Invited Review [Revisión invitada]

AMERICAN CONSORTIUM FOR SMALL RUMINANT PARASITE CONTROL INVESTIGATIONS ON THE USE OF PLANT SECONDARY COMPOUNDS OF SERICEA LESPEDEZA FOR THE CONTROL OF SHEEP AND GOAT PARASITES †

[INVESTIGACIONES DEL CONSORCIO AMERICANO PARA EL CONTROL DE PARÁSITOS DE PEQUEÑOS RUMIANTES SOBRE EL USO DE COMPUESTOS SECUNDARIOS DE SERICEA LESPEDEZA PARA EL CONTROL DE PARÁSITOS DE OVEJAS Y CABRAS]

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SUMMARY

Introduction: Sericea lespedeza (SL; *Lespedeza cuneata*) is a warm-season perennial legume well-adapted to the warm, moist climate of the southeastern USA. High in condensed tannins and other secondary compounds, SL has potential as an anti-parasitic nutraceutical forage for sheep and goats in this region and throughout the world where it is adapted. **Objectives**: To summarize the nearly 20 years' work of the American Consortium for Small Ruminant Parasite Control (ACSRPC) related to the anti-parasitic properties of SL in the diet of small ruminants. **Main findings**: In a series of experiments with goats and sheep fed SL in fresh (grazed), dried (hay, leaf meal, pellets) or preserved (ensiled) forms, this forage showed promising anti-parasitic efficacy against GIN, particularly *Haemonchus contortus*, and coccidia (*Eimeria* spp.), lowering gastrointestinal nematodes (GIN) fecal egg counts (FEC), coccidial fecal oocyst counts (FOC), and reducing GIN larval development and worm burdens. **Implications**: These results indicate the potential of SL as a component of integrated, novel (non-chemical) parasite management programs for on-farm application by small ruminant producers. **Conclusions**: Sericea lespedeza has very good anti-parasitic activity against GIN and coccidial infection in sheep and goats and has excellent potential as a nutraceutical forage for small ruminant producers, either for their own use or for sale as nutraceutical hay or pellets.
Key words: Sericea lespedeza; Tannins; Gastrointestinal nematodes; Coccidia; Goats; Sheep.

RESUMEN

Introducción: Sericea lespedeza (SL; *Lespedeza cuneata*) es una leguminosa perenne de estación cálida bien adaptada al clima cálido y húmedo del sureste de Estados Unidos. Con un alto contenido de taninos condensados y otros compuestos secundarios, SL tiene potencial como forraje nutracéutico antiparasitario para ovejas y cabras en esta región y en todo el mundo donde está adaptado. **Objetivos:** Resumir el trabajo de casi 20 años del Consorcio Americano para el Control de Parásitos de Pequeños Rumiantes (ACSRPC) relacionado con las propiedades antiparasitarias de SL en la dieta de pequeños rumiantes. **Resultados principales:** En una serie de experimentos con cabras y ovejas alimentadas con SL en forma fresca (pastore), seca (heno, harina de hojas, pellets) o conservada (ensilada), este forraje mostró una eficacia antiparasitaria prometedora contra GIN, particularmente *Haemonchus contortus* y coccidias (Eimeria spp.), reduciendo el recuento de huevos fecales (FEC) de nematodos gastrointestinales (NGI), el recuento de oocistos fecales de coccidias (FOC) y reduciendo el desarrollo larvario de NGI y la carga de nematodos. **Implicaciones:** Estos resultados indican el potencial de SL como componente de programas integrados y novedosos (no químicos) de manejo de parásitos para su aplicación en granjas por parte de pequeños productores de rumiantes. **Conclusiones:** Sericea lespedeza tiene muy buena actividad antiparasitaria contra NGI y coccidias en ovinos y caprinos y tiene un excelente potencial como forraje nutracéutico para pequeños productores de rumiantes, ya sea para uso propio o para su venta como heno o pellets nutracéuticos.
Palabras clave: Sericea lespedeza; taninos; Nematodos gastrointestinales, Coccidia; Cabras; Oveja.

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INTRODUCTION

Infection with internal parasites, including gastrointestinal nematodes (GIN) and coccidia (*Eimeria* spp.), are a severe threat to health and productivity of sheep and goats worldwide, causing unthriftiness, and in severe cases, death. With hot, wet late spring, summer, and early fall months, the southeastern United States (US) has an ideal climate to support growth and development of the free-living stages (eggs, larvae) of GIN, and this is particularly true for the tropical/subtropical parasite *Haemonchus contortus* (Miller *et al.*, 1998; Besier *et al.*, 2016). Due to global warming, *H. contortus*, a voracious blood-feeder, is becoming a greater problem in the northern US, Canada, and northern Europe where it never used to be an issue (Waller and Chandrawathani, 2005; Emery *et al.*, 2016; Gasser and Samson-Himmelstjerna, 2016). Infection with *Eimeria* spp. is also a major challenge for small ruminants, particularly for lambs and kids during times of stress, such as at weaning (Da Silva and Miller, 1991).

For the last several decades, the most common treatment for infection with GIN and coccidia has been the use of broad-spectrum anthelmintics and coccidiostats, respectively, despite reports of their reduced effectiveness. There have numerous reports of anthelmintic resistance in small ruminant GIN, both in the US (Terrill *et al.*, 2001; Mortensen *et al.*, 2003; Howell *et al.*, 2008) and overseas (Kaplan, 2004; Papadopoulos *et al.*, 2012; Salgado and Santos, 2016), and several reports of resistance to coccidiostats in poultry (Greif *et al.*, 1996; Haberkorn, 1996). In view of this growing problem, much research in recent years has been dedicated to the development and validation of alternative, novel parasite control technologies, including the use of medicinal plants (Terrill *et al.*, 2012; Hoste *et al.*, 2015).

BACKGROUND

I did not intend to do parasitology research when I started at Fort Valley State University (FVSU) in Georgia nearly 30 years ago. My training was in forage agronomy, and I accepted a position in animal science at FVSU in 1992, working with small ruminants (goats and sheep). After starting in the new position, I acquired a herd of young meat goats from a farm in southern Georgia with the intention of completing forage research. As a forage scientist, I was trained that animals should be dewormed prior to each experiment and then assumed to be parasite-free in the data analysis. Of course, this was not the case. When I tried to deworm the goats with ivermectin (Ivomec), which most farmers in Georgia were using at the time, it was not effective. So, I tried a series of other anthelmintics with the animals, none of which were effective, after which I decided that my first study should be testing for level of anthelmintic resistance in the goats. In a study published in 2001 (Terrill *et al.*, 2001), we evaluated efficacy of 7 different drugs, including some from each of the three major classes of anthelmintics, in Research Station goat herds from FVSU and the University of Georgia (UGA). Of the drugs tested, including albendazole, fenbendazole, ivermectin, doramectin, moxidectin, levamisole, morantel tartrate, and a combination of albendazole and ivermectin, there was resistance in both herds for everything except moxidectin. In a follow up on-farm study, out of 18 goat farms tested in Georgia and South Carolina, there was resistance to ivermectin on 17 farms and multiple anthelmintic resistance on 14 farms (Mortensen *et al.*, 2003). In this study, resistance to moxidectin was found on one farm, with suspected resistance on three others. In a later study with goats and sheep from on 46 farms in 8 southern states, Puerto Rico, and St Croix in the US Virgin Islands, there was resistance of *H. contortus* to benzimidazole, levamisole, ivermectin, and moxidectin on 98%, 54%, 76%, and 24% of farms, respectively, with total anthelmintic resistance (resistance to all 3 classes plus moxidectin) on 17% of farms (Howell *et al.*, 2008).

Prior to starting this work, I had attended the Second International Conference on Novel Approaches to the Control of Helminth Parasites of Livestock at Louisiana State University (LSU) in March, 1998, which was my introduction to parasitology research. At this conference, I met Drs. James Miller (LSU), Ray Kaplan (UGA), and Michael Larsen (Danish Center for Experimental Parasitology, The Royal Veterinary and Agricultural University, Denmark), and we began planning a collaborative research program. Later that summer, a colleague from FVSU (Dr. Oreta Samples) and I traveled to LSU for a week of training in Dr. Miller's laboratory, after which Dr. Samples helped me set up a parasitology research laboratory at FVSU, with the first project being the anthelmintic resistance testing (Terrill *et al.*, 2001; Mortensen *et al.*, 2003). As anthelmintic resistance in small ruminant GIN was emerging as the greatest constraint to profitable sheep and goat production at the time, our research group began to focus on novel methods for parasite control to address this challenge. I received a small amount of funding for a planning meeting, and Dr. Miller, Dr. Kaplan, and others met at FVSU in June, 2001, to discuss how to address the situation moving forward. At this meeting, it was decided that collaborative research on parasite control in small ruminants should initially focus on anthelmintic resistance evaluation, FAMACHA© validation in sheep and goats in the U.S. (Kaplan *et al.*, 2004; Burke *et al.*, 2007) and use of nematode-trapping fungi (Terrill *et al.*, 2004) and tannin-containing plants (Shaik *et al.*, 2004). At a follow-up meeting in 2002, we were trained in the use of the FAMACHA© system (van Wyk and Bath, 2002) by Dr. Adriano Vatta, who was at the Onderstepoorte Veterinary Institute at the University of Pretoria in South Africa at the time.

Following the 2001 meeting, I submitted a proposal on novel approaches for GIN control in small ruminants in September, 2001, which was funded in 2002. After this project was initiated, I suggested that our research group form a consortium, Dr. Miller suggested the name 'Southern Consortium for Small Ruminant Parasite Control (SCSRPC), and the SCSRPC was formed in 2003. After 20 years, the Consortium, which was later renamed the American Consortium for Small Ruminant Parasite Control (ACSRPC), is still going strong and has been expanded to include 43 scientists and extension specialists from multiple institutions in North America, Europe, Africa, and Asia, all with a common goal of (1) developing novel methods for sustainable control of gastrointestinal parasites in small ruminants and (2) providing information to the stakeholders in the small ruminant industry on the most up-to-date methods and guidelines for management of gastrointestinal parasites (from ACSRPC Mission Statement, wormx.info). Our group meets twice per year to plan research and outreach on sustainable parasite control. Initially, all of the meetings were face-to-face, usually with one at FVSU and the second at another Consortium member's institution. More recently, one of the meetings each year has been held remotely, and since the Covid-19 pandemic started, all of our meetings have been online.

SERICEA LESPEDEZA – INITIAL STUDIES

My research on the use of anti-parasitic tannin-containing plants has focused primarily on sericea lespedeza (SL; *Lespedeza cuneata*), a warm-season perennial legume well adapted to the southeastern US. and other parts of the world with similar climates, such as in southern Africa (Terrill and Mosjidis, 2015). The initial project was completed with ground SL hay because we did not have established SL pastures at the time. We did not expect the hay to be effective because of my PhD project with the same plant, which showed that extractable condensed tannin content of SL was greatly reduced when fresh forage was sun-dried for hay (Terrill *et al.*, 1989; 1990). We assumed that extractable tannin was more bioactive than protein-bound tannin (Terrill *et al.*, 1992). Much to our surprise, the SL hay effectively reduced fecal egg counts (FEC) of the goats, with significant reductions compared to a bermudagrass (*Cynodon dactylon*) hay control diet by the 3rd and 4th weeks of the 28-day trial (Shaik *et al.*, 2004). This data was presented as a poster at the 8th International Goat Conference in Pretoria, South Africa, during July, 2004, where I met Gareth Bath and Jan van Wyk (University of Pretoria), which led to on-farm research with SL in South Africa and other collaborative research projects ever since.

Because of the success of the initial project with SL, an 11-week study was completed during summer, 2005, comparing SL and bermudagrass hays fed to artificially-infected 7-8 month-old intact male Boer goats at 75% of the diet with a 16% crude protein corn and soybean meal-based feed supplement making up the remaining 25% of daily intake (Shaik *et al.*, 2006). All the goats were fed the control diets during the first 5 weeks of the trial, after which half the animals were switched to the SL hay ration. There was an 80% reduction in FEC in the SL-fed goats a week after starting the treatment feeds, and these differences remained until the end of the experiment. There was also a significant increase in blood packed cell volume (PCV) and a reduction in development of GIN eggs to infective larvae in the SL-fed goats. At the end of the trial, adult female *H. contortus*, *Teladorsagia circumcincta*, and *Trichostrongylus colubriformis* numbers were reduced by 76%, 36%, and 50%, respectively (Shaik *et al.*, 2006). Despite these very positive results with goats at FVSU, there was skepticism that similar results would be observed in feeding an SL hay diet to a different species (sheep) in a different location (LSU). In a study with 4-month-old naturally and artificially-infected ewe lambs fed diets of SL or bermudagrass hays, FEC were reduced (67-78%) in both groups due to SL feeding, while worm burdens in the naturally-infected lambs fed SL hay were 67% lower than for control animals (Lange *et al.*, 2006).

SERICEA LESPEDEZA – LEAF MEAL PELLETS

Our research group has completed a number of grazing studies with SL showing positive anti-parasitic effects against small ruminant GIN in different regions of the US., including Georgia (Mechineni *et al.*, 2014), North Carolina (Luginbuhl *et al.*, 2013), and Arkansas (Burke *et al.*, 2012a; 2012b), as well as in an on-farm study completed in South Africa (Botha, 2015). While this gives farmers in these regions a natural (non-chemical) tool for parasite management in their herds or flocks, what about farmers in regions where SL is not well-adapted? To address this question, we initiated research to determine the effect of pelleting SL on its bioactivity against GIN and coccidia (*Eimeria* spp.) in both goats (Terrill *et al.*, 2007; Kommuru *et al.*, 2014) and sheep (Burke *et al.*, 2013). We felt that this was an essential step to determine if farmers could grow and market SL as a nutraceutical feed for livestock (Hoste *et al.*, 2015).

The initial challenge to overcome in starting this work was to find a mill that would process SL hay into pellets. When we began this work in 2006, I had to pick up a load of SL hay in Alabama and haul it to Texas for pelleting. Because of slick roads and high winds in East Texas, the trailer I was driving jackknifed on the highway. After hauling the truck and trailer to a garage for repairs, we had to unload the hay onto a flatbed trailer and complete the trip to the mill for pelleting. The pellets were successfully processed at the mill and then shipped back to FVSU by a courier service. Even so, we were concerned that the pelleting process, which includes grinding and then pushing the feed through a die to form the pellets, all generates heat that could potentially reduce tannin bioactivity by altering its structure or increasing the amount of tannin bound to protein. Sure enough, although total condensed tannin concentrations were similar, the amount of extractable tannin in the SL pellets was lower, with higher concentrations of protein-bound tannins compared with ground, unpelleted SL (Terrill *et al.*, 2007). However, when we completed the study comparing pelleted SL, ground SL hay, and ground bermudagrass hay diets fed to 6-month-old naturally-infected Kiko-Spanish cross male kids, the FEC and adult abomasal worm number reductions relative to control were greater in the SL pellet-fed kids than in those on the ground SL diet (Terrill *et al.*, 2007). Possible explanations for this result were that pelleting improved overall intake of the ration in the goats, leading to greater intake of total tannin, that tannin structure (prodelphinidin to procyanidin ratio and mean degree of polymerization, or molecule size) may be more important than tannin level in the plant, or that tannin bound to protein may be released in the acid environment of the abomasum (Terrill *et al.*, 2007; Kommuru *et al.*, 2014). Regardless of the exact reason for these results, pelleting SL hay should add value to its use as a nutraceutical forage by increasing flexibility for feeding, storage, and shipping.

After this initial study with pelleted SL, our Alabama partner (Sims Brothers Seed Company, Union Springs, AL) began making SL pellets, allowing us to run a series of additional SL pellet experiments with small ruminants, both as the primary diet (Kommuru *et al.*, 2014) and as a supplement to animals grazing grass pasture (Gujja *et al.*, 2013; Burke *et al.*, 2014; Hamilton *et al.*, 2017). To test the efficacy of pelleted SL against coccidia (*Eimeria* spp.) of goats, we had to create conditions leading to a natural increase in coccidial infection in the animals. To do this, we purchased recently-weaned (16 weeks old) Kiko-cross male goats from southern Georgia, transported them for 2 hours in a stock trailer to the FVSU Agricultural Research Station, held them for 72 hours on pasture, and then placed them into covered pens with either SL leaf meal pellets or a commercially-available goat pellet as the sole diet for a 28-day trial (Kommuru *et al.*, 2014). A second set of kids (20-week-old Spanish bucks) were allowed to graze for 21 days and then moved to the covered pens with the same feeds for a 28-day trial. In Experiment 1, the fecal oocyst count (oocysts per gram, OPG) of control animals increased from 1200 to over 7000 within a week, while the SL pellet-fed goats' OPG decreased (96.9% reduction compared to control) and remained low for the duration of the trial (Kommuru *et al.*, 2014). Gastrointestinal nematode FEC were reduced by 78.7% in the SL-fed goats after 7 days. In the second experiment, both groups averaged 24,000 OPG at the start of the trial, and the kids fed the SL pellets had a 92.2% lower OPG after a week, suggesting that feeding SL pellets had both a preventive (Experiment 1) and a therapeutic effect (Experiment 2) against coccidial infection in goats.

SERICEA LESPEDEZA – SILAGE

In addition to SL grazing, hay, leaf meal, and pellet studies, the anti-parasitic potential of ensiled SL was tested in naturally-parasitized goats. The challenge was ensiling enough lespedeza to complete a feeding trial. To do this, fresh SL forage was cut and chopped into approximately 1.27 cm lengths using a forage harvester (Troy-Bilt Chipper-Shredder CS 4323, Troy-Bilt, Valley City, OH) and deposited onto large plastic sheets (30.5 m × 7.6 m). Half the chopped material was immediately packed into 132.3 L black plastic bags and tied after manual (packing by hand and foot) removal of as much air as possible. The bags were then placed inside a second bag, tied, and stored in a barn for at least 12 weeks to allow the bagged material to ensile. The other half of the chopped SL material was allowed to sun-dry on the plastic sheets for 72 Hours while being periodically turned to allow uniform drying, then bagged for storing. After 3 months, the bags with the high-moisture plant material were opened, and after removal and discarding of the top material (approximately 10 cm), the remaining ensiled SL in each bag was fed within 24 hours to naturally-infected 9-month-old intact Spanish bucks. The treatments in this study were ensiled SL, chopped, sun-dried SL, and ground bermudagrass hay at 70% of the diet, with the remainder consisting of a grain mixture formulated to balance dietary protein and energy. Despite some initial reluctance for the goats to consume the ensiled SL, after a few days, both of the SL groups were eating at a similar level, and both had significantly lower counts of nematode eggs and coccidial oocysts than goats on the bermudagrass diet during the 28-day trial (Whitley *et al.*, 2018).

MECHANISM OF ACTION

With a series of experiments showing unusually positive anti-parasitic results from feeding SL to small ruminants in various fresh, dried, and ensiled forms, the obvious research question was to determine why this was so. To look for answers to this question, we started a search to determine the possible mode of action of SL against GIN. In two studies, 8-10 month old male Alpine x Spanish cross kids were fed ground SL leaf meal or ground bermudagrass hay as the sole diet (Joshi *et al.*, 2011). The goats for both experiments (35 total) were maintained on concrete and dewormed twice at 3-week intervals with levamisole (Levasol, 12 mg/kg) and albendazole (Valbazen, 20 mg/kg) to remove existing infections. In experiment 1, 10 goats (5 per treatment) were fed the experimental diets for 35 days, starting 1 week prior to a one-time dosing with 5000 *H. contortus* L3, with the goats then humanely slaughtered after 28 days to determine GIN establishment in the abomasum and small intestines. In experiment 2, the remaining 25 kids were artificially infected with 5000 *H. contortus* L3 and fed the bermudagrass diet for 35 days to allow a patent infection and then randomly allocated to a diet of SL (n = 13) or bermudagrass (n = 12) for an additional 28 days, with fecal and blood samples taken weekly for FEC and PCV determination, respectively. Four animals for each treatment group were slaughtered for worm counting on days 42, 49, and 63 post-infection (7-28 days on SL diet), except for day 42, when 5 SL treatment goats were processed (Joshi *et al.*, 2011). Worm counts, female worm fecundity, worm length and mucosal eosinophils, mast cells and globule leucocytes were measured in the goats after slaughter. In experiment 1, *H. contortus* establishment was 33% lower ($P < 0.05$) in goats on the SL diet compared with those fed ground bermudagrass, while in experiment 2, FEC were significantly lower in the SL-fed kids compared to the control group after 7 days, and blood PCV values higher in the SL group after 28 days (Joshi *et al.*, 2011). There were no differences in worm counts, female worm fecundity, worm length and mucosal eosinophils, mast cells and globule leucocytes between the two groups.

To determine the chemical structure of tannins in SL, freeze-dried, ground SL leaf and stem material and SL leaf pellets were sent to the laboratory of Prof. Irene Mueller-Harvey at the University of Reading in Great Britain. Her team's analysis revealed much higher tannin content in SL leaves than stems (16.0 g vs. 3.3 g/100 g dry weight), larger molecules in leaf (42 mean degree of polymerization, mDP) than stem (18 mDP) CT, and a predominance of prodelphnidin (PD) tannin subunits in both SL leaf and stem CT (98% and 94%, respectively; Mechineni et al, 2014). The concentration of CT in SL leaf meal pellets was also high (13.2%), with nearly pure PD (97.4%) and high molecular weight compounds (26,316 Daltons or 86 mDP; Kommuru *et al.*, 2014). Our conclusions from this work was that this unique structure of SL CT was at least partially responsible for its anti-parasitic effectiveness against both GIN and coccidia in small ruminants (Kommuru *et al.*, 2014). To further investigate the potential mechanism of action of SL CT against internal parasites, adult females of *H. contortus* were recovered directly from the abomasum of goats fed SL pellets in a pen study or as a supplement in a bermudagrass grazing study and fixed for scanning electron microscopy examination (Kommuru *et al.*, 2015). Eight of 10 worms (3 of 5 in pen study, 5 of 5 in grazing supplement study) from the SL treatment animals showed cuticular damage compared with no damage for the worms recovered from control animals, suggesting a direct effect of SL CT on the cuticle of adult female *H. contortus* in goats (Kommuru *et al.*, 2015).

There is additional research needed to elucidate the anti-parasitic mechanism of action in SL, including whether it is due principally to the unique structure of its condensed tannins or to the many other secondary compounds in this plant (Baek *et al.*, 2018; Kang *et al.*, 2021), or a combination of both. Application of next generation analytical techniques, including metabolomics and metagenomics, will also likely be useful in determining the role of SL secondary compounds in enhancing the nutraceutical properties of SL, and our team is already utilizing these technologies (Pannell *et al.*, 2022).

SERICEA LESPEDEZA – ON-GOING AND FUTURE WORK

Our team's recent work with SL has focused on expanding the use of this bioactive forage to larger numbers of farmers and a wider geographic area world-wide. Forage quality and yield data for SL grown in small plots in North Carolina, Georgia, Alabama, Louisiana, and Texas (Muir *et al.*, 2014; 2017; 2018) were used, along with soil and weather data from each site, to develop a prediction model for optimal conditions for establishment and production of lespedeza (Panda *et al.*, 2020). The model was applied to the entire country of Eswatini in southern Africa, most of which was predicted to be highly suitable for SL production (Panda *et al.*, 2020). Data from on-farm SL production sites in the US and Africa will be used to validate and improve the prediction model over the next few years.

Also looking to the future potential of lespedeza as a nutraceutical forage for livestock, we obtained seeds of additional SL cultivars, as well as other *Lespedeza* species from a germplasm collection at the USDA Plant Genetic Resources Conservation Unit in Griffin, GA, and established them in small plots at the FVSU Agricultural Research Station. After establishment, the plants were cut, freeze-dried, and ground, with tannins extracted from each SL cultivar and *Lespedeza* species and analyzed for anti-parasitic and protein-binding bioactivity (unpublished data). It is hoped that this will provide useful information to future plant breeders of nutraceutical forages. Other current projects include the use of statistical and analytical tools to further characterize the positive effects of lespedeza in the diet of ruminants. Through meta-analysis of recent literature on the nutritional properties of SL, we concluded that keeping lespedeza as 60% of the diet of ruminants or less will prevent anti-nutritional effects of SL tannins (Pech-Cervantes *et al.*, 2021).

SERICEA LESPEDEZA -ON-FARM APPLICATION

Despite ongoing and planned future research with SL, successful farm-level application of this nutraceutical forage in fresh (grazed), dried (hay, leaf meal, pellets), and preserved (ensiled) forms is not dependent upon future research outcomes and is currently underway in the southern U.S. and southern Africa (Mosjidis and Terrill, 2013; Terrill and Mosjidis, 2015). In fact, the number of farmers producing SL as a nutraceutical forage for sale or for their own use has been growing steadily in recent years, and this trend is expected to continue (R. Edwards, Foxpipe Farm, Laurens, SC, pers. comm.).

CONCLUSIONS

Overall, the work of FVSU and our partners in the ACSRPC with SL over the last twenty years has demonstrated the value of this plant as an anti-parasitic nutraceutical forage for both sheep and goats when fed fresh (grazed), as hay, in pelleted form, or as silage (Terrill *et al.*, 2012; Whitley *et al.*, 2018). This research has laid the groundwork for expanded use of SL to improve the health and productivity of sheep and goats in the US and worldwide, particularly for small and limited-resource farmers.

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Data availability. Data are available from the corresponding author (terillt@fvsu.edu) upon reasonable request.

Author contribution statement (CRediT). **Thomas H. Terrill**: Conceptualization, data curation, formal analysis, methodology, validation, visualization, writing – original draft – review and editing.

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