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Feasibility of Biowaste available in Konkan region for anaerobic digestion

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Abstract

Biowaste, also known as biodegradable waste, is a waste that mainly consists of organic materials. The biowaste comprises of agro residue, domestic wastes, municipal solid waste, garden waste, paper, waste from poultry farms, cattle farm, slaughter houses, waste from dairy, sugar mill, distillery, paper mill, oil extraction plants, food processing, starch processing and leather industries etc. Biowaste have a large unexploited energy potential that could be harnessed by the production of methane (CH_4)-rich biogas through 'Anaerobic Digestion' (AD). The various cellulolytic crop residues like straw of wheat, rice and sorghum, maize stalk can be a good feedstock for anaerobic digestion with a suitable pretreatment. The composition of biomass is largely diverse and dependent upon its origin and species plant type, climatic conditions etc. The viability and feasibility of bio-energy generation from agricultural biomass depends upon the characteristics of biomass available. Characteristics of biomass feedstock vary greatly which impacts the quality of the fuels derived thereof. Elemental composition of biomass is an important property, which defines the energy content and determines the clean and efficient use of the biomass materials.

The selected biowaste available from crop residues along with weeds available in konkan region were considered for study. Physiochemical properties of selected biowaste were carried out by using standard analytical procedures. Proximate analysis gives moisture content higher in weed Bhamburda i.e. 74.18% and lowest in cowpea crop waste i.e. 7.38%. Volatile matter was more in mustard straw i.e. 76.91% and lowest in weed Bhamurda i.e.21.07%. The highest value for Ash content is for weed Lajalu i.e. 11.45% and lowest in Brinjal crop waste i.e.2.30%. The fixed carbon was calculated as highest 25.47% for weed Grass and lowest 0.75% for Mustard straw. Ultimate analysis estimated percentage of carbon wase highest 55.09% in Cowpea crop waste and lowest 0.25% in weed Bhamburda. Highest Hydrogen, Nitrogen and Oxygen percentage was in Mustard straw i.e 10.44%, weed Bhamurda i.e. 87.77, Cowpea crop waste i.e. 30.57% respectively. Similarly, lowest Hydrogen, Nitrogen and Oxygen percentage was in weed Grass i.e 5.10%, weed Grass i.e. 1.49, weed Bhamburda i.e. 1.77% respectively. The calorific value was highest in weed Reshimkata i.e. 6991.03 kcal/kg and lowest in mustard crop waste i.e. 3264.63 kcal/kg.

Keywords: Biowaste, characterization of biomass, proximate analysis, ultimate analysis

Introduction

Agriculture is the prime source of biomass in India which generates large quantities of crop residues as a waste. Agricultural waste is the material obtained other than consumable parts of crop or plants. According to the Indian Ministry of New and Renewable Energy (MNRE), India generates on an average 500 Million tons of crop residue per year. The majority of this crop residue is in used as fodder, fuel for other domestic and industrial purposes. However, there is still a surplus of 140 Mt, out of which 92 Mt is burned in farm every year. This is a major cause of air pollution in Northern India. In the past this biomass and agricultural waste were either burnt or naturally converted into organic fertilizer under favorable condition. But now biomass produced from agricultural waste can be used to generate energy because it has a great potential for conversion in various forms of energy. (NPMCR, 2019). Crop residues have a large unexploited energy potential that could be harnessed by the production of methane (CH_4)-rich biogas through 'Anaerobic Digestion' (AD). The various cellulolytic crop residues like straw of wheat, rice and sorghum, maize stalk can be a good feedstock for anaerobic digestion with a suitable pretreatment. It has been estimated that, India's potential of biogas production from crop residue and agricultural waste is about 45.8 Mm^3/day. (Rao *et al.* 2010)

The konkan has large areas of marginally fertile lands which are used for millet and horticultural crops. The major field crops in the konkan region are Rice, pulses (Lablab bean, Cow pea, Black gram, Horse gram, etc.), Goundnut; Fruit crops (Mango, Cahew, Sapota), different vegetable crops (chilli, cucurbits, okra, brinjal, leafy vegetables), Plantation crops (Coconut, Arecanut) etc. These crops produce residue which is considered as biomass. (Agri Farming, 2022) [1]. In Konkan region despite of control of perennials in interplant spaces, seasonal grasses mainly *T. quadrivolus* grow naturally to the height 0.75 to 1.5 m on large scale with underneath growth of many other grasses like *O. burmannii*, *O. composites* etc. In Konkan, incidence of Coix *lacryma jobi* and I. *rugosum* and such other weeds is common biomass (Rajemahadik *et al.* 2020) [23].

Characterization of biomass as fuel

Agricultural wastes and forest residues are the most promising biomass feedstock for their abundance and relatively low cost (Vertes *et. al.* 2011) [27]. By means of thermo chemical or biochemical conversion routes, lignocellulosic biomass can be converted into energy or energy carriers. Thermo chemical conversion uses heat and chemical processes to produce energy products from biomass, including combustion, pyrolysis, gasification, and liquefaction (Goyal *et. al.* 2008) [15]. Biochemical conversion of biomass involves the use of bacteria, microorganisms or enzymes to breakdown biomass into gaseous or liquid fuels, such as biogas or bioethanol (Brethauer and Studer, 2015) [8]. Typical biomass conversion technologies and their primary products and end-uses are illustrated in Figure 1 (Cai *et.al.* 2017) [9].

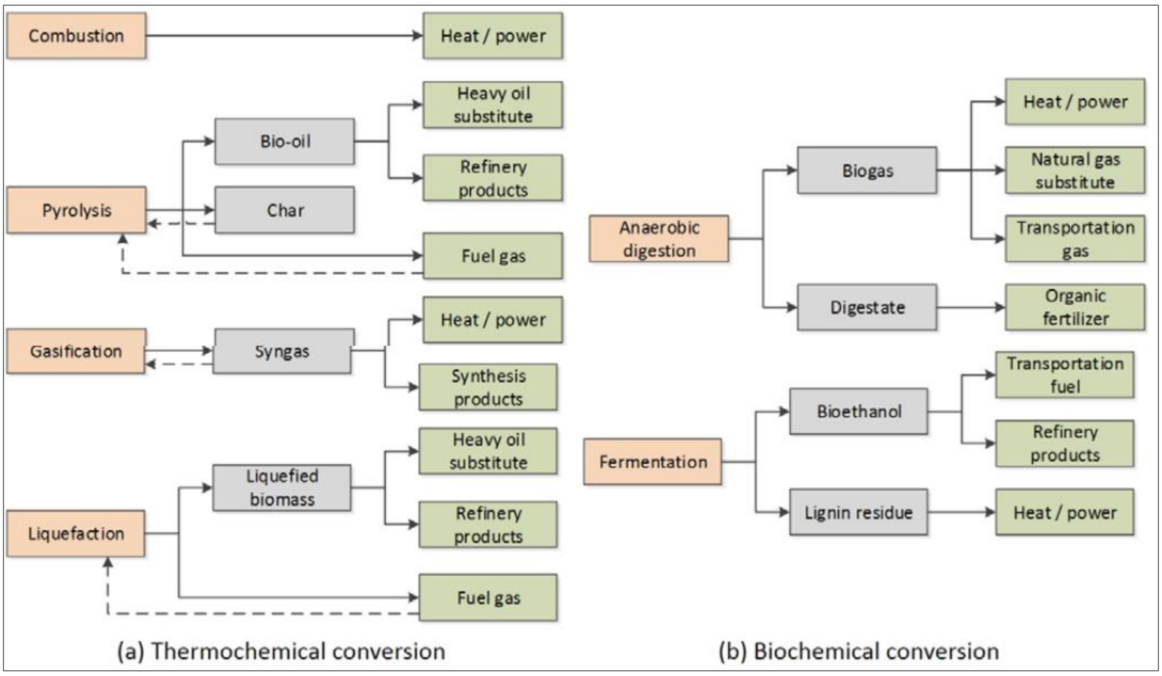

Fig 1: Thermo chemical and biochemical conversion of lignocellulosic biomass (Cai *et al.* 2017) [9]

Biomass is a readily available renewable resource of energy having potential to replace conventional fuels in many applications mainly as bio-fuels. Biomass comprises of mainly three elementary components such as Carbon, Oxygen and Hydrogen. The composition of each biomass type varies depending on origin, species, plant type, climatic conditions etc. Heterogeneity is an inherent characteristic of biomass materials. The constituents of biomass fuel vary from region to region. Constituents of biomass also depend upon sources from which biomass is collected and method of preparation of bio-fuels. The viability and feasibility of bio-energy generation from agricultural biomass depends upon the characteristics of biomass available. Biomass could be employed for energy conversion by means of different processes, such as chemical, biochemical, thermal-chemical etc. The process choice specifically depends on the biomass characteristics; therefore biomass characterization is essential to study various biomass related properties, fuel value, ash handling, combustion, information for design, development and operation of biomass conversion system (Singh, 2015) [28].

Methodology

Physicochemical properties of available biowaste were carried out. The standard analytical procedures were used to determine the following chemical and thermal properties of biowaste.

i) Chemical properties

A) Proximate analysis
(a) Moisture content,%
(b) Volatile matter,%
(c) Ash content,%
(d) Fixed carbon,%
B) Ultimate analysis (C, H, N, O%)

ii) Thermal properties

(a) Calorific value, kcal/kg

1. Chemical properties of biowaste

In this section, a brief description for the determination of chemical properties like proximate analysis and ultimate analysis of biowaste has been presented.

1.1 Proximate analysis

The proximate analysis of biowaste was carried out using the analytical method ASTM D-3173, 3174 and 3175 (Ndecky, *et al.* 2022) [19]. Study of proximate analysis were carried out for determination of moisture content, volatile matter, ash content and fixed carbon content in the biowaste.

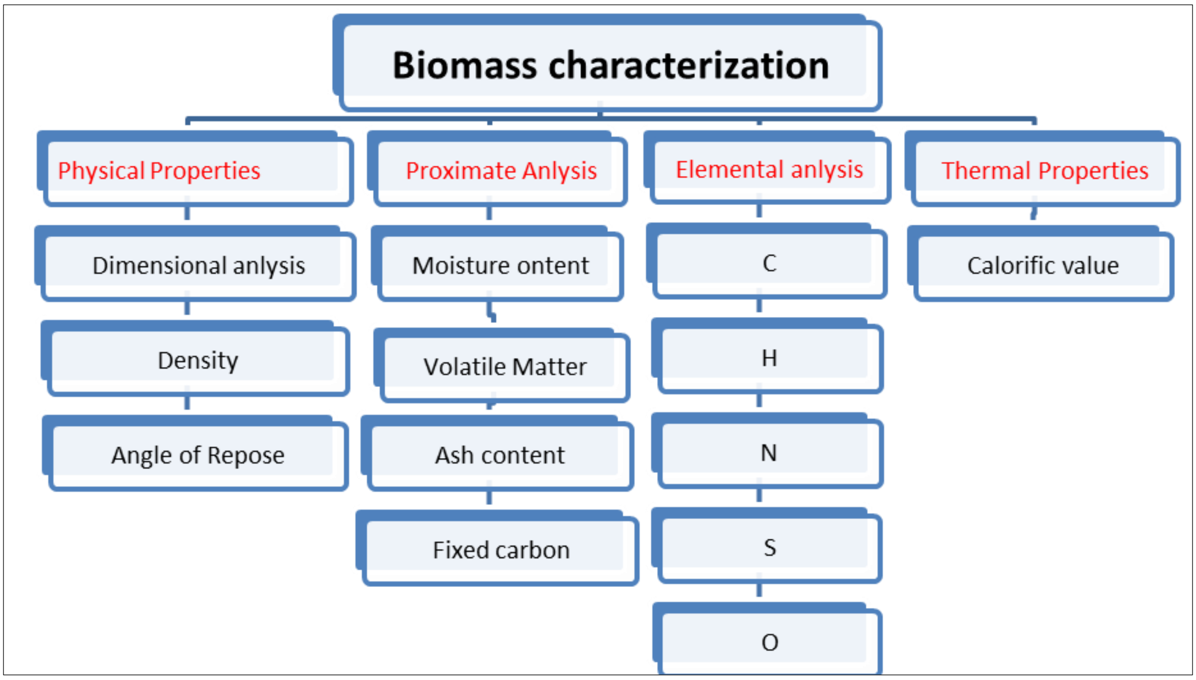

Fig 2: Biomass Characterization as fuel (Singh, 2015) [28]

A. Moisture content,%

The moisture content of a solid material is defined as the quantity of water per unit mass of the wet solid material. The moisture content played an important role in the methane production. Known quantity of finely powdered air-dried sample of waste was weighed in crucible. The crucible was placed in an electric hot air-oven maintained at 105 ± 5°C as per ASTM D-3173. The crucible was allowed to remain in oven for 1 hour and then taken out with the help of a pair of tongs, cooled in desiccators and weighed. Loss in weight was reported as moisture content (on percentage-basis) (Dara, 1999) [10]. The moisture content of sample on wet basis was calculated by following equation.

$$M.C.(\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (1)$$

Where,
M.C. = Moisture content,%
W1 = Weight of crucible, g
W2 = Weight of crucible + sample, g
W3 = Weight of crucible + sample, after heating, g

B. Volatile matter,%

The volatile matter was determined by keeping the dried sample of biowaste obtained after moisture content determination in a crucible with lid at 925 ± 20 °C for seven minutes in a muffle furnace as per ASTM D-3175. The crucible was taken out, cooled first in air, then in desiccator and weighed. The difference in the weight due to loss of volatiles was taken as the volatile matter present in the biowaste sample on percentage basis. The volatile matter of biowaste sample was calculated by following equation.

$$V.M.(\%) = \frac{W_3 - W_4}{W_2 - W_1} \times 100 \qquad (2)$$

Where,
V.M = Volatile matter,%
W1 = Weight of crucible, g
W2 = Weight of crucible + sample, g
W3 = Weight of crucible +weight of sample before keeping in muffle furnace, g
W4 = Weight of crucible + weight of sample after keeping in muffle furnace, g

C. Ash content,%

The residual samples of biowaste obtained after volatile matter determination in crucible without lid were heated gradually in a muffle furnace to 700 ± 50 °C for half an hour as per ASTM D-3174. The crucible was taken out, cooled first in air, then in desiccator and weighed. Heating, cooling and weighing was repeated till constant weight was obtained. The weight of residue was reported as the ash content of the biowaste sample on percentage basis.

$$Ash\ content\ (\%) = \frac{W_5 - W_1}{W_2 - W_1} \times 100 \qquad (3)$$

Where,
W1 = Weight of crucible, g
W2 = Weight of crucible + sample, g and
W5 = Weight of crucible + Constant weight of sample after keeping in muffle furnace, g

D. Fixed carbon,%

The fixed carbon content was the value obtained after subtracting the value of moisture content (MC), volatile matter (VM) and ash content (AC) of biowaste sample from the hundred percent, gives the percentage of fixed carbon.

$$\%\ of\ Fixed\ Carbon\ = 100 - \%\ of\ (MC + VM + AC) \qquad (4)$$

Where,
MC = Moisture content,%
VM = Volatile matter,%
AC = Ash content,%

1.2 Ultimate analysis / Elemental Composition

Carbon, hydrogen, oxygen, and nitrogen content of biowaste were found out under the ultimate analysis. Almost, while designing all energy conversion systems and projects, elemental composition of coal and biomass are significant parameters. The elemental composition of coal and biomass cannot sometimes be obtained by laboratory tests, especially when considering small to medium-size engineering projects. The laboratory tests to determine the elemental composition of coal and biomass are time-consuming and costly. The experimental method of finding the elemental compositions was however, costly and requires sophisticated equipment (Demirbas, 1997) [11]. It also needs highly skilled engineers or analysts. Therefore, having proper correlations for predicting the major elemental compositions would always be an asset for a design engineer (Nhuchhen, 2016) [21].

Hence, prediction model for elemental composition was developed by using proximate analyses data by using Multiple Linear Regression (MLR) as the prediction tool. The prediction model developed had strong prediction capacities and could be used to estimate the elemental composition of coal and biomass. (Lawal *et al.* 2020) [17]. The correlations could be used for computation of elemental composition (C, H and O) and HHV of any biomass material, from its proximate analysis (Parikh *et al.* 2007) [22].

The obtained MLR equations for the three dependent variables are as presented in Eqs. 5 to 8

$$\%\ \text{Carbon} = 348.4658 - 2.36909FC - 2.97122VM - 3.5354A - 3.67567M \qquad (5)$$

$$\%\ \text{Hydrogen} = -6156.21 + 61.44349FC + 61.66506\ VM + 61.74224A + 61.65248M \qquad (6)$$

$$\%\ \text{Oxygen} = 31071.46 - 309.621\ FC - 310.437VM - 312.201A - 310.789\ M \qquad (7)$$

$$\%\ \text{Nitrogen} = 100 - (C + H + O + Ash) \qquad (8)$$

Where,
FC – Fixed Carbon,%
VM- Volatile Matter,%
A – Ash Content,%
M- Moisture Content,%
C- Carbon,%
H- Hydrogen ,%
O- Oxygen ,%

2. Calorific value of biowaste, kcal kg-1

The calorific value of biowaste was determined by using Bomb calorimeter. It was determined by using standard procedure as per Bureau of Indian Standards (IS: 1359-1959) [7] and the Institute of Petroleum (IP 12/63 T). The bomb calorimeter (Make: ISSCO, Digital Bomb Calorimeter, Model: ISSCO/200) consisted of a strong cylindrical stainless steel bomb in which the combustion of biowaste sample (fuel) took place. The bomb was placed in a copper calorimeter, which was surrounded by an air jacket and water jacket to prevent heat losses due to radiation. The known mass of fuel (one gram) was placed in clean crucible supported by a ring, a fine fuse wire tightly screwed and the bomb was filled with oxygen gas at 25 atmospheric pressure. After that bomb was lowered down into the copper calorimeter containing a known quantity of water, the stirring was performed and the initial temperature was noted. The electrodes on the bomb were connected to electric supply for firing out the fuse wire so as to start the ignition in the bomb. Due to the combustion of the fuel, heat was liberated and the temperature of the water surrounding the bomb increased. The rise in temperature of the water in the calorimeter was noted till the stagnation temperature was obtained. The rise in temperature was due to combustion of the biowaste sample (fuel) and it was used for determination of the calorific value of biowaste sample (fuel). The calorific value is mainly used to determine the fuel quality of the biowaste (fuels). Greater the calorific value, greater is the fuel quality of the biowaste (fuel) and better the use as fuel. Mathematically, it was calculated by following equation (Rathore *et al.* 2007) [28].

Heat liberated by burning of fuel = $X\ L + E_1$

Heat absorbed by water and apparatus, etc. = $(W + w)\ (t_2 - t_1)$

But heat liberated by the fuel = Heat absorbed by water, apparatus etc.

$$X\ L + E_1 = (W + w)\ (t_2 - t_1 + t_c) \qquad (9)$$

$$\text{Higher calorific value of fuel } (L) = \frac{[(W+w)(t_2 - t_1 + t_c)] - E_1}{X},\ \text{cal g}^{-1} (\text{or Kcal kg}^{-1}) \qquad (10)$$

Where,
X = Mass of biowaste sample (fuel) placed in the crucible, g
W = Mass of water placed in the calorimeter, g
w = Water equivalent of the bomb, stirrer, thermometer, g
t_1 = Initial temperature of water in calorimeter, °C
t_2 = Final temperature of water in calorimeter, °C
t_c= Cooling Correction, °C
L = Higher calorific value of the biowaste sample (fuel), cal g^{-1}
E_1 = Correction for heat of combustion of firing wire and cotton thread, cal

Water equivalent (w), g

Weight of benzoic acid (X) = 1.0 g
Weight of water in calorimeter (W) = 2100 g
Initial temperature (t_1) = 28.1 °C
Final temperature (t_2) = 30.6 °C
Cooling Correction (t_c) = 0.26 °C
Calorific value of benzoic acid (L) = 6324 cal/g

$$6324 = \frac{[(2100+w)(30.6 - 28.1 + 0.26)]}{1} \qquad (11)$$

w = 192 g
W = (W + w) = 2292 g

Correction factor (E_1), cal

E_1 = Correction for heat of combustion of firing wire and cotton thread, cal
= (Length of wire, cm × Calorific value of nichrome wire, 0.82 cal cm^{-1}) + (Weight of cotton thread, mg × Calorific value of cotton thread, 4.180 cal mg^{-1})

Cooling correction (t_C): If the time taken for the water in the calorimeter to cool from the maximum temperature to room temperature is x minutes and the rate of cooling is dt°/min, then the cooling correction will be ‘x.dt’. This should be added to the rise in the temperature ($t_2 - t_1$).

Results and Discussions

Selected Biowaste

The season wise biowaste available from two seasons were considered, kharif season (September to February) and rabi Season (March to August). During kharif season ten crop wastes and weeds were considered and during rabi season seven crop wastes and weeds were considered. The details of the crop waste are given in Table 1.

Table 1: Season wise crop waste available

Sr. no.	Crop waste		
	Local name	**Common name**	**Scientific name**
	Kharif Season		
1	Nachani Kadhi	Finger millet straw	*Eleusine coracana*
2	Bhat Kadi	Rice straw	*Oryza sativa*
3	Lajalu	Lajalu	*Mimosa pudica*
4	Bhamburda	Bhamburda	*Blumea malcolmii*
5	Reshimkata	Reshimkata	*Alternanthera sessilis*
6	Amba pane	Mango leaves	*Mangifera Indica*
7	Kapal Phodi	Ran popati	*Physalis minima*
8	Dhur	Dhur	*Elymus repens*
9	Glyricidia	Glyricidia (Stem & leaves)	*Gliricidia sepium*
10	Gavat	Grass	*Iseilema laxum*
	Rabi season		
1	Bhuimug Kadhi	Groundnut/Peanut stalk	*Arachis hypogaea*
2	Mohari plant waste	Mustard stalk	*Brassica nigra*
3	Gavat	Grass	*Iseilema laxum*
4	Chawali kadai	Cowpea stalk	*Vigna sinensis Savi.*
5	Maka plant waste	Maize stalk	*Zea mays*
6	Mirchi plant waste	Chilli stalk	*Capsicum frutescens*
7	Vangi plant waste	Brinjal/Eggplant stalk	*Solanum melongena*

Characterization of biowaste

Physicochemical properties of available biowaste were determined. The standard analytical procedures were used to determine the following chemical and thermal properties of biowaste.

Proximate analysis of biowaste

Proximate analysis of biowaste available in Kharif and Rabi season in terms of moisture content, volatile matter, fixed carbon content and ash content were determined as described above. The results obtained are summarized in Table 2 and Figure 3.

Table 2: Proximate analysis of biowaste available during Kharif and Rabi season

Sample no.	Biowaste	Proximate Analysis			
		Moisture Content (%) wb	**Volatile Matter (%)**	**Ash Content (%)**	**Fixed Carbon Content (%)**
	Kharif Season				
1	Finger millet straw	20.30	62.94	11.42	5.33
2	Rice straw	10.78	66.16	6.27	16.79
3	Lajalu	30.31	54.65	11.45	3.59
4	Bhamburda	74.18	21.07	1.46	3.30
5	Reshimkata	69.85	23.30	1.49	5.36
6	Dry Mango leaves	12.42	65.10	14.30	8.18
7	Ran popati	65.84	27.88	2.52	3.75
8	Dhur	37.06	40.12	7.69	15.13
9	Glyricidia (Stem & leaves)	66.40	26.96	2.49	4.15
10	Grass	14.69	51.63	8.22	25.47
	Rabi season				
1.	Groundnut/Peanut stalk	21.45	66.06	7.90	4.60
2.	Mustard stalk	15.76	76.91	6.59	0.75
3.	Grass	37.01	31.93	4.71	26.36
4.	Cowpea stalk	7.38	64.77	6.71	21.14
5.	Maize stalk	50.45	43.84	3.82	1.90
6.	Chilli stalk	42.94	44.45	5.98	6.63
7.	Brinjal/Eggplant stalk	58.54	36.60	2.30	2.57

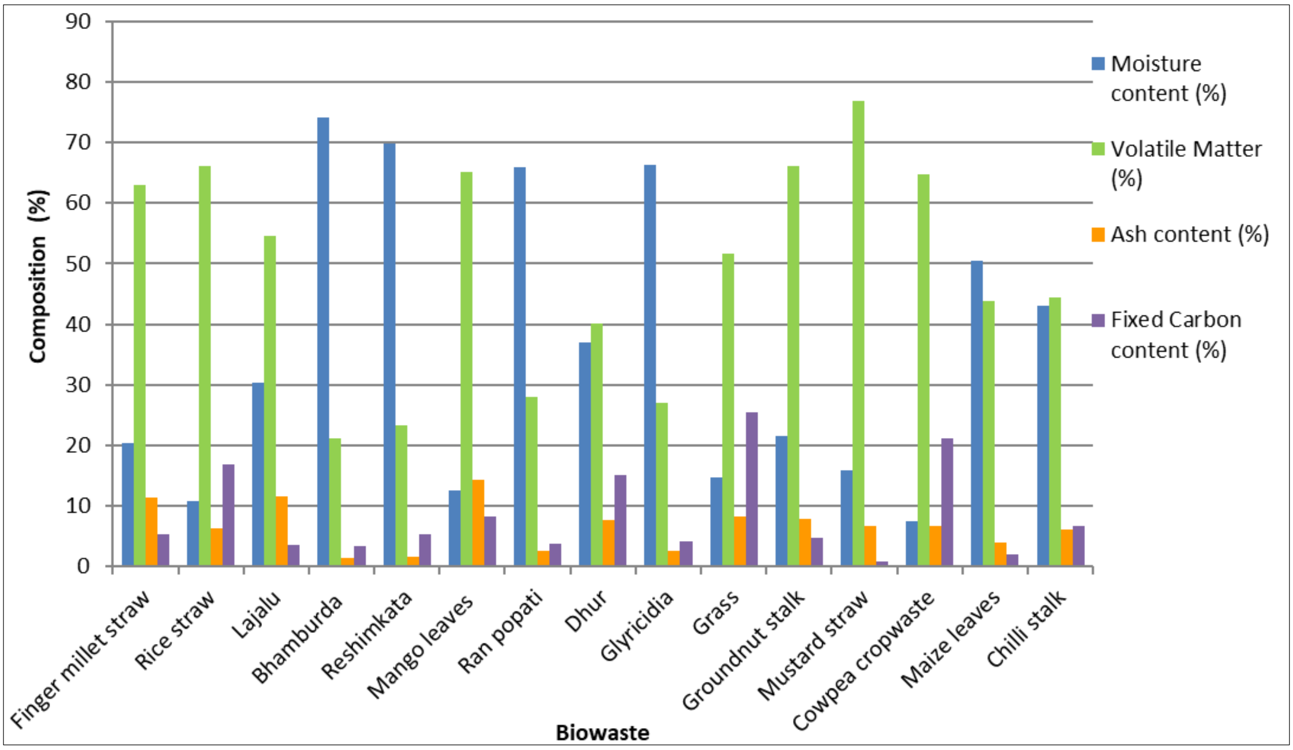

Fig 3: Proximate analysis of biowaste available during Kharif and Rabi season

High moisture content in a feedstock favors the biochemical conversion process that proceeds without the addition of water hence reducing the cost contributed to water. Moisture content within the substrate affects microbial activity, temperature and the rate of decomposition as well as facilitates the transportation of nutrients. (Gumisiriza and *et al.* 2019). The result showed moisture content for kharif season biowaste was in the range of 10.78 to 74.18 per cent. The moisture content for rice straw, mango leaves, grass and finger millet straw were 10.78 per cent, 12.42 per cent, 14.69 per cent and 20.30 per cent respectively and comparatively less as compared to the moisture content of weeds *viz.* Bhamburda 74.18 per cent, Reshimkata 69.85 per cent, Glyricidia (Stem & leaves) 66.40 per cent and Ran poapti 65.84 per cent. The result showed that, moisture content for Rabi season biowaste was in the range of 7.38 to 50.45 per cent. The biowaste from brinjal crop, maize crop and chilli crop showed higher moisture content *viz.* 58.54 per cent, 50.45 per cent and 42.94 per cent moisture content. Therefore the biowaste could be a good candid for bioethanol and biogas production. The bio waste having lower moisture content *viz.* cowpea waste, mustard straw, groundnut crop waste, more water was needed for slurry preparation. Fajobi *et al.* 2022 [14] reported that, although bio gasification is accompanied by an anaerobic digestion process, a rated level of moisture content is required to aid microbial activities on the biomass; thus, slurry preparation is essential before incubation. Therefore the weeds *viz.* Bhamburda, Reshimkata, Glyricidia, Ran poapti, brinjal crop waste, maize crop waste and chilli cropwaste could be a good candid for bioethanol and biogas production. The bio waste having lower moisture content, more water was needed for slurry preparation.

The amount of methane produced depends on the amount of volatile matter, which is the amount of solids present in the waste and its degradability (Mohammed *et al.* 2022) [18]. The volatile matter for kharif season biowaste was in the range of 21.07 to 66.16 per cent. The volatile matter for Rabi season biowaste was in the range of 31.93 to 66.06 per cent. The volatile matter was more in rice straw because of higher cellulose content. Volatile solids were responsible for biogas production; therefore, Rice straw, finger millet straw, mango leaves, Mustard stalk, Cow Pea Stalk and Maize stalk had good prospects as a feedstock for biogas production.

Ash is a percentage of non-combustible inorganic minerals present in a substance. High ash content had an inert effect on the calorific value of the fuel and its apparent heat. High ash content (25 – 35%) reduced biogas production potential as only organic matters could be converted. Therefore, biomass with higher ash content will be less efficient in biogas production (Mohammed *et al.* 2022) [18] The lowest value of ash content for kharif season biowaste was 1.46 per cent for Bhamburda and Mango leaves had high ash content as 14.30 per cent, which was in desired range. The lowest value of ash content for Rabi season biowaste was 2.30 per cent for Brinjal plant waste and Groundnut plant waste had high ash content as 7.90 per cent. Hence all the biowaste studied during kharif and Rabi season had the potential for biogas production.

Fixed carbon (FC) is the solid combustible residue left behind when biomass is heated and volatiles are expelled from. The fixed carbon content of biomass had a positive effect on its energy potential. The fixed carbon for kharif season biowaste was calculated as highest 16.79 per cent for rice straw and lowest 3.30 per cent for weed bhamburda. The fixed carbon for rabi season biowaste was calculated as highest 26.36 per cent for grass and lowest 0.75 per cent for mustard plant waste.

The similar results of Proximate analysis for Rice Straw (V.M.- 60.55 to 69.70% and Ash-13.26 to 22.70%, Fixed carbon- 11.10 to 16.75%), Herbaceous biomass (M.C.- 4 to 48%, V.M.- 41 to 77% and Ash-1 to 19%, Fixed carbon- 9 to 35%), Straw (V.M.-77.3 Ash- 3.4 Fixed carbon- 18.3), Maize stalk (V.M.-62.9, Ash- 17.2 Fixed carbon-19.9), Napier Grass

(M.C.-77.74% , Ash- 3.18) were reported by Van Hung *et al.* 2019 [26]; Anukam and Berghel, 2020 [5]; Parikh *et al*. 2007 [22]; Dussadee *et. al*. 2016 [12] respectively.

Ultimate analysis

Carbon, hydrogen, oxygen, and nitrogen content of biowaste were estimated as per the prediction model. Prediction model developed by Lawal *et al.* 2020 [17] using Multiple Linear Regression (MLR) as the prediction tool was used for elemental composition by using proximate analyses data. The MLR equations for the three dependent variables are as presented in Eqs. 5 to 8. The results obtained are summarized in Table 3 and Figure 4.

Table 3: Ultimate analysis of biowaste available during Kharif and Rabi season

Sample No.	Biowaste	Ultimate Analysis			
		Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)
Kharif Season					
1	Finger millet straw	33.81	9.74	40.21	4.82
2	Rice straw	50.33	6.92	9.87	26.61
3	Lajalu	25.70	10.00	53.03	5.36
4	Bhamburda	0.25	8.74	87.77	1.77
5	Reshimkata	4.53	8.34	80.72	4.91
6	Dry Mango leaves	39.45	9.43	31.98	4.84
7	Ran popati	5.80	8.83	79.65	3.21
8	Dhur	30.01	7.07	41.74	13.49
9	Glyricidia (Stem & leaves)	5.66	8.73	79.73	3.38
10	Grass	51.70	5.10	1.49	28.88
Rabi season					
1.	Groundnut/Peanut stalk	34.55	9.62	37.90	10.04
2.	Mustard stalk	36.98	10.44	34.79	11.20
3.	Grass	38.49	4.35	24.50	27.94
4.	Cowpea stalk	55.09	6.04	1.59	30.57
5.	Maize stalk	14.80	9.53	67.03	4.82
6.	Chilli stalk	21.71	8.75	56.05	7.51
7.	Brinjal/Eggplant stalk	10.36	9.17	72.98	5.19

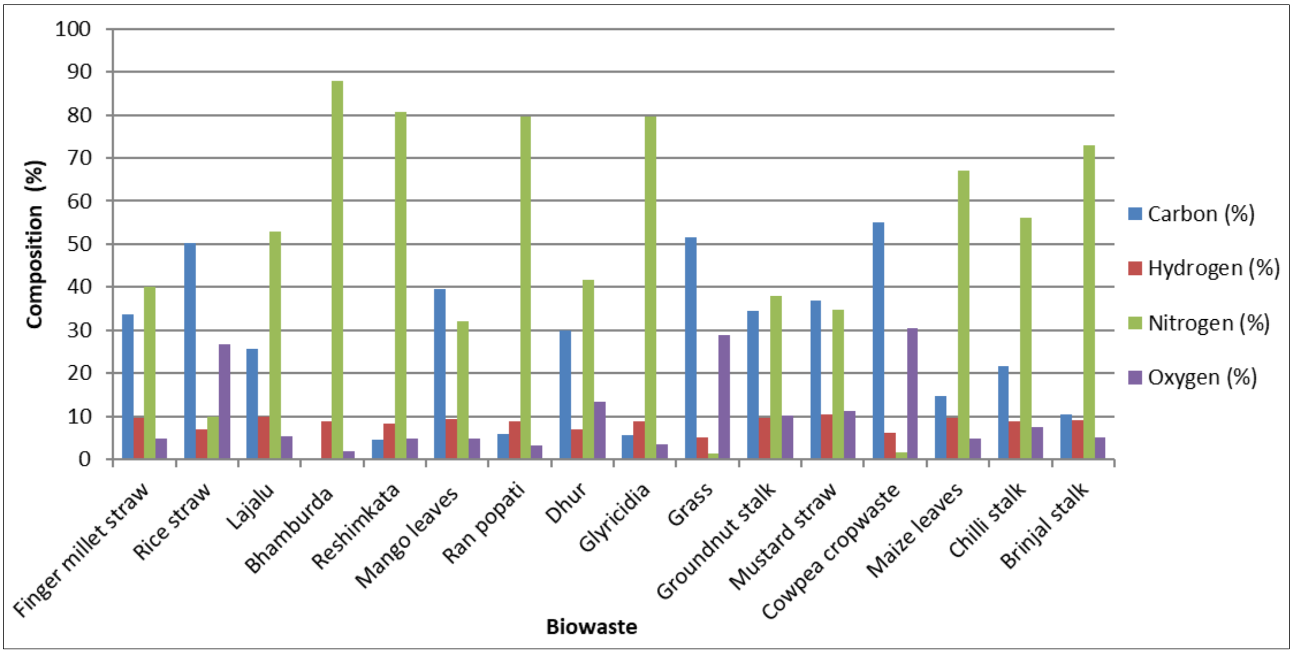

Fig 4: Ultimate analysis of biowaste available during Kharif and Rabi season

The results estimated for ultimate analysis as per prediction model for Kharif season waste showed that the percentage of Carbon, Hydrogen, Nitrogen and oxygen varied from 0.25 to 51.70, 5.10 to10.00, 1.49 to 87.77 and 1.77 to 28.88 per cent respectively. All biowaste studied during kharif season, have less hydrogen and oxygen content. The crop waste *viz*. Finger Millet Straw and Rice straw had high carbon content as compared to weeds *viz*. Lajalu, Bhamburda, Reshimakata, Mango Leaves, Ran popati Dhur, Glyricidia, and Grass. Hence, crop waste directly could be utilized for anaerobic digestion but weed should be utilized in combination with each other for appropriate digestion. During Rabi season, the results estimated for ultimate analysis as per prediction model showed the percentage of Carbon, Hydrogen, Nitrogen and oxygen varied from 10.36 to 55.09, 4.35 to 10.44, 1.59 to 72.98 and 4.82 to 30.57 per cent respectively. All biowaste studied, had less hydrogen and oxygen content. The crop waste studied during rabi season had high carbon content except maize waste, chilli plant waste and brinjal plant waste. Hence, crop waste directly can be utilized for anaerobic digestion except maize waste, chilli plant waste and brinjal plant waste. They should be utilized in combination with other waste for appropriate digestion.

Both acid forming and methane forming bacteria require a C:N ratio ranging from 25 -30 for optimum functioning. All the biowaste except grass have lower C:N ratio, hence they should be mix with dung with optimum proportion to get optimum C:N ratio. For kharif season biowaste, the Grass showed higher C:N ratio as 34.6 and for rabi season biowaste Cowpea waste showed higher C:N ratio as 34.64. It showed that the Grass and cow pea were suitable for more biogas generation. All the biowaste except grass and cowpea waste have lower C:N ratio, hence they should be mix with dung with optimum proportion to get optimum C:N ratio.

The similar results of Ultimate analysis for Rice straw (C- 33.70– 44.40%, H- 3.91 to 7.46%, O- 36.26 to 47.07% , S- 0.03 to 0.18 and N- 0.71 to 1.71%), Herbaceous biomass (C- 42–58%, H- 3 to 9%, O- 34 to 49% , S- <1 and N- < 1 to 3%), Straw (C-39.47%, H- 5.07%, O-38.09%), Napier Grass (C- 44.19%, H- 6%, O- 43.80% , S- 0.06 and N- 2%) were reported by Van Hung *et al.* 2019 [26]; Anukam and Berghel, 2020 [5]; Parikh *et al.* 2007 [22]; Dussadee *et al.* 2016 [12] respectively.

Calorific Value of Biowaste

The thermal property calorific value of biowaste was determined with the help of Bomb Calorimeter as described in above section. The results obtained are summarized in Table 4 and Figure 5.

Table 4: Calorific Value of biowaste available during Kharif and Rabi season

Sample No.	Biowaste	Calorific value (kcal/kg)
Kharif Season		
1	Finger millet straw	3922.23
2	Rice straw	3483.83
3	Lajalu	5895.03
4	Bhamburda	5018.23
5	Reshimkata	6991.03
6	Dry Mango leaves	5237.43
7	Ran popati	4141.43
8	Dhur	4799.03
9	Glyricidia (Stem & leaves)	4799.03
10	Grass	5237.43
Rabi season		
1.	Groundnut/Peanut stalk	3264.63
2.	Mustard stalk	4908.63
3.	Grass	5018.23
4.	Cowpea stalk	3593.43
5.	Maize stalk	4799.03
6.	Chilli stalk	4360.63
7.	Brinjal/Eggplant stalk	5456.63

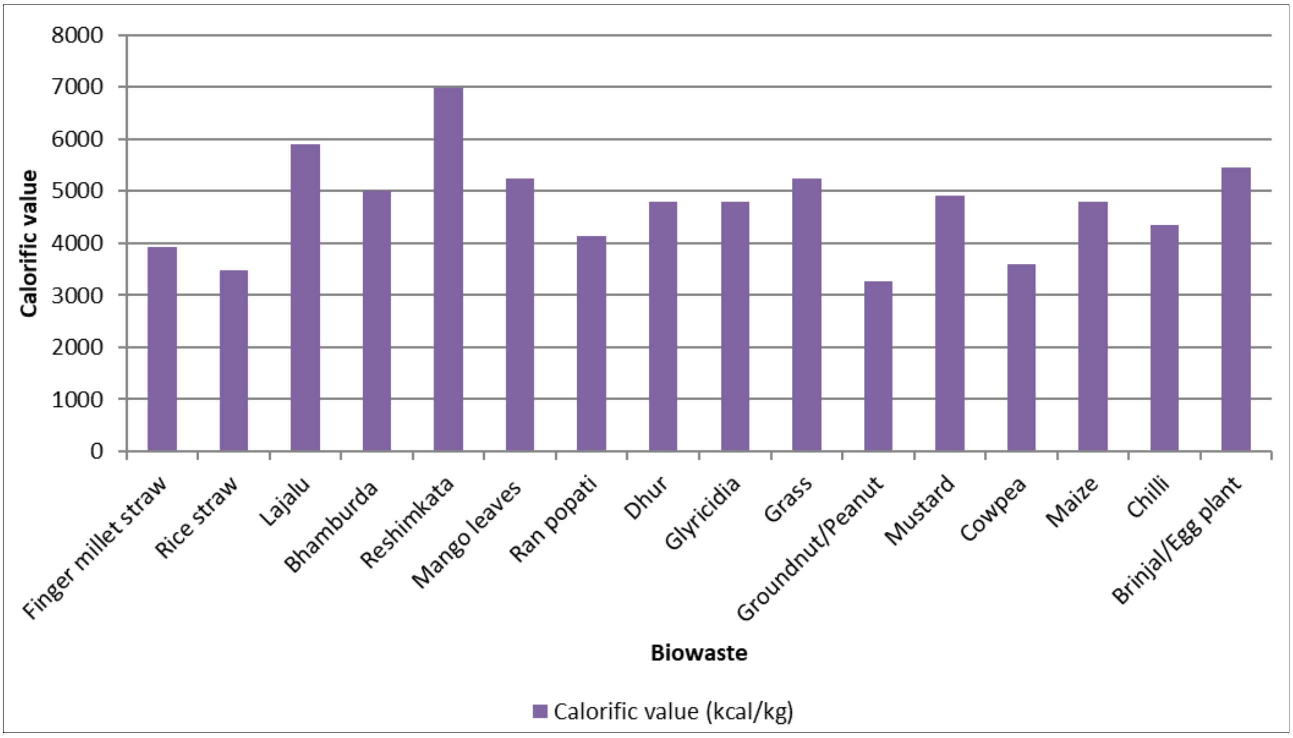

Fig 5: Calorific Value of biowaste available during Kharif and Rabi season

For kharif season bio waste the weed Reshimkata had highest calorific value 6991.03 kcal/kg while rice straw had lowest calorific value 3483.83 kcal /kg. For rabi season bio waste the Brinjal plant waste had highest calorific value 5456.63 kcal/kg and Groundnut plant waste had lowest calorific value 3264.63 kcal/kg.

The similar results of Calorific Value for Rice straw (3365.20 to 3606.59 kcal/kg), weed (3873 kcal/kg), straw (4215 kcal/kg) maize stalk (4241 kcal/kg) were reported by GEMCO Energy Machinery Co, Ltd (GEMCO) 2023. For Mustard straw (4200 kcal/kg), Rice straw (3500 kcal/kg) were reported by Eco Stan Machineries. 2023 [13].

Summary and Conclusions

For experiment, during kharif season, 10 bio wastes(finger millet straw, rice straw, Lajalu, Bhamburda, Reshimkata, Mango leaves, Ran popati, Dhur, Glyricidia and Grass) and during rabi season, 07 bio wastes (Groundnut waste, Mustard straw, Cowpea waste, Maize waste, Chilli and Brinjal plant waste and Grass) were considered. For kharif season biowaste the moisture content, volatile matter, ash content and fixed carbon were found varied in the range of 10.78 to 74.18, 21.07 to 66.16, 1.46 to 14.30 and 3.30 to 16.79 percent respectively. For rabi season biowaste the moisture content, volatile matter, ash content and fixed carbon were varied in the range of 7.38 to 50.45, 31.93 to 66.06, 2.30 to 7.90 and 0.75 to 26.36 percent respectively. For Kharif season bio waste the Carbon, Hydrogen, Nitrogen and oxygen were found varied from 0.25 to 51.70, 5.10 to10.00, 1.49 to 87.77 and 1.77 to 28.88 percent respectively. The Grass showed higher C:N ratio as 34.6. For Rabi season biowaste the Carbon, Hydrogen, Nitrogen and oxygen were found varied from 10.36 to 55.09, 4.35 to 10.44, 1.59 to 72.98 and 4.82 to 30.57 percent respectively. Cowpea waste showed higher C:N ratio as 34.64, which indicated that the cow pea was suitable for more biogas generation. Calorific value for Kharif season bio waste, the weed Reshimkata had highest calorific value 6991 kcal/kg while rice straw had lowest calorific value 3484 kcal /kg. For rabi season bio waste the Brinjal plant waste had highest calorific value 5457 kcal/kg and Groundnut plant waste had lowest calorific value 3265 kcal/kg. All the biowaste available on experimental plot could be utilized as raw material for anaerobic digestion. The biowaste mixed along with dung can give better result in some biowaste.

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