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*Full Length Research Paper*

# A comparative and evaluative study of potential biogas production from crops of teff (*Eragrostis tef* (*Zucc*) *Trotter*) in Ethiopia

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**The research on suitable alternative clean energy carriers to substitute for the use of fossil fuels is rapidly attracting attention. Biogas is an energy carrier that is considered as a possible alternative in both the developed and the developing world. However, finding suitable energy crops to extract biogas without affecting food security is still a debatable issue. In this context, the present study was conducted with the aim of assessing the potential adoption of teff for biogas production to meet part of the energy needs of Ethiopia. The methane potentials of teff grown for one, two and three month as well as the teff seeds were determined and compared with the methane potentials of corn and wheat. It was found that teff plants that were harvested after two months had higher methane potential, then one and three months teff and the two months teff had a methane potential similar to that of corn. Pre-treatment of two months teff with alkali ash or hydrolytic enzymes did not increase its methane potential.**

**Key words:** Biogas, Methane, Ethiopia, Teff.

## INTRODUCTION

Currently, questions related to global energy supply are attracting a lot of attention as alternative solutions to today's fossil fuel dominated situation have to be found. Fossil fuels are the main contributor to the emission of green house gases causing climate change and un-precedented environmental problems (Confalonieri et al., 2007). The impact of climate change is projected to increase rapidly because of continued dominance of the use of fossil fuels in many countries (Confalonieri et al., 2007). In addition, many households in the developing world today burn biomass in traditional stoves to obtain heat, this burning can result in indoor pollution and human health problems (Karve, 2005).

In this context, biogas production has gained popularity as a possible renewable energy carrier. It can also, when produced from locally available raw materials, be cheaper than petroleum fuels (Karve, 2005). Biogas as an energy carrier has benefits when produced from digestion of organic waste and residues, however, production from fresh biomass might also be of interest, given that there is no competition with food and water supplies for human con-sumption and that the energy balance of the production is positive, that is, the final product contain more energy that is consumed for its production.

Biogas is generated through anaerobic digestion of organic matter such as organic industrial- and household wastes, manure, sludge from waste water treatment and energy crops (Johansson et al., 2004). Biogas is mainly

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methane and carbon dioxide in the ratio of 50 to 65% and 35 to 50%, respectively (Levin et al., 2006). Methane is the energy carrying molecule of biogas and it can be used for electricity and heat production and also, after upgrading, as vehicle fuel (Pakarinen et al., 2008).

Small scale production of biogas can be used to meet household energy needs such as cooking, lighting and also for electricity generation. Thus, biogas can be used for both rural and urban households, particularly, in the developing world where the burning of biomass in traditional stoves without proper ventilation and chimneys is a common heat source (Practical Action Consulting, 2009). Burning biomass in such traditional stoves is known to cause adverse environmental and human health problems such as eye and respiratory diseases (Practical Action Consulting, 2009).

Factors that affect the production of biogas from energy crops includes: 1) The substrate nutrient content (N, P, K, Ca, Na, S and trace metals such as Fe, Co and Ni) as well as the amount and characteristics of the digestible part of the substrate (Boe, 2006), and 2) the age of the harvested biomass; studies have shown that the age at which the energy crop is harvested for biogas processing is important and significantly affect the crops methane potential (Lehtomäki et al., 2006). This is mainly because the chemical composition and/or organic content of the energy crop vary in the crop life cycle and is largely due to the extent of lignification of the biomass; 3) Pre-treatment of the substrate can enhance the methane yield from anaerobic digestion by increasing the rate of hydrolysis. Examples of pre-treatment methods are alkaline-, mechanical- and enzyme pre-treatment (Hendriks and Zeeman, 2008; Taherzadeh and Karimi, 2008; Elliott and Mahmood, 2007). Alkaline pre-treatment involves the addition of a strong basic solution to the substrate in order to break lignin structures. The economical attractiveness of alkaline pre-treatment depends on its effectiveness to disintegrate the lingo-cellulose structures and this varies with the type of chemical applied and the lignocellulose structures of the particular substrate (Hendriks and Zeeman, 2008). Mechanical pre-treatment is conducted by shredding the organic material. However, so far, this is not an economically or sustainable viable pre-treatment method in large scale as most shredding methods consume large amounts of energy (Hendriks and Zeeman, 2008). The enzyme pre-treatment involves the use of hydrolytic enzymes to break down macromolecules in the biomass, thus making the material more available for microbial attacks.

From the above, it can be depicted that the type of energy crop, age at which the crop is harvested, and the type of pre-treatment are important factors that will affect the biogas yield (the amount of biogas that can be produced per unit substrate). It should however be noted that the energy-, nutrient- and water consumption during the production of an energy crop (sowing and harvesting etc. as well as fertilizer requirements) have to be considered when evaluating if a crop is suitable for production of biogas. In addition, the prerequisites for cultivation of different crops in a particular region should be taken into account. In this context, the present study was conducted to assess the biogas yield from teff, one of the predominant crops cultivated by farmers in Ethiopia. Teff can be grown in wastelands (Stallknecht et al., 1993) and hence may not necessarily compete with other food crops. In addition, it matures in three months, which makes is possibility to be harvested several times a year.

Ethiopia is located at the Horn of Africa and borders to Eritrea in the north and north east, Djibouti, Somalia and Kenya in the south, and Sudan the west and south west. Ethiopia has a lot of high plateaus at 1800 to 3000 m above sea level. The annual rainfall varies from region to region with a range of 1200 mm/year in the southern to 150 mm/year in northern part of the country. Agriculture and agricultural byproducts are the dominating sources of income for the country (Environmental Protection Authority, 2003). The dominating source of energy in Ethiopia is biomass with firewood and charcoal covering more than 90% of the energy need, the rest is obtained from imported oil and electricity from hydropower plants within the country (Mulugetta, 2007). Biogas was introduced in Ethiopia in the early 1960's, however the expansion was very limited, during the period of 1980 to 2000 about 1000 biogas plants were constructed throughout the nation, mainly linked to governmental institutions, private sector and communities. Most of them were established for demonstration purposes and most of the earlier existing biogas plants were traditionally proposed for heating and cooking purpose (Worku, 2009).

The main objectives of this study were to assess the methane yields of one, two and three months old teff leaves and stalks and teff seeds and to compare these methane yields to those of corn and wheat. The impact of pre-treatment of two months old teff with alkali ash and hydrolytic enzymes on the methane yield was also investigated.

## MATERIALS AND METHODS

### The substrates for methane yield tests

Teff seeds were brought from Ethiopia and sown in a laboratory green house (in Linköping, Sweden) in three containers of 1 x 0.5 m. The plants were then harvested one, two and three months after germination. The harvested plants were stored at -20°C until used in the methane yield tests. Teff seeds, corn seeds and whole seed wheat meal were also used in the methane yield tests. In addition, two pre-treatments (alkaline and enzyme) were tested on two months old teff plants.

**Table 1.** Total dry solids (TS) and volatile solids (VS) of the investigated substrates.

| Parameter | Teff | | | | WWM | Corn |
|---|---|---|---|---|---|---|
| | 1 month | 2 month | 3 month | Seed | | |
| TS (%) | 13 | 20 | 14 | 88 | 91 | 33 |
| VS of TS (%) | 92 | 98 | 95 | 97 | 98 | 97 |

WWM, Whole wheat meal.

### Methane yield tests

To assess the possible methane yields of the above substrates, anaerobic batch digestion tests were performed. Each substrate was incubated in triplicate, in gas tight 300 ml glass bottles sealed with rubber stoppers and aluminum screw caps. The amount of substrate added corresponded to 2.5 g volatile solids (VS) per Litre All bottles contained 135 ml anaerobic growth medium (Karlsson et al., 1999) and 15 ml inoculum (source of active anaerobic micro-organisms). The inoculum was for the tests of one, two, three month teff plants, teff seeds, corn and wheat (Table 1) taken from a laboratory scale biogas reactor that treat sewage sludge and fiber materials, while for the pre-treatment tests with alkali and enzymes, material from a laboratory scale reactor digesting a mixture of cow manure and glycerol was used.

The teff plant material was chopped into 1 to 2 cm pieces before added to the bottles, while the teff- and corn seeds as well as the wheat meal were added as is. Control samples without substrate addition were included in the set-up to monitor the background methane formation from the inoculum. All preparation of the incubation bottles were done while flushing with $N_2$ and the gas phase of the bottles were after sealing changed to $N_2/CO_2$ (80:20). All bottles were incubated in the dark at 37°C until the gas production from the respective substrate had levelled off. Bottles with the one, two and three month's old teff plants and the corn seeds and wheat meal were incubated for 34 days, while bottles containing the seeds of Teff were incubated for 60 days.

### Pre-treatment with alkali and hydrolytic enzymes

Two months old teff plants were used to investigate the effect of pre-treatment on the methane yield. For the alkali pre-treatment, a water solution of wood ash (10 g of ash in 100 mL of water) was used. The main composition of wood ash is $CaCO_3$ and $K_2Ca(CO_3)_2$ from combustion of wood at low temperature (600°C) (Misra et al., 1993). A water solution of wood ash was chosen instead of using commercially available chemicals as it was considered to be a locally available residue.

For the treatment, 9 g wet weight of teff was added to 10 mL ash solution in triplicate. 50 mL-beakers were used for the treatment. The pH of the solution was >10 (determined using pH-indicator strips; special indicator pH 6.5 to 10.0 Merck KgaA, Darmstdt, Germany). The two month teff plants were treated for 24 h with the alkaline solution and then used in methane yield tests as described above.

For the enzyme pretreatment, a stock solution of hydrolytic enzymes (Kemzyme) from Novozymes Biopharama Sweden AB (Lund, Sweden) was used according to the manufacturer's instructions. The prepared enzyme solution was then added to triplicate bottles containing teff plant, anaerobic growth medium and inoculums as described above. The pre-treated teff was incubated for 44 days.

### Sampling

The biogas production in the batch tests was determined by measuring the overpressure in the bottles using a 10 ml glass syringe (Fortuna® OPTIMA® Poulten and Graf GmbH) equipped with a needle (0.50 x 16 mm of 25Gx5/8"Sterican B Braun Melsungen AG) at days two, five, seven, nine, 12, 16, 19, 21, 23, 30, 37 and 44 from incubation start. 1 ml samples were taken by piercing the rubber stopper and collecting 1 ml of gas, the needle was then pulled up into the stopper so that the tip was closed by the stopper. The plunger was then released and the gas allowed was to expand in the syringe, the expanded volume corresponded to the overpressure. After each sampling, the overpressure of the incubation bottles was returned to ambient. In all sampling days, 1 ml gas was also transferred from each serum bottle to a gas tight 31 ml bottle for sample dilution prior to analysis of the gas methane content. The methane content was determined by injection of gas samples into a gas chromatograph equipped with a flame ionization detector (Karlsson et al., 1999).

Total solid (TS) and volatile solid (VS) of the substrates were determined according to Swedish Standard method (SIS, 1981). All gas yields are given as normal ml (Nml), that is, at 273 K and 1 atmosphere pressure.

### Statistics

The non-parametric Hodges-Lehmann estimator with a 95% confidence interval (Helsel and Hirsch, 1992) was used to evaluate pair-wise differences in methane yields between the substrates. The yield of two months teff leaves and stalks was compared with that of all other substrates tested, in addition, the yield of one and three months Teff was compared. Median differences in methane yields between substrates were estimated. Methane data from days 10 to 34 was used for teff leafs and stalks as well as corn and wheat, while for teff seeds, data from days 17 to 55 was used.

## RESULTS AND DISCUSSION

The methane yield tests with one, two and three months teff leaves and stalks showed that the two months teff had the highest methane potential. Final mean values ± standard deviation (n = 3) are given in Table 2. The statistical Hodges-Lehmann estimator, comparing the methane yields of two months teff to that of one and three months teff, showed a significant difference in both cases (Table 3), while no difference could be seen between the methane yields of one and three months teff (Table 3). The methane formation over time for one, two and three months teff plants given in Figure 1, show that

**Table 2.** Total methane production in Nml/g added VS from the tested substrates.

| S/N | Subsstrate | Accumulation of $CH_4$ |
|---|---|---|
| 1 | 1 month old teff plant | 229±23 |
| 2 | 2 months old teff plant | 285±31 |
| 3 | 3 months old teff plant | 235±32 |
| 4 | Seeds of teff | 231±24 |
| 5 | Whole wheat meal | 325±61 |
| 6 | Seeds of corn | 313±37 |

**Table 3.** Median differences between two months teff (2 m. teff) and one month teff (1 m. teff), three months teff (3 m. teff), corn seeds (CoS), whole wheat meal (WWM) and teff seeds (TeS) were calculated, respectively. An estimate of the difference between one and three months teff was also done. Data (methane per g added VS) from days 10 to 34 (n = 21) was used (except for teffs seeds where data from days 17 to 55 was used (n=21)) to get the Hodges-Lehmann estimates with a 95% confidence interval, the ranges are given within parenthesis. If the range includes zero, there is no significant difference between the compared yields.

| Compared substrates | Median difference (range; NmL/g VS) |
|---|---|
| 1 m. vs. 2 m. teff | 50 (28-72) |
| 3 m. vs. 2 m. teff | 44 (21-65) |
| CoS vs. 2 m teff | –23 (–52-9) |
| WWH vs. 2 m teff | –40 (–70 - –14) |
| TeS vs. 2 m teff | 67 (47-84) |
| 3 m. vs. 1 m. teff | –5 (–30-16) |

the final potential was reached after 17 days of incubation for all three substrates.

The higher methane yield of the two months teff is likely explained by differences in protein, sugar, starch and lignin content of the teff with age. Normally, young plants contain a higher proportion of living cells and thus more easily degradable macromolecules, while the cellulose and lignin proportion increases with age (Holmes, 1989). Thus, in the three months plant, a larger part of the biomass was likely found as lignin, while we had no explanation for the lower methane potential of the one month plants. Crops proposed for biogas production should be harvested before lignin develops, because lignin structures are normally resistant to degradation under anaerobic conditions (Weiland, 2003). The finding that two month teff have a larger potential than the three month teff is consistent with the decrease in specific methane yield of barley and wheat with the age of the plant after the plants “milky stage” (Amon et al., 2006). The specific methane potential reported for grass silage of a timothy grass (270 Nml/gVS, (Lehtoma et al., 2008) is lower than the methane potential obtained for two months teff in this study. The difference might be due to differences in nutrient content of the two substrates.

Incubations with seeds of corn gave final yields similar to the two months teff (Table 2) and no significant difference could be shown between these substrates (Table 3), while a significantly higher yield was obtained for the whole wheat meal as compared to the two months teff (Tables 2 and 3). Also, for corn and wheat, the maximum yield was reached at about day 17, and the pattern of methane formation was similar for the three substrates from day eight (Figure 2). The slowest methane formation rate and the lowest final yield was obtained from teff seeds (Table 2 and Figure 2).

The results show that the teff leaf and stalks have a methane potential similar to that of corn seeds. The potentials obtained for corn and wheat is in the same range as reported elsewhere for corn (350 ml/g VS) and wheat (390 ml/g VS; (SGC 200, 2009)). Teff leafs and stalks biogas yield per VS, can be regarded as equivalent to that of corn and it is only slightly lower than that of wheat.

The teff biomass yield per hectare when grown in

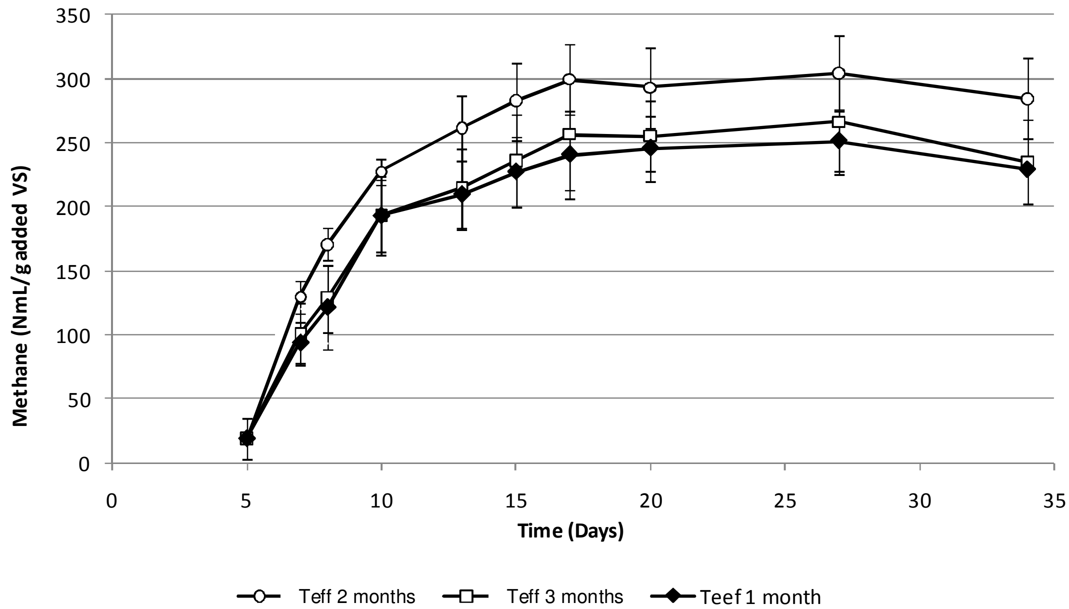


**Figure 1.** Methane production over time in methane yield tests with 1, 2 and 3 months teff leaves and stalks.

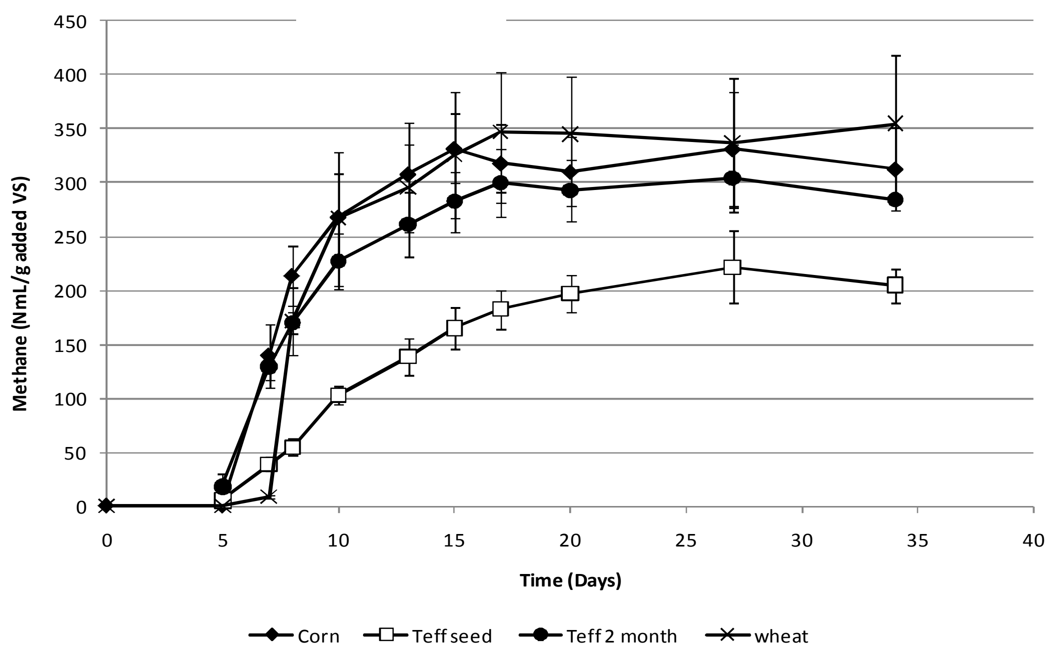


**Figure 2.** Methane production over time in methane yield tests with corn seeds, teff seeds, whole wheat meal and 2 months teff leaves and stalks.

Ethiopia is lower than that of corn and wheat (800 as compared to 1600 and 1200 kg, respectively) (Ministry of Economic Development and Copperation, 1992) but, when choosing a suitable energy crop for biogas production, many other factors need to be taken into account besides the yield. Teff can likely, as indicated in the results above, be harvested after two months while corn and wheat normally need three to eight months and three to four months to mature, respectively (Katinila et al., 1998).

Hence, due to the short teff maturation period, it is possible for farmers to cultivate several crops of teff in the same piece of land per year. In addition, the possibility of growing teff on wastelands also gives the crop an advantage over corn and wheat. Moreover, teff is a drought-, disease- and insect resistant plant as compared to other cereal crops grown in Ethiopia (Katinila et al., 1998). This implies that there is a much lesser demand for water, insecticides and fertilizers when growing teff as compared to other crops (Miller, 2007).

The use of teff grown on waste lands for biogas production might thus positively affect socio-economic conditions of the rural society through the creation of new income opportunities (FAO, 2007; Jumbe, 2009; Piccinin, 2002). The possible substitution of firewood for biogas for household heating purposes can also positively affect indoor climate (Karve, 2005).

That the teff seeds have a lower methane potential than the leaf and stalks was unexpected but is likely due to a longer degradation time of the untreated seeds which is protected by its outer shells. A mechanical pretreatment of the seeds would likely have resulted in a higher potential. The alkali and enzyme pretreatments did not give any positive effect on the methane potential of two months teff (data not shown).

## Conclusions

The most suitable age of harvesting teff for optimal biogas yield was shown to be two months.

The teff was shown to have a methane potential in the same range as corn.

Teff´s high methane potential together with its possibility to grow on wastelands makes it an interesting potential substrate for biogas production.

No effect of alkali and enzyme pretreatment was seen on the methane yield of teff leaves and stalks.

Finally, we would like to emphasize that the production of any energy crop, if implemented without proper planning can adversely affect food production and hence food security. Teff can be grown and perform well on abandoned lands e.g. waterlogged or wastelands where other crops such as corn cannot be successfully cultivated (Piccinin, 2002). This implies that there could be a window of opportunity to cultivate the crop for biogas production without interfering with food production, however further investigations regarding consequences on food security and energy consumption during growth and harvesting of teff is needed.

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