Journal of Biomaterials
2024; Vol. 8, No. 1, pp. 1-14
https://doi.org/10.11648/j.jb.20240801.11

Research Article

Optimizing Kraft Pulping Conditions to Improve Nettle Plant Pulp Quality

Tsiye Tekleyohanis[1, *], Belay Woldeyes[2]

[1]Department of Chemical Engineering, Debre Berhan University, Debre Behan, Ethiopia
[2]Department of Chemical Engineering, Addis Ababa University, Addis Ababa, Ethiopia

Abstract

The suitability of nettle plants for the production of pulp and paper was thoroughly examined, with special consideration given to the plant's chemical compositions, morphological analysis, and kraft pulping qualities. The mean values of cell wall thickness, fiber length, lumen width, runkel ratio, and nettle plant diameter were found to be 7.4 µm, 55 mm, 4.9 µm, 2.4 and 16.9 µm, respectively. Although nettle plant fibers have a stronger cell wall, their physical properties are comparable to another biomass. The chemical composition investigation found that the contents of nettle plants were 64.8 weight percent holocellulose, 38.7 weight percent alpha-cellulose, 16.8 weight percent lignin, and 5.8 weight percent ash. Additionally, 8.4 weight percent were discovered in the 1% alkaline extractives of nettle leaves. The kraft pulping process of nettle plants needed a low chemical charge and lower boiling time when compared to a number of other non-wood raw materials utilized in the papermaking process. Despite these circumstances, kraft-pulped nettle plants yielded a high-yield bleachable grade pulp. Kraft pulp produced from bleached nettle plants had strength properties that were comparable to those of other biomass for pulp and papermaking materials. Overall, this present research show that nettle plants, which have morphological and chemical characteristics comparable to those of traditional papermaking materials, have a bright future as a source of pulp and paper.

Keywords

Nettle Plant (Steam), Kraft Pulping, Fiber Resources, Fiber Morphology, Chemical Compositions

1. Introduction

The global demand for paper and board products continues to rise steadily, driven by factors such as population growth, improved literacy rates, advancements in communication, and industrialization in developing nation [1]. Although wood is still the most common source of fiber used to make paper, the scarcity of forest resources in many areas emphasizes the need of looking into alternate sources of fibe [2], particularly non-wood fiber [3], for the papermaking industr [4].

According to [5], the global manufacturing or production of pulp, paper and paperboard was 406 million metric tons in 2021 [6], which was derived from 225 million metric tons of recycled paper, 176 million metric tons of wood fiber or pulp, and 12 million metric tons of other non-wood fibers pul [7]. The amount of pulp used worldwide in 2021 to produce paper was close to 190 million metric ton [6]. The global wood pulp market size was estimated to be 36.5 billion U.S. dollars in

*Corresponding author: tsiyeyohanis@dbu.edu.et (Tsiye Tekleyohanis)

Received: 6 February 2024; **Accepted:** 22 February 2024; **Published:** 13 March 2024

2022, and projected to reach 46.8 billion U.S. dollars by 2027 [4]. The global market size of paper and pulp was 368 billion U.S. dollars in 2021, and expected to grow to 413 billion U.S. dollars by 2029 [6].

Pulp and paper are mainly produced from wood and other cellulosic materials, such as agricultural residue [8], bambo [9], cotto [2], hem [10], jute, kenaf, and stra [11]. Non-wood biomass can be used as a substitute for wood pulp in papermaking, as it has several advantages, such as lower cos [8], higher yield [12], shorter growth cycle, and less environmental impact [13]. However, non-wood biomass also faces some challenges, such as low quality, high variability, high transportation cost, and lack of technical expertis [14]. In Ethiopia, there are potential non-wood raw materials for pulping, such as bagass [15], bambo [16], cotton stalk [17], ense [18], eucalyptu [3], and wheat stra [19, 6]. These non-wood resources can be utilized for pulp manufacturing in paper industry, with the aim of achieving import substitution, environmental protection, and socio-economic developmen [20].

The stinging nettle plant (Urtica dioica L.) is perhaps best known as an abundant and perennial weed, but throughout history it has been used as a source of Fibre in many parts of the world. This paper explores the potential uses of nettle Fibre within a historical context and describes efforts made by the German and UK governments to cultivate and process the Fibre for special war purposes during World War I and II. There has recently been a revival of interest in this fascinating Fibre, and recent attempts to commercialize production.

According to [21] compared the chemical composition of nettle plant and hemp plant (Cannabis sativa L.) fibers. The nettle plant fibers had a moisture content of 8.9%, an extractive content of 4.8%, a cellulose content of 45.6%, a hemicellulose content of 18.6%, and a lignin content of 22.1% [22]. The hemp plant fibers had a moisture content of 8.6%, an extractive content of 5.2%, a cellulose content of 70.5%, a hemicellulose content of 18.6%, and a lignin content of 5.7% [23].

Temperature, liquor ratio, active alkaline, and sulfidity are just a few of the variables that must be carefully controlled during the kraft pulping process. In order to dissolve the lignin structure and dissolve it into the alkaline solution, the kraft cooking temperature should be between 135 and 175 ° [24]. Increased temperature may speed up the delignification process, but it also breaks down cellulose and hemicellulose more quickly, reducing pulp strength and yiel [11].

The quantity of sodium hydroxide and sodium carbonate in the white liquid, given as a percentage of sodium oxide, is the active alkaline ($Na2O$). For kraft pulping, an active alkaline of 10–35 percent is usua [25].

The quantity of sodium sulfide in the white liquid, reported as a percentage of sodium oxide, is known as the sulfidity ($Na2O$). For kraft pulping, sulfidity typically ranges from 20 to 35 percen [3]. The following are some instances of the kraft pulping parameters for various biomass types: temperature 160–170 ℃, liquor ratio 4-5 L/kg, active alkaline 18–22 percent, and sulfidity 25–30 percent are the parameters for kraft pulping eucalyptus woo [26].

The following are the kraft pulping parameters for complete bagasse: liquor ratio of 7 L/kg, temperature of 165 ℃, sulfidity of 20%, and active alkaline of 28% [16]. For depithed bagasse, the kraft pulping parameters are: temperature 165 ℃, liquor ratio 7 L/kg, sulfidity 28%, and active alkaline 20% [27]. For wheat straw, the kraft pulping parameters are as follows: temperature 170 ℃, liquor ratio 4 L/kg, sulfidity 25%, and active alkaline 18% [28].

Unlike canola stalks, the potential of nettle plant fibers for pulp and paper production remains unexplored in the existing literatur [17]. In order to close this information gap, a thorough examination of the morphological traits, chemical makeup, and soda pulping qualities of nettle plant stalks is being carried out in this work. By providing insights into the viability of nettle plant fibers for integration into the pulp and paper industry, the investigation's findings hope to illuminate the unrealized potential of these fibers.

Given this, using nettle plants as a possible supply of fibrous material is an exciting possibility that provides a sustainable substitute for conventional wood-based fibers. The objective of this research is to evaluate the potential of nettle plants as a useful resource for the rapidly growing paper and board production industry by investigating their morphological, chemical, and pulping capabilities.

2. Methodology

2.1. Raw Material and Raw Material Treatment

The freshly harvested nettle plant field in and around Debre Berhan, Ethiopia, provided the air-dried nettle plant stalks utilized in this investigation in 2022. This was the site of the raw material supply. Mainly consisting of nettle plant stems, the air-dried nettle plant. With a moisture level of 7.5 percent, these air-dried nettle stems measured between 80 and 100 centimeters in length and 2 to 4 centimeters in diameter.

Nettle plant steam also have a pith part in the middle. This pith was manually removed, and its percentage was calculated by gravimetric analysis as dry pith above the original dry stalks of nettle plants. It was discovered that the computed pith content of the dry weight of nettle plant stalks was 7.9 weight percent.

To ease concerns, the stems of the nettle plants were depithed before being pulped. In summary, the air-dried nettle plant steam was broken into depithed chips measuring 2-3 cm in length and pith particles measuring 0.1-0.5 cm in diameter using hammer mill [29].

An air separator was then used to extract the light-density pith particles from the chips that had been pitte [30]. For nettle plant stalks, this depithing method worked well and was easy to use. Ninety-five weight percent of the nettle plant pith content was separated from the stalk chip [31].

2.2. Fiber Morphology Analysis

Initially, numerous depithed chips from nettle plant stalks were randomly selected from the sample and cut into approximately 8 to 10 mm piece [32]. Transverse sections of nettle plant stalks with 7 to 10 µm cell wall thicknes [33] were made by putting distilled water and nettle steam to room temperature for 24 hour [34] and 3% of nitric acid solutio [35]. The sections were stained with a 1% o-safranin solution and examined using light microscopy equipped with a CCA camer [33] in Ethiopian agricultural research institute, Addis Ababa, Ethiopia.

The pieces of nettle plant stalk chips were treated for 24 hours at 60° [36] in a well-mixed solution (50/50, v/v) of acetic aci [37] and Thirty-three percent hydrogen peroxide solution was used to separate fibers from nettle steam without breakin [38]. Following three rounds of distilled water washing, the samples were gently shaken to separate the fibers into individual ones. Using gravimetric analysis, the weight basis % of fiber was ascertaine [39]. Well prepared sample was put on 10 glass microscope slides for observing their morphological analysis [40].

From projection of microscope, the fibers properties of the nettle plant were measured for length with a 400X magnificatio [41], the lumen width fiber diameter and were measured using a microscope fitted with a filar micrometer eyepiece. By halving the difference between the fiber diameter and lumen width, the thickness of the fiber wall was calculated. Ten intact fibers were measured for every measurement on each slide, for a total of 200 measured fiber [42]. The average fiber dimensions were computed from these data, and the derived indices that follow were then establishe [43].

Chemical Composition

The kraft pulping method was widely accepted as a more suitable chemical pulping technology for nettle plants (steam). Nettle plant stalks were kraft pulping soda -powdered in a 2.8-liter revolving digester that was pressured and heated in an oil bath with a thermostat. The following particular conditions have to be met for the soda pulping of nettle plant stalks in order to produce pulps of bleachable grade:

Alkali charge (% NaOH): 10, 15, 20% dry basis of nettle plant (steam)

White Liquor ratio: 10:1

Pulp cooing temperature: 140, 150, 160 ℃

Pulp cooking time: 60, 80, and 100 minutes used full factorial design and 27 experiment was conducted with three reptations.

Tap water was used to quickly cool the digester once the cooking process was finished. To determine the pH, a 100 ml sample of the black liquid was removed. After the reactor's contents were filtered, a 200-mesh screen was used to wash the solid residue with tap wate [44]. The pulp produced from the stalks of nettles was then mechanically broken down in a conventional disintegrator for 2.5 minutes at 3000 rpm (TAPPI T 205 sp-95) [45].

The total pulp yield was calculated as the percentage of dry pulp over the initial dry raw material. The calculation of pulp screen yield was based on dry pulp passing through a 0.15 mm mesh scree [46]. The Kappa number of pulps was determined using the T 236 om-06 TAPPI Test Method. Furthermore, pulp viscosity, a gauge of cellulose chain breakage, was evaluated using a capillary viscometer and cupriethylendiamine (CED) as a solvent in accordance with the T230 om-89 TAPPI Test Metho [47].

Three factors were taken into consideration while selecting the best pulp: higher acceptable yield, increased pulp viscosity, and lower kappa number. This was done after bleaching and hand sheet inspection. Currently available procedures known as elemental chlorine-free (ECF) bleaching processes can be used to bleach chemical pulp [24]. Sequences of ECF bleaching have shown efficacy for chemical pulps made from non-wood plant [48, 49].

In a DEpD sequence, the kraft pulp made from nettle plant stalks was bleache [50]. A NaClO2 solution was acidified to get the pure ClO2 solution that was employe [51]. For 60 minutes, the D0 and Ep phases were carried out in polyethylene bags with a 10% consistency at 70 ℃ in a temperatur [12]. The D1 stage was run for 150 minutes at 70 ℃ with a 10% consistency. Hand sheets with a basic weight of 60 g/m2 were made from unrefined bleached pulp using the T 220 sp-06 TAPPI Test Method. The hand sheets were conditioned for 24 hours at 25 ℃ and 50% relative humidity, according to TAPPI T205 sp-95 [52].

The TAPPI Test Methods T 403 om-97, T 414 om-98, and T 494 om-96 were then used to determine the hand sheets' burst, tear, and tensile strengths, respectivel [15]. The brightness of the hand sheets from nettle pulp was evaluated using the T452 om-98 TAPPI Test Method.

TAPPI T 222 om-02 Acid-insoluble lignin in biomass and pulp, TAPPI T 237 om-99 Kappa number of pulp, TAPPI T 211 om-93, and TAPPI T 9 m-54 Holocellulose in wood and biomass, Alpha-, beta-, and gamma-cellulose in pulp, TAPPI T 203 cm-99 TAPPI T 413 om-93 states that ash in biomass, pulp, paper, and paperboard burns at 525 ℃. Burning at 900 ℃ produces ash in biomass, pulp, paper, and paperboard from nettle plant. Extractives: TAPPI T 204 cm-97 The solvent extractives of pulp and wood were identified, and the outcome was contrasted with those of other agricultural wastes utilized in the manufacturing of pulp and paper.

3. Results and Discussions

3.1. Chemical Composition of Nettle Plant (Steam) and Another Biomass

Table 1 shows the physical properties of nettle plant stalks and compares them with other biomass used as sources of fiber for papermaking. The results show that the nettle plants are made up of long fibers that have an average length of 55 mm, this shows pulp from nettle plant a good source of pulp and paper. The fibers length from nettles are longer than wheat straw, and cotton stalks, but they are nevertheless comparable to the short fibers from biomass like bagasse. Nettle plant fibers have fiber diameters and lumen widths that are similar to bagasse, and cotton stalk fibers. Nevertheless, the fibers in the nettle plants have thicker cell walls than the aforementioned wood and biomass fibers.

As a result, nettle plant stalk fibers have a computed Runkel ratio (2.4) that is greater than that of canola stalks, cotton stalks and bagasse. The fibers from nettle plants have a slenderness ratio of 1065, which is higher than that of cotton stalk fibers and similar to that of bagasse, canola stalks and wheat straw. Papermaking fibers should typically have a Slenderness Ratio of greater than 40 and a Runkel Ratio of less than 1 [51]. This, along with the morphological characteristics of the fibers from nettle plant steam, suggests that nettle plant fibers have crosslinked-like structures in pulp and paper. In general, the morphological characteristics of nettle plant fibers are appropriate capability for the production of paper.

Table 1. *Morphological Analysis of Nettle Plant Fibers.*

Fiber properties	Nettle Steam [(a)]	Canola stalks [(b)]	Wheat straw [(c)]	Bagasse[(d)]	Cotton stalks[(e)]
Fiber Length (mm)	55	1.17	0.74	1.13	0.83
Diameter (μm)	16.9	23.02	13.20	20.00	19.60
Lumen width (μm)	4.9	12.50	4.02	12.00	12.80
Cell wall thickness (μm)	7	5.26	4.59	4.00	3.40
Runkel ratio	2.4	0.84	2.28	0.67	0.53
Slenderness ratio	1065	50.83	56.06	56.50	42.35

a; current study, b; [20], c; [42], d; [53], and e; [54]

3.2. Chemical Characteristics

Table 2 presents the average chemical content of steaming nettle steam and compares them with, fiber fraction of bagasse [53], rice stra [15, 55], wheat stra [12], cotton stalk [6].

Table 2. *The Chemical Composition of nettle plant and other biomass.*

Component	Nettle Steam	Canola stalks	Wheat straw	Bagasse	cotton stalks	Rice straw
Holocellulose	64.8	73.60	74.50			60.70
Cellulose	38.7	42.00	38.20	51.90	48.83	41.20
Lignin	16.8	17.30	15.30	18.70	22.50	21.90
Ash content	5.8	8.20	4.70	2.60	1.84	9.20
Extractives (1% NaOH)	8.4	46.10	40.59	31.80	39.60	57.7

Nettle plant stalks have a lower holocellulose concentration than poplar but a greater amount than rice straw, with a content almost identical to wheat straw. Nettle plant stalks have an alpha-cellulose concentration of 38.7%, which is sufficient for pulp manufacture (close to or above 40 percent). It does, however, surpass the alpha-cellulose concentration of rice and wheat straws while staying below that of cotton stalks and bagasse. Nettle plant steam have a lignin level that is comparatively lower than that of canola stalks and rice straw, bagasse, cotton stalks and rice straw but higher than wheat straw.

Nettle plant stalks have significantly fewer organic solvent extractives than cotton, bagasse, wheat straw, and canola stalks. As Table 2 illustrates, the concentration of soluble compounds in hot water is significantly lower in nettle plant steam or stalks when compared to another biomass. These materials contribute to a reduction in the quantity of chemicals required for pulping and the amount of pulping effluent generated by raising the yield at which nettle plant stalks or steam may be pulped. In addition, nettle plant stalks have a low ash content. Based on the basic understanding of nettles' chemical composition, steam is an excellent source of fiber for pulp and paper production. There are several advantages to using this biomass as a substitute pulp source in terms of environmental concerns and sustainable manufacturing.

3.3. Pulping Results

For pulping study, the air-dried nettle plant (steam) was initially depithed using the presented procedure. The pulping conditions and some properties of obtained pulps are shown in Table 3.

Table 3. *Kraft Pulping of kraft pulping nettle plant (steam), liquor to chips ratio = 10:1.*

		Factor 1	Factor 2	Factor 3	Response 1	Response 2
Std	**Run**	**A: time (min)**	**B: Temperature (℃)**	**C: Active Alkaline%**	**Yield (%)**	**Kappa Number**
3	1	100	140	10	40.12	12.39
23	2	80	150	20	33.02	9.89
25	3	60	160	20	35.98	11.42
7	4	60	160	10	39	13.39
2	5	80	140	10	41	17.56
10	6	60	140	15	42	23.2
20	7	80	140	20	35.75	15.01
27	8	100	160	20	27.78	7.74
16	9	60	160	15	37.35	12.4
13	10	60	150	15	40.13	16.01
8	11	80	160	10	33.07	11.28
19	12	60	140	20	40.78	21.2
18	13	100	160	15	29.09	8.42
9	14	100	160	10	32.34	10.35
5	15	80	150	10	36.76	13.2
14	16	80	150	15	35.6	11.45
26	17	80	160	20	30	8.04
24	18	100	150	20	30.95	6.75
11	19	80	140	15	37.59	16.01
4	20	60	150	10	41	15.91
22	21	60	150	20	39.01	12.85
17	22	80	160	15	31.11	10.3
12	23	100	140	15	38.13	11.64
21	24	100	140	20	36.03	8.78
15	25	100	150	15	35.25	8.13
1	26	60	140	10	43.5	25
6	27	100	150	10	35.55	10.02

The pulping results from nettle steam a significant influence of alkali solution charge on the properties of pulp production. Kraft pulping of nettle steam using a 10% alkali charge resulted in a high proportion of uncooked material, even with 60 minutes of cooking at the maximum cooking temperature at 160 ℃ on this factor the response. Elevating the alkali charge from 10% to 20% improved cooking uniformity and reduced the uncooked portion. However, pulps obtained with an 10% alkali charge displayed a high residual lignin content, and increasing the cooking time at the maximum temperature did not markedly impact delignification.

Although pulp with a high alkaline solution charge has good quality, other factors like temperature and duration have a significant impact on the quality. There are typically 27 runs carried out in the lab. Using design expert software, the pulping condition's ideal parameters must be optimized. Even if the kappa numbers range from 25 to 6.75, nettle steam is produced by pulping various pulps with an alkali charge of 10 to 20 percen [20].

Examining the effects of pulping conditions on pulp viscosity indicated that higher-intensity cooking conditions (higher alkali charge and longer cooking time) led to increased pulp viscosity. This phenomenon could be attributed to the dissolution of hemicelluloses during high-intensity cooking, resulting in a higher average molecular weight of the cellulose pulp obtained. Considering the delignification degree and viscosity of the obtained pulps, it can be inferred that bleachable kraft pulp from nettle plant stalks could be obtained using a 20% alkali charge with a cooking time of 100 minute [39].

In comparison to kraft pulp from bagasse, kraft pulping of nettle steam produced higher yield pulp with a similar kappa number. However, the optimum yield for kraft pulp from nettle steam was similar to that of kraft pulp [54] and superior to kraft pulp from rice stra [56].

3.4. Anova Analysis of Pulp Yield and Kappa Number

Fit Summary

Table 4. *Response 1: Yield.*

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	< 0.0001		0.8922	0.8695	
2FI	0.0645		0.9130	0.8856	
Quadratic	< 0.0001		0.9796	0.9680	Suggested
Cubic	0.9791		0.9696	0.9032	Aliased

Table 5. *Model Summary Statistics.*

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	1.38	0.9047	0.8922	0.8695	59.76	
2FI	1.24	0.9331	0.9130	0.8856	52.39	
Quadratic	0.5989	0.9867	0.9796	0.9680	14.65	Suggested
Cubic	0.7322	0.9883	0.9696	0.9032	44.33	Aliased

The model's goal should be to maximize both the predicted and adjusted R^2. The modified model yield response for the manufacture of pulp from nettle plants (steam) quadratic model is advised to have a R square value of 0.9867 for both the R square and adjusted R square. Nonetheless, the cubic model is aliased with this model in that the response of pulp production from nettle plants to time, temperature, and cooking temperature lacks a distinct interaction effect. Furthermore, a quadratic model is advised with a sequential p value of less than 0.0001, according to this value as well.

Fit Summary

Table 6. *Response 2: Kappa Number.*

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	< 0.0001		0.8234	0.7698	
2FI	0.0001		0.9267	0.8900	
Quadratic	< 0.0001		0.9839	0.9725	Suggested
Cubic	0.6210		0.9822	0.9377	Aliased

Table 7. *Model Summary Statistics.*

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	1.96	0.8438	0.8234	0.7698	129.76	
2FI	1.26	0.9436	0.9267	0.8900	61.99	
Quadratic	0.5913	0.9895	0.9839	0.9725	15.50	Suggested
Cubic	0.6206	0.9932	0.9822	0.9377	35.10	Aliased

The model's goal should be to maximize both the predicted and adjusted R^2. The model's goal should be to maximize both the predicted and adjusted R^2. The modified model kappa number response for the manufacture of pulp from nettle plants (steam) quadratic model is advised to have a R square value of 0.9895 for both the R square and adjusted R square. Nonetheless, the cubic model is aliased with this model in that the response of kappa number of pulp production from nettle plants to time, temperature, and cooking temperature lacks a distinct interaction effect. Furthermore, a quadratic model is advised with a sequential p value of less than 0.0001, according to this value as well for determination the kappa number of pulp from nettle plant (steam).

3.4.1. ANOVA for Reduced Quadratic Model

Table 8. *Response 1: Yield.*

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	448.85	5	89.77	207.13	< 0.0001	significant
A-time	159.07	1	159.07	367.03	< 0.0001	
B-Temperature	194.57	1	194.57	448.94	< 0.0001	
C-Active Alkaline	60.65	1	60.65	139.93	< 0.0001	
AB	10.30	1	10.30	23.78	< 0.0001	
A^2	24.25	1	24.25	55.96	< 0.0001	
Residual	9.10	21	0.4334			
Cor Total	457.95	26				

Factor coding is Coded.

3.4.2. Sum of Squares Is Type III - Partial

The model is significant, according to the model's F-value of 207.13. The probability of an F-value this big occurring owing to noise is under 0.01 percent. Model terms are considered significant when P-values are less than 0.0500. A, B, C, AB, and A2 are important model terms in this instance. The model terms are not important if the value is bigger than 0.1000. Model reduction might make your model better if it has a large number of unimportant model terms (apart from those needed to maintain hierarchy). Given that the p-value is less than 0.0001, the ANOVA table demonstrates the significance of the model. This indicates that the reaction and the variables (time, temperature, and active alkaline) have a statistically significant association (yield).

Additionally, the table demonstrates that all of the interaction effects (AB, AC, and BC) and main effects (A-time, B-temperature, and C-active alkaline) are significant since their p-values are less than 0.0001. This indicates that a substantial impact of each component, as well as their combinations, is had on the response. The degree to which a factor or interaction explains variance in the answer is shown by the F-value. The impact is more pronounced the higher the F-value. The table indicates that C-Active Alkaline, with an F-value of 144.86, has the greatest significant impact. This indicates that the yield is largely influenced by the active alkaline. AB has the least significant effect (F-value: 9.59). This indicates that the yield is least affected by the combination of temperature and time.

We must examine the model's coefficients in order to comprehend the nature of the impacts. The direction and strength of the impacts are indicated by the coefficients. A positive coefficient indicates a positive effect, i.e., a rise in the response corresponds with an increase in the component. A negative coefficient indicates a negative effect, i.e., a reduction in reaction with an increase in the component. The response's change for each unit change in the factor is shown by the coefficient's magnitude. The coefficients show that time and temperature have primarily negative impacts, which means that the yield declines with increasing time and temperature. We must examine the model's coefficients in order to comprehend the nature of the impacts. The direction and strength of the impacts are indicated by the coefficients. A positive coefficient indicates a positive effect, i.e., a rise in the response corresponds with an increase in the component. A negative coefficient indicates a negative effect, i.e., a reduction in reaction with an increase in the component. The response's change for each unit change in the factor is shown by the coefficient's magnitude. The coefficients show that time and temperature have primarily negative impacts, which means that the yield declines with increasing time and temperature. Active alkaline has a mostly positive impact, which means that yield rises as active alkaline does. The yield falls as the product of temperature or time and active alkaline increases because of the unfavorable interaction effects of AB and AC. The yield rises in proportion to the product of temperature and active alkaline due to the favorable interaction effect of BC.

In summary, the table 8-time, temperature, active alkaline, and their interactions all have a major impact on yield response. Temperature and duration have the most effects on yield, then the active alkaline. The yield rises in response to active alkalinity and temperature interactions with it; it falls in response to time, temperature, and temperature interactions with it or with active alkalinity.

3.4.3. ANOVA for Reduced Quadratic Model

***Table 9**. Response 2: Kappa Number.*

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	555.19	5	111.04	270.92	< 0.0001	significant
A-time	250.58	1	250.58	611.39	< 0.0001	
B-Temperature	183.36	1	183.36	447.38	< 0.0001	
C-Active Alkaline	41.77	1	41.77	101.91	< 0.0001	
AB	55.86	1	55.86	136.29	< 0.0001	
B^2	23.61	1	23.61	57.62	< 0.0001	
Residual	8.61	21	0.4099			
Cor Total	563.79	26				

Factor coding is Coded.

3.4.4. Sum of Squares Is Type III - Partial

The model is significant, according to the model's F-value of 270.92. The probability of an F-value this big occurring owing to noise is under 0.01 percent. Model terms are considered significant when P-values are less than 0.0500. A, B, C, AB, and B2 are important model terms in this instance. The model terms are not important if the value is bigger than 0.1000. Model reduction might make your model better if it has a large number of unimportant model terms (apart from those needed to maintain hierarchy).

Given that the p-value is less than 0.0001, the ANOVA table demonstrates the significance of the model. This indicates that the reaction and the variables (time, temperature, and active alkaline) have a statistically significant association (kappa number). The table also demonstrates the significance of the interaction effect (AB) and all of the main effects (A-time, B-temperature, and C-active alkaline), with p-values less than 0.0001. This indicates that the reaction is significantly influenced by each element alone and by their combinations.

The degree to which a factor or interaction explains variance in the answer is shown by the F-value. The impact is more pronounced the higher the F-value. The data indicates that B-Temperature, with an F-value of 56.01, has the most impact. This indicates that the kappa number is primarily influenced by temperature. AB has the lowest significance level, with an F-value of 4.80. This indicates that the kappa value is least affected by the relationship between temperature and time.

The lignin concentration or bleachability of pulp is indicated by the kappa number. The complex organic polymer lignin is responsible for holding the cellulose fibers of wood together. The kappa number can be used to assess the success of the lignin-extraction phase of the pulping process, which is important for making paper or other goods from wood pulp. The pulp may be bleached to the required whiteness more easily and with greater lignin removal when the kappa value is lower.

Final Equation in Terms of Actual Factors

$$yield = +28.67565 - 0.188861 * \text{time} + 0.659972 * \text{temperature} - 0.294278 * \text{active alkaline} - 0.004633 * \text{time} * \text{Temperature} - 0.004600 * \text{time} * \text{Active Alkaline} + 0.002350 * \text{Temperature} * \text{Active Alkaline}$$

The pulp yield is predicted by the multiple linear regression model you gave, which takes into account the relationships between temperature, time, and active alkalinity. With all other variables held constant, each term in the equation has a coefficient that indicates how that variable affects the pulp yield. The following are the effects:

When all the independent variables are zero, the projected pulp yield is represented by the intercept term (+28.67565). Since this number is outside of the realistic range of the variables, it could not signify anything in practice.

Assuming that the temperature and active alkaline remain constant, the time term (-0.188861*time) shows that the pulp yield falls by 0.188861 units for every unit increase in time. This might be a result of the extended heating times degrading the wood components more and producing less pulp.

Assuming that the time and active alkaline remain constant, the temperature term (+0.659972*temperature) shows that the pulp yield rises by 0.659972 units for every unit increase in temperature. The fact that a higher temperature quickens the delignification process and raises pulp production may be the cause of this.

Assuming constant time and temperature, the active alkaline term (-0.294278*active alkaline) shows that the pulp production falls by 0.294278 units for each unit rise in active alkaline. This might be a reflection of the fact that a greater active alkalinity decreases the pulp yield by causing more carbs to dissolve.

According to the time-temperature interaction term (-0.004633*time * Temperature), temperature affects pulp yield and vice versa. The negative coefficient indicates that longer durations have a weaker beneficial influence of temperature and a bigger negative effect of time at higher temperatures. This might be a reflection of the fact that the ideal cooking conditions rely on a temperature and time balance.

According to the time-active alkaline interaction term (-0.004600*time * Active Alkaline), the active alkaline influences pulp yield and vice versa. The negative coefficient indicates that longer times have a greater negative impact on alkalinity and that higher levels of alkalinity have a larger negative influence on time. This might be an indication that the ideal cooking circumstances rely on a temporal and active alkaline balance.

The relationship between temperature and active alkaline (expressed as +0.002350*Temperature * Active Alkaline) shows that the active alkaline influences pulp yield and vice versa. The positive coefficient indicates a stronger positive relationship between temperature and active alkalinity and a lesser negative relationship between active alkalinity and temperature. This might be a reflection of the fact that the ideal cooking environment requires a balance between active alkaline and temperature.

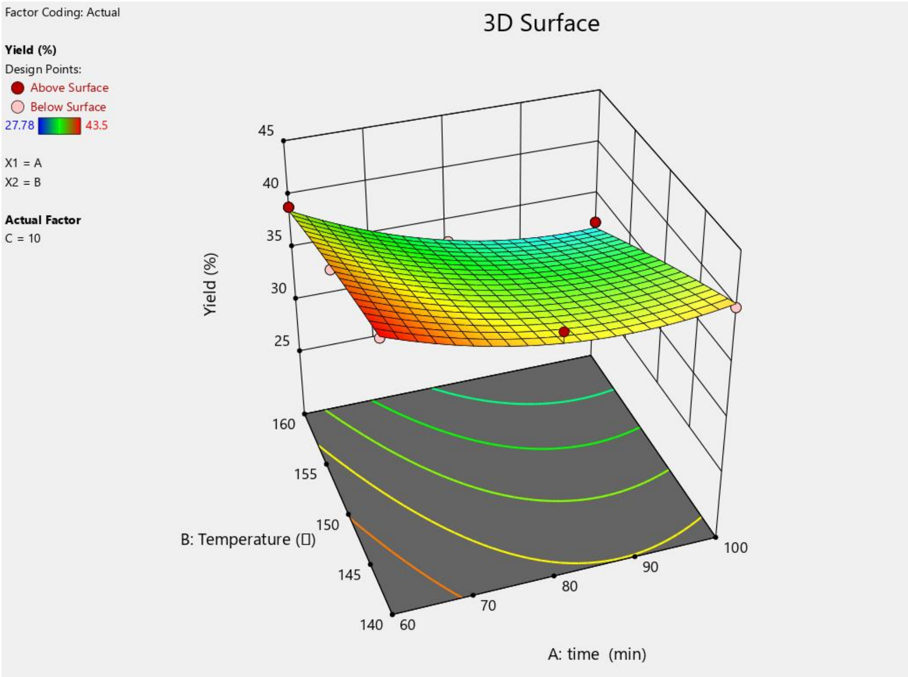

Figure 1. *Interaction effect of time and temperature on yield of pulp from nettle steam.*

3.5. Interaction Effect of Time, Temperature and Active Alkaline on Kappa Number of Pulp

The kappa number of pulp is predicted by the multiple linear regression model you gave, which takes into account the interplay of temperature, time, and active alkaline. By using a defined analytical procedure, the kappa number indicates the residual lignin concentration or bleachability of wood pulp. With all other variables held constant, each term in the equation has a coefficient that shows how that variable affects the kappa number. The following are the effects:

When all the independent variables are zero, the estimated kappa number is represented by the intercept term, which is +654.77333. Since this number is outside of the realistic range of the variables, it could not signify anything in practice.

Assuming that the temperature and active alkaline remain constant, the time term (-1.80468*time) shows that the kappa number declines by 1.80468 units for every unit increase in time. This could be a reflection of the fact that longer cooking times result in lower kappa numbers and greater lignin elimination.

Assuming that the time and active alkaline remain constant, the temperature term (-7.13383*temperature) shows that the kappa number drops by 7.13383 units for every unit increase in temperature. This might be a result of the fact that a greater temperature decreases the kappa number and speeds up the delignification process.

Assuming constant time and temperature, the active alkaline term (-0.304667*active alkaline) shows that the kappa number drops by 0.304667 units for each unit rise in active alkaline. This might be a result of the fact that a greater active alkaline decreases the kappa number and causes more lignin to dissolve.

The relationship between temperature and time is indicated by the time-temperature interaction term (+0.010787timetemperature), which also shows that temperature affects kappa number. Given the positive coefficient, it can be concluded that longer periods and higher temperatures have less of an adverse influence on time. This might be a reflection of the fact that the ideal cooking conditions rely on a temperature and time balance.

Final Equation in Terms of Actual Factors

$$kappa\ number = +654.77333 - 1.80468 * \text{time} - 7.13383 * \text{temerature} - 0.304667 * \text{active alkaline} + 0.010787 * \text{time} * \text{temeprature}$$

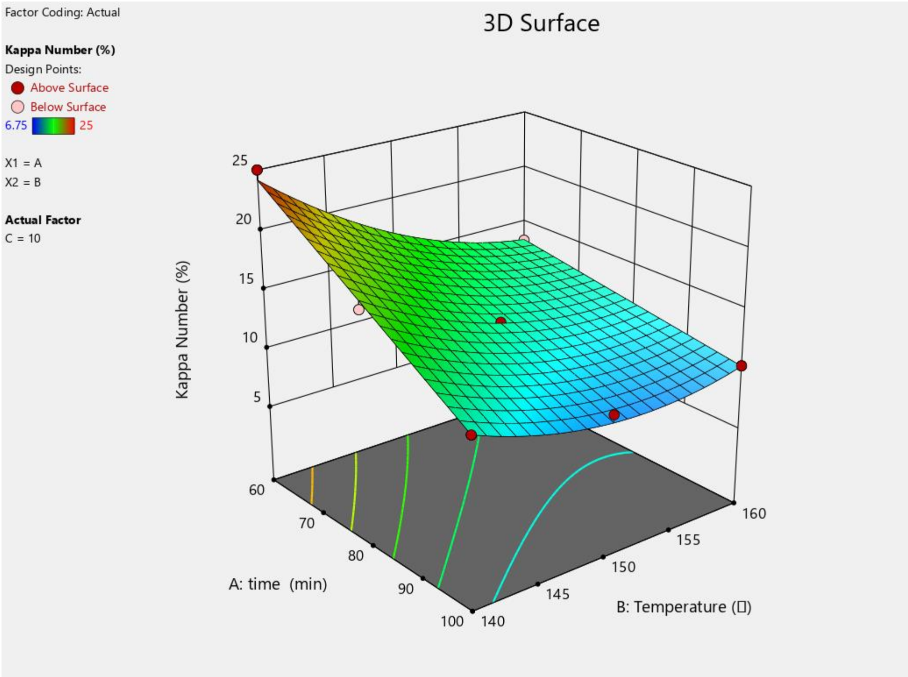

Figure 2. Interaction effect of time and temperature on the kappa number of pulp from nettle plant (steam).

3.6. Bleaching and Hand Sheet Paper Properties

The tensile, burst, and tear indices of hand sheet paper made from kraft pulps from bleached and unbleached nettle plants are shown in Table 10. The kraft pulps made from nettle plants had strength characteristics that were on par with birch chemical pulps and other non-wood pulps. Kraft pulp made from nettle plant stalks had tensile and burst qualities comparable to raw rice straw kraft pulp. Unrefined kraft pulp made from nettle plant stalks had a greater rip strength than kraft pulp made from rice straw, vine shoots, or eucalyptus. In the Wonji pulp and paper facility in Wonji, Ethiopia, all the characteristics of paper made from nettle steam are done.

Table 10. Properties of paper from nettle steam using kraft Pulping process.

Biomass	Freeness (ml CSF)	Tensile index (Nm/g)	Burst index (k Pa.m2/g)	Tear index (m N.m2/g)
Nettle steam (a)	480	24	1.22	5.07
Wheat straw (b)	443	23.1	1.39	4.76
Rice straw (c)	660	26.11	1.20	0.31
Enset (d)	600	6.45	1.01	0.9

A; current study, b; [57], c; [15], d; [6]

3.7. Optimization of Kraft Pulping from Nettle Steam

The Anova study that was presented indicates that at 100 minutes, 141.56 degrees Celsius, 10% active alkaline, and a pulp yield of 39.8416 and a kappa value of 11.6573 are obtained. This indicates that, in these circumstances, around 40% of the nettle plant (steam) is turned into pulp, and that pulp is simpler to bleach since it contains less lignin. These values are nearly identical to the variable optimum values discovered in the current investigation utilizing response surface approach. In the current investigation, the ideal values for time, temperature, and active alkaline were determined to be 100 minutes, 142.5 degrees Celsius, and 10.5 percent, respectively, based on three laboratory repeats of the variables. This produced a pulp yield of 40.12 percent and a kappa number of 11.55. As a result, the information supplied suggests that nettle stem pulp has excellent quality and promising papermaking potential.

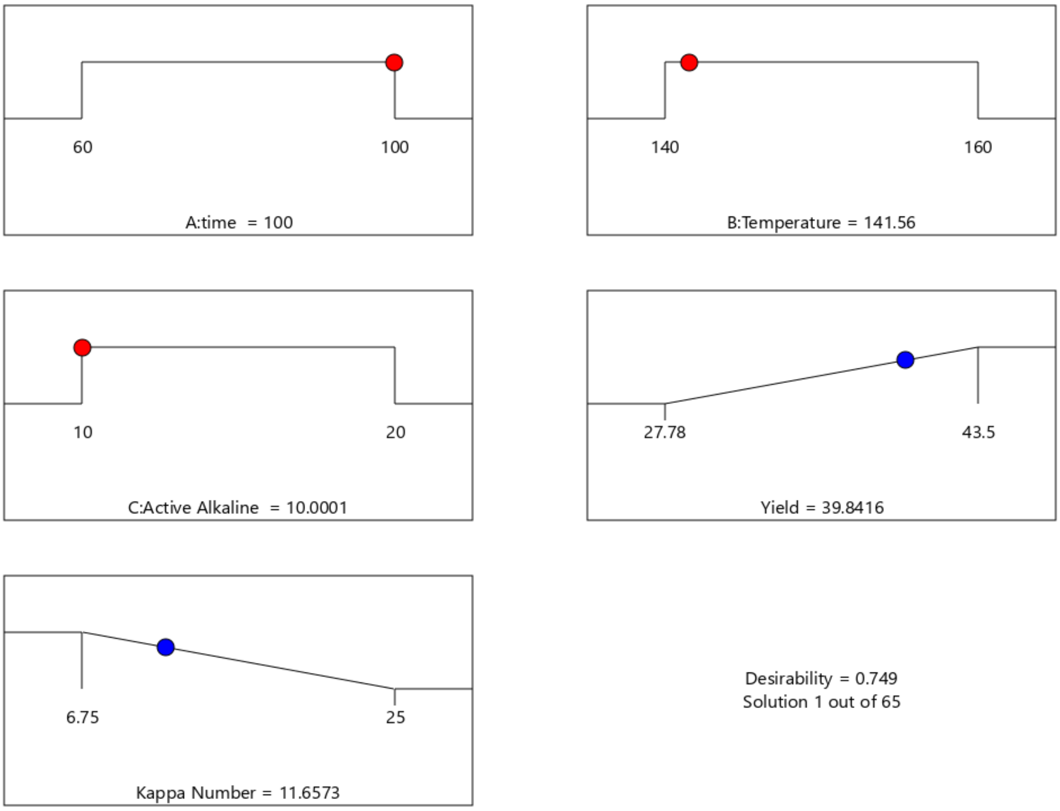

Figure 3. *Optimization of Yield and Kappa Number of Pulp From Nettle Steam.*

4. Conclusions

According to the results of a morphological research, the steam from nettle plants had longer fibers that had morphological characteristics with popular non-woody fiber materials including canola, rice, wheat, and bagasse, with the exception that canola fibers had a considerably thicker cell wall. The lignin concentration of steam from nettle plants was found to be similar to other non-wood papermaking fiber sources, according to a chemical composition study. The nettle plant's (steam) small amounts of hot water and diluted alkali extractives were discovered. According to the kraft pulping results, nettle plants (steam) generated high-yield bleachable grade pulp with low chemical charge and a low kappa number, in contrast to other non-woody plants. Nettle plants have chemical compositions that are comparable to other biomass, making them appropriate for pulp manufacture. In three easy steps, the kraft pulp of nettle plants (steam) bleached. Unrefined bleached nettle plant (steam) kraft pulp was found to have strength characteristics similar to hardwood and common non-wood raw materials used in papermaking. Overall, the findings demonstrated that using nettle plant (steam) in conjunction with hardwood or softwood pulps for papermaking has considerable potential.

Abbreviations

CED: capillary Viscometer and Cupriethylendiamine
DF: Degree of Freedom
ECF: Elemental Chlorine Free
NaOH: Sodium Hydroxide
Na_2S: Sodium Sulfide

Conflicts of Interest

The authors declare conflicts of interest.

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