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Review

Potential influence of Yucca extract as feed additive on greenhouse gases emission for a cleaner livestock and aquaculture farming - A review

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ABSTRACT

Creating a balance between minimizing environmental impacts and intensification, of livestock and aquaculture, is important to ensure sustainable animal-protein production. Application of natural additives that are suitable for cleaner animal production is a necessity. *Yucca schidigera* is capable of this and because it could grow in desert area, makes it a potential asset in the face of global warming-related climate changes. Thirty-five studies were used as data, which include *in vitro and in vivo* evaluations. About 43%, 28.6% and 31% were proportion of ruminant, monogastric and aquaculture species used for this study. *Yucca schidigera* showed that it is capable of reducing aerial ammonia concentration in pens, and ammonia odour from manure. In ruminant, Yucca could reduce methane emission, lower nitrous oxide emission, reduce urinary and fecal nitrogen. Yucca extract could be used to improve water quality by reducing the concentration of total ammonia nitrogen and nitrate in fresh and marine water used for aquaculture. Therefore, to reduce livestock footprint, Yucca may be included in the diet of cattle, sheep, goat, horses, rabbit, fishes, and shrimps with a positive result. The reviewed publications provide strong support for the use of Yucca extract as feed additive to reduce nutrient excretion and environmental impact of animal-protein production. This study, however, shows that there is need for more *in vivo* studies of Yucca in swine rabbit, horses and even poultry.

Contents

Abbreviations: CH_4, Methane; N, Nitrogen; CO_2, Carbon di oxide; GHG, Greenhouse gas (es); $NH_3{-}N$, Ammonia nitrogen; NH_3, Ammonia; H_2, Hydrogen; NH_4^+, Ammonium; NO_2^-, Nitrite; NO_3^-, Nitrate; Ppm, part per million; g/kg, Gram/kilogram; mg/kg, Milligram/kilogram; ml, Milliliter; Tg, Teragram; Gt, Gigaton; Eq, Equivalent; Yr, Year; mg/L, Milligram/Litre; ml/L, Milliliter/litre; TAN, Total ammonia nitrogen; µm, Micrometer; %, Percent; $, Dollar; ppm/ml, part per million /milliliter.

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1. Introduction

The combined manufacturing, agricultural and electricity sectors account for the largest contribution to GHG emissions. Overall, the manufacturing and electricity sector accounts for 21 and 25% gases respectively, which represents 46%, while, agricultural sector emits 24% (IPCC, 2014)-Fig. 1. In pursuit of the sustainable development goal two – which promotes sustainable agricultural practices, while ensuring cleaner animal production and nutrition security, reducing CO_2 and Non-CO_2 emission, and other pollutants from livestock and cultivated aquacultures is a necessity. As such, methods and strategies to create a balance between minimizing environmental effects and intensification (Richards et al., 2018) of livestock and aquaculture needs to be identified. This is necessary to promote nutrient-use efficiency, and reduce nutrient excretion that pollutes the air and contaminate waterbodies.

Without effective actions, the rising demand for animal product is likely to push the global environment close to, or beyond a sustainable threshold (Bodirsky et al., 2014; Campbell et al., 2017). It is anticipated that in a business-as-usual scenario, there will be a significant increase in non-CO_2 emission from Asia, Africa and Latin America between 21 to 37% by 2050 (Frank et al., 2019). Further, due to the ecological interdependence of our climate (CTA, 2008), non-agricultural economies willalso bear the consequence of these environmental impacts. Data shows that, global livestock sector produces about 15% of all anthropogenic greenhouses gasses (7.1 of 49 Gt CO_2eq/yr.), where ruminants contribute nearly (5.7 Gt CO_2eq/yr.) of the greenhouse gases and approximately 44% of these emissions is methane (Gerber et al., 2013). Further, about 4% of the anthropogenic N in agricultural systems is returned to the atmosphere as N_2O universally (Crutzen et al., 2008) which depletes the stratospheric ozone layer (Ravishankara et al., 2009). Other non-GHG nitrogenous pollutant like ammonia has negative effects such as, atmospheric haze and N deposition that affects human health and causes eutrophication, respectively (Kanter, 2018). Greenhouse gas emissions and non-GHG pollutants from livestock have health and economic implications. People staying in areas polluted with NO_2, and other air pollutants are associated with tearing and ocular irritation, conjunctivitis, and Crohn's disease (Schraufnagel et al., 2019). Economically, it is estimated that damages caused by GHG from ruminants to the eco-system and human health is about US$0.679 trillion and US$13 billion, respectively (Goedkoop et al., 2008; Weidema, 2009).

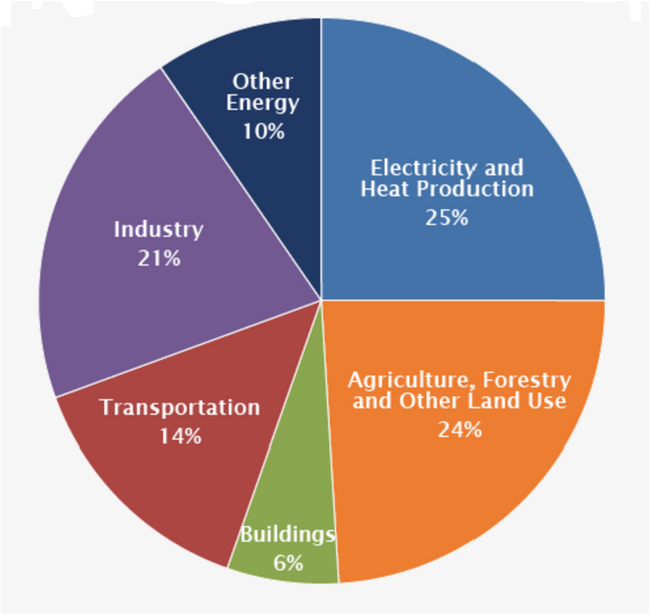

Fig. 1. Greenhouse gas production by Sector (IPCC, 2014).

Several mitigation methods from both demand and supply sides have been suggested, including structural and technical options (Ripple et al., 2014; van Vuuren et al., 2018; Frank et al., 2019). Animal feed supplementation is one of these. Animal feed supplementation method could be adopted by farmers, because it has multiple benefits such as, growth promotion, animal health, GHG mitigation effects on livestock, and it is a sustainable practice. Supplementing feed/diet with additives could enhance nutrient digestibility, and aid nutrient retention. Now that the scientific and animal-protein producing world is deviating from the use of antibiotics as growth promoter due to resistance of microbes, alternatives are also needed. There is increasing interest in the use of phytogenic products in animal production as feed supplements. This renewed interest between phytogenic products and livestock is not novel (Adegbeye et al., 2018) but, its application in health and GHG mitigation productivity could be.

Plants such as *Salix babylonica* (Elghandour et al., 2017), *Azadirachta indica* and *Carica papaya* (Akanmu and Hassan, 2017) have been used in mitigation studies with positive results. However, with climate changes and global warming effects such as increasing ambient temperature, prolonged drought, irregular pattern of rainfall, there is bound to be alteration in the bioactive components of plant and possible changes in animal responses to them. The adaptation of Yucca to grow in desert areas characterized by high temperature, and water scarcity makes it an excellent option for future phytogenic feed additives especially in regions that will experience new dimension of high temperature. Growing Yucca in regions experiencing increase in temperature might be a good option in the future to mitigate pollution in livestock and aquaculture. *Schidigera* is a species of the Yucca family and it is well-known for its high saponin content. This plant is known to be native to the Southwestern United States and Mexico. Its syrup and powder are of interest in animal nutrition (Tenon et al., 2017) due to the bioactive compounds, such as saponin and resveratrol, which if used in right quantity has the ability to modulate methane, and N pollution in livestock and aquaculture industries. Therefore, Yucca could be a good feed additive for farmers and researchers looking to reduce pollution from livestock-food production system. Hence, this review is focused on the potential of Yucca to reduce pollution from Livestock and aquaculture (Table 1, Table 2, and Table 3).

2. Methods

In this review, studies relevant to our objectives of *Yucca schidigera* reducing agricultural pollution were searched. We limited our search to peer-reviewed journal articles published in English. Databases of Scopus, Science Direct, Google scholar, Academia, ResearchGate, and Wiley online, were used for the literature search between December 2018 and May 2019. The initial keywords search was Yucca or *Yucca schidigera*. For more focused search, we looked into "*Yucca schidigera* and methane" "*Yucca schidigera* and nitrous oxide" "*Yucca schidigera* and ammonia or total NH_3–N″, *Yucca schidigera* and nutrient digestibility". All were done for ruminant, pigs, aquaculture, rabbit, poultry and horses. Subsequently, articles generated from the initial search were checked manually through abstract and scanning the full text. We excluded studies, focused only on (i) performance and meat quality without N digestibility (ii) studies that only checked rumen fermentation parameters without greenhouse gases, (iii) digestibility studies without N digestibility. In the next step, we sort articles on rabbit, poultry, aquaculture, horses, and ruminant separately. We mapped out the content of the selected literatures by extracting information based on the following question (i) Does Yucca improve nutrient digestibility of N? (ii) Does it reduce N excretion in urine and feces? (iii) Does it increase N retention? (iv) Does it reduce ammonia N excretion? (v) Does it reduce NH_3 emission? (vi) Does it reduce methane? (vii) Does it reduce nitrous oxide emission?

2.1. Secondary component in Yucca schidigera

Yucca plant is used as feed additive, because it contains saponin and glyco-compounds. Saponins are surface active glycosides that exist in various forms and structures in plants (Vincken et al., 2007) such as hydroxyl, hydroxymethyl, carboxyl, and acyl groups, as well as, distinctions in linkages and numbers of sugar chain (Patra and Saxena, 2009). This results in various *in vivo* and *in vitro* biological responses, according to the aglycone portion and combined sugar body of the structures (Hassan et al., 2010). Saponins comprise of a fat-soluble nucleus that has steroid or triterpenoid structure (Cheok et al., 2014)-Fig. 2, and possesses amphiphilic/hydrophilic and lipophilic properties (Liu et al., 2018). In addition, this plant contains steroidal glycosides, sarsaponins, and polyphenols, including resveratrol and other stilbenes (yuccaols A, B, C, D, and E) - (Chrenková et al., 2012).

3. Mode of action of Yucca on greenhouse gases emission

Saponin is the main bioactive component of *Yucca* extract and it is present in steroidal form. This component reduces the level of free ammonia by physically binding to ammonia (Sahoo et al., 2015). Saponin extract from plants has been used to manipulate rumen fermentation and was observed to inhibit methanogens and methane production, reduce protozoa, as well as, decrease ammonia emission (Mao et al., 2010). Reducing protozoa population is important in controlling methane production. This is because, protozoa harbors an active population of methanogenic archaea both on their external and internal surfaces (Finlay et al., 1994; Newbold et al., 1995). Therefore, the common anti-methanogenic mechanism of saponin is its antiprotozoal activity. Yucca exert its antiprotozoal activity by attaching its saponin to the cholesterol or lipid sterol in the cell membrane of protozoa, which results in the curving of cell membrane, pore formation or lipid raft disruption (Sampedro and Valdivia, 2014). This eventually leads to breakdown, cell lysis and death (Cheeke, 2000; Saeed et al., 2018). However, care must be taken when aiming for protozoa reduction, especially in areas with pronounced mycotoxins contamination. This is because of protozoa's role as mycotoxin degrading agent (Zebeli and Metzler-Zebeli, 2012), which has chronic health and economic implications for ruminant, and consumers of animal products like milk and meat. Yucca saponin could reduce enteric methane through methanogens inhibition (Carulla et al., 2005) or suppress the genes that control methanogenesis without changing population of methanogens (Guo et al., 2008). In addition, Yucca

Table 1
Effect of *Yucca schidigera* on greenhouse gasses emission.

Source	Doses	Animal/ organism	Effects	References
Yucca schdigera saponin	15, 30 and 45 g/kg of substrate DM	Dairy cow	8.49%, 15.50% and 25.83% reduction in CH_4	Holtshauen et al. (2009)
Yucca schdigera extract	2, 4, 6, and 8 mg/ml	*In vitro*	23, 46, 61 and 69% decrease in CH_4	Rira et al. (2015)
Yucca schdigera extract	650 μg/ml	*In vitro*	15.22% reduction in CH_4	Narvaez et al. (2013)
Yucca schdigera Sarsaponin	1.2, 1.8, 2.4 and 3.2 g/L	*In vitro*	17.89–51.94% and 17.05–49.86% reduction of CH_4 from soluble potato starch and CH_4 corn starch substrate respectively.	Lila et al. (2003)
Yucca schdigera syrup	80 g/h	Dairy cow	33.1 and 4.7% reduction in protozoa and CH_4 respectively.	Budan et al. (2013)
Yucca schdigera saponin	Not specified	*In vitro*	22.3% reduction in CH_4	Jayanegara et al. (2014)
Yucca schdigera extract	1.5 kg/ton	Pregnant Awassi Ewe	75% reduction in N_2O emission and 53.06% increase in nitrogen digestibility	Yurtseven et al. (2018)
Yucca schdigera Sarsaponin	0.5 and 1%/DM sarsaponin	Steer	8.39–12.75% CH_4 reduction	Lila et al. (2005)
Yucca schdigera extract	0.1%	Awassi ewe	11.53% and 62.72% reduction in CH_4 and N_2O/kg dry matter intake, respectively	Yurtseven and Al (2018)
Yucca schdigera extract	110 mg/kg	*In vitro*	2.4–12.88% reduction in CH_4	Xu et al. (2010)
Yucca powder	120 ppm	Sheep	5.4% and 7.1% decreased in CH4 production and CH_4 energy losses respectively.	Santoso et al. (2004)

Table 2
Effect of *Yucca schidigera* on Environmental pollution.

Source	Doses	Animal/ organism	Effects	References
Yucca schdigera saponin	15, 30 and 45 g/kg of substrate DM	Dairy cow	81.51–99.84% reduction in ammonia.	Holtshauen et al. (2009)
Yucca schdigera extract	650µg/ml	*In vitro*	30.21% decrease in ammonia nitrogen	Narvaez et al. (2013)
Yucca schdigera extract sarsaponin	50, 100 and 150 g/ head	Cow	10.31–30.60% reduction in ammonia nitrogen	Singer et al. (2008)
Yucca schdigera syrup	80 g/h	Dairy cow	23.5% reduction in ammonia	Budan et al. (2013)
Yucca schdigera saponin	Not specified	*In vitro*	29.99% reduction in NH_3–N	Jayanegara et al. (2014)
Yucca schdigera extract	1.5 kg/ton	Pregnant Awassi Ewe	33.89% reduction in NH_3–N from manure	Yurtseven et al. (2018)
Yucca schdigera Sarsaponin	0.5 and 1%/DM sarsaponin	Steer	12.5–13.66% reduction in urinary-N	Lila et al. (2005)
Yucca schdigera saponin (40 mg saponin/g)	240 ppm	Sheep	12.52% reduction in NH_3-Nand 14.70% in urinary-N	Santoso et al. (2006)
Water extract of *Yucca schdigera*	40% concentration of Yucca extract	Poultry manure	39.25 and 39.13% reduction in ammonia and hydrogen sulphide emissions respectively.	Matusiak et al. (2016)
Yucca schdigera	0.12 g/kg	Broiler	15.29% reduction in ammonia concentration in pen	Cabuk et al. (2004)
Yucca schdigera powder	0, 50,100 and 200 ppm	Poultry	100 ppm reduced ammonia emission by 44 and 28% on first and second day respectively, compared to other concentration combined	Chepete et al. (2012)
Yucca schdigera product	3 g/h/d	Horse	22.27% reduction in ammonia level	Warren and Codner (2012)
Yucca schdigera extract	250 mg/kg diet	Rabbit	33% reduction in ceca NH_3–N	Hussain et al. (1996)
Yucca schdigera extract	125 ppm	Pig	22% reduction in aerial ammonia concentration	Colina et al. (2001)
Yucca powder	120 ppm	Sheep	5.4% reduced total N loss, and increased retention of N	Santoso et al. (2004)
Yucca schidigera extract	250 mg/kg	Rabbit	6.7 and 12% decreased in fecal and urinary N, respectively, and 37.6% increased N balance	Amber et al. (2004)
Yucca extract	120 mg/kg	Pigs	2.90% increased protein digestibility, 11% decreased excreted N	Min et al. (2001)
Yucca schidigera extract	60 ppm, 120 ppm and 150 ppm	Pigs	1.5–1.9% increase in N digestibility in finishers, 36.35%. Reduced ammonia emission in growers, and lower feed conversion ratio	Hong et al. (2001)
Yucca schidigera extract	0.5 and 1 g/kg	*Channel carfishes.*	Reduce ammonia excretion, increasing the final weight.	Kelly and Kohler (2003)
Yucca extract	Not specified	Sheep	Reduction in NH_3–N	Pen et al. (2007)
Yucca schidigera powder	5 g and 20 g/100 kg	Rabbit	No effect on the ceca NH_3–N	Chrenková et al. (2012)

extract could decrease methane output by reducing H_2 production (Xu et al., 2010) which happens when steroidal saponins inhibit cellulolytic bacteria and fungi (Wang et al., 2000). Yucca could reduce urine and fecal nutrient excretion by improving protein digestibility, and enhancing efficient use of NH_3–N in the rumen, or gut. The glyco-component fraction in Yucca helps to reduce ammonia output by binding (Benchaar et al., 2008; Khalifa et al., 2014). Ammonia emissions may be mitigated by reducing urease activities, which would result in slow ammonia release (Muhammad et al., 2002).

4. Nitrogen pollution and methane emission

Developed and developing nations contribute to greenhouse gas emissions, albeit in different proportion depending on the parameters of measurement, such as, emission per animal product, or total emission. In regions of the world where it is warmer and wetter, nitrous oxide emissions is expected to increase (Trenberth, 2011) and perhaps other GHG like CH_4. For instance, between 2014 and 2017 there was a very strong atmospheric methane growth worldwide and this was attributed to the warmer climate and increased ruminant population (Nisbet et al., 2019). Methane emission is very peculiar to ruminant and its output in intensive system is high. It is produced as a metabolic by-product of rumen fermentation or during anaerobic fermentation of organic matter, mostly, manure, manure left on pasture, and waste products that has met anaerobic conditions in the presence of methanogens.

Literary evidence shows that diets high in protein causes significant faecal N, urinary N and gaseous N losses (Agle et al., 2010). This is partly caused by poor protein digestibility and absorption, and such nitrogenous output contaminates the environment and biophysical resources like land, air, and water bodies etc. Nitrogenous waste from animals are degraded to various form of nitrogenous compounds like N di oxide, N oxides, nitrous oxide, and ammonia. Fecal N is less susceptible to decomposition and evaporative losses, compared to urinary N present as urea and is rapidly converted to NH_4^+ (Bussink and Oenema, 1998; Philippe et al., 2011). Therefore, reducing urinary N emission is paramount. Nitrogen that occur in manure (urine and feces) is transformed into NH_3 by mineralization, and nitrification processes turn N into nitrite (NO_2^-) and then into nitrate (NO_3^-). Further denitrification results in N_2 and a by-product of nitrous oxide (N_2O) (Philippe et al., 2011) that is

Table 3
Effect of *Yucca schidigera* on water quality.

Source	Doses	Animal/organism	Effects	References
Yucca schdigera	0.75, 1, 1.5 g/kg dry matter	Aquaculture	20–33.78% reduction in TAN	Guroy et al. (2012)
Yucca schdigera	150 mg/kg	Nile tilapia diet	34.82, 34.02 and 47.61% reduction of TAN, NH_4 and NH_3 in 36 h respectively.	Hassan et al. (2017)
Yucca schdigera extract	72 and 108 mg/L of 30% Yucca extract concentration	*In vitro* using fresh water	1 mg/L of NH_3–N reduced by 80 and 100% in 24 h, 3 mg/L of TAN reduced by 83 and 100% in 60 h, 9 mg/L of TAN reduced by 50% and 55.56% in 96 h	Santacruz-Reyes and Chien (2009)
Yucca schdigera extract	0.2% and 0.3%	Pacific White shrimps (*Litopenaeus vannamei*)	15.38–30.76% reduction in total NH_3–N. 25.33–30.66% reduction in nitrite nitrogen.	Yang et al. (2015)
Yucca schdigera extract	18, 36 and 72 mg/L	In vitro using shrimp culture system effluent	78.7, 99.7 and 99.7% reduction in TAN in 12–24 h while 18 mg/L of Yucca reduced it further by 88.1% in 24 h	Santacruz-Reyes and Chien (2012)
Yucca schdigera extract	1 and 2 ml/L	Lake water	1 ml/L reduced of 1.2 mg/L ammonia concentration by about 100% while 2 ml/L reduced 1.8 mg/L of ammonia by 100% in 48 h	Yu et al. (2015)
Yucca schidigera extract	*0.5 and* 1 g/kg	*channel carfishes.*	25.34%–2.48% reduction in ammonia excretion and increasing the final weight.	Kelly and Kohler (2003)
Y. schidigera powder extract	750 mg/kg	Aquaculture	70%, 14.69, and 14.09% increased final body weight, feed efficiency ratio, and protein efficiency ratio respectively and 11.23%. Lower feed conversion ratio, increased digestibility coefficient of protein, fat and energy by 10.89, 17.25 and 11.46% respectively.	Gaber (2006),
Yucca extract	0.25 mg/L and 0.75 mg/L	Juvenile fishes	46.6–66.6% decrease ammonia, decreased nitrate and nitrite in a water recirculating system, 91.6–100% increased survival rate of the juvenile fishes	Castillo-Vargasmachuca et al. (2015)
Liquid extract of *Y. schidigera*	1 mg/m^3	Tilapia (*Oreochromis niloticus*).	Reduced water NH_3–N, decreased $NO3^-$ concentration in water and $NO2^-$	Reham et al. (2018)
Yucca Schidigera extract	18, 36 and 72 mg/L	Shrimps (*Marsupenaeus japonicus)* postlarvae	91.67% reduction in TAN in a system holding shrimps postlarvae in 12 h	Santacruz-Reyes and Chien (2010)

noxious to the atmosphere. In aquaculture, fishpond operations induce emissions, mainly as CO_2, oxygen, NH_3, CH_4, N_2O and nitrogen (N_2) (Efole Ewoukem et al., 2013). This is mainly from the high-protein rich feed offered to fishes, but, was poorly digested or utilized leading to its high excretion into water.

5. Yucca as feed additives

Methane and ammonia emission are major concerns for ruminant and monogastric researchers respectively, while Nitrous oxide emission is a concern for both. Reducing the environmental footprint is essential for sustainable livestock production- (Fig. 3). Yucca has been used as feed additives in domesticated animal feed because its phytochemicals can influence methane, ammonia, nitrous oxide emission and improve nutrient digestibility.

5.1. Effect of Yucca on emissions from ruminant

Many unhealthy gasses are produced in livestock systems. Some have global warming potential, while others do not. Common GHG from ruminants are known as CH_4, CO_2, and N_2O while non-GHG pollutants are ammonia, and ammonium etc., emitted from urine and feces excretion, during storage and manure application. These non-GHG affects human health, causes odour, and precipitates in the air. Scientific evidence indicates that, cattle, buffalo, sheep and goat emits 4.6, 0.6, and 0.5 Gt CO_2eq/yr., respectively (Gerber et al., 2013) while products, such as, beef, mutton, and milk production contributes 80% of total GHG emissions (Ripple et al., 2014) and 75% of NH_3 emissions (Behera et al., 2013) in the livestock sector. Faniyi et al. (2019) report that diets and additives influence animal productivity, and feed digestion. Metabolites produced and gasses emitted during and after feed intake influences productivity, and livestock environmental footprint. Patra (2012) and Adegbeye et al. (2018) reported the positive relationship between saponin concentration and its antimicrobial activity. At appropriate dose, saponins or saponins containing plants have been shown to suppress protozoal population (Sirohi et al., 2009). To this end, Holtshausen et al. (2009) observed that 15–45 g/kg of Yucca reduced methane production and NH_3–N. This decrease in methane output may be due to reduction in protozoa – caused by saponin; since approximately 25% of methanogens have hydrogen-transfer relationship with ciliate protozoa (Newbold et al., 1995) or the steroidal nature of Yucca saponin (Patra and Saxena, 2009). The reduction in ammonia nitrogen could help to reduce the quantity of nitrogen excreted.

Increase in rumen ammonia nitrogen due to low microbial population/growth affects efficient nutrient utilization. As such, ammonia in the rumen is converted to urea by the liver while excessive ones are excreted, which causes environmental pollution. Improved use of rumen ammonia will reduce the excretion of unabsorbed ammonia in the form of urea through urine or as nitrogen in feces. Studies of (Takahashi et al., 2000; Pen et al., 2007; Singer et al., 2008; Narvaez et al., 2013) showed that Yucca extract reduced rumen NH_3–N by 10.31–31.84% and methane by 15.22%. This was possible due to glyco-components of Yucca which binds to ammonia and other detrimental nitrous gases and suppress the release of these gases to the atmosphere (Lyons, 1992). Although continuous feeding of high starch diet affects rumen health and ruminant welfare negatively, such as, acidosis, and laminitis etc., (Faniyi et al., 2019), it is known that high carbohydrate diets produce less methane compared to high forage diets, due to shift from acetogenic to glycogenic metabolites in the gut. High starch diets produce hydrogen as part of its products, and could potentially increase methane output, but, the high output (animal product)

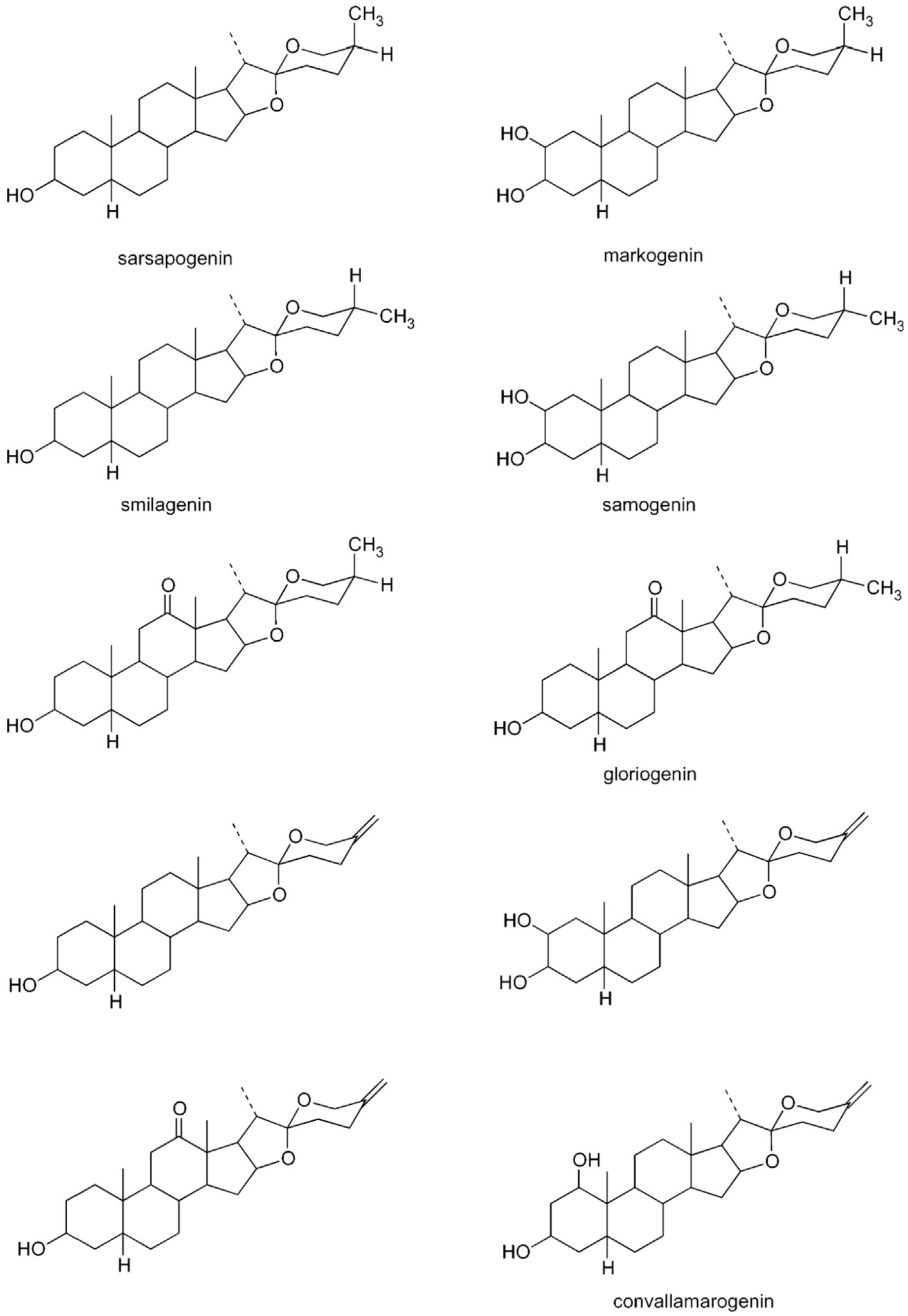

Fig. 2. Chemical structures of yucca saponin (Piacente et al., 2005).

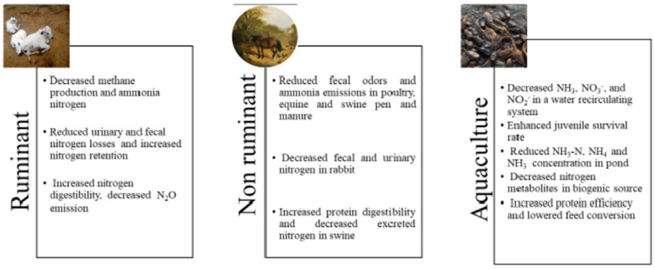

Fig. 3. Summary of effect of yucca on livestock and aquaculture.

derived from such animal reduces the emission intensity. Yucca decreased methane output from starch substrates in Lila et al. (2003) *in vitro* assay. This imply that adding Yucca to diets may reduce methane emission from feedlot system. Many ruminant farmers in sub-Saharan Africa, South East Asia and Middle East, feed ruminants with crop by-products such as straw, hulls, peels etc., with or without adding concentrate. However, Blummel et al. (2005) report that straw-based diets lead to increase in methane output. Poor digestibility is also associated with high fibrous diet and most of the undigested nutrients will excreted as feces and produce CH_4, N_2O, and ammonia after further microbial degradation. In addition, there is need to reduce the energy lost through methanogenesis and nutrient losses that would have been partitioned for productive purposes. 0.1% of Yucca extract added to the diet of Awassi ewe fed with ration containing 30% wheat straw (Yurtseven and Al, 2018) decreased GHG emission (N_2O and CH_4). This shows that Yucca could be used as supplement in high fibre diets to reduce emissions.

Poor use of ammonia by rumen microbes is an important factor for urinary nitrogen losses (Tamminga, 1992). Urinary nitrogen is quickly degraded and converted to ammonia than fecal nitrogen; because, urine urea is quickly transformed by the urease present in the environment and feces (Santoso et al., 2006). Further, nearly 75% of nitrogen consumed by dairy cows is excreted in feces and urine (Tamminga, 1992; Patra, 2012). This has negative impact in the environment by increasing nitrous oxide and ammonia emission. Nitrogenous and methane energy losses could be manipulated with Yucca powder to reduce the twin noxious emission from livestock. Santoso et al. (2004) and Santoso et al., (2006) observed that adding 120–240 ppm Yucca to sheep fed silage-based diet or (70 orchardgrass silage: 30 concentrate diet) decreased NH_3–N and urinary-N, and increased nitrogen retention. Lowering urinary nitrogen losses is an excellent option to reduce production of other forms of nitrogen pollutant, because nitrogen from urine is more volatile. Lila et al. (2005) observed that 0.5 and 1% of sarsaponin/dry matter in steer diet reduced urinary N losses. This is an indication of efficient use of nitrogen in the body.

Poor manure management during storage leads to ammonia emission and methane when conditions are met. Mineral contents such as carbon and nitrogen, influences emissions from manure. Therefore, efficient mineral use by animal will reduce its fecal and urine excretion. Nitrogen digestibility was improved, while N_2O emission *i.e.,* 5.04 *vs.* 20.8 ppm/ml, and manure nitrogen output were reduced when 1.5 kg of Yucca extract/ton of ration was added to pregnant Awassi ewes' diet (Yurtseven et al., 2018). The reduction in emission may be due to the low fecal nitrogen or improved nitrogen efficiency. Thus, Yucca could help to reduce ruminant nitrogen load in the environment and perhaps if added to the concentrate of pasture fed animals it could reduce the amount of nitrogen excreted to the field, thereby reducing the GHG emission from pasture.

5.2. *Impact of Yucca on emissions from non-ruminant*

In many developed and developing countries, commercialization of poultry, rabbit, and horses are done in confinement/intensive system. In this system, livestock are given protein rich diets compared to free range or scavenging system of production. Besides, the diffrent metabolic programming of ruminants compared to monogastric permit ruminants to synthesise microbial protein (for production) whereas monogastric cannot. This necessitates, the need for high nutritional quality diet in monogastric. Consequently, the fecal and urinary content of monogastric are nutrient-dense especially of nitrogen; because a linear relationship exists between dietary crude protein level and urinary urea excretion (Colmenero and Broderick, 2006). For example, about two-third of dietary N could be excreted in urine and feces, while near one-third of urinary and fecal nitrogen could be lost through ammonia emission (Aarnink and Verstegen, 2007). Unfortunately, ammonia from livestock manure causes air pollution for people residing in farm areas and even goes farther to places not proximal to the farm. Further, the ammonia causing air pollution is a fine particle with aerodynamic diameter less than 2.5 μm and has negative effect on human health (Miller et al., 2007), animal health and economic consequences. In animals, exposure up to 50 ppm of ammonia can cause respiratory problem and poor growth performance (Headon and Walsh, 1994).

5.2.1. *Poultry*

Poultry birds are fed quality diet rich in nutrients compared to ruminant that mainly feed on fibrous ingredient. This leads to high nutrient content in the feces of poultry. Poultry N is excreted in the form of uric acid, ammonia and undigested protein (Behera et al., 2013). During decomposition, microbes alter manure chemical composition and its nitrogen-containing compounds during deodorization (Matusiak et al., 2016) and this alteration leads to polluting odour. *Yucca schidigera* could help to reduce fecal odour and ammonia emissions emanating from farms and surrounding regions (Vlckova et al., 2017). Yucca is applied to absorb harmful and volatile chemicals, such as ammonia and hydrogen sulfide, so as to reduce their buildup in the air or animal environment (Singer et al., 2008). Hydrogen sulphide, dimethyl disulfide and dimethyl trisulfide that emanates from poultry farm have side effects on humans' and birds' health (Wadud, 2011). Exposure of poultry manure to *Yucca schidigera* in 48 h decreased ammonia and hydrogen sulphide odourous emission (Matusiak et al., 2016). This shows that Yucca can reduce the volatile odorous compound from poultry manure.

Many poultry farms in Nigeria practice semi-automated system (i.e., automated water but manual feeding). As a result, poultry feces or litters are packed or flushed manually every three or more days in a cage system and deep litter system. In Nigeria, poultry litters from many farms are disposed by burning, flushing with water or disposing in bushes due to poorly managed or nonexistent manure storage system. This results in buildup of odour in the pen houses of layers and broilers and further spread by air movement into the neighbourhood. Ammonia emission can cause respiratory problems through several aerosol compounds of fine particulate matter that affects visibility and human health (Lelieveld et al., 2015). Adding 0.12 g/kg of Yucca to broiler diet was able to reduce ammonia concentration in poultry house (Cabuk et al., 2004). Similarly, 100 ppm Yucca powder decreased the ammonia emitted from manure of birds on the first and second day after application by 44 and 28% respectively (Chepete et al., 2012). This could be due to Yucca ammonia binding ability or decrease in rate of microbial breakdown of organic matter to release ammonia. However, Yucca extract binds negligible amount of ammonia (Killeen, 1996). Hence, the possibility that microbial modulation is responsible the decrease in ammonia emission. Therefore, Yucca could be added to poultry diets to reduce the ammonia odour in poultry houses and disposed poultry manure.

5.2.2. *Equine*

Several inputs such as biochar, cellulase enzyme, xylanase enzyme, yeast, and soybean hull have been used to reduce methane emission in equine (Elghandour et al., 2019). *Yucca schigidera* may also be used in equine to mitigate emission. Over a million horses produce about 8 million tons of manure each year (Garlipp et al., 2011). In an anerobic condition, such manure could cause GHG emission due to imbedded carbon and nitrogen minerals. Limited work has been done on horses using Yucca. However, 3 g/head/day of Yucca product (De-Odorase®, Alltech Inc.) reduced the ammonia level emitted in the stable from equine excrete by 27.27% (Warren and Codner, 2012). More studies on the effect of Yucca in equine is needed.

5.2.3. *Rabbit*

Rabbits have some similarities with horses because they are hindgut fermenter because of their functional caecum (similar to rumen). Poor ventilation in a rabbitry could cause ammonia buildup. Also, increased nitrogen excretion is an indication of poor absorption, digestion or nutrient utilization. Supplementation of 250 mg/kg Yucca *schidigera* extract in New Zealand rabbit diet decreased fecal and urinary N and increased nitrogen balance per percent of intake by 10.23% (Amber et al., 2004). Similarly, Hussain et al. (1996) showed that adding 250 mg/kg diet of Yucca to rabbit diet containing urea decreased caeca ammonia nitrogen by 33%. This reduction may be attributed to the inhibition of urease enzyme activity, which decreased the rate of converting urea to ammonia (Ellenberger et al., 1985) or modification of the colonic microbiota (Bingham et al., 1978). In contrast, 5 g and 20 g of Yucca/100 kg feed had no effect on the caeca ammonia nitrogen (Chrenková et al., 2012).

5.2.4. *Piggery*

As the demand for animal product like pork increases, global warming challenges and high animal density could lead to increasing NH_3 and nitrous oxide emission in an unprecedented manner if pig production practices continue with the business-as-usual approach. Pig production is responsible for 15% of livestock NH_3 emissions globally (Olivier et al., 1998) and mostly comes from pig houses and litters. Moreover, emitted ammonia contributes indirectly to nitrous oxide by redepositing itself few kilometers away from site of emission and it is re-emitted as nitrous oxide (IPCC, 2006). Decreasing dietary nitrogen content, the use of additives to increase nitrogen retention, redistributing nitrogen into fecaes rather than urine will be vital to reducing nitrogenous pollution. Although, there are many report on the benefits of Yucca on pig performance, it is surprising that there are few recent studies on ammonia and nitrous oxide emission in swine despite the high consumption of pork globally, especially in Asia. Notwithstanding, in Colina et al. (2001) preliminary study 125 ppm of Yucca extract in pigs reduced aerial ammonia concentration by 22%. Also, addition of 120 mg/kg Yucca extract to pigs' diet increased protein digestibility and decreased excreted nitrogen (Min et al., 2001). Increasing nutrient digestibility and decreasing feed conversion ratio could be a good indicator of nutrient use efficiency. 60, 120, and 150 ppm of Yucca extract added to grower and finishers diet increased nitrogen digestibility, lowered the feed conversion ratio in finishing pigs and decreased ammonia gas production in growing pigs (Hong et al., 2001). The decrease in ammonia production will reduce air pollution and improve animal health and the health of farm attendants working with them daily and could improve productivity.

5.3. *Effect of Yucca extract on aquaculture pollution*

Disproportionate nitrogen load from culture ponds is caused by poor management practices like overfeeding and excessive fertilization and it is a concern for farmers and environmentalists. The nitrogen load could be turned into ammonia, due accumulation and degradation of organic matter like feces, uneaten feed making waterbodies toxic to aquatic animals (Martinez-Cordova et al., 1998; Páez-Osuna, 2001). Further, CH_4 and N_2O could be produced from incomplete mineralization of organic matter (Efole Ewoukem et al., 2013).

Global increases in aquaculture will lead to shift towards manufactured feed or concentrate use, and so will increase in nutrient rich excreta. Controlling nitrogenous waste in aquaculture is necessary to maintain production, survivability of fishes, water quality, and "clean" production system. In the future, there would be need for a more efficient use of water for food production. Presently, the volume of water used in aquaculture is huge, either from natural river, earthen pond or concrete pond. In concrete pond, more water is required if there is no recycling system of water treatment. During cultivation of fishes, polluted water is released into drainage or directly into the rivers or streams. Therefore, reducing concentration of nitrogen pollutants such as NO_3^- in aquaculture wastewater is important. Aside pollution, ammonia-N and nitrate-N at higher level are toxic to fishes, shrimps' and other aquatic organisms (Alcaraz et al., 1999). They increase gill ventilation, hyper-excitability, convulsions and mortality (Thurston et al., 1981; Maltby, 1995).

To remove ammonia concentration, zeolites has proven to be useful in fresh water system (Yu et al., 2015). However, it is highly inefficient in salty water/seawater due to the high ion concentration which inhibits its ammonia uptake (Burgess et al., 2004). Other means of reducing ammonia is through water exchange (Santacruz-Reyes and Chien, 2010), yet, such practice pollutes coastal waterways (Read and Fernandes, 2003). Bioactive plant component could be used to reduce the accumulation of nitrogenous wastes that limit production intensity in aquaculture (Francis et al., 2002). For instance, 0.25 mg/L and 0.75 mg/L of Yucca extract decreased ammonia, nitrate and nitrite in a water recirculating system and also, enhanced the survival rate of the juvenile fishes (Castillo-Vargasmachuca et al., 2015).

5.3.1. *Effect of yucca on reducing water pollution*

Total $NH_3{-}N$ is the combination of NH_3 (non-ionized) and NH_4^+ (ionized) (Hassan et al., 2017) and it is used to measure ammonia concentration in water. NH_3 is considered as $NH_3{-}N$ most toxic form and it is excreted freely through fish gills (Silva et al., 2013). Controlling nutrient losses in the form of N or fecal nitrogen will go a long way in reducing waterbodies pollution from aquaculture. Güroy et al. (2012) showed that 0.75–1.5 g/kg dry matter of Yucca reduced $NH_3{-}N$. Similarly, 150 mg/kg of Yucca in the basal diet of Nile tilapia decreased $NH_3{-}N$, NH_4 and NH_3 in 36 h (Hassan et al., 2017). A commercial extract containing 30% of *Yucca schidigera* used in freshwater *in vitro*, decreased total ammonia nitrogen by 34% (*i.e.*, 111 vs. 77) compared to the control (Santacruz-Reyes and Chien, 2009). The reduction of $NH_3{-}N$ could be explained by the theory of urease inhibition or binding of ammonia with some fractions of Yucca extract, including the two active ingredients i.e., the steroidal saponin which has surface-active properties, and the glycol component which binds to ammonia (Cheeke, 2000; and Ayasan et al., 2005).

Polluted aquaculture practices could have negative impact on water quality and hydrology ecosystems. This occur when biogenic effluents are released into rivers or streams, which renders the water unhealthy and unfit for drinking by people that depends totally on such water source. Ammonia-N and nitrate-N at higher level are toxic to fishes, shrimps' and other aquatic organisms (Alcaraz et al., 1999). Adding 0.2% and 0.3% Yucca extract in white shrimps (*Litopenaeus vannamei*) diet reduced $NH_3{-}N$ and Nitrite nitrogen (Yang et al., 2015). Similarly, adding 18–72 mg/L Yucca to biogenic source (shrimp culture system effluent) decreased over two-third of the initial $NH_3{-}N$ concentration in 12 h (Santacruz-Reyes and Chien, 2012). The reduction in ammonia nitrogen and other nitrogen metabolites indicate that adding Yucca to pond or aquaculture effluents before releasing them into waterbodies, will reduce water pollution and such could be used before wastewater treatment or before uisng such water to irrigate farms thereby reducing environmental pollution and increasing water productivity.

5.3.2. *Improving feed efficiency to reduce pollution*

Meanwhile, domesticated aquatic organisms are fed high-protein quality diet, that contains fishmeal, groundnut cake or soybean. In ponds, particularly when overstocked, toxic ammonia levels are quickly reached, especially when the nitrogen cycle has not been established, has been interrupted or suddenly become overloaded (Hertrampf and Piedad-pascual, 2000). It has been observed that there exist a correlation between dietary protein and ammonium excretion (Engin and Carter, 2001) which starts briefly post feeding (Peres and Oliva-Teles, 2006). Diets rich in protein ingredients could increase the amount of nitrogen excretion, which pollute the water for raising aquatic organisms. To prevent/reduce the rate of occurrence, *0.5 and* 1 g Yucca extract/kg added to a fish feed containing 40% crude protein reduced the rate of ammonia excretion and increased the final weight of the *channel carfishes* (Kelly and Kohler, 2003). The increased final weight of the fishes and less total ammonia nitrogen produced could be attributed to increased digestion, absorption, and utilization of the nutrient that would have been excreted as undigested feed into the water as fecal nitrogen.

Losses of nutrient to the environment have increased due to intensification that gives room for higher stocking and nutrient use, which leads to increased occurrence of large ‘point sources’ of pollution (Sutton et al., 2013). Increasing nutrient-use efficiency is another option of reducing nutrient pollution in the environment. Fishmeal is a high-quality ingredient and efficient utilization of feed containing such ingredient will be economic, productive as a result of lower feed conversion ratio and higher final weight, and ecofriendly due to less environmental pollution. As such, six months supplementation of 750 mg/kg of *Yucca schidigera* powder extract increased final body weight, feed efficiency ratio, protein efficiency ratio, lowered feed conversion ratio by 11.23% and increased digestibility coefficient of protein, fat and energy by 10.89—17.25% (Gaber, 2006). This indicates that Yucca can substantially save nutrient waste by improving livestock nutrient use for growth.

6. Conclusion

Livestock and aquaculture contributes to air, land and water-body pollution, especially when fishes are raised in the earthen pond or in flowing river and scientist are looking for ways to reduce environmental risk posed to biophysical resources. This review has established that Yucca could increase nitrogen metabolism, which will reduce the amount of excreted nitrogen causing different forms of environmental pollution in livestock. Yucca can reduce methane, total ammonia nitrogen in water, and nitrous oxide in a range of, 8.49%—69%, 50%—100% and 75% respectively. Cultivated aquaculture and monogastric farming may increase in the future as farmers could be drifting away from ruminant. As such, increasing interest in the cultivated aquaculture, also, comes with potential for increasing pollutants in waterbodies. Therefore, farmers using earthen ponds mainly in developing countries - where biogenic water is released into nearby rivers or streams, concrete pond and cage in free-flowing river can include Yucca as fish feed additive for the purpose of improving nitrogen use efficiency. In monogastric and ruminant, including Yucca as additives will help to reduce pen odour, methane emission and improve nutrient-use efficiency. The barrier to use of yucca might be the availability/accessibility in regions where it is not cultivated. However, giant feed manufacturing companies may overcome this, by importing Yucca and use it as feed additives and with proper marketing it could give such feed an edge in international and/ or local markets. In the future, we believe that commercial feed manufacturers will play key roles in ensuring adherence to “clean and green” animal-based protein production and partly to consumers safety. This could be achieved by including Yucca, novel resources like nanoparticles, “generally regarded as safe” biocontrol agents like lactobacilli, streptococci, bacilli and other well-established additives in livestock and aquaculture feed. With the climate changes, Yucca can serve as an important future ecofriendly additive in livestock production. This is because of its ability survive in desert area - an attribute that will be important for survival or adaptation in regions that would be hot in the future. This promises to improve sustainability of livestock because plant-based products are used to reduce problems accentuated by agriculture and other sectors. For future studies, researchers should study more on the effect of Yucca on nitrous oxide emission in ruminant. Research should also evaluate how Yucca can improve water quality in earthen pond, because this is an important pollutant of water bodies in some developing countries. This is because there would be need for clean water in the future for human consumption and more efficient use of water for producing animal-based protein, because water scarcity either physical or economic is increasing. Research on phytogenic feed additives must focus not only on production, but also, how efficient the nutrient input was used for animal product. Although there might be questions about animal welfare, we hope that studies that involve using feed additives to reduce livestock pollution, conduct such experiment in an environment that depicts the projected increase in average ambient temperature. Achieving sustainable animal productivity that reduces environmental footprint while meeting nutritional needs is possible. Other benefits such as, digestibility and feed conversion ratio, increased final weight indicate Yucca could be used as growth promoter and a good substitute for antibiotics and ionophores.

Declarations of interest

None.

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