Original Research Article

Anatomical Characteristics and Fibre Dimensions of Some Grass Species of Arunachal Pradesh and their Potential for Pulp and Paper

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Abstract: Non- woody plants are potential sources of raw material for pulp and paper and supplement the depleted wood fibre resources. The present study was conducted on grass species namely *Eleusine indica* (L.) Gaertn., *Imperata cylindrica* (L.) P. Beauv., *Neyraudia reynaudiana* (Kunth) Keng ex Hitch., *Phragmites karka* (Retz.) Trin. ex Steud., *Saccharum arundinaceum* Retz., *S. spontaneum* L., *Setaria glauca* (L.) P. Beauv., *Sporobolus indicus* (L.) R. Br. Var. fertilis, *Themeda caudate* (Nees) A. Camus, *Thysolaena maxima* (Roxb.) O. Ktze collected from district Papumpare to evaluate their suitability as a raw material for pulp and paper making. The basal portion of the mature culms of selected grass species were taken to study the anatomical characteristics, fibre and vessel dimensions. The derived indices like Runkel ratio, flexibility coefficient, slenderness ratio, Luce's shape factor and solid factor were also evaluated and were compared with that of *Bambusa tulda*, a promising bamboo species in NE India for pulp and paper making. The selected grass species had well developed fibrous sheath around the vascular bundles. The additional fibrous ring was present in the periphery of *Eleusine indica, Imperata cylindrica, Phragmites karka* and *Sporobolus indicus*. The fibre percentage was more than vessel and parenchyma in all selected grass species. The number of vascular bundles per mm^2 was maximum in *Imperata cylindrica* and minimum in *Phragmites karka*. Based on the results, all the selected grasses species have fibres with desirable derived indices and can be used as an alternative source of raw material for pulp and paper making.

Key words: Derived indices, Fibre dimensions, Grass species, Pulp and paper making, Tissue proportion, Vascular bundles

Introduction

Grasses are cosmopolitan in distribution and occur in different ecosystems. The have number of uses starting from food to building materials. Due to presence of fibrous roots, the grasses act as a major source of soil binder and check the soil erosion in hills and sand dunes (Shukla, 1996). They play a significant role in carbon sequestration and environmental conservation. In addition, these have been considered as a raw material for the paper making since a long time before the use of wood. The evidences of pressed pith tissue of *Cyperus papyrus* as a writing material in Egypt shows the use of grasses as a writing material dates back to 3000 BC.

Paper is a versatile material and is used for writing, printing, packaging and number of industrial processes. There is tremendous increase in consumption of paper. According to Tandon *et al.* (2013), Indian pulp and paper industry requires 22.0 million tonnes of paper and paper board till 2025 with an average growth rate of 7.8% per annum. Due to depletion of forest resources, most of the workers have evaluated non-wood plants as an alternative source of raw material for pulp and paper due to their short growth life cycle, easily availability, ecologically feasible, low lignin content and moderate irrigation requirement (Sridach, 2010). Agricultural residues like stalk and husk of principle crops and naturally growing plants like bamboos, reeds, grasses and weeds have cellulosic fibres and are potential sources of pulp and paper (Sharma *et al.*, 2013, 2015; Ekhuemelo and Tor, 2013). Therefore, it is the need of hour to explore other sources of fibres for pulp and paper.

Though number of grasses like *Festuca arundinacea*, *Arrhenatherum elasticus*, *Thynopyrum ponticum*, *Cymbopogan* species, *Pennisetum purpureum* have been evaluated for pulp and paper making (Madakadze *et al.*, 2010; Kaur and Dutt, 2013; Ververis *et al.*, 2004, Danielwicz *et al.*, 2015) but such type of information is lacking in grasses of Arunachal Pradesh. In Arunachal Pradesh, large number of grasses grow widely. They have very fast growth with high biomass. Some of species are used for forage, thatching, broom making etc. and while most of the species are growing in open areas remain unutilized. The present study is an attempt to study the anatomical and fibre characteristics of some species of grasses for evaluation of their suitability for pulp and paper making by comparing them with *B. tulda*, an important bamboo species used as raw material for pulp and paper in NE India.

Materials and methods

The grass species namely *Eleusine indica* (L.) Gaertn., *Imperata cylindrica* (L.) P. Beauv., *Neyraudia reynaudiana* (Kunth) Keng ex Hitch., *Phragmites karka* (Retz.) Trin. ex Steud., *Saccharum arundinaceum* Retz., *S. spontaneum* L., *Setaria glauca* (L.) P. Beauv., *Sporobolus indicus* (L.) R. Br. Var. fertilis, *Themeda caudate* (Nees) A. Camus, *Thysolaena maxima* (Roxb.) O. Ktze were collected from Nirjuli (27^0 07' 54" N and 93^0 44' 38"E) Karsingsa (27^0 14' 0" N and 93^0 61' 0"E) and Itanagar (27^0 06' 0" N and 93^0 37' 0"E) of district Papum Pare, Arunachal Pradesh (Fig. 1). Five randomly selected mature plants of each species were uprooted. The unwanted parts like roots and leaves were removed and the height and diameter of each culm of selected species were measured (Table 1). The culms were thoroughly washed 2-3 times with running water to remove the dust particles and air dried. Samples of 3-4cm. length were cut from the middle portion of 2-3 internodes at bottom position. A few samples were kept in FAA solution for 24 hours and then preserved in 50% alcohol for anatomical studies. Cross sections of each species were cut with the help of sliding and rotary microtomes depending on the hardness of the species. Permanent slides were prepared by following standard methods.

Small slivers were cut from the remaining samples and were macerated with mixture of hydrogen peroxide and glacial acetic acid solution (Franklin, 1945) by keeping the material in test tubes in an oven at 60^{0}C for 24-48 hours. Since *Bambusa tulda* is commonly used as raw material for pulp and paper, therefore, slivers taken from the middle portion of basal internodes were also macerated. Various dimensions of fibres and vessels namely fibre length, fibre diameter, fibre wall thickness, fibre lumen diameter, vessel length and vessel diameter were measured with the help of an ocular micrometer fitted in one of the eye pieces of binocular microscopes. Fibre length and vessel length were taken at 40X magnification while other

Table 1. Height and diameter of selected grass species

Sl.No	Name of species	Common name	Height (m)(Range)(Mean ±S.D)	Diameter (mm) (Range)(Mean ±S.D)
1.	*Eleusine indica*	Indian goose grass	0.26-0.6242.5±15.31	0.16-1.461.03±0.50
2.	*Imperata cylindrica*	Cogon grass	0.89-1.08595.2±8.81	1.22-2.441.83±0.48
3.	*Neyraudia reynaudiana*	Burma reed	3.35-4.753.88±0.58	9.80-12.1011.18±0.93
4.	*Phragmites karka*	Nal	2.70-3.503.10±0.29	9.86-12.8610.90±1.22
5.	*Saccharum arundinaceum*	Hardy sugarcane	2.56-4.103.41±0.70	9.01-11.4110.49±1.03
6.	*Saccharaum spontaneum*	Kans grass	1.88-2.182.05±0.14	4.45-6.165.27±0.78
7.	*Setaria glauca*	Yellow bristle grass	1.50-1.901.70±0.15	4.36-5.984.93±0.61
8.	*Sporobolus indicus*	Smut grass	1.10-1.281.2±0.08	0.58-1.370.78±0.33
9.	*Themeda caudata*	Rumputpimpin	3.70-4.404.12±0.28	176.00-180.20177.25±1.71
10.	*Thysolaena maxima*	Broom grass	2.13-3.002.59±0.32	9.40-10.9810.35±0.68

dimensions were taken at 400X magnification. A random sample of 50 fibres and 25 vessels per sample were selected for each species. The number of vascular bundles per mm^2 were taken with the help of a graph eye piece. For tissue percentage and number of vascular bundles per mm^2 10 fields were taken randomly from each sample of selected species. The percentage of fibres, vessel and parenchyma was determined from the permanent slides. To assess the suitability of selected species for pulp and paper making, the derived indices like Runkel ratio (Runkel, 1949), flexibility ratio (Wangaard, 1962), slenderness ratio (Varghese *et al.*, 1995), Luce's shape factor (Luce, 1970, solid factor (Barefoot *et al.*, 1964) and rigidity coefficient (Dutt *et al.*, 2004) were determined to see the suitability of selected grass species for pulp and paper making. The photomicrographs of cross sections and xylem elements were taken with the help of Leica image analysis system.

Results

The anatomical characteristics of culms of selected grass species were presented (Fig. 2, 3). All the species had thick walled epidermis and scattered vascular bundles in ground tissue. The vascular bundles were small towards the periphery and large in the center. Each vascular bundle was surrounded by well developed sclerenchymatous (fibrous) sheath. The cortical cavities were present in *I. cylindrica* and *P. karka*. A ring of fibrous sheath was observed in *E. indica*, *I. cylindrica*, *P. karka* and *Sporobolus indicus* (Fig. 2, 3). The number of vascular bundles per mm^2 presented in Fig. 4 showed that the minimum number of vascular bundles per mm^2 was in *P. karka* (mean 3.7±0.82) and maximum in *I. cylindrica* (mean17.7±2.67). In the present study the percentage of fibres, vessels and parenchyma varied from 51-65%, 18-37% and 10-20% (Fig. 5). The fibre and vessel percentage were higher than *B. tulda*. The dimensions of fibres and vessels presented in Table 2 showed that the fibres were quite long in all selected species. The fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness varied from 1400.95±259.88 μm (*I. cylindrica*) to 3806.38 ± 517.54 μm (*T. caudata*), 10.73 ± 2.00 μm (*E. indica*) to 20.56 ±5.19 μm (*S. glauca*), 6.00 ± 1.31 μm (*S. indica*) to 13.66 ±4.76 μm (*S. glauca*) and 2.48 ± 0.96 μm (*I. cylindrica*) to 4.68 ± 0.71 μm (*S. spontaneum*) respectively. The vessel length and vessel diameter varied from 182.40 ± 44.88 μm (*S. indicus*)

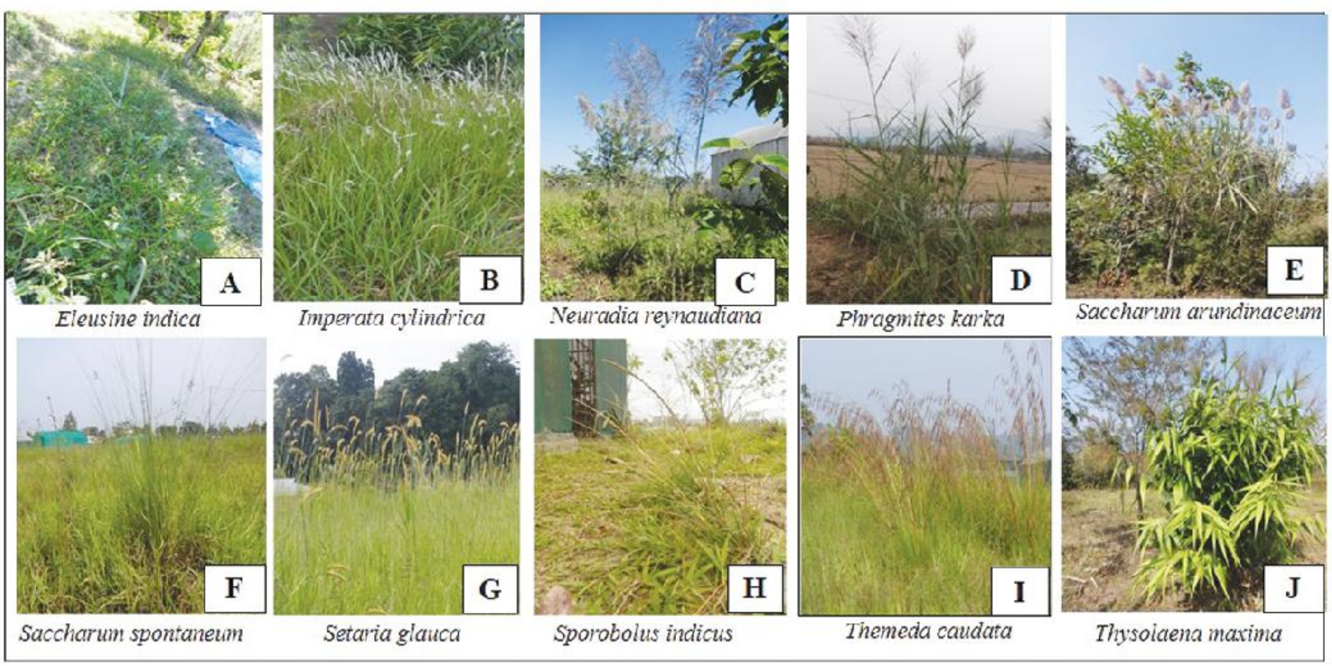

Fig. 1. Morphological characteristics of selected grasses showing culms, leaves and inflorescence

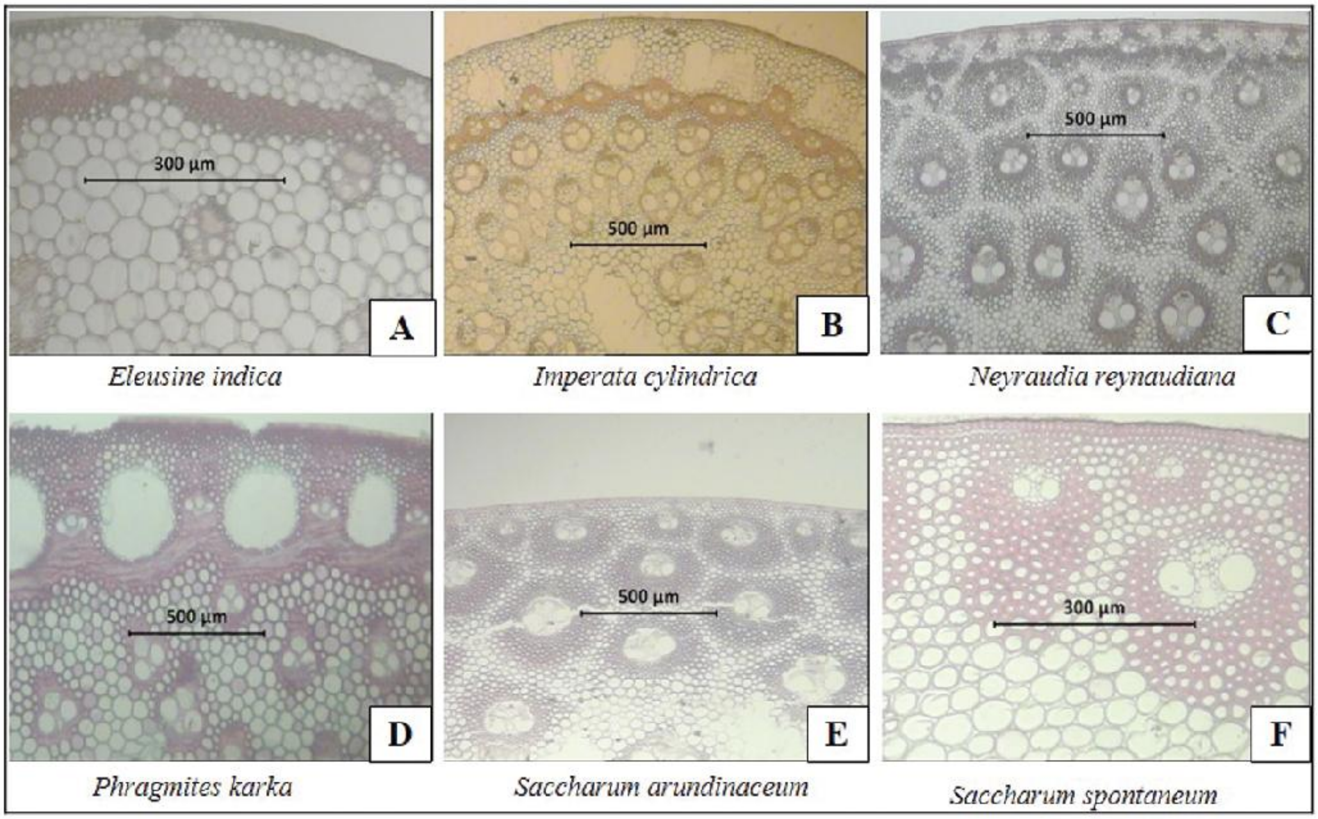

Fig. 2. C. S. of culms of selected grass species showing vascular bundle sheath (A-F), peripheral sclerenchymatous ring (A, B and D) and cortical cavities (B and D)

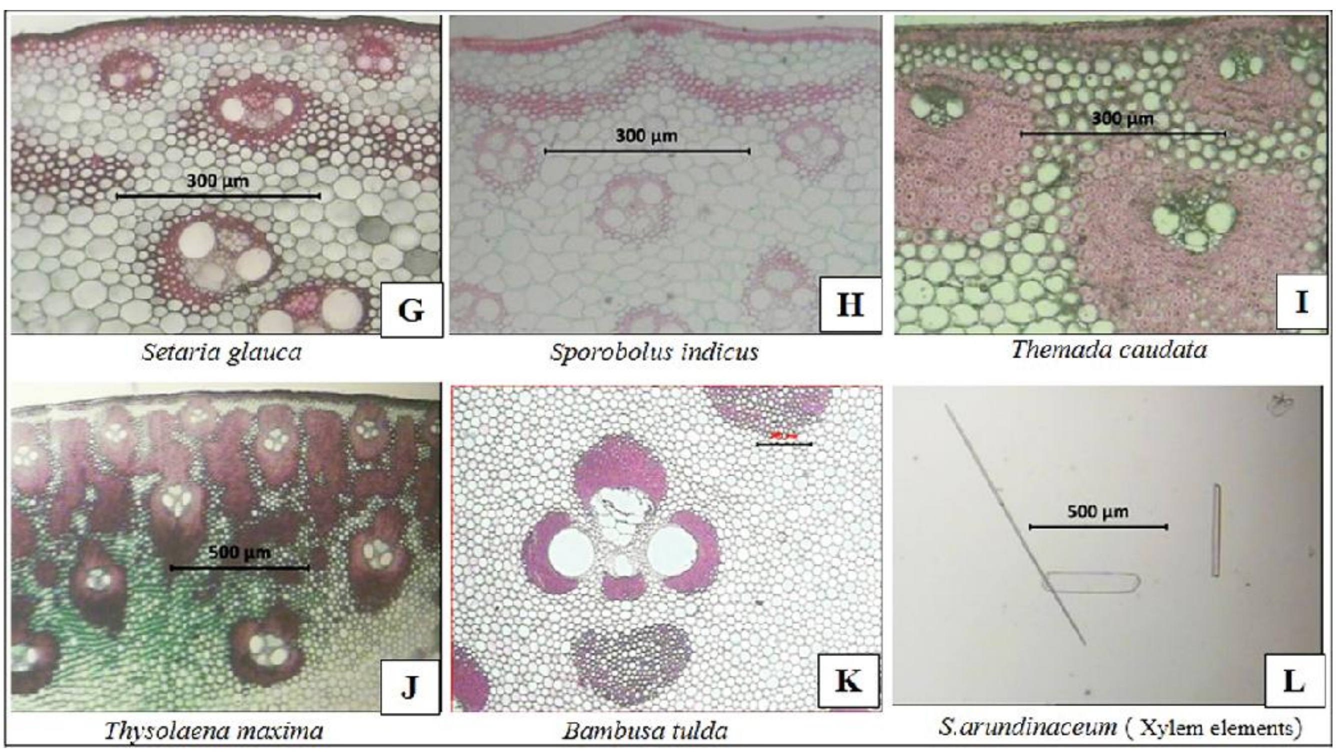

Fig. 3. C. S. of culms of selected grass species showing vascular bundle sheath (G-K) peripheral sclerenchymatous ring (H), fibre, parenchyma and vessel (L)

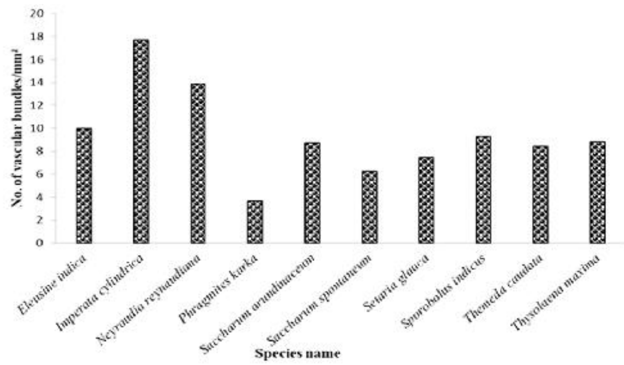

Fig. 4. Number of vascular bundles per mm^2 in selected grass species

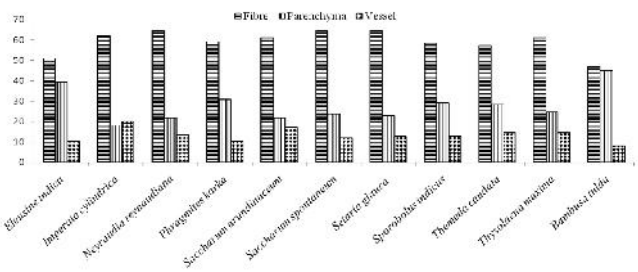

Fig. 5. Tissue percentage in selected grass species

to 342.02 ±99.3 µm (*N. reynaudiana*) and 29.61 ±6.91µm (*I. cylindrica*) to 81.80 ± 28.06 µm (*N. reynaudiana*).

The results given in Table 3 showed that Runkel ratio varied from 0.50 (*Thysolaena maxima*) to 0.95 (*P. karka*), flexibility ratio from 50.18 (*T. maxima*) to 65.47 (*Setaria glauca*), slenderness ratio from 125.30 (*I. cylindrica*) to 210.80 (*T. maxima*). Luce's shape factor from 0.40 (*S. glauca*) to 0.60 (*Thysolaena maxima*). Solid factor from 0.11 (*T. caudata*) to 0.89 (*S. spontaneum*) and rigidity coefficient from 0.35 (*Setaria glauca*) to 0.50 (*T. maxima*).

Discussion

A number of non woody plants like weeds, agricultural and industrial residues have been examined for their suitability in pulp and paper making (Sharma *et al.*, 2013, 2015). The fibre characteristics play an important role in determining the suitability of any raw material for pulp and paper production.

Table 2. Dimensions of fibrous and non-fibrous cells of selected grass species

S. No	Species name	Fibrous cells: Fibre length(µm) (Range)(Mean±S.D)	Fibre diameter (µm) (Range)(Mean±S.D)	Fibre lumen diameter (µm) (Range) (Mean±S.D)	Fibre wall thickness (µm)(Range) (Mean±S.D)	Non-fibrous cells: Vessel length(µm) (Range)(Mean±S.D)	Vessel diameter (µm) (Range)(Mean±S.D)
1.	*Eleusine indica*	1100.88-2502.00	5.20-18.20	2.60-15.60	1.30-2.60	100.08-475.38	18.20-78.00
		(2012.94±206.45)	(10.73±2.00)	(7.07±2.54)	(3.66±0.64)	(204.66±86.1)	(37.26±13.41)
2.	*Imperata cylindrica*	875.70-2326.86	7.80-18.20	2.60-13.00	1.30-5.20	100.08-300.24	18.20-52.00
		(1400.95±259.88)	(11.42±2.08)	(6.47±2.01)	(2.48±0.96)	(183.15±51.5)	(29.61±6.91)
3.	*Neyraudia reynaudiana*	1701.36-3252.60	10.40-31.20	5.20-20.80	2.60-6.50	200.16-650.52	33.80-143.00
		(2343.21±358.00)	(18.51±4.69)	(10.09±3.33)	(4.21±1.11)	(342.02±99.3)	(81.80±28.29)
4.	*Phragmites karka*	1501.20-3652.92	10.40-26.00	5.20-18.20	1.30-6.50	150.12-550.44	26.00-119.60
		(2387.58±391.53)	(15.93±3.45)	(8.58±2.84)	(3.63±1.07)	(258.71±72.8)	(60.63±16.11)
5.	*Saccharum arundinaceum*	1626.30-4003.20	10.40-31.20	5.20-20.80	1.30-5.20	125.10-625.50	23.40-140.40
		(3151.52±536.55)	(16.43±3.69)	(9.45±3.21)	(3.49±0.99)	(294.49±94.6)	(72.88±19.79)
6.	*Saccharum spontaneum*	2251.80-4053.24	13.00-31.20	5.20-20.80	2.60-7.80	125.10-550.44	31.20-137.80
		(2935.01±493.15)	(20.38±3.60)	(11.02±2.92)	(4.68±0.71)	(299.99±92.4)	(69.00±20.88)
7.	*Setaria glauca*	725.58-4953.96	10.40-44.20	5.20-31.20	1.30-7.80	150.12-575.46	28.60-98.80
		(3441.75±708.70)	(20.56±5.19)	(13.66±4.76)	(3.45±1.18)	(289.73±73.76)	(54.16±13.24)
8.	*Sporobolus indicus*	950.76-2001.60	7.80-18.20	2.60-10.40	1.30-3.90	100.08-300.24	18.20-85.80
		(1511.88±252.40)	(11.30±1.95)	(6.00±1.31)	(2.65±0.80)	(182.40±44.88)	(44.90±11.31)
9.	*Themeda caudata*	2977.38-6004.8	10.40-36.40	5.20-26.00	2.60-5.20	100.08-650.52	23.40-122.20
		(3806.38±517.54)	(19.45±4.19)	(10.37±3.35)	(4.54±0.78)	(206.16±69.79)	(66.90±24.89)
10.	*Thysolaena maxima*	2126.70-3352.68	7.80-20.80	2.60-10.40	1.30-5.20	100.08-450.36	31.20-75.40
		(2590.74±261.23)	(12.72±2.59)	(6.38±1.64)	(3.17±0.83)	(206.16±66.54)	(49.63±10.62)
11.	*Bambusa tulda*	1242.70-1482.90	13.52-13.87	6.07-7.45	3.21±3.77	524.29-540.43	149.15-166.05
		(1381.00±261.09)	(13.65±3.22)	(6.76±2.89)	(3.45±0.93)	(537.51±143.64)	(157.39±37.72)

Table 3. Derived indices of selected grass species for pulp and paper making

Sl.No.	Name of species	Runkelratio	Flexibility ratio	Slenderness ratio	Luce's shape factor	Solid factor	Rigiditycoefficient
1.	*Eleusine indica*	0.65	64.49	194.06	0.41	0.13	0.36
2.	*Imperata cylindrica*	0.87	56.84	125.30	0.51	0.13	0.43
3.	*Neyraudia reynaudiana*	0.90	53.97	132.53	0.55	0.61	0.46
4.	*Phragmites karka*	0.95	53.68	155.05	0.55	0.44	0.46
5.	*Saccharum arundinaceum*	0.83	56.73	198.62	0.51	0.59	0.43
6.	*Saccharum spontaneum*	0.90	53.49	147.01	0.55	0.89	0.47
7.	*Setaria glauca*	0.57	65.47	173.16	0.40	0.86	0.35
8.	*Sporobolus indicus*	0.93	53.55	137.01	0.55	0.15	0.46
9.	*Themeda caudata*	0.94	53.44	203.75	0.57	0.11	0.48
10.	*Thysolaena maxima*	0.50	50.18	210.80	0.60	0.33	0.50
11.	*Bambusa tulda*	1.18	45.82	105.27	0.62	0.20	0.51

In the present study peripheral sclerenchymatous ring and vascular bundle sheath are the valuable source of fibres in grasses. All the selected species showed greater percentage of fibres than vessel and parenchyma which varied from 51-65% and were higher than *B. tulda*. The present study corroborates the investigations of Albert *et al.*, 2011 and Kaur and Dutt, 2013. The fibre dimensions namely fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness are important parameters to assess the suitability of any cellulosic raw material for pulp and paper. The tearing resistance of paper depends on fibre length whereas the pulp beating, bursting, tensile strength and folding endurance are affected by fibre diameter and wall thickness (Sharma *et al.*, 2011). In the present study, the fibres were longer than *B. tulda*. Most of the selected grass species were thin walled and had greater diameter than *B. tulda*. The selected grass species also had better derived indices than *B. tulda*. The fibres with Runkel ratio less than 1 are suitable for pulp and paper making as they are thin walled and highly flexible. The Runkel ratio of all grass species varied from 0.50 – 0.95 which was less than 1 and also that of *B. tulda*. On contrary to it, Kaur and Dutt (2013) reported this value more than 1 in *Cymbopogon citratus* and *C. martinii*. The ratio of percentage of lumen diameter to fibre diameter determine the flexibility coefficient. Based on the value of flexibility coefficient the fibres are of 4 types (Bektas *et al.*, 1999) - highly elastic fibres with flexibility coefficient more than 75, elastic fibres with flexibility coefficient in the range of 50-70, rigid fibres with flexibility coefficient 30-50 and very rigid fibres have flexibility coefficient less than 30. The flexibility coefficient in the selected grass species varied from 50-64 which indicate that fibres are elastic and can be easily flattened to give pulp and paper of high strength.

The derived indices which has impact on tear, burst, breaking strength and double folding resistance of pulp and paper is slenderness ratio. Its value more than 33 is considered good for pulp and paper making (Xu *et al*, 2006). It varies from 35-87.9 in different grasses (Tutus *et al.*, 2010; Madakadze *et al.*, 2010; Kaur and Dutt, 2013) whereas Kasim *et al.* (2016) reported high slenderness ratio (138) in *Imperata cylindrica*. In the present study, slenderness ratios of all selected grasses were higher than other grasses as reported in the literature and it may be due to presence of longer fibres.

The paper sheet density and breaking strength of paper are related to Luce's shape factor and solid factor (Ona *et al.*, 2001). The low value of Luce's shape factor is considered best in paper making. The present study reveals that all grass species have low value of Luce's shape factor and solid factor than other grasses and is in agreement with the findings of Gautam *et al.*, 2016 and Kaur and Dutt, 2013.

The fibres with low rigidity coefficient are suitable for pulp and paper making as they are quite flexible. The selected grass species had rigidity coefficient 0.31-0.50 and comparatively lesser than *B. tulda*. It is in agreement with the findings of Sharma *et al.*, 2015. Thus, from derived indices point of view, all the selected grass species are suitable for pulp and paper making.

Vessel dimensions like vessel length and vessel diameter also affect the pulp and paper quality. Long vessels with large diameter are considered unsuitable due to occurrence of vessel picking. In the present study, the vessels are short with small diameter than *B. tulda* and other plant species (Chowdhury *et al.*, 2009; Pirralho *et al.*, 2014). Thus, the vessel morphology also indicates the suitability of all selected grass species for pulp and paper making.

Conclusions

The fibre, vessel characteristics and all the derived indices of all selected grass species are better than *B. tulda*. Hence, they are suitable as raw material for pulp and paper production. Among all selected species *Thysolaena maxima* and *Imperata cylindrica* are the most suitable species from anatomical characteristics and derived indices point of view.

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