastic industry has been experimenting with floss to add strength to polymers.
- Continued research is recommended concerning the use of milkweed floss as a water-proof/resistant coating for packaging.

Citations

Berkman, Boris, (1949) Milkweed: A War Strategic Material and a Potential Industrial Crop for Sub-Marginal Lands in the United States, *Economic Botany* Vol. 3, No. 3 (Jul. - Sep.), pp. 223-239.

Ducey, Marjie (2018) "Monarch food shortage has butterfly advocates planting milkweed 'from Nebraska to Pennsylvania'", downloaded April 13, 2019 from https://www.omaha.com/living/monarch-food-shortage-has-butterfly-advocates-planting-milkweed-from-nebraska/article_e74bafe3-0ef9-56eb-9d60-dbc4b86695de.html

Grace, N. H. ct al.(1944) Extraction of rubber from milkweed in Canada. *Chem. Ind. 54*: 842-845. 1944.

McCaskill, Andrew, (2014) "Consumer-Goods' Brands That Demonstrate Commitment to Sustainability Outperform Those That Don't", downloaded April 2019 from https://www.nielsen.com/us/en/press-room/2015/consumer-goods-brands-that-demonstrate-commitment-to-sustainability-outperform.html.

Miao, C. Hui, L. F. Liu, Z. Tang. X. (2013) Evaluation of hemp root bast as a new material for papermaking, *BioResources 9(1)*, 132-142.

Reddy, Narendra and Yang, Yiqi (2009) "Extraction and characterization of natural cellulose fibers from common milkweed stems", *Polymer Engineering and Science*, 49:11, pp. 2212–2217.

Shah, M. (2019) "Global Industrial Packaging Market to Surpass US$ 97.2 Billion by 2025, with Construction Industry Poised to be the Growth Engine" downloaded April, 2019 from https://www.marketwatch.com/press-release/global-industrial-packaging-market-to-surpass-us-972-billion-by-2025-with-construction-industry-poised-to-be-the-growth-engine-2019-01-22

Smith, K.T. (2010), "An examination of marketing techniques that influence Millennials' perceptions of whether a product is environmentally friendly", *Journal of Strategic Marketing*, Vol. 18 No. 6, pp. 437-450. [Crossref], [Google Scholar] [Infotrieve]

Taylor, David "Common Milkweed (Asclepias syriaca L.)", downloaded Oct. 5, 2018 from https://www.fs.fed.us/wildflowers/plant-of-the-week/asclepias_syriaca.shtml.

van Hoeven, Helen (Director Market Transformation Initiative), (2012) "Better Production for a Living Planet" downloaded April, 2019 from http://assets.worldwildlife.org/publications/357/files/original/wwf___better_production_for_a_living_planet___2012_web.pdf?1345735175

Whitford, A. C. (1941) Textile fibers used in eastern aboriginal North America. *Am. Mus. Nat. Hist., Anthrop. Papers 38*(1).