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Cereal Crops for Biogas Production: A Review of Possible Impact of Elevated Temperature

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Abstract: Biogas production from crops and their residues is widely used as feed because of its availability and high methane content due to its calorific value. The aim of this study is to estimate the response of cereal crops such as maize, sorghum, wheat, barley and rice to elevated temperature and his impact on biogas production by meta-analysis method. Studies show that increasing temperature by 1°C and 2°C respectively decreased biomass yield by -5% to -7% (wheat), -5% to -16% (rice), -7% to -12% (sorghum), -10% to -14% (maize) and -4% (barley). On the other hand, key element which determine the quality of the plant and which are negatively affect by elevated temperature are the basic elements for a good quality and quantity of biogas such as (lipids, carbohydrates, micro and macro-element). If protein concentration increases under warming, decrease in grain is largely due to lower starch concentration under elevated temperature, -13 to -33% for barley, -2 to -33% for wheat and -2 to -6% for rice. Lipids also decrease under elevated temperature and some nutrients like Selenium (Se), Cobalt (Co) and Aluminum (Al) which decrease respectively by -43.5%, -15% and -22%. Based on these results, we can argued that biogas production from cereal crops is threatened in the future.

Keywords: Anaerobic Digestion, Biogas, Energy Crops, Elevated Temperature

1. Introduction

Biogas production is a complex biochemical process that takes place in the absence of oxygen and in the presence of highly sensitive micro-organisms that are mainly bacteria. The predominant component of flammable biogas is methane (CH_4) and CO_2 with traces of other gases like H_2S, NH_3, CO, H_2, N_2 and water vapor etc.

It has a heating value of 22 MJ/m^3. Consequently biogas can be utilized in all energy consuming application designed for natural gas [1]. Biogas is also being used increasingly for heat production. In developed countries, it is used primarily in combined heat and power plants (CHP), with relatively small amounts used in heat-only plants. In developing countries biogas is combusted directly in small domestic-scale digester to provide bio-heat for cooking.

Bio-methane (biogas after removal CO_2 and H_2S) is now used widely as a vehicle fuel. The number of fueling stations selling 100% bio-methane more than tripled from 35 to 119 in 2012 [2].

Various form of biomass such as vegetation, animal dung and plant products are providing safe and convenient sources of energy as in the form of biogas and liquid fuel. Biomass such as cattle dung, agro-residues, plant residues, organic wastes from industrial processing in spite of being biodegradable, create much nuisance in the environment. These easily available alternative resources can be harnessed by anaerobic fermentation of this waste matter production biogas as efficient gaseous fuel [3].

Another benefit of anaerobic digestion (AD) is the reduction of natural methane emission from the selfdecomposition of biomass in landfills or other open environments because the global warming potential of methane is estimated to be 20 times higher than carbon dioxide while the AD system captures and utilizes the methane for energy production [4].

Energy crops are being used increasingly for biogas production and occupied an important part in the global substrates used. In Germany 41% of substrates are energy crops and among the energy crops, cereals such maize silage (78%) is the most used in several biogas plant by its quantity of production and methane content. Another cereals such sorghum, rice, wheat and barley are frequently used for biogas production. The potential of methane varied from 280l/kg to 420l/kg organic dry matter (ODM) for maize and sorghum [5, 6].

Crops vary in response to elevated temperature. To date, most studies of crops response to warming have focused on biomass yield and fewer studies on the effect of elevated temperature on quality of plant such as protein, carbohydrates, lipid, micro-element and macro-element.

However studies on the effect of elevated temperature on biogas produced from crops are still lacking. This study aims to elucidate the future of biogas production from crops under the rising of temperature. In this review, we first summarize findings in the literature related the impact of elevated temperature on biomass yield and crops quality. In the second part we show the important role of element that constitutes the quality of plant on biogas before to conclude on the effect of elevated temperature on biogas production from cereal crops.

2. Effect of Elevated Temperature on Crops

2.1. Effect of Elevated Temperature on Crops Yield

As a result, global surface air temperature has increased about 0.74°C since 100 years ago from 1906 to 2005.

The expected changes in temperature over the next 30-50 years are predicted to be in the range of2-3°C and will rise with about 1.1-6.4°C by the end of this century, influencing soil temperature in agricultural areas as well [7].

With regard to warmer temperature crop yield may be affected at anytime from sowing to grain maturity, but it is the time around flowering, when number of grain is established and during the grain filling stage, when the average grain weight is determined that high temperature has the most impact on the final harvestable crop as found in cereal.

High temperature affects both plant growth and development. The most significant factors for yield loss in cereals are heat stress-induced decrease in the duration of development phases, leading to fewer and smaller organs, reduced light perception over the shortened life cycle, and perturbation of the processes related to carbon assimilation [8].

Mean while, flowering may also be partially triggered by high temperature, while low temperature may reduce energy use and increase sugar storage [9]. In temperate cereals, optimum mean temperature ranges for maximum grain yield were between 14 and 18°C. On the other hand, as maturation processes of cereals are related to specific temperature sums, moderate increases in average temperature by 1-2°C result in shorter grain filling periods are negatively affect yield components in some regions. Reduction in grain yield can be attributed to temperature induced metabolic changes to the shorter duration of crop growth and development. Earlier studies thus demonstrated that grain yield of cereal were decreased by 4% to 10% due to increase of the seasonal average temperature by 1°C [10]. Yield loss associated with global warming for C_3 may reach values up to 6% per °C and that for C_4 by up to 8% [11]. Maize is projected to decline by about 30% compared with a decrease of only 2% for sorghum by 2030 in southern Africa [12]. In the same way Knox et al, [13] Through a simulation method show that by 2050, the yield in Africa could decline by up to 17% for wheat, 5% for maize and 15% for sorghum.

The maximum growth period is expected to be 24 days for barley, 20 days for wheat, 2 to 3 days for rice and 2 to 4 days for maize. The range of production changes are 2.5% to 20.7% in wheat, 1.4 to 17.2% in barley, 2.1 to 9.5% in rice and 5.7 to 19.1% for maize. Their result indicated that potential production declined by 2.5% to 12.5% across all studies due to elevated temperature [14].

World-wide, barley is considered the fourth most cultivated crop with a production in the range of 150-160 million tons in recent years. Grain weight in barley decreases of 4% due to elevated temperature of 2°C above ambient temperature. But biomass and yield were not significantly affected by elevated temperature. He argued that total aboveground biomass is detected to be no change or decrease [10].

Wheat and barley exhibit similar responses under warming, the highest grain dry mass for wheat were found when plants were grown at 18°C. The rise in growth temperature from 18°C to 25°C decreased grain dry mass of 3 different wheat in the control plants by 11%; 31% and 34% [15]. In the same way, You et al,[16] show that 1°C increase of temperature is equivalent to 5.6-20% of relative change, according to him 3-10% decline of wheat yield for each 1°C increase of temperature. An increase of 1.5°C leads to a reduction in length of the entire growth period by 10 days. Warming increased grain yield by 16% whereas no significant effects were found on the aboveground biomass [17]. In his meta-analysis, using the full dataset from 90 articles, Wilcox et al, [18] show that more than 50% of the RCY (relative percentage change in average yield) values are negative (yield loss) when mean temperature change is higher than 2.3°C.

Both temperate and subtropical cereals grow optimally at 20-30°C; wheat is susceptible to temperature above this range resulting in losses of 10-15%. Some wheat varieties can lose 10-15% of yield with every 5°C increase in temperature [19].

Khan el al, [20] found a decrease of -5%, -7% and -25% by elevated temperature of 1, 2 and 3°C respectively above ambient temperature.

Yield of maize increases until the temperature reaches 29°C and decreases continually with a higher temperature. Simulations by Li et al, [21] show that a 1°C warming at times when maximum temperatures occurred would reduce maize yields by 2-9% at different sites.

According to Lu [22], the optimum temperature for grain development in maize is between 27 and 32°C. Lu show that grain yield were most sensitive to heat stress applied at early day by a decrease of 35.8%, 15.8%, 37.5% and 27.7% for 4 different maize than heat stress at throughout grain filling respectively by 5.7%, 10%, 12.7% and 8.1%. In sub-Saharan Africa and southeastern African, maize yields are negatively affected by elevated temperature which exceeds commonly 30°C. A yield loss of 10% per 1°C of warming is estimated [23]. Elevating temperature by respectively 1, 2 and 3°C reduce maize yield by -10%, -14% and -21% [20].

Rice becomes sterile if exposed to temperature above 35°C for more than 1h during flowering and consequently produces no gain. Negatives effects on rice yield were observed under elevated temperature ranged by +2.68, -18, -28, -36.5 and -42% at temperature increases of 1, 2, 3, 4 and 5°Crespectively [24]. Experimental warming also tended to reduce grain yield. According to Dong, warming decrease the aboveground biomass by 9.1, 10.3 and 3.3% respectively under all day warming (AW), daytime warming (DW) and nighttime warming (NW). The grain yield was respectively 0.9%, 6.4% and 6.1% lower in AW, DW and NW [25]. Increase of 2°C result in 10-16% reduction in yield, while 4°C led to 21-30% in rice. He found by elevating temperature by 1, 2 and 4°C a decrease between -5 to -8%, -10 to -16% and -21 to -30% respectively [20].

For sorghum, mean optimum temperature range is 21-35°C for seed germination, 26-34°C for vegetative growth and development and 25-28°C for reproductive growth. Further increase in temperature is projected to accelerate the loss in grain yield by 6-37% with rise in temperature up to 5°C. The analysis indicated a net vulnerability of 2-3% with rise in temperature by 1°C; 5-8% by 2°C; 7-11% by 3°C; 8-14% by 4°C; and 12-17% by 5°C [26]. Elevated temperature of 1 and 2°C decreases sorghum yield by -7 and -12% respectively [20].

2.2. Effect of Elevated Temperature on Crops Quality

For cereals, high temperature during grain filling decrease grain weight resulting in the reduction of grain yield. Heat stress during grain filling decrease the grain weight restraining starch biosynthesis and increased the protein contained in maize. Several reviews indicated that heat stress increases protein content. Lu et al [22] found an increase of protein contents of grains for all 4 varieties of maize and the increments were higher during the early grain filling stage than during the late grain filling stage.

Heat affects the growth and development of wheat plants as well as grain quality. Flour protein is a major indicator of end-use quality of wheat. According to Barnabas, the effect of temperature on storage protein composition are unclear, experimental results indicate that changes in the protein fraction composition under heat are mainly caused by the altered quantity of total N accumulated during grain filling [9].

High temperature (37°C) during grain filling led to the detection of significant changes in 37 wheat proteins; so far 25 heat-induced proteins and one whose synthesis was decreased by high temperature have been identified. Spiertz et al [15] shows that heat shock clearly increased the protein concentration of the flour by 22-84% at 18/13°C for 3 varieties of wheat.

Protein composition of barley is affected by a number of environmental factors and from these factors temperature is known to be of significance [27]. Increased protein for barley and thus a nutritional value have been found in association with temperature exposure. In several studies grain protein concentration was increased by warmer temperature in barley, resulting from suppression in the starch synthesis rather than an increase in protein per grain. Neither total protein concentration nor total protein yield was affected by soil warming [10].

Elevated temperature decreases significantly the total lipid concentration by 7.1% [10]. According to Williams et al, growth for wheat at elevated temperature had the general effect of reducing the amount of accumulated lipids, particularly non-polar lipids (1322 mg fatty acids per 100g fresh weight at ambient temperature, as opposed to 777 mg at 4°C above ambient temperatures) [28].

Table 1. *Percentage change in crops yield under elevated temperature.*

Cereal crops		Temperature	Method	Percentage yield change
Barley	+2°C	Multimodel	-4%	[14]
Wheat	18 → 25°C	Climate control Glasshouse	-11 → -34%	[15]
	+1°C	Panel dataset	-5.6 → -20%	[16]
	+2.3°C	Meta-analysis	-50%	[18]
	+1°C	Simulation	-5%	[20]
	+2°C	Simulation	-7%	[20]
	+3°C	Simulation	-25%	[20]
Maize	+1°C	Simulation	-2 → -9%	[21]
	+1°C	Simulation	-10%	[23]
	35°C	Control condition	-15 → -38%	[22]
	+1°C	Simulation	-10%	[20]
	+2°C	Simulation	-14%	[20]

Cereal crops		**Temperature**	**Method**	**Percentage yield change**
	+3°C	Simulation	-21%	[20]
Rice	+1 → +5°C	Simulation	2.68→-42%	[24]
	+1 → +2°C	Free Air Temperature Increase (FATI)	-0.9 → -6.1%	[25]
	+1°C	Simulation	-5 → -8%	[20]
	+2°C	Simulation	-10 → -16%	[20]
	+3°C	Simulation	-21 → -30%	[20]
Sorghum	+1°C	Simulation	-2 → -3%	[26]
	+2°C	Simulation	-5 → -8%	[26]
	+3°C	Simulation	-7 → -11%	[26]
	+4°C	Simulation	-8 → -14%	[26]
	+5°C	Simulation	-6 → -37%	[26]
	+1°C	Simulation	-7%	[20]
	+2°C	Simulation	-12%	[20]

Starch represents the most abundant carbon pool in barley grain accounting for 65% to 70% of DW (dry weight). The decrease in grain yield is largely associated with the lower final starch concentration due to elevated temperature. A significant decline by 5% in starch concentration in barley under soil warming was observed by Hogy in agreement with Barnabas [9, 10]. According to Lu, heat stress decreases the starch content of barley, rice, wheat and maize [22]. High temperature (37°C) from flowering to grain maturity caused a significant reduction in the starch accumulation period in development wheat grain [29]. According to Thitisaksakul et al, [19] both temperate and subtropical cereals grow optimally at 20-30°C, between 30-40°C barley starch reduced by 13-33% and wheat starch by 2-33%. In contrast, reduction in starch content was only 2-6% in tropical rice.

Slight increase and decrease were noted in macro and micro-element: phosphorus (P) -2.2%, magnesium (Mg) -0.8%, potassium (K) +1.7%, calcium (Ca) +1.9%, sulfur (S) +1.8%, manganese (Mn) -2.6%, iron (Fe) -0.6%, selenium (Se) -43.5% and zinc (Zn) +2.5%. Decrease in trace elements like aluminum (Al) -15% and cobalt (Co) -22.5% were also noted for barley. Nevertheless, the carbon/nitrogen ratio remains unaffected under elevated temperature [10].

3. Effect of Elevated Temperature on Biogas Production

The previous studies [1-29] showed that energy crops will be affected in the future due to elevated temperature in both yield and quality. This threat touches indirectly the biogas production from energy crops which will also be affected due to mainly the impact of elevated temperature on quality of crop. The mains effects of elevated temperature on crop are the decrease of starch, lipid, micro-element and trace element except proteins which increase. The biogas potential and degradation rate of different substrates vary widely based on their chemical composition (carbohydrates, protein and fat contents) [30].

Crude protein, an essential element for biogas production is positively affected by elevated temperature. In his study, Oslaj et al [31] argued that biogas production depends on the content of crude protein after testing 15 varieties of maize. Wagner et al [32] concluded that using protein-rich compounds as a co-substrate resulted in high methane production after testing several substrates and finding the highest methane yield for protein containing substrate turkey and gelatine.

The major biotechnology companies are attempting to increase protein content in crop. Anaerobic of protein yields 587 liter of biogas with 84% methane content per kg of volatile solid (VS) destroyed [33].

Lipids exhibit a much higher potential than carbohydrates and protein [32]. Lipids are characterized either as fats, oil and greases. In practice, however, the anaerobic digestion of lipids does not easily achieve theoretical levels of methane production due to the accumulation of long chain fatty acids (LCFAs).

Fats have a high methane potential and are generally degraded to volatile fatty acid (VFAs), (LCFAs) and glycerol. Substrates containing lipids have the higher values of biogas and methane yield like slaughterhouse fat, STEP, cooking oil.

Pastore et al, [34] found a yield of 970Nl per Kg of VS of biogas by using oil as substrate during 47 days with 77% of methane e.g. 748 Nl/kg VS (Normal liter per kilogram of volatile solid). Anaerobic of fats yields 1535 l/kg VS with around 70% methane contents [33]. Studies have shown that elevated temperature affected negatively lipid content and thus will decrease biogas rate.

Carbohydrates are known to be easily and rapidly converted via hydrolysis to simple sugars and subsequently fermented to VFAs. Starch has positive effect on biogas due to its digestibility. Starch has an influence on micro algal biomass recovery, settle ability and biogas production. Raquel et al argued that starch has a potential of increment of biogas production ranged between 8 to 15%. To its high starch content, ear is the most important of the plant. The corn ear due to high starch content is characterized by a higher biogas production (7960m^3/ha) compared to the silage of the whole plant (10200m^3/ha)[23]. In the same way Avci et al, [35] found a yield of 320 Nl of methane for the whole maize crops against 316 Nl for corn cob mix. Results found by Peerawat [36] show a quantity between 260-290 L of CH_4/COD (chemical demand of oxygen) produced by corn starch of rice against 280-290 L of CH_4/COD for rice starch. Carbohydrates yield 885 l/kg VS of biogas with methane content of around 50% [33]. Starch is the most affected by elevated temperature regarding previous studies thus a decrease in methane content should be observed through using cereal crops growing under elevated temperature.

It has been reported that the optimum C/N ratio for anaerobic digestion is in the range of 20-30 because microorganism consume 30 more than N and N does not enter in biogas composition but appears in the digestate in which it is the main element with P. N is the most important element after C, at high C/N ratio low gas is obtained, the digester could fail due to a drop in system pH and the lowered buffering ability; methanogens will rapidly consume the N for meeting their protein requirements and will no longer react with the left over carbon content of the material. On the other hand, under lower C/N ratio, N will be liberated and accumulated in the form of ammonium ion which inhibits methane fermentation [37]. Through studies nevertheless, the C/N ratio remain unaffected under elevated temperature.

Besides nutrient elements (C, H, O, N), metal elements including light metal ions (Na, K, Mg, Ca, Al) and heavy metal ions (Cr, Co, Cu, Zn, Ni, etc.), are also required by anaerobic bacteria because these cations play an important role in enzyme synthesis as well as maintaining enzyme activities [28].

In addition to carbon and nitrogen, phosphorus and sulfur are also essential nutrients. A micronutrient shortfall is very common in the single-fermentation energy crops. Elements whose methanogenic archaea need are cobalt (Co), nickel (Ni), molybdenum (Mo) and selenium (Se) and sometimes also tungsten (W). Nickel, cobalt and molybdenum are required in cofactors for reactions essential for metabolism. Magnesium (Mg), iron (Fe) and manganese (Mn) are also important micronutrient for transporting electrons and the function of some enzymes. According to Demirel et al [39], enhancement of mesophilic biogas production from grass by 40% was obtained by daily addition of Ni, Co, Mo and Se with decreasing VFA. He shows that addition of Fe, Co and Ni provided 35% more biogas production. Macro-nutrients mainly Co, Cu, Fe, Mo, Ni, Se and Zn during thermophilic digestion of OFMSW (organic fraction of municipal solid waste) helped to elevated the gas production rate by 30% and increase the stability of the digester.

Elevated temperature, excepted Ni which increase by 19%, decrease main element whose methanogenic archaea need like Co by -23% and Se by -43%.

4. Conclusion

Temperature leads to increase and may reach 6.4°C above ambient temperature at the end of the century. There is broad consent that elevate temperature has negative effects on agriculture. Yield and quality of energy crops will be affected, and thus indirectly also affect biogas produced. Meta-analysis shows that decrease in yield can reach -34% for barley and wheat, -21% for maize, -30% for rice and -12% for sorghum. Basing elements (lipids, carbohydrates and nutrients) for biogas production excepted crude protein are negatively affected by elevated temperature, thus a decrease in biogas production from cereal crops growing under warming is projected. Sorghum seems to be less affected and will be the suitable energy crops for biogas production under climate change.

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