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News Print from Corn Stalk Fiber: Industrial and commercial Trials

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Abstract

The chemical composition of corn stalk as well as fiber morphology, fiber length and diameter were carried out. Furthermore, Kraft pulping process using different cooking conditions (temperature, 125 – 170ºC, time, 15 - 40 min., and % alkali 9 - 12%) were done at laboratory scale. The obtained pulps were characterized with respect to %yield, %rejects, kappa number and rest alkali. Effect of chemical composition of corn stalk on yield and kappa number was discussed.The mechanical properties of hand sheet paper were explained in details, according to different cooking conditions. The high ash content and the relatively short fiber of corn stalk can attribute to positive effect with respect to bulk, opacity and the necessary strength of paper which are important properties in newspaper. Industrial trials were carried out using Pandia continuous digester (74 tons corn stalk kraft pulp was produced) and 90 tons newsprint paper (furnish: 86.5% bleached corn stalk pulp + 13.5 bleached soft wood pulp) was obtained using Furdirinier paper machine. The produced newsprint was printed and commercialized by four famous newsprint companies in Cairo – Egypt (about twenty tons for each).Comparison with the imported newsprint paper was done, the produced newsprint has better qualities with respect to opacity, and strength properties. Findings from industrial and commercialized trials in this study provide insights into new opportunities to utilize corn stalk pulp as better alternative to produce good quality of newsprint.

Keywords: corn stalk, strength properties, pulping, newsprint, kraft, Alkali, soft wood, fiber.

1-Introduction

The increase demand of various types of paper production in developing countries motivated researcher's activities to cover a wide range of new type of agricultural residues. Alkaline pulping of bagasse and rice straw was extensively studied, compared to the limited studies on the acid pulping process. Nassar, 2003 produced high yield rice straw pulp by neutral sulfite process with high opacity and satisfactory paper strength. A modified process using nitric acid pulping carried out using rice straw (El-Traboulsietal, 1983-a), and using bagasse (El-Traboulsi etal,1983-b. The aim of using nitric acid is to overcome problems of pollution caused from spent liquor (specially from rice straw) by using the pulping effluent as liquid fertilizer.

Different agricultural residues were used to produce paper. Trials were focused on using corn stalk as a promising raw material for paper production. Atchison1987 used cold soda process to produce pulp with satisfied paper strength. Mac Govern et al, 1987reported that the corn stalk soda pulping yield can be in the range of 36 to 39% based on alkali charge. JahanLatibari et al, 1996 measured soda pulp yield from corn stalk as 40.5% and kraft pulp as 47.5 %. Byrd and Hurter, 2005, showed that on pulping whole corn stalk by soda-Anthraquenon,the total pulp yield was 57.9% (no values of rejects was reported).

ValeriiBarbah et al, 2012 produced pulp from corn stalk by alkaline sulfite – anthraquinone –ethanol and they reported that the produced pulp was similar to the pulp produced from hard wood. Ana-Maria Chesca et al 2006 stated that soda and Kraft pulps are easy to beat, due to both their high hemicellulose content and their short fiber length. This is an advantage since beating corn stalk pulp requires low energy consumption. Pulping of corn stalk was investigated by Lotibari et al 2011, to produce pulp for corrugating board with pulp yield 42.5% when depithed corn stalk was used. The chemi-mechanical pulp utilizing corn stalk by sodium sulfite process was carried out by Latibari et al, 2008. They found that the defibrated pulp yield

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was between 53% and 68% with acceptable level of paper strength and can be used as filler for paper manufacture.

In FAO conferences held in Tokyo (1960), and Cairo (1955) newsprint was defined in such a way as to eliminate any requirement for specific furnish. The main considerations were those of run ability, printability and low cost. This general specification was mainly intended to allow the later inclusion of other raw materials that can be used as the main furnish in newsprint.

Generally, there are two schools of thoughts for producing newsprint from agricultural residues. The first are suggests the use of mechanical pulp to produce filler pulp with addition of a large amount of long fiber (softwood) to compensate for the low strength. While the second approach suggests the use of high yield chemical or semi chemical pulp, to compensate for the low opacity by addition clay and / or ground wood pulp.

From the first school, Nassar 1975, produced chemimechanical bagasse pulp by alkaline sulfite process (yield 95 % and opacity 98 %) as the main furnish of newsprint. The newsprint furnish was 80 % chemimechanical bagasse pulp and 20 % bleached softwood pulp. The opacity of the produced newsprint was 95 % and the physical strength was satisfactory, but the basis weight was high(53 g/m^2)the high basis weight was aimed to compensate the low strength for smooth run ability.

Another furnish was made with acceptable basis weight (48g/m^2) with a furnish 70 % and 30 % chemimechanical bagasse and bleached softwood pulp respectively. To control opacity(14% clay as ash was added). The newsprint obtained was matching the standard newsprint.

From the second School, Samariha *et al* 2013, used neutral sulfide semichemical bagasse(NSSCB) pulp (73% yield) as the main furnish in newsprint. The optimal furnish was 80%NSSCB and 20% hardwood chemimechanical pulp to produce satisfactory newsprint. The high yield soda bagasse pulp(47% yield) was also tried by JafarimPetroudy et al, 2011. They used two furnish blend mixture composed of bagasse pulp (BP),hardwood chemimechanical pulp(HWCM), and long fiber softwood pulp (SW). The first furnish blend was 30 % BP, 53 % (HWCM) and 17 % (SW), while the second furnish was 30 %(BP), 65 % (HWCM) and 5 % (SW). They stated that the two furnishes produce good newsprint that satisfied the opacity and the strength. However, the advantages of the second blend, with 5%(SW) is more economical. Corn stalk pulp has not been previously examined to produce newsprint. Therefore, the aim of this study is to produce newsprint with corn stalks pulp as the main furnish. Also industrial trials in Misr-Edfu Pulp Mill (Egypt), was carried out as well as commercial newsprint was produced.

2-Experimental

Raw corn stalks were depithed (grinded and screened) to oversize (2-5 cm) in laboratory, wet cleaned then left to dry. Characterization of corn stalk fibers and fiber length were carried out using scanning electron microscope (SEM) model FEI Quanta 250 FEG. The chemical composition of corn stalks was determined according to TAPPI standard method. The evaluation of water solubility, 1 % NaOH solubility, ethanol-benzene extractives, lignin and pentosane were carried out according to (T-207), (T-212), (T-204), (T-222) and (T-223) respectively.

Pulping of depithed corn stalks was carried out using laboratory thermo stated stainless-steel rotating autoclave – digester (3liters capacity) temperature and pressure devices are available to control the cooking conditions. Batches of 200 g of depithed corn stalks, on dry base were cooked under the following conditions:

Temperature from 125 to170°C, cooking time from 15 to 40 minute, and active alkali from 9 to12% as Na_2O, the liquor to raw material ratio and sulfidity were kept fixed at 10:1 and 17 % respectively. The cook was ended by quenching the autoclave in cold water. The cooked material was separated from the black liquor, dispersed in water, disintegrated and finally washed with hot water. The washed pulp was screened by using vibrating screen with slot size of 0.14 mm. lignin content in the pulp was assessed by determining Kappa number (TAPPI-T326 cm 13). Pulp freeness (shopper regular, SR°) was determined as ISO 5267 method. Hand sheets of 60 g were made on sheet former TAPPI method (T220- sp-16). Strength properties of hand sheets were determined accordingly to TAPPI test. The carried out test are: Tensile breaking strength, internal tearing resistance index, burst strength and folding endurance, according to the following TAPPI standards: (T404 wd-03), (T414 om-12), (T403 om-15) and (T 511 om-13) respectively.

3- Result and Discussion

The most important factors which can affect the suitability of agricultural residues for paper manufacture are chemical composition, physical properties, and fiber morphology.

Composition of corn stalks:

The chemical composition of raw corn stalk is shown in table 1. Data revealed that the chemical composition of corn stalk is close to the most common types of agricultural residues, with high cellulose content (55%), low lignin (11 %), and high ash, silica, 4.5 % and 2.86 % respectively.

The high cellulose content, and low lignin content, suggested the suitability of corn stalks to produce good quality pulp. The low lignin content and high hemicellulose are an advantage, it indicates easy pulping with lower percentage of active chemicals.(Aziz Ahmed and J.Y.Zhu) [corn stalk as a source of fiber and energy]. Ash and silica contents are high; this is a common property of all agricultural residues. In spite they can have adverse effect paper strength, but they increase paper opacity which is important property in newsprint paper (the aim of this work).

Table.1 Chemical composition of corn stalk:

Cellulose %	Pentosane %	Lignin %	Ash %	Silica %
55	26	11	4.50	2.86

Morphology and fiber length of corn stalk:

Figures 1 - 3 show different magnifications of raw corn stalk. SEM analysis and Figures 1 and 2 show the surface area of the corn stalk and the condensed arrangement of the fiber where it can increase the fiber strength and the quality of the paper,(ZawawiDaud et al 195(2015)2047-2050) [Oil palm leaf and corn stalk-Mechanical properties and surface characterization]. Also corn stalk fiber shows a closely packed arrangement. Corn stalks also show a thicker fiber could yield a strong fiber bundle and hence give a higher strength of paper produced (Bhaduri et al, 1995). Since fiber length of corn stalk (1.6 mm) is similar to that of hard wood and bagasse, it is expected to produce paper with adequate strength properties. Figure 3 shows a presence of fibers with different diameters from 12.4 – 28.83µm. Vessel elements are also present, which have larger diameter than fiber, see fig.2, left side, upper and lower corners. Generally, fibers are stiff, thus may produce bulky paper and consequently with high opacity (which is an important property of newsprint) the fiber dimensions are shown in table.2.

Fig.1. SEM Scan of corn stalk fiber, magnification 500 x

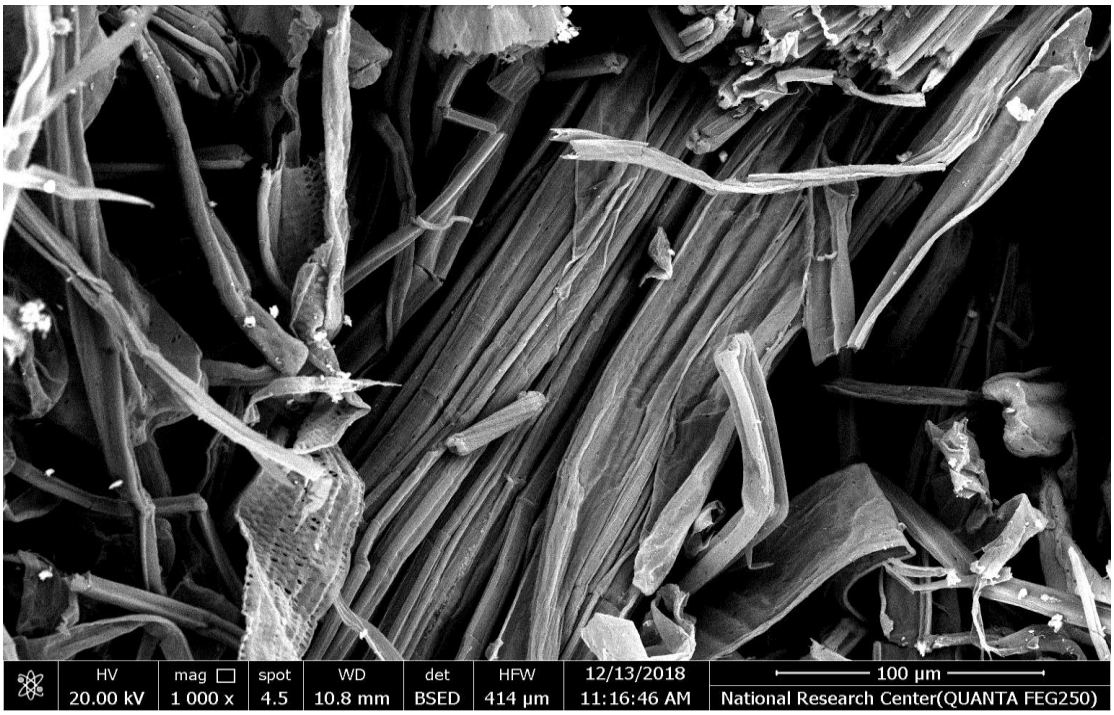

Fig.2. SEM Scan of corn stalk fiber, magnification 1000 x

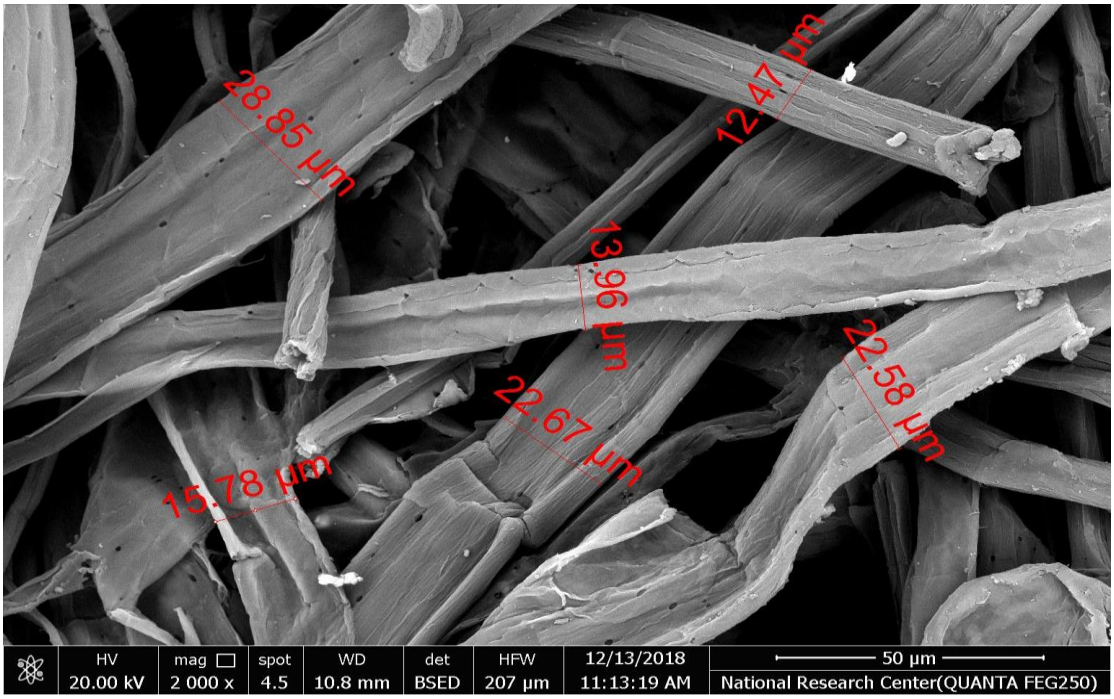

Fig.3. SEM Scan of corn stalk fiber, magnification 2000 x

Table.2 fiber dimensions of corn stalk as well as of bagasse and hardwood:

Items	Length mm	Diameter μ m	Aspect ratio L/d
Corn stalk (present work)	1.6	20	80
Bagasse (1) Av.	1.7	20	85
Hardwood (2) Av.	1.6	20	80

Data in table 2 show that fiber dimensions of corn stalk are comparable to bagasse and hard wood.

Pulping of corn stalk:

Tables 3-5 show the effect of temperature, percentage of alkali and time on the quality of pulp produced from corn stalk. Each property has certain effect on pulp properties according to certain mechanism.

Effect of temperature:

As temperature increased, percentage of the accepted pulp (yield) decreased from 44.6% to 33.5%, reject decreased from 15.7% to 1.35 % and Kappa number decreased from 19 to 10.6. This is attributed to the increase of temperature raises the average kinetic energy of the reactant molecules. Therefore, a greater portion of active alkali molecules will have the minimum energy necessary for an effective collision between moles of alkali and moles of lignin. Consequently increase the rate of solubilization of lignin. As lignin (cementing element between fibers) dissolved, fibers will be separated and high quality pulp is produced. The decreasing of yield is also due to solubilization some of pentosane (hemi celluloses) associated with lignin. At the same time amount of rejects (uncooked part) is decreased which improve the quality of the produced pulp. The Kappa number is the key measure to indicate the amount of lignin left after delignification of corn stalk. As temperature increased Kappa number is decreased as a consequence of decrease lignin in produced pulp. The lower lignin content (low Kappa number) is an economic advantage, it reduces energy required to separate fibers during chemical pulping and easy defibrillation of fibers by mechanical action of beaters as a consequence stronger paper is produced.

The Higher temperature, the higher rate of reaction between active chemicals and lignin, therefore the rest alkali is decreased in the spent liquor from 2.1 to 0.92 g/L, this is attributed to the fact that, increase of temperature increases the rate of reaction, consequently more alkali will be consumed during cooking process.

Effect of alkali:

Increase percentage of alkali from 9 % to 12% increases the rate of mass transfer and the rate of diffusion of alkali molecules from the cooking liquor to the surface of corn stalk fibers. Consequently, more alkali molecules will pass through fiber lumen, then through the different fiber walls and eventually reach the middle lamella where lignin is concentrated to dissolve it.

The rapid reaction between alkali and lignin is attributed to the high driving force as the result of increase the percentage of alkali. High amount of alkali leads to rapid dissolution of lignin between fibers and increase the amount of good fibers in the pulp. Yield is decreased from 40.03 % to 28 %, due to dissolution of lignin and associated pentosane.

As the amount of lignin is decreased, Kappa number decreased from 16 to 7.4.

The increase of rest alkali from 1.23 g/L to 1.93 g/L in spent liquor is attributed to the increase of initial alkali.

Effect of time:

Increase time from 15 to 40minute, decrease the yield from 40.3% to 30.1%, rejects from 5.6 to 1.13 %, rest alkali from 1.26 to 0.7 g/L, and kappa number from 18 to 6.4Increase time increase rate of reaction between active alkali and lignin due to more successful collision per unit time, that will occur between the reactants (alkali and lignin).

Finally, more good fibers will be produced with less rejects and lower kappa number.

Paper strength:

Hand sheet paper strength values are shown in table 3. As yield decreased all strength properties are positively affected, except tear factor due to different mechanisms. As stated above, the decrease

in pulp yield is attributed to dissolution of the cementing lignin between fibers which leads to separation of individual good fibers. Fibers produced without the en-clustering lignin are flexible, collapsed and easy swells. The fibers are also fibrillated due to internal stresses by swilling action (due to dissolution of lignin) therefore, primary fiber walls will tear off and the microfibers from the secondary fiber wall will be exposed out. This is reflected in increasing the shopper regular (SR) of pulp from 18 to 29.

The surface of the fibrillated fibers is covered with large number of hydroxyl groups. The hydroxyl groups of the neighboring cellulose on the fiber surface form chains of hydrogen bonding and provide the strength of paper. As a consequence, the severity level of pulping (increase the temperature, the percentage of alkali and time) affect positively, not only on the number of hydrogen bond (more hydroxyl groups) but also on area of contact between fibers (more flexible fibers). Hydrogen bonds play an important role in developing the high values in tensile strength, burst strength as well as folding endurance. In case of tear strength fiber length is the dominating factor. Corn stalk is inherited with short fibers which can affect negatively on tear strength values.

Table (3.): The Effect of temp. on pulping of corn stalk fiber.

Temp. ℃	Yield %	Reject %	Residual Alkali (R A) g/L	Kappa N0	Shopper regular (SR)	Tensile index Nm/g	Burst index Kpa.m2/g	Tear index mN.m2/g	Double fold No
125	**46.6**	**15.7**	**2.10**	**19.0**	**18**	**35.0**	**3.0**	**4.2**	**40**
135	**45.5**	**12.5**	**1.93**	**18.0**	**19**	**36.9**	**3.1**	**4.4**	**49**
145	**41.5**	**6.80**	**1.30**	**17.8**	**23**	**38.3**	**3.4**	**4.9**	**53**
160	**40.3**	**4.23**	**1.23**	**16.0**	**27**	**41.0**	**3.59**	**6.0**	**61**
170	**33.5**	**1.35**	**0.92**	**10.6**	**29**	**57.2**	**4.0**	**5.8**	**125**

The values of time, Alkali and liquor ratio are fixed and they were 18 min, 9, 1:10 respectively.

Table. (4.) effect of alkali on pulping of corn stalk fiber.

Alkali %	Yield %	Reject %	Residual alkali g/L	Kappa N0	Shopper regular	Tensile index Nm/g	Burst index Kpa.m2/g	Tear index mN.m2/g	Double fold No
9	**40.03**	**4.23**	**1.23**	**16**	**27**	**40.2**	**3.5**	**5.88**	**61**
10	**38.16**	**2.38**	**1.50**	**12**	**30**	**51.0**	**4.9**	**4.31**	**180**
11	**32.10**	**1.80**	**1.60**	**8.7**	**28**	**59.7**	**5.1**	**2.94**	**244**
12	**28.00**	**1.52**	**1.93**	**7.4**	**29**	**57.7**	**4.8**	**2.65**	**218**

The values of time, temperature and liquor ratio are fixed and they were 18 min, 160°C, 1:10 respectively.

Table. (5.) Effect of time on pulping of corn stalk fiber.

Time (min)	Yield %	Reject %	Residual alkali g/L	Kappa N0	Shopper regular	Tensile index Nm/g	Burst index Kpa.m2/g	Tear index mN.m2/g	Double fold (No)
15	40.3	5.6	1.26	18	24	39.2	3.14	5.00	50
18	40.0	4.23	1.23	16	27	40.3	3.5	5.88	61
30	35.5	2.2	0.95	10	28	54.9	4.02	5.29	160
40	30.1	1.13	0.7	6.4	29	52.1	4.3	4.80	218

The values of temp., Alkali and liquor ratio consumption are fixed and they were 160 C, 9, 1:10 respectively.

Industrial newsprint production:

To the best of our knowledge, this is the first time that the corn stalk pulp has been used as the main furnish in newsprint.

Depithed corn stalk was pulped in Misr-Edfu pulp mill – Egypt (2019). Pulping was carried out in Pandia continuous digester (capacity 5.8 – 6 tons per hour). Kraft process was used under the following conditions: Temperature =162ºC, time = 10.6 min, under 5.5 bars pressure. Chemical consumption = 8.8 – 9%, sulfidity = 22%, cooking liquor = 14.4 m^3/h, (A.A = 58g/l).

Amount of depithed corn stalk used was 192 tons /12 hrs. the amount of pulp produced was 71.4 tons on dry base, consequently the yield is 37.2%.

Evaluation of unbleached pulp:

Kappa number = 7.5, SR= 38 and rest alkali in black liquor = 4 g/l.

Pulp brightness = 40 ISO, and opacity 97%.

Mechanical properties of hand sheet unbleached pulp:

Tensile index = 67.5 Nm/g

Tear Index = 6.57 mNm^2/g

Burst index = 6.37 k pa m^2/g

Double fold = 128

Bleaching was carried out in Misr-Edfu pulp mill by oxygen bleaching and sodium hypochlorite stages (OH stages). Soda extraction was done before oxygen delignification, soda consumption = 8 kg/ton pulp, and sodium hypochlorite consumption =15kg/ton.

Condition of OH stages:

Oxygen stage: 1h at 90 ºC.

Hypo stage: 3h at 35 ºC.

Evaluation of bleached pulp:

SR =49 Brightness= 60.65 ISO, Opacity =93%

Mechanical properties of hand sheet bleached pulp:

Tensile index =69.9 Nm/g

Tear index =6.4 mNm^2/g

Burst index =5.5 k pa m^2/g

Double fold =235

Newspaper production was also carried out in Misr-Edfu mill. The used Fourdinier paper machine with the following specifications:

Head box width = 6.4 m, the Trim sheet width =5.8 m and

Paper machine speed = 600m/min

Newsprint pulp furnish: 86.5% bleached corn stalk pulp and 13.5% imported soft wood pulp. In addition, calcium carbonate filler was added to give 8% ash in the newsprint paper. 90 tons news-print paper was produced.

Characterization of the produced newsprint:

Basis weight = $44g/m^2$

Thickness =55 µm

Brightness =60 ISO

Opacity =93.5%

Tensile index MD/CD =52.61/25.4 Nm/g

Tear index MD/CD = 6.4/5.2 mNm^2/g

Burst index =6.3 k pa m^2/g

Double fold MD/CD = 66/30

Ash =8%

Moisture = 5%
Roughness MD/CD =340/240 mm/min
Cobb = 75

The Fourdinier's paper machine was run smoothly without any trouble and percentage of broke was only 2.1%

Table 6: specifications of the produced and the imported news print.

Properties	Produced newsprint	Imported newsprint
Basis weight g/m²	44	45.8
Thickness µm	55	60
Bulk cc/g	1.25	1.31
Brightness ISO	69	59.77
Opacity %	93.5	96
Breaking length m MD/CD	52.64/25.49	46.54/10.9
Tear index mNm²/g MD/CD	6.37/5.19	3.52/2.25
Burst index K pa m²/g	6.27	2.9
Double fold MD/CD	66/30	23/2
Cobb g/m²	75	83
Roughness ml/min. top/back	340/240	75/115
Ash %	8	7.3
Moisture %	5	7

Twenty-two tons of the produced newsprint was sent to the following Journalism organization: [Al-Ahram Newsprint paper, Al-Akbar Newspaper, Al-Gomhouria Newspaper and Rose Al-Youssef Newspaper, all are in Cairo-Egypt] for producing newsprint journal. The workers do not find any troubles, and the quality of the produced journal from corn stalk pulp(main furnish) is better than the imported newsprint.

The following remarks can be drawn out on studying data given in table 6.

1- All mechanical properties (Breaking length, tear, burst, and double fold) of the produced newsprint are higher than the imported newsprint paper, as a consequence, the percentage of the soft wood pulp in the furnish can be decreased.
2- The basis weight of the produced newsprint is lower than the imported, again more reduction of soft wood pulp can be done to keep a smooth paper machine runability.
3- Roughness of the produced newsprint is high; this means that the calendar needs to be grinded.
4- Brightness in the produced newsprint is higher and opacity is lower than in the imported newsprint, therefore, brightness can be decreased to the standard level, which can save bleaching chemicals and increase opacity in the produced newsprint.

4-Conclusion

This study aimed to fill the gaps existing in the related literatures, and it is the first time to use corn stalk pulp as the main furnish in newsprint.

The economic advantages of low lignin content in corn stalk may leads to use less chemicals and low power during pulping and beating of pulp. The high ash content, could be an advantage to increase opacity of newsprint.

The laboratory studies, proofs the suitability of corn stalk to produce different types of pulp, one of them is newsprint paper.

Industrial trials in Misr-Edfu mill– Egypt to produce the pulp and
news paper, shows the smooth run ability and high quality of newsprint paper.

Production and commercialization newsprint journal was carried out through four famous Journalism association in Cairo-Egypt.

They justified that the newspaper from corn stalk pulp is matching the imported newsprint paper with respect to run ability and printability.

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   b- Al-Gomhouria Newspaper, Cairo-Egypt.
   c- Al-Akbar Newspaper, Cairo-Egypt.
   d- Rose Al-Youssef Newspaper, Cairo Egypt.
3- Egyptian Company for Solid Waste Recycling (ECARU) for supplying the depithed corn stalk.

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