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Review Article

Preponderance of polythene-mediated ruminal impaction disease syndrome impeding ruminant livestock production systems in the Sahel

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ABSTRACT: Ruminal impaction disease syndrome (RIDS) is a severe, menacing gastrointestinal disease of ruminant livestock. The ingestion of the aetiologic agent, indigestible polythene materials, and its accumulation in the rumen culminate in disrupted ingesta flow, rumen impaction, indigestion, recurrent tympany, emaciation, lethargy, and mortality. The disease principally occurs amongst ruminant livestock under semi-intensive or extensive types of animal rearing, predominantly in developing countries. The ruminants are predisposed to RIDS by mineral deficiencies, feed scarcity, pica, etc. The occurrence of RIDS due to the ingestion of polythene material poses a severe threat to ruminant livestock production systems due to its high frequency. The prevalence of 67.46% translates to an estimated N820.675 billion ($538.75 million) loss annually amongst the 152.48 million ruminant livestock population in Nigeria. Despite the high frequency and attendant economic losses, no statutory provisions for prevention and control have been enacted, making RIDS a major but neglected disease of ruminant livestock. Moreover, the polythene material production explosion and growth of consumerism generate enormous polythene waste that litters the environment, which in turn fuels the incidence of RIDS. To date, exploratory rumenotomy remains the choice that guarantees resolution for diagnosis and treatment of RIDS. Even then, the affected animal will mostly be presented at the terminal stage of the RIDS, and the surgical success rate is very low. Rumenotomy in such animals is associated with frequent complications like infection, peritonitis, hemorrhage, and wound dehiscence. Utilization of digital non-invasive imaging and minimally invasive surgery, such as laparoscopy, diagnostic markers, and nanotechnology, can enhance the accuracy of diagnosis and prompt treatment of RIDS. Re-establishment of livestock health and welfare will directly boost the productivity and profitability of free-range or semi-intensive ruminant livestock systems in Nigeria.

Keywords: Preponderance, polythene, ruminant livestock, ruminal impaction disease syndrome, Sahel, production systems.

OVERVIEW OF RUMINAL IMPACTION DISEASE SYNDROME

Ruminal impaction disease syndrome (RIDS) is an emerging threat to free-range and semi-intensive reared ruminant livestock populations in urban, semi-urban, and peri-urban settlements (Kamalakar *et al*., 2021) and is rapidly cascading into rural communities of developing countries. RIDS is a menacing and preponderant disorder of ruminant livestock such as cattle, buffaloes, sheep, and goats (Abu-Seida and Al-Abbadi, 2016; Mekuanint *et al*., 2017; Kamalakar *et al*., 2021). RIDS due to polythene material is amongst the most common and important gastrointestinal disorders that could rapidly degrade the body condition of the animal and consequently the economy of the farmer. Moreover, the growth of the plastic industry generates enormous polythene waste (Priyanka and Dey, 2018) that litters the environment, ending up in landfills, oceans, and other waterways. This, in turn, fuels and precipitates the incidence of RIDS and consequently represses ruminant livestock productivity and profitability amongst the animal rearers in developing countries. Despite the high incidence and the untoward impact on the livestock economy, there is no established diagnostic or treatment protocol for timely intervention.

Aetiologic agent

RIDS arises from indiscriminate ingestion by ruminants of indigestible polythene material such as polythene bags, wraps, films, and membranes (Adane and Muleta, 2011; Ramaswamy and Sharma, 2011; Kamalakar *et al*., 2021). The aetiologic agent, polyethylene or polythene (IUPAC name: polyethene or poly[methylene]; abbreviated PE) is the most commonly produced plastic (Achilias *et al*., 2007; Araújo *et al.,* 2008). Plastics start out as fossil fuels (natural gas or oil) hidden deep underneath the earth and end up as deadly waste in landfills, refuse dumps, and the ocean. Ethylene double bond allows untrammeled polymerization into High Density Poly Ethylene (HDPE) or Low Density Poly Ethylene (LDPE) that can be molded into the congealed state of any shape (Achilias *et al*., 2007; Royer *et al.,* 2018). While HDPE is versatile thermoplastic polymer used in a wide variety of applications as plastic bottles, jugs, cutting boards, toys, recycling bins and pipes; the LDPE, a soft, flexible, lightweight thermoplastic polymer can be melted, then moulded and reshaped easily into plastic bags, films, geomembranes and sheets many times over by application of heat and pressure (Araújo, *et al*., 2008; Royer *et al*., 2018). LDPE, the most common type of consumer plastic noted for its low temperature flexibility, water-resistance, hardiness, corrosion resistance, and transparency, is primarily used for packaging food products (Adane and Muleta, 2011).

Predisposing factors

Ruminant livestock reared under free range or semi-intensive systems in urban, sub-urban, and peri-urban areas are more prone to the development of RIDS (Reddy *et al*., 2004; Ngoshe, 2012). Such livestock roam and scavenge or freely graze any feed matter, including polythene garbage litter on the streets, roadsides, open areas, and refuse dump sites (Figure 1). Ruminant livestock ingest polythene laced with salt, sugar, or other spices and seasoning, mistaking it for feed. Ingestion of polythene materials also occurs as a result of fodder scarcity, pica (Vanitha *et al*., 2010b), mineral and nutrient deficiencies such as calcium, phosphorus, and other micronutrients (Bokko *et al.,* 2003; Otsyina *et al.,* 2017), poor nutritional supplementation, negative energy balance status, especially during pregnancy and lactation (Della *et al*., 2005; Kamalakar *et al.,* 2021). The current widespread use of polythene and other non-biodegradable materials without proper disposal is a foremost predisposing factor to the development of RIDS. Protracted dry season, diminished grazing land, rapid urbanization and industrialization continue to escalate the incidence of foreign body ingestion in ruminants (Tiruneh and Yesuwork 2010; Mekuanint *et al*., 2017). In contrast, ruminant livestock maintained under the intensive farming system are not exposed to polythene waste. Cases of RIDS in these animals are extremely rare (Kamalakar *et al*., 2021).

Prevalence/frequency

Prevalence of RIDS in ruminant livestock, mainly in urban, suburban, and peri-urban areas of developing countries, has been extensively reported (Fromsa and Mohammed, 2011; Sheferaw *et al*., 2014; Mushonga *et al*., 2015; Akraiem *et al*., 2016; Bwatota *et al.,* 2018; Eriksen *et al*., 2021). Slaughterhouse preponderance in domestic ruminants shows a 30.73% (Duresa *et al*., 2022) and 40.1% in Ethiopia (Ame *et al*., 2022), 72.3% in Kenya (Otsyina *et al*., 2015), 67.46% (Rabana *et al*., 2022), and up to 77% in Nigeria (Remi-Adewunmi *et al*., 2004). Conversely, clinically diagnosed prevalence of RIDS in cattle was 0.44% - 3.20% in a 10 year retrospective study in Ethiopia (Kamalakar *et al*., 2021). Similar low hospital prevalence rates of 5.96% (Athar *et al*., 2010); 7.51% (Hussain and Uppal, 2012); 8.6% (Nugusu *et al*., 2013); 10.79% (Vakare *et al*., 2022), and 13.22% (Tesfaye and Chanie, 2012) in ruminant livestock were reported. The low incidences arise as the majority of cases express vague signs and go unnoticed. Sometimes owners cull animals non-responsive to conservative symptomatic treatment (Kamalakar *et al*., 2021). The two extreme prevalence rates of RIDS, where very high rates are detected after slaughter and very low rates in veterinary hospitals, indicate the high incidence in the ruminant livestock population, but low definitive detection techniques clinically.

Cattle tend to be more vulnerable to the development of RIDS than sheep and goats (Tiruneh and Yesuwork 2010; Ramaswamy and Sharma, 2011). This is attributable to the

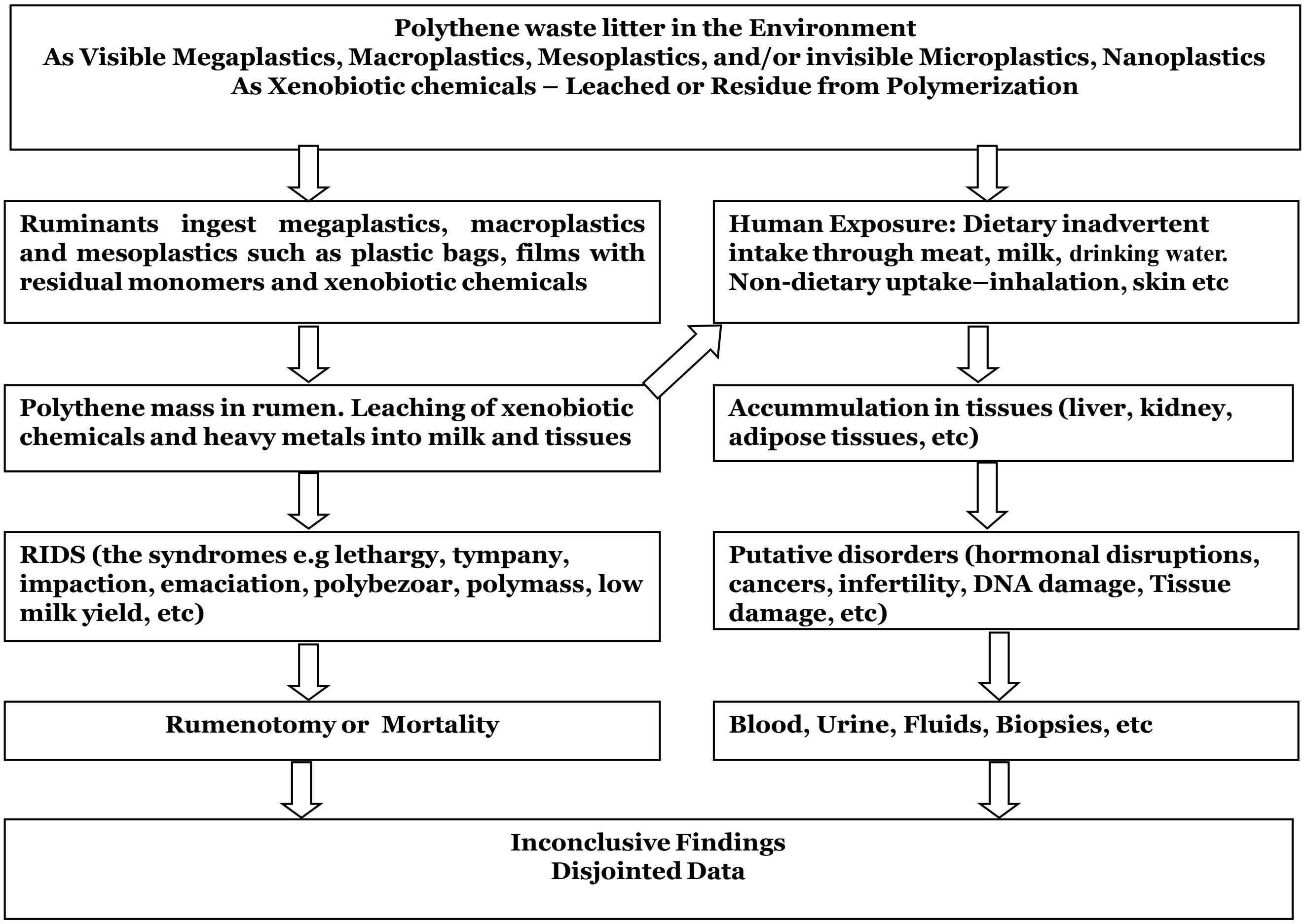

Figure 1. Pathways of polythene material deleterious effects in ruminant livestock and humans. Laboratory tests on body fluids and biopsy are performed erratically and findings are inconclusive. RIDS = Ruminal Impaction Disease Syndrome.

prehensile nature of the bovine having the least sensitive and goats with highly sensitive prehensile organs as lips and tongues, to distinguish between prospective feeds and inedible items (Fromsa and Mohammed, 2011; Uzal *et al*., 2016). Sheferaw *et al*. (2014) reported significantly higher prevalence of RIDS in cattle (41.8%) than sheep (20.6%) and goats (11.9%). Similarly, the prevalence of ruminal polythene mass at Addis Ababa abattoir at slaughter was 35.7% in cattle, 18.6% in sheep, and 15.3% in goats (Mekuanint *et al*., 2017).

Furthermore, the female (cows, ewes, does), owing to greater nutritional demand, negative energy balance, and propensity to mineral deficiency, especially during gestation and lactation, are more susceptible to the development of RIDS than respective males (Hailat *et al*., 1996; Remi-Adewunmi *et al*., 2004; Tiruneh and Yesuwork, 2010). Moreover, as ruminant livestock and their respective products, such as milk and meat, become commercially attractive, along with artificial insemination services, emphasis has shifted to keeping females longer, mainly for fecundity, while culling males soon after reaching market weight (Mushonga *et al*., 2015; Kamalakar *et al*., 2021). This will contribute significantly to the higher prevalence of RIDS amongst females kept under free-range or semi-intensive systems.

Cattle above 10 years of age, and sheep and goat over 4 years showed a higher prevalence of RIDS with an average frequency of 46.7% than younger age groups (12.9%) (Vanitha *et al*., 2010b; Tesfaye and Chanie, 2012; Duresa *et al*., 2022). Longer exposure, continual ingestion, and gradual accumulation of polythene waste, as well as the absence of signs indicative of RIDS, result in higher prevalence in older animals (Kamalakar *et al.,* 2021; Mekuanint *et al*., 2017).

Economic impact on livestock

Occurrence of RIDS impedes ruminant livestock production systems in Nigeria due to its high frequency

(Remi-Adewunmi *et al*., 2004; Bokko, 2011). RIDS rapidly degrade the body condition of the affected ruminant livestock (Athar *et al*., 2010; Tesfaye and Chanie, 2012) and consequently the economy of the farmer. The prevalence of 67.46% translates to an estimated N820.675 billion ($538.75 million) loss annually amongst the 152.48million ruminant livestock in Nigeria (Aminu *et al*., 2024); from infertility, foetal loss, poor milk yield, poor weight gain, low meat and leather quality, high morbidity, high health costs, and high mortality rates (Bokko, 2011; Sheferaw *et al*., 2014; Kamalakar *et al*., 2021). Thus, RIDS impede the profitability of the ruminant livestock production systems in developing countries such as Nigeria.

Pathophysiology

Continual ingestion of indigestible polythene waste over time accumulates in the rumen (Figure 1). Ruminal contractions and churning form a nidus and entangle more polythene, leading to the formation of loose mass (Leask *et al*., 2012). Additional ingestion of polythene mass either forms a new nidus or intertwines with the pre-existing polythene mass that hardens with continual churning movement. The polythene material in the rumen minimally degrades, cannot be digested or excreted as such through faeces, and remains in the rumen through the lifespan of the affected animal. The presence of polythene mass hinders ingesta flow to the distal digestive system (Ramaswamy and Sharma, 2011). Additionally, plastic mass decreases rumen motility, causes ruminal atony, rumen stasis, and may lead to fatal bloat or tympany (Igbokwe *et al*., 2003; Remi-Adewunmi *et al*., 2004; Singh, 2005).

Furthermore, feed gets trapped in the plastic mass and becomes unavailable for digestive and fermentative processes. This hampers volatile fatty acids (VFA) production and absorption in the rumen and reticulum, increasing energy demand and reducing fattening rate (Kamalakar *et al*., 2021). The animals ultimately become lean from gradual weight loss or stagnated weight gain (Igbokwe *et al*., 2003; Kamalakar *et al*., 2021). Additionally, altered rumen microflora populations culminate in the loss of about 80% of the supplements from the rumen, leading to energy imbalances, protein loss and a cascade of deleterious events like indigestion, tympany, and worsening the pathogenesis of the RIDS (Ismail *et al*., 2007; Bokko, 2011; Priyanka and Dey, 2018).

Clinical signs and symptoms

The RIDS offers no pathognomonic or signature signs that confirm the disorder, as in many diseases. The signs exhibited by ruminant livestock with RIDS vary greatly depending on the amount, location, and duration of the plastic mass in the rumen, and the degree of interference with the flow of ingesta (Reddy and Sasikala, 2012; Tesfaye and Chanie, 2012). The severity of pathology in the ruminal tissue is directly proportional to the quantities of polythene material (Otsyina *et al*., 2017).

Ruminant livestock harbouring little quantities of plastic mass in the rumen remain asymptomatic. However, when the polythene load attains a clinically significant threshold and consequential reduction in the digestive surface area and function of the rumen, clinical signs start to appear (Ramaswamy and Sharma, 2011; Ngoshe, 2012). Although such animals may appear healthy, they gradually develop a plethora of nonspecific, nondiagnostic signs. The signs start out as mild forms of inappetence, indigestion, recurrent bloat, ruminal stasis, rumen impaction, low-grade pain, inflammation, scanty faeces, weakened immunity, and increased susceptibility to other diseases (Singh, 2005; Vanitha *et al*., 2010b). As RIDS assumes a chronic pattern, major clinical signs exhibit increased severity. Among these are persistent ruminal impaction, recurrent severe tympany, starvation, poor milk yield, emaciation, rumen acidosis, dehydration and lethargy, among many other adverse health effects and eventual fatality (Ghurashi *et al*., 2009; Reddy and Sasikala, 2012; Otsyina *et al*., 2017; Sasikala *et al*., 2019).

Sometimes, the polythene in the rumen may also occlude the esophageal orifice, leading to hindered eructation resulting in death (Ghurashi *et al*., 2009). The duration of active clinical disease ranged from 0.5 to 24 months (Ismail *et al*., 2007; Khose *et al*., 2010). Athar *et al.* (2010) recorded a 5.20 ± 1.39 days duration of illness in cattle diagnosed with end-stage RIDS.

Effects in ruminants

Furthermore, megaplastics (>50 mm) and macroplastics (>25 mm – 50 mm) plastic forms in rumen subjected to churning, ruminal contractions, microbial action, hydrolysis, mechanical degradation and enzyme activity cause subtle disintegration producing mesoplastics (>5 mm – 25 mm), microplastics (1 μm – <1 mm), nanoplastics (1nm – <1μm) or plastic nanoparticles (≤100 nm), even into monomeric forms (Coffin *et al*., 2022; Walker *et al*., 2022; Ali *et al*., 2024); with each form posing yet to be determined health risks and dangers to ruminant livestock.

Plastic forms along uncoupled xenobiotic chemicals and heavy metals, their salts and complexes incorporated during polythene production, have been reported in ruminal fluid of free range or semi intensively reared ruminants in urban, suburban and peri-urban areas (Kunisue *et al*., 2004; Vanitha *et al*., 2010b; Mulekeet *al*., 2013). These are leached out slowly from the rumen into circulation, entering tissues including liver, gonads, kidneys, muscles, udder, and seep into milk and meat products in the food chain (Kunisue *et al*., 2004; Muleke *et* *al*., 2013). Thus, predisposes ruminants with RIDS to immunosuppression, endocrine dysfunction, oxidative stress, infertility, carcinogenicity, and teratogenicity (Singh, 2005; Ghurashi *et al*., 2009). Other systemic effects of plastic masses in bovine (Abu-Seida and Al-Abbadi, 2016; Akraiem *et al*., 2016; Mahadappa *et al*., 2020), goats (Otsyina *et al*., 2015), sheep (Beriot *et al*., 2021; Otsyina *et al*., 2017), and camels (Sadan *et al*., 2020; Eriksen *et al*., 2021) have been published.

Impact of plastics and associated chemicals on human health

Microplastics and nanoplastics prevalent in the food chain as well as the environment and water supplies, are the major source of human exposure to polythene material (Carbery *et al*., 2018). Although humans are vulnerable to exposure through multiple routes, inhalation, skin contact, and dietary ingestion of microplastics and nanoplastics have been recognized as the main source of exposure (Prata *et al*., 2018; Revel *et al*., 2018; Yee *et al*., 2021; Rahman *et al*., 2021). Humans unknowingly consume 39,000 – 52,000 particles of microplastic annually, with age and gender impacting the total amount (Cox *et al*., 2019). Inhalation of plastic particles can push up the figures to 74,000 – 121,000 particles per year (Cox *et al*., 2019). Microplastics and nanoplastics in the gut can be internalized in cells via the common endocytic pathways such as phagocytosis, macropinocytosis, micropino-cytosis, as well as clathrin-and caveolae-mediated endocytosis for cellular uptake of plastic particles (Doherty and McMahon, 2009; Kaksonen and Roux, 2018; Mani and Pandey, 2019; Ma *et al*., 2021). Inhaled airborne microplastic and nanoplastic particulates originate from synthetic textiles, rubber tyres, landfills, sewage sludge, and waste incineration (Dris *et al*., 2015; Dris *et al*., 2016; Kole *et al*., 2017; Prata, 2018; Vianello *et al*., 2019; Ali *et al*., 2024). Although the exposure to microplastics and nanoplastics by inhalation is lower, the alveolar surface area of the lungs is vast and thin (<1 μm) enough for nanoparticles to permeate through and enter the capillary blood system and the entire body (Lehner *et al*., 2019). While dermal exposure is considered the least important entry route, evidence suggests that microplastics and nanoplastics in personal care products can pass through the skin barrier (Revel *et al*., 2018), skin wounds, sweat glands, or hair follicles (Schneider *et al*., 2009).

The presence of microplastics and nanoplastics in the food chain creates a risk to human health due to their wide bioavailability, persistence, nonbiodegradability, toxicity, and ubiquity (Cole *et al*., 2011; Kolandhasamy *et al*., 2018; Wang *et al*., 2020; Yee *et al*., 2021). Numerous studies have found microplastics and nanoplastics in human lungs, liver, spleen (Amato-Lourenço 2021; Horvatits, 2022), blood, placenta, kidney, heart (Ragusa *et al*., 2021; Allen *et al*., 2022; Leslie *et al*., 2022; Walker *et al*., 2022) as well as muscle, liver, and gonads of aquatic organisms (Abbasi *et al*., 2018; Collard *et al*.,. 2017; Kolandhasamy *et al*., 2018). *In vitro* and *in vivo* studies have shown that microplastics and nanoplastics induced cellular damage, apoptosis, inflammation, oxidative stress, and deleterious immune responses in the human body (Wright *et al*., 2017; Qiao *et al*., 2019; Ali *et al*., 2023). Microplastics and nanoplastics also caused myocardial pyroptosis, mitochondrial damage, increased reactive oxygen species (ROS) production, DNA damage, infertility (Matthews, 2021), induced gut microbiota dysbiosis and carcinogenicity (Yee *et al*., 2021; Ali *et al*., 2024). Microplastics and nanoplastics have also been linked to endocrine disruption, reproductive dysfunction, metabolic insufficiencies, and disrupted neurodevelopment (Deng *et al*., 2017; Stock *et al*., 2019; Lu *et al*., 2018; Goodes *et al*., 2022). Inhalation of microplastics and nanoplastics culminates in particulate and chemical toxicities, pulmonary inflammation, and lung damage (Vethaak *et al*., 2016; Ohlwein *et al*., 2019) and cancer (Prata, 2018).

Microplastics and nanoplastics also contain lead, mercury, chromium, fluorides, radium salt, aluminum, copper, cobalt, barium, nitrates, arsenic, cadmium, etc, actively incorporated during plastic production (Vandenberg *et al*., 2012; Wiesinger *et al*., 2021; Ali *et al*., 2023). Additionally, common xenobiotic chemicals such as plasticizers, resins, bisphenol A (BPA), di-(2-ethylhexyl) phthalate (DEHP), triphenyl phosphate (TPP), polychlorinated biphenyl's (PCBs), dioxins, per- and polyfluoroalkyl substances (PFASs), additives (antioxidants, catalysts, stabilizers, flame retardants, pigments, fillers and unintentional added chemicals) are also associated with microplastics and nanoplastics (Kunisue *et al*., 2004; Oskam *et al*., 2005; Vanitha *et al*., 2010a; Chobtang *et al*., 2011; Vandenberg *et al*., 2012; Wiesinger*et al*., 2021; Dey *et al*., 2022). The heavy metals and xenobiotic chemicals bind either chemically or physically into the polymers in their original or altered form (Teuten *et al*., 2009; Mitra *et al*., 2019). When such a bond is not strong, minor external influences can cause uncoupling from polymers, in addition to residual quantities following the polymerization process (Araújo *et al*., 2008). Microplastics and nanoplastics, xenobiotic chemicals and heavy metals exhibit high toxicity, long half life, insolubility in water, lipophilicity, resistance to degradation, bioaccumulation in vital organs and widespread dispersal through food chain (Halden 2010; Adane and Muleta 2011; Muleke *et al*., 2013) with propensity to causing array of disorders over time in humans and animals (Priyanka and Dey 2018).

Xenobiotic chemicals such as PCBs were detected at higher levels in the liver and kidney than in other tissues (skin, gonad, muscle) due to their high lipid content (Allen *et al*., 2022; Coffin *et al*., 2022). Leached bisphenol A (BPA) and epoxy resin, lining food and beverage cans has been shown to cause cardiovascular diseases, hormonal disruption, alters pancreatic β cell function (Ropero *et al*., 2008; Cipelli *et al*., 2014; Lang *et al*., 2008; Melzer *et al*., 2012) and alteration of reproductive and neurological functions in humans (Srivastava and Godara, 2013).

Very low (picomolar to nanomolar) doses of endocrine-disrupting chemicals (EDCs) such as Bisphenol A (BPA) and phthalates culminate in adverse and irreversible effects as early embryonic mortality, early puberty, birth defects, growth and cognitive impairment (Oskam *et al*., 2005; Crain *et al*., 2007; Gray, 2009; Halden, 2010; Vandenberg *et al*., 2012; Rani *et al*., 2015; Ali *et al*., 2024). Xenobiotic chemicals can be teratogenic to foetus during uterine life, causing developmental defects (Della *et al*., 2005; Gray, 2009; Kandarakis *et al*., 2009). Xenobiotic chemicals have also been linked to low spermatozoa count, infertility, hypothyroidism, cryptorchidism, Type II diabetes, increased cardiovascular disease risk, and stroke (Duty *et al*., 2003; Della *et al*., 2005; Oskam *et al*., 2005; Gray, 2009; Halden, 2010; Vandenberg *et al*., 2012; Priyanka and Dey, 2018). Several xenobiotic chemicals and heavy metals are immunosuppressants and allergenic (Singh,2005). Continuous human and animal exposure to xenobiotic chemicals such as unpolymerized monomers, PCBs, dioxins, BPA, phthalate esters such as butyl benzyl phthalate (BBP) and DEHP (Vanitha *et al*., 2010a) increases risk of hepatocellular carcinoma, testicular carcinoma, prostate, breast, and ovarian tumors (Della *et al*., 2005; Kandarakis *et al*.,2009; Gray, 2009; Halden, 2010; Jafarabadi *et al*., 2019; Yee *et al*., 2021). Xenobiotic chemicals in the body increases oxidative stress triggering the release of ROS – a group of short-lived, highly reactive, molecules capable of independent existence that include superoxide anion radical ($O2^{\bullet-}$), hydroxyl radical ($^{\bullet}OH$), hydroperoxyl radical, hydrogen peroxide (H_2O_2), singlet oxygen ($^1O_2$) (Blokhina and Fagerstedt, 2010; Heyno *et al*., 2011). The ROS can induce DNA damage and affect the DNA damage response (DDR) (Blokhina and Fagerstedt, 2010; Heyno *et al*., 2011).

Despite these findings, the effects of leached xenobiotic chemicals, various plastic forms, and heavy metals in humans (Muleke *et al*., 2013; Priyanka and Dey, 2018) or ruminant livestock are largely overlooked and hence remain unknown. These xenobiotic chemicals may act synergistically to cause or amplify the deleterious health conditions in humans. Putative effects of xenobiotic chemicals, heavy metals, microplastics, and nanoplastics have a propensity to overlap. However, there is not enough data to distinguish discrete deleterious effects attributable to either of them. More data to delineate between the discrete effects of xenobiotic chemicals, heavy metals and microplastics, and nanoplastics needs to be deciphered. The toxicity mechanisms and long-term effects of microplastics and nanoplastics in humans, including their interactions with other pollutants, are not fully understood. Animal and cell studies can determine adverse effects, while biomarker-based studies help gain deep insights. Moreover, sublethal effects found in other species (eg, algae, zooplankton, fish, mice) provide early warning of both environmental danger and potential human health risk (Ali *et al*., 2023).

Histopathological changes

During rumenotomies or necropsy examinations on animals with RIDS, rumen mucosae seemed diametric to the default appearance (Steele *et al*., 2014; Martin *et al*., 2021a). In particular, rumen papillae are stumpy and thickened (1.243 units) compared to the long, slender, regular, white to grey papillae (3.097 units) (Uzal *et al*., 2016; Martin *et al*., 2021a). The significant reduction in length of the rumen papillae is attributable to the polythene material pressing and rubbing against the rumen wall, exacerbated by mechanical injuries from the churning movement of the rumen (Martin *et al*., 2021a). Moreover, the continuous presence of polythene material in the rumen causes erosion, denudation, sloughing, excoriations, ulceration, and loss of ruminal papillae (Hailat *et al*., 1998; Bakhiet, 2008; Otsyina *et al*., 2017; Sasikala *et al*., 2018). Dystrophic changes in ruminal mucosa occurred due to continual deleterious effects of polythene in the rumen (Martin *et al*., 2021a). Thinning of the ruminal wall and rumenitis impede normal digestion and fermentation processes in cattle, sheep, and goats (Bakhiet, 2008; Sasikala *et al*., 2018; Martin *et al*., 2021a).

Additionally, hyperemia, haemorrhagic rumen mucosa, exocytosis with the presence of leukocytes, intense hyperkeratosis, with areas of pseudo-carcinomas, interstitial oedema, congestion, vacuolar degeneration (spongiosis), and intense acanthosis of the squamous epithelium of the ruminal mucosae were present (Hailat *et al*., 1996; Bakhiet, 2008; Otsyina *et al*., 2017). Epithelial hyperplasia was the most frequent finding in the rumen (Martin *et al*., 2021a). Cornified epithelium appears mushy, sloughs easily, leaving a dark, hemorrhagic surface beneath (Constable *et al.,* 2017), while stratum corneum showed ruminal parakeratosis and extensive sloughing (Steele *et al.,* 2014). Massive vacuolar degeneration of squamous epithelium in rumen and reticulum, presence of intraepithelial leukocytes, and vascular alterations of the lamina propria occur (Sasikala *et al*., 2018; Martin *et al*., 2021a).

Diagnosis

As clinical signs of RIDS due to polythene are nonspecific, diagnosis can be a real challenge. RIDS signs exhibited amongst ruminants do not help in directional thinking amongst clinicians towards RIDS. Instead, RIDS is frequently an inadvertent finding, such as during rumenotomy, identified at "the fag end" or necropsy (Priyanka and Dey,2018). Polythene is found mainly in the rumen (86.43%) and occasionally the reticulum (13.56%) (Duresa *et al*., 2022). Usually large shapeless mass of tightly compacted polythene (Figure 2) or polybezoars with polythene material as the main component are recovered (Figure 3). Polythene mass recoveries were 4.2kg (Tiruneh and Yesuwork, 2010) and up to 5.5 kg (Martin *et al*., 2021b) in sheep and goats; a significant amount for small ruminants with a bodyweight range of 18–52 kg. Mekuanint *et al*. (2017) reported 13 kg of plastic mass from the rumen of an ox and 1.8 kg in a buck via rumenotomy. A team of veterinarians in Vepery, Chennai, Tamil Nadu, India recovered 52 kilograms of plastic from a cow via rumenotomy (Sasikala *et al*., 2019). A 4.3kg Polythene mass from a goat (Figure 2) or a 3.8 kg polybezoar (Figure 3) was recovered from goats during routine wetlab rumenotomy in April 2024 at the large animal clinic of the Veterinary Teaching Hospital, University of Maiduguri, Nigeria. While foreign mass content is predominantly polythene, polybezoars or other indigestible foreign materials such as nails, coins, leather, screws, pins (Tiruneh and Yesuwork, 2010), wood, textile pieces, and trichobezoars from ruminant livestock with RIDS have been recovered (Tiruneh and Yesuwork, 2010; Mekuanint *et al*., 2017). In Eastern Ethiopia, a study showed that free-range ruminant livestock had foreign body type prevalence of 79.2% polythene, 15.3% cloths, and 12.3% nylon rope (Negash *et al*., 2015).

Treatment

Conservative approaches, such as the use of anti-bloat agents, laxatives, or purgatives, do not resolve RIDS due to polythene material. Rumenotomy remains the therapeutic intervention that guarantees resolution of RIDS in affected ruminants (Priyanka and Dey, 2018). Moreover, rumenotomy through the paralumbar fossa incision involves the exteriorization of the rumen, which *per se* is a tremendous stressor to ruminants. Even then, the affected animal will mostly be terminally ill, and surgical intervention success rate is very low. Surgery on such ruminants with poor body condition shows propensity to infection, fatigue, shock, severe peritonitis, adhesion formation, wound dehiscence, protracted morbidity, slow recovery, and delayed healing (Ismail *et al*., 2007; Sasikala *et al*., 2019; Martin *et al*., 2021b). Hence, the continual search for better approaches for the diagnosis and treatment of RIDS to curtail the preponderance.

Today, prospects of digital non-invasive imaging & minimally invasive surgery, clinical profiling upgrade, diagnostic biomarkers, and nanotechnology are innovative newer technologies that can be utilised for enhancing the accuracy of diagnosis and expeditious treatment of RIDS (Bokko, 2018). For instance, the advent of laparoscopy is a milestone in surgery that initiated a shift from the era of open abdominal surgery to the minimally invasive surgery revolution (Modlin *et al*., 2004; Kooby, 2006). Laparoscopy, a revolutionary and versatile technique that is minimally invasive, fast, and also proffers safety for diverse applications in the diagnosis, therapeutic interventions, and/or biopsy from organs of the abdominal cavity without laparotomy (Karateke *et al*., 2013; Sasikala *et al*., 2019). Laparoscopy can therefore be key technique for accurate diagnosis and minimally invasive treatment of RIDS (Bokko, 2018). Laparoscopy also proffers direct visualization to clarify hidden pathology when physical examination or imaging tests - radiography, computed tomography (CT scan), ultrasonography, magnetic resonance imaging (MRI) scans–don't provide enough information to confirm a diagnosis (Allen *et al*., 2016; Bokko, 2018). Laparoscopy has been shown to be more accurate than radiography for staging cancers of the digestive system (Kooby, 2006). Laparoscopy can greatly reduce cost and remove open surgery for the treatment of RIDS. Diagnostic laparoscopy (rumenoscopy) or laparoscopic surgery (rumenotomy) in ruminant livestock is performed in the abdomen through multiple (2 - 5) stab incisions, 1 - 5 cm long, to allow placement of lap instruments. The cardinal surgical tool is the laparoscope, an imaging device equipped with a halogen illuminated telescope allowing two directional movement (upward 180º and downwards 100º) to enable enhanced real-time visualization of the abdominal contents, assessment, digital recording, and storage (Sasikala *et al.,* 2019). The appearance, shape, location, size, orientation, and topography scores of the rumen and the enclosed polythene material without open surgery can be established. Moreover, laparoscopy proffers reduced tissue trauma, brief morbidity, negligible hemorrhage, minimal scaring, alleviated post-operation pain, abated infection and contamination risks, faster convalescence, and better cosmesis.

Prevention and control

Exploitation of the full potential of ruminant livestock resources is impeded by RIDS in domestic ruminants kept by semi-intensive or free-range systems in developing countries. This, coupled with drought, untapped genetic potentials, poor animal husbandry practices, and endemic diseases, poses a severe threat to ruminant livestock production systems with huge economic loss, threat to food security, and human health. Despite the high incidence, deleterious impacts on livestock economy and human health, there is no deliberate undertaking or established diagnostic or treatment protocol for timely intervention, making RIDS a major but neglected disease of ruminant livestock. For instance, RIDS is a significant factor in the diminution of the quality of meat, milk, leather,

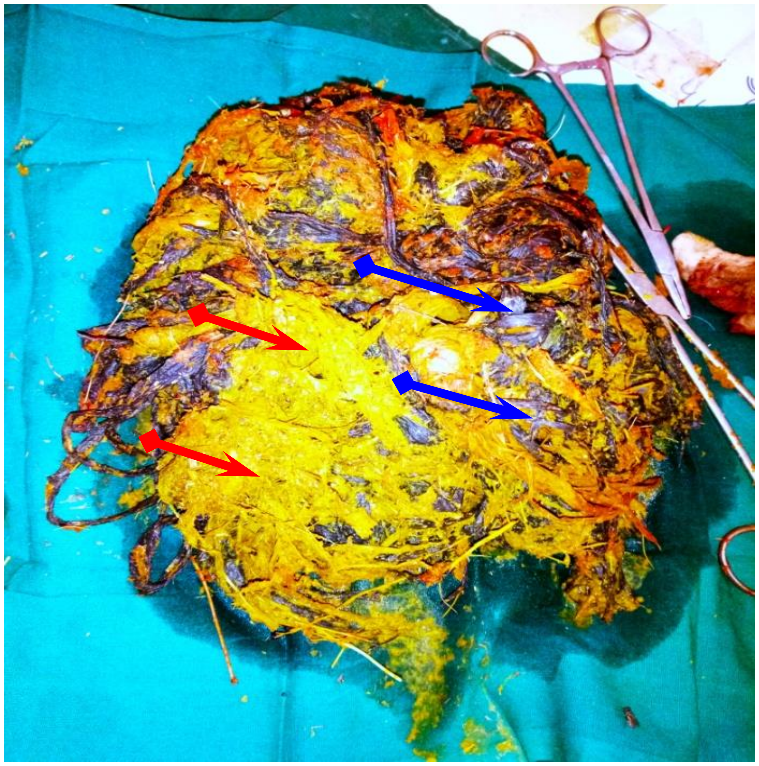

Figure 2. Polythene mass weighing 4.3 kg recovered via rumentomy from a 6 year old Sokoto Red Doe. The mass is intertwined polythene material (blue arrows) with trapped feed material (red arrows). Forceps and needle holder not part of the recovery.

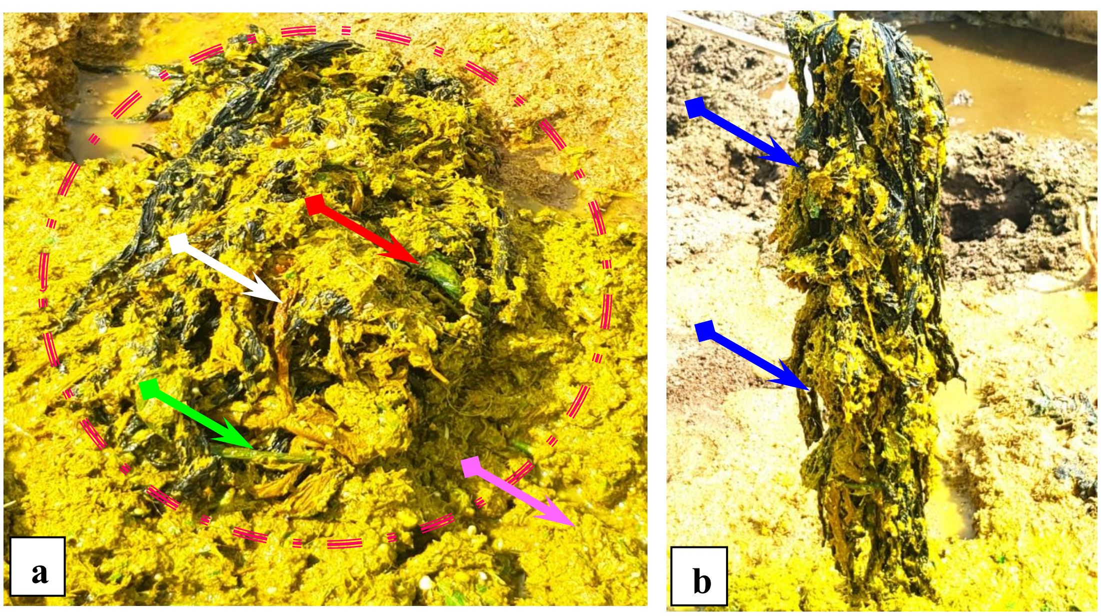

Figure 3. Polybezoar weighing 3.8kg recovered following reumenotomy in a 5 year old Borno white Sahel Buck. **(a).** Polybezoar (polythene entangled with other indigestible materials: nylon rope (red arrow), leather (green arrow), cloth (white arrow) including trapped feed material (pink arrow); **(b).** The polybezoar partially freed of feed material (blue arrows).

manure, and household livelihoods from the 152.48 million ruminant population in Nigeria.

Moreover, population explosion, ineffective waste management, urbanisation, global plastics production, growth of consumerism with attendant generation of huge polythene waste litter (Andrady and Neal, 2009; Adane and Muleta, 2011) only fuel the incidence of RIDS. This only continues to wreak havoc on the ruminant livestock sector and consequently represses ruminant livestock productivity in developing countries (Borrelle *et al*., 2020; Lau *et al*., 2020).

One way to definitively halt the menace of RIDS is a plastic-free revolution. The holy grail of the complex global issues of plastic waste pollution requires extraordinary efforts to transform the global plastics value chain to achieve a truly sustainable plastics and zero plastic waste (Walker and Xanthos, 2018; Lau *et al*., 2020; Walker and Fequet, 2023). Implementation of these initiatives, however, is still a pipedream owing to extreme interest in the polythene industry. The global plastic production reached 368 million metric tons in 2019 (Lebreton and Andrady, 2019), stood at 390 million metric tons in 2021 from 2 million tons in 1950, generating over $609.2 billion annually with attendant huge polythene wasteland (Kamalakar *et al*., 2021). Plastic waste generation has resulted in a global plastic pollution crisis (Sequeira *et al*., 2020; Walker *et al*., 2022). Up to 50% macroplastics are single-use purposes with limited recyclability – utilized for just a few moments, but remain sequestered in natural ecosystems on the planet for an estimated two centuries (Geyer and Jambeck, 2017; Kumar *et al*., 2021; Walker and Fequet, 2023). Owing to low cost, ease of production, versatility, and moisture resistance, availability, strength, flexibility, plastic has gained widespread industrial applications. Moreover, plastic production has already displaced many traditional materials such as wood, stone, leather, and many others (Andrady and Neal 2009). As such, halting plastic production is insurmountable in the near future; a clear indication that, incidence of RIDS will only increase (Bokko 2011). The alternative is the desirable thrust to develop early, rapid, and definitive diagnostic techniques as well as minimally invasive treatment for early-stage RIDS.

Additionally, deliberate downstream strategies must be enacted to curb plastic pollution in the face of current plastic production and waste generation at a pace with existing global regulations (Walker and Fequet, 2023). Furthermore, society needs to drastically reduce plastic consumerism; radically increase domestic recycling and reusing plastics to achieve a sustainable plastics future. The measure will prevent animals from accessing indigestible polythene waste. Furthermore, concerted legislation by governments for creating awareness and enlightenment programmes among the public and, in particular, livestock farmers about the harmful effects of plastic material should be enacted. Moreover, the dangers of RIDS and the impact on overall performance of ruminant livestock productivity, and in turn its effects on animal and human health, must be emphasized. Although fairly easy, convenient, and practical recovery and recycling of this omnipresent waste remain insufficient in Nigeria, leading to environmental littering with an estimated 87% littered or burned in the open. Provision of good animal husbandry practices, such as intensive livestock farming technologies of the "barn" type or controlled grazing (electric shepherds), fodder banks, water facilities, shelter, mineral supplements, as well as proper plastic disposal, will check ruminant livestock access to polythene waste, thereby reducing RIDS prevalence. These, along with laparoscopy, diagnostic markers, and nanotechnology for clinical practice, will minimise RIDS incidence.

Few attempts have been made to study RIDS, the detection of xenobiotic chemicals, early diagnosis, and heavy metals leached from polythene materials in ruminal fluid, milk samples, meat, and other body parts. Still, more deliberate and continual in-depth research is required for their determination and documentation at the governmental level in Nigeria. Priority funding for research into RIDS is very basic at best and performed by researchers as a non-priority domain. Our attempts at getting funding to study the pathophysiology, innovative methods for early diagnosis, and minimally invasive treatment of RIDS due to plastic materials in vulnerable ruminant livestock did not receive the exigency with which we viewed the disease. Additionally, the impact of putative plastic residues and associated xenobiotic chemicals and heavy metals in milk and meat products of animals with RIDS due to plastic materials on human health has not received the urgent attention it deserves.

CONCLUSION

The prevalence of RIDS keeps escalating and poses a major threat to the health and welfare of free-range and semi-intensive reared ruminant livestock. Plastic-free revolution is insurmountable in the foreseeable future, as generated plastic waste exceeds efforts to mitigate plastic pollution. Innovation and implementation of new high-tech diagnostic and treatment approaches will proffer better, faster detection and early treatment of RIDS to obviate the debilitating course, averting complications and greatly enhancing recovery. Diminution of the incidence of RIDS will turn around the economic losses and improve ruminant livestock productivity. Restoration of livestock health and welfare will directly boost the profitability of free-range or semi-intensive ruminant livestock systems.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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