

NIFA SCRI Project 2023-05687 SPINACH REPORT (09/2024-08/2025)

Project Title: Development of germplasm resources and molecular breeding tools to combat endemic and emerging diseases in US spinach production

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Total Awarded Budget: \$3,578,418.00

Project Duration: 09/15/2023 – 09/14/2027

Project Report Period: 09/14/2024 – 09/15/2025

Recipient Name: *University of Arkansas*

Project Contact: *Ainong Shi/479-879-0159/ashi@uark.edu;*

Project PD: Ainong Shi – University of Arkansas

Project Co-PD:

- James Correll- University of Arkansas
- Carlos Avila - Texas A&M AgriLife
- Larry Stein- Texas A&M AgriLife
- Juan Enciso- Texas A&M AgriLife
- Samuel Zapata - Texas A&M AgriLife
- Beiquan Mou- USDA-ARS
- Lindsey du Toit- Washington State University
- Bindu Poudel-Ward, The University of Arizona (Detranaltes, Christopher)
- Susan B. Scheufele, University of Massachusetts,

Non-Technical Summary

Spinach (*Spinacia oleracea* L.) production is threatened by several diseases that individually or together severely reduce yield and quality. The most effective approach to improving productivity, marketability, and sustainability in spinach cultivation is by developing resistant cultivars. Traditionally, spinach breeding has relied on the time-consuming phenotypic selection that delays cultivar release. Alternatively, molecular breeding offers an advantage by accelerating the development of disease-resistant cultivars. The project builds upon the achievement of a previously awarded NIFA-SCRI project (2017-51181-26830), which focused on molecular breeding through molecular characterization of resistance to three predominant diseases of spinach: downy mildew (DM), white rust (WR), Fusarium wilt (FW), which laid the foundation for genetic tools, including SNP markers and genetic maps. Building upon this solid groundwork of molecular breeding initiative in spinach, the current project takes on a renewed focus by concentrating on quantitative trait loci mapping, marker validation, and the strategic integration of these findings into cultivar development. This project aims to expedite the development of spinach cultivar resistance to DM, WR, FW, and two emerging leaf spot diseases, namely Stemphylium leaf spot (SLS) and anthracnose leaf spot (ALS). This project aims to generate improved genome-enabled resources to introduce resistant traits into the cultivar development pipelines to effectively manage prevalent and emerging diseases in spinach. The project's long-term goal is to develop new disease-resistant cultivars by utilizing advanced genetic tools and selection methods delivered from this project that will serve as a valuable resource for spinach improvement. The breeding process will be expedited by integrating newly developed molecular breeding tools benefitting both public and private breeders and growers. The project will address disease threats and contribute to effective disease management strategies by leveraging genetics, genomics, and innovative breeding techniques. This project will address the following areas of the USDA-SCRI program: (1) “Research in plant breeding, genetics, genomics, and other methods to improve crop characteristics”; and

(2) “Efforts to identify and address threats from pests and diseases,” including “emerging and invasive species.”

Goals / Objectives

Spinach (*Spinacia oleracea* L.) is an economically important vegetable crop worldwide with an estimated annual value of \$11.8 billion. The US is the second-largest spinach producer globally while leading in the fresh market segment with an annual product value of around \$500 million. Over the past three decades, the increasing interest in health-conscious diets has led to a consistent demand for spinach. Despite this increase in demand and production, the commercial cultivation of spinach faces a significant threat from several diseases. These diseases, individually or in combination, reduce yield and quality. Downy mildew (DM), white rust (WR), Fusarium wilt (FW), Stemphylium leaf spot (SLS), and anthracnose leaf spot (ALS) are five key diseases threatening spinach production in the US and worldwide. The spinach industry seeks continued development of improved, locally adapted germplasm and cultivars with resistance to major pathogens. Thus, the overarching objectives of this project are to develop spinach germplasm with resistance to these five key pathogens and to develop molecular tools for effectively introducing these traits into the breeding pipeline for cultivar development. The practical long-term goal of this proposal is to generate molecular breeding tools to expedite disease resistance breeding efforts and the release of resistant spinach cultivars against endemic and emerging diseases suitable for both conventional and organic production markets that can dramatically reduce fungicide use for disease control. To meet this goal, the project aims to develop efficient molecular breeding methods and phenotyping tools to accelerate the cultivar development process and serve the industry's needs. The specific research objectives of this proposal are to:

1. Characterize and validate molecular markers for resistance to endemic and emerging spinach diseases.

Hypothesis: *Genetic diversity in spinach germplasm collections includes sources of resistance to these five diseases that can be used for cultivar development.*

2. Introgress disease resistance into spinach breeding lines for cultivar development.

Hypothesis: *Combining molecular and disease phenotyping approaches will expedite cultivar development in spinach.*

3. Develop a spinach grower-oriented outreach program based on experiential learning and economic decision tools for disease management in spinach.

Hypothesis: *Interactive and demonstrative methods can increase the adoption of management practices to reduce production risks and increase production profits.*

The proposed efforts encompass identifying genomic regions that govern disease-resistant mechanisms, optimizing practical genetic tools to improve selection processes, and developing resistant spinach cultivars. In summary, this project endeavors to extend our ongoing efforts to make advances in spinach breeding, develop genomic and phenotyping tools, generate new knowledge, and expand genetic resources to expedite disease-resistant cultivar development to support sustainable and economically viable spinach production in the US.

*** Target Audience**

Spinach Producers, Growers, and Seed Companies: The target audience includes spinach producers, growers, and seed companies engaged through field days and various communication channels. Seed companies have actively utilized our molecular markers associated with disease resistance to enhance their spinach breeding programs.

Scientists: Our research outputs—including novel QTL and association mapping results, SNP marker discoveries, and our published articles, abstracts, presentations, and reports—serve as valuable resources for the scientific community. These contributions support continued advancements in plant science and breeding technologies.

Students: Multiple students, postdoctoral researchers, and research associates have received training in both classical and molecular breeding techniques. This training has included practical experience in traditional breeding methods such as crossing, advancing generations, and variety development. In addition, students have gained expertise in molecular breeding technologies, including QTL and association mapping, genome-wide association studies (GWAS), genomic prediction, SNP discovery and genotyping, and next-generation sequencing approaches such as whole genome sequencing (WGS), whole genome resequencing (WGR), and genotyping-by-sequencing (GBS). They have also been trained in the use of bioinformatics tools and the application of marker-assisted selection (MAS) and genomic selection (GS) in crop improvement.

*** Products**

Publications

2025

1. Bhattarai, K.*, A.B. Ogden*, S. Pandey, G.V. Sandoya, A. Shi, A.N. Nankar, M. Jayakodi, H. Huo, T. Jiang, P. Tripodi, and C. Dardick. 2025. Improvement of Crop Production in Controlled Environment Agriculture through Breeding. *Frontiers in Plant Science, Sec. Plant Breeding*, 15:1524601. <https://doi.org/10.3389/fpls.2024.1524601>.
2. Gyawali, S., G. Bhattarai, J.C. Correll, A. Shi*, and L.J. du Toit*. 2025. Genome wide association study of Fusarium wilt resistance in *Spinacia turkestanica*). *Scientific Reports* (2025) 15:15486 | <https://doi.org/10.1038/s41598-025-98932-x>.
3. Islam, ASM. F., J.J. Rameneni, C.A. Avila*, and A. Shi*. 2025. Improving genomic prediction of vitamin C content in spinach using GWAS-derived markers. *BMC Genomics* 26:171. <https://doi.org/10.1186/s12864-025-11343-0>.
4. Zima, H.V, K.J. Clark, B. Poudel-Ward, S.L. Slinski, S. Klosterman, and J. Correll. 2025a. Evaluation of spinach cultivars for downy mildew resistance in Yuma, AZ, 2023. *Plant Health Progress*. Published Online:21 Mar 2025. <https://doi.org/10.1094/PHP-12-24-0141-PDMR>
5. Zima, H.V, K.J. Clark, B. Poudel-Ward, S.L. Slinski, S. Klosterman, and J. Correll. 2025b. Evaluation of spinach cultivars for downy mildew resistance in Yuma, AZ, 2024. *Plant Health Progress*, Published Online:21 Mar 2025. <https://doi.org/10.1094/PHP-12-24-0142-PDMR>
6. Li, N., B. Wang, X. Shang, Q. Yang, L. Yang, M. Tao, S. Muhammad, A. Shi, C. Deng*. 2025. SpMS1, a Male Sterility Factor, Interacts with SpAP1 to Regulate Unisexual Flower Development in Dioecious Spinach. *Plant and Cell Physiology* 66: 60–74, <https://doi.org/10.1093/pcp/pcae135>

Submission

- Alatawi, I., H. Xiong, H. Alkabkabi, K. Chiwina, B. Mou, Y. Qu, R. Du, Q. Luo, D. J. Harrison, and A. Shi*. 2025. Genome-wide association study and genome prediction of tallness trait in spinach tallness phenotyping (Submitted to *Frontiers in Plant Science*)
- Bhattarai, G., B. Liu, J. Correll*, and A. Shi*. 2025. Genome-wide association study and genomic

prediction of leaf spot (*Stemphylium vesicarium*) resistance in spinach diversity panel (Submitted to Frontiers in Plant Sciences)

- Khuimphukhieo, I, Jose Carlos Chavez, Carlos Avila, Ainong Shi, Waldo Ojeda, and Juan Enciso. 2025. The use of unmanned aerial system (UAS) – based high throughput phenotyping (HTP) for yield prediction and growth analysis of spinach. 2025. Under review: Manuscript number:JAFR-D-25-00926. Journal of Agriculture and Food Research.

In Preparation

- Daba, S. D., Gyawali, S., Shi, A., and du Toit, L. J. 202X. Screening cultivated (*Spinacia oleracea*) and wild (*Spinacia turkestanica*) spinach accessions against two races of *Fusarium oxysporum* f. sp. *spinaciae*. Plant Disease: *In preparation*.
- Daba, S. D., Gyawali, S., Shi, A., and du Toit, L. J. 202x. Genome-wide association study and candidate gene identification for Fusarium wilt resistance in a panel of cultivated spinach (*Spinacia oleracea*) accessions. Molecular Breeding: *In preparation*.
- Gyawali, S., J.C. Correll, A. Shi*, and L.J. du Toit*. 2025. Genome wide association studies and genomic prediction of spinach Fusarium wilt resistance using SNP markers
- Olaoye, D., G. Bhattarai, J. Correll*, and A. Shi*. 2025. Genetic analysis reveals novel genomic regions for downy mildew resistance and the potential for predictive breeding in spinach (*Spinacia oleracea*) Horticulture Research: *In Preparation*)
 - Srungarapu, R.S., A. Shi*, C.A. Avila*. 2025. Genome wide association mapping and genomic prediction of anthracnose (*Colletotrichum dematium*) resistance in spinach (*Spinacia oleracea* L.). Journal of Experimental Botany

ABSTRACTS/MEETING presentation

2025

1. Alatawi, I., H. Xiong, B. Mou and A. Shi. 2025. Genome-Wide Association Study and Genomic Prediction of Leafminer Tolerance in Spinach. PAG 32 / January 10-15, 2025 • San Diego, USA. <https://pag.confex.com/pag/32/meetingapp.cgi/Paper/59122>.
2. Alkabkabi, H., I. Alatawi, H. Xiong, K. Chiwina, Y. Qu, R. Du, M.M. Ullah, D.J. Harrison, Q. Luo, and A. Shi. 2025. Evaluation of Salt Tolerance in USDA Spinach (*Spinacia oleracea* L.) Germplasm at the Seedling Stage. ASHS 2025 annual conference, July 28 – August 1, New Orleans, USA
3. Avila, C.A., J.J. Rameneni, A.S.M. F. Islam, A. Shi. 2025. Genomic prediction of Vitamin C in Spinach. Annual meeting of the Society for Experimental Biology. July 8-11th, 2025, Antwerp, Belgium
4. Du R., Y. Qu, K. Chiwina, H. Alkabkabi, M.M. Ullah, I. Alatawi, H. Xiong, Q. Luo, D.J. Harrison, B. Mou, and A. Shi. 2025. Genome-Wide Association Study and Genomic Prediction of Leaf Texture in USDA GRIN Spinach Germplasm. ASHS 2025 annual conference, July 28 – August 1, New Orleans, USA
5. Enciso, J., C.A. Avila, J.C. Chavez, I. Khuimphukhieo, A. Shi, and Waldo Ojeda. 2025. Unmanned aerial system (UAS)-based phenotyping for selection of spinach varieties. Annual meeting of the Society for Experimental Biology. July 8-11th, 2025, Antwerp, Belgium
6. Qu, Y, R. Du, K. Chiwina, H. Alkabkabi, M.M. Ullah, I. Alatawi, Q. Luo, D.J. Harrison, B. Mou, and A. Shi. 2025. Genome-wide association study of seed spine in spinach. ASHS 2025 annual conference, July 28 – August 1, New Orleans, USA

7. Rameneni, JJ. A.S.M. F. Islam, A. Shi, and C.A. Avila. 2025. GWAS-derived Markers Improves Genomic Prediction of Vitamin C Content in Spinach. ASHS 2025 Annual Conference. July 28th – August 1st, 2025. New Orleans, LA.
8. Scheufele, S. 2025. Leafy Greens pest Management and Climate Adaptations. Cornell Cooperative Extension-Eastern New York Commercial Horticulture Program, Leafy Greens Intensive. Hudson, NY. 65 attendees.
9. Scheufele, S.B. and E. Golonka. 2025. High Tunnel Crop Planning. New Entry-Farming Under Cover Series. January 14, 2025. Online. 62 attendees.
10. Shi, A., H. Xiong, J. Vijay, B. Analin, C.A. Avila and B. Mou. 2025. Genome-Wide Analysis for Nutritional Components in Spinach. PAG 32 / January 10-15, 2025 • San Diego, USA. <https://pag.confex.com/pag/32/meetingapp.cgi/Paper/56498>
11. Ullah M.M., A. Riaz, H. Alkabbabi, K. Chiwina, Y. Qu, R. Du, B. Mou, and A. Shi. 2025. Genome-wide association study reveals genetic loci associated with leaf base color variation in spinach (*Spinacia oleracea* L.). ASHS 2025 annual conference, July 28 – August 1, New Orleans, USA

2024

12. Higgins, G. 2024. Winter High Tunnel Spinach Production. New England Vegetable and Fruit Conference. December 18, 2024. Manchester, NH. 250 Attendees.
13. Higgins, G. 2024. Winter Spinach Fertility. Perennia TunnelTalks. November 6, 2024. Online.
14. Higgins, G. 2024. Winter High Tunnel Spinach Production. Perennia TunnelTalks. September 4, 2024. Online.
15. Scheufele, S.B., 2024. High Tunnel Pest Management. New Entry-Farming Under Cover Series. October 17, 2024. Online. 62 attendees.

Submission

16. Daba, S. D., Gyawali, S., Shi, A., and du Toit, L. J. 2025. Resistance screening and genome-wide association studies in spinach accession against two races of *Fusarium oxysporum* f. sp. *spinaciae*. Planned presentation for 11th International Spinach Conference, Monterey, CA, 21-22 October 2025

* Other Products

* Accomplishments

What was accomplished under these goals?

1. Characterize and Validate Molecular Markers for Resistance to Spinach Diseases

1.1 Downy Mildew (DM)

- Seventy genotypes tested in CA and AZ (2023–2025); over 30 lines showed resistance (Zima et al. 2025a,b).
- 24 of 243 accessions resistant to race 5. GWAS identified SNPs on chr1, chr3, and chr4 with high predictive ability ($r = 0.73\text{--}0.87$) (Olaoye et al., 2025, submitted).

1.2 White Rust (WR)

- 105 breeding lines screened in Crystal City, TX (2025). Most showed partial resistance due to low epidemic pressure (Spawton et al., 2024a; Avila & Stein, 2024). Resistant plants were isolated for seed increase.

1.3 Fusarium Wilt (FW)

- In *S. turkestanica*, 8 resistant accessions, 12 SNPs, and a QTL on chr6 identified (Gyawali et al., 2025a).
- In 364 accessions, 21 highly resistant; 36 SNPs associated with resistance to race 1. Candidate gene SOV5g023000 on chr5 (Gyawali et al., 2025b).
- Evaluated 379 accessions against Fos races 1 & 2; 52 accessions resistant to race 1; only 5 to race 2. GWAS found 27 and 34 loci linked to resistance. Results to be presented at 2025 Spinach Conference.

1.4 Stemphylium Leaf Spot (SLS)

- GWAS on 311 genotypes identified 4 key associated SNP markers. Prediction accuracy reached $r = 0.51$ (Bhattarai et al., submitted).

1.5 Anthracnose Leaf Spot (ALS)

- Syringe infiltration method optimized for phenotyping.
- GWAS on 266 accessions found 20 significant associated SNP markers; top SNP on chr6 linked to a jasmonate-induced gene. Marker sets had prediction accuracies of $r = 0.33$ – 0.47 . Manuscript drafted.

2. Introgress Resistance into Spinach Breeding Lines

- Recurrent selection increased downy mildew resistance in 34 crosses evaluated in Salinas, CA.
- 640 lines screened at Texas A&M Weslaco for disease resistance and leaf traits.
- 200 new lines grown during 2023–2025 winters; will be evaluated in October 2025 at Alma Station, AR.

3. Outreach and Economic Tools for Growers

3.1 Commercial Showcase Trial in Crystal City, TX

- 30 top varieties from global seed companies were tested in TX (Dec 2024–Feb 2025). Four diseases rated; Baboon showed no symptoms but had poor stand. Promising varieties for SLS include Shearwater, PV-1569, Bonnethead, and Gerenuk.

3.2 Economic Impact in Texas

- Drought, disease, and processing facility closure strained spinach production. Screening at Tiro Tres Farms identified tolerant varieties.
- Adoption of Life-Gard reduced fungicide use by 40%, lowering costs and supporting industry sustainability.

3.3 White Rust Economic Analysis

- Four management scenarios analyzed historical yields, market data, and estimated production costs:
 1. Baseline: 730.1 cartons/acre; \$4,053.40
 2. No treatment: 291.6 cartons/acre; \$3,910.30
 3. GH-107 lines: 687.6 cartons/acre; \$3,981.85
 4. GH-108 lines: 710.6 cartons/acre; \$3,993.82
- Monte Carlo simulations (1,000 iterations) showed resistant lines significantly improved profitability, with GH-108 lines performing best.

4. Other Significant Research Findings

- Downy Mildew Transmission: Oospores shown to transmit the disease via seed, confirming seedborne pathway (Klosterman et al., 2025).
 - Vitamin C Content: 62 SNPs linked to vitamin C; GWAS-derived markers had r up to 0.82 (Rameneni et al., 2025).
 - Salt Tolerance: 17 of 150 accessions salt-tolerant. SNPs linked to chlorophyll and height inhibition (Alkabkabi et al., 2025, ASHS).
 - Seed Spines: 3 SNPs on chr3 associated with seed spines (Qu et al., 2025, ASHS).
 - Leaf Texture: 4 SNPs associated with flat vs. savoy texture; max $r = 0.43$ (Du et al., 2025, ASHS).
 - Leaf Base Color: 3 SNPs on chr3 associated with base color (Ullah et al., 2025, ASHS).
 - Spinach Improvement: 200 breeding lines evaluated and harvested in 2024–2025 winter at Alma Station.
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What opportunities for training and professional development has the project provided?

1. Personnel Training and Hiring

- Two postdoctoral research associates were hired: one in Dr. Avila's lab (Texas A&M AgriLife, January 2025) and one in Dr. du Toit's lab (2024).
- A research associate joined Dr. Shi's lab in June 2024, and a Ph.D. student began in January 2025.

2. Undergraduate Training

- Three undergraduate students completed a 15-week professional internship at Texas A&M AgriLife, Weslaco.
 - One intern, supervised by Dr. Zapata, developed a stochastic framework for economic analysis of new spinach cultivars.
 - Two interns, under Dr. Avila's supervision, were trained in DNA isolation, PCR, marker-assisted selection, and conventional breeding.
- Another undergraduate student from the University of Texas – Rio Grande Valley completed a 10-week summer internship in Dr. Avila's lab through the USDA-funded PANACEAS REEU program. Training included produce quality evaluation, seed collection, disease identification (conventional and molecular), PCR diagnostics, and marker-assisted selection.
- Genevieve Higgins at Susan Scheufele's lab gave two professional development presentations to Canadian agricultural service providers at Perennia.

3. Academic Course Instruction

- A specific topics course related to Molecular Plant Breeding was offered in Fall 2024 and Spring 2025, with seven students trained in key topics related to molecular marker development and application in breeding.
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How have the results been disseminated to communities of interest?

1. Field Days and Demonstrations

- **Crystal City, TX – February 18, 2025:** Hosted at Tiro Tres Farms by Dr. Larry Stein, Paige Ritchie, and Maribel Alonzo (Texas A&M AgriLife) at Tiro Tres Farms ([Field Day Program](#))

(<https://uvalde.tamu.edu/wp-content/uploads/sites/3/2025/04/2025-Spinach-Field-day-book-FINALCOPY-TOTAL.pdf>)

- Approximately 65 attendees including growers, seed representatives, faculty, and stakeholders. Continuing Education Units (CEUs) were offered.
- Presentations covered fungicide trials, disease screening (SLS), seedling diseases, and SCRI project updates.
- Field tours featured commercial trials, white rust, and *Stemphylium* resistance trials.
- Key outcomes: Of 48 cultivars screened for *Stemphylium vesicarium*, 18 cultivars (38%) showed no symptoms; 20 cultivars (42%) were partially resistant; 8 cultivars (17%) were highly susceptible; and Strong performers included: Galago, Bonnethead, Gerenuk, Diamondback, Limestone (PV 1664), Flourite (PV 1526), and Obsidian (PV 1980).
- **Yuma, AZ – February 18, 2025:** Spinach Field Day with approximately 70 attendees, showcasing disease trials and variety evaluations.
- **Upcoming Field Trials:** Additional trials are scheduled for January–February 2025 in Yuma, AZ, and September–October 2025 in Salinas, CA. The Salinas trial will coincide with the International Spinach Conference.
- **Previous Field Days:**
 - San Juan Bautista, CA – November 8, 2023: Hosted by Dr. Correll and ENZA.
 - Yuma, AZ – February 21, 2024: Hosted by Dr. Correll (University of Arkansas) and University of Arizona, with over 100 attendees.
 - Crystal City, TX – February 20, 2024: Similar format to the 2025 event, with 70 participants.

2. Plant Diagnostic Clinic – Yuma County Cooperative Extension (University of Arizona)

- Led by Poudel-Ward, Martin Porchas Sr., and Rebecca Ramirez.
- Diagnosed 231 spinach samples:
 - Abiotic (88), *Alternaria* Leaf Spot (30), Damping off (31), *Fusarium* (30), *Pythium* (16), Inconclusive (34), Bacterial (2).

3. Scientific Presentations

- Dr. Mou presented the USDA-ARS leafy greens breeding program at the Seed Central & California Leafy Greens Research Board Joint Event (Salinas, CA – June 26, 2025), attended by over 200 participants.

4. Fungicide Trial – Yuma Valley Agricultural Center (2025)

- Downy mildew control trial demonstrated effective performance by: Orondis Ultra, Zampro, Stargus, Cevya, and Eject.

5. Extension Publications

- 2024–25 High Tunnel Spinach Variety Trial by G. Higgins (UMass): Evaluated 12 varieties for germination, disease resistance, and yield.
 - Published in *Vegetable Notes* (Vol 37, Issue 3), which has over 3,500 subscribers in the Northeastern US (<https://ag.umass.edu/vegetable/publications/newsletters>).
- The UMass Extension team continues to share best management practices for spinach production and disease management via *Vegetable Notes*, grower meetings, and online/in-person conferences, reaching 439 individuals during the reporting period.

6. National Media Coverage

- *Western Farm Press* (March 11, 2025): Dr. Jim Correll (University of Arkansas) featured in the article “Researchers race to stay ahead of spinach disease,” discussing downy mildew resistance trials in Yuma, AZ (<https://www.farmprogress.com/crops/researchers-race-to-stay-ahead-of-spinach-disease>).
- *Vegetable Growers News* (November 13, 2024): Reported on the challenge of evolving downy mildew strains in commercial spinach crops (<https://vegetablegrowersnews.com/news/evolving-downy-mildew-strains-test-spinach-growers/>).
- *Phys.org* (May 20, 2025): Covered Washington State University’s identification of wild spinach as a genetic resource to breed resistance to deadly soilborne pathogens (<https://phys.org/news/2025-05-wild-spinach-path-disease-resistance.html>).
- *MSN* (May 20, 2025): Published an article titled “Wild spinach may prevent total wipeout of US seed crops by deadly soil fungus.” (<https://www.msn.com/en-us/news/us/wild-spinach-may-prevent-total-wipeout-of-us-seed-crops-by-deadly-soil-fungus/ar-AA1nkmUZ>).
- *Morning Ag Clips* (June 2, 2025): Reported on research by WSU and Texas A&M showing wild spinach’s potential to enhance commercial spinach varieties (<https://www.morningagclips.com/wild-spinach-offers-path-to-breed-disease-resistance-into-cultivated-varieties/>).
- *Ambrook | Offrange*: Featured a story titled “The Spinach Is Wilting” highlighting current research addressing spinach crop disease threats (<https://ambrook.com/offrange/studies/the-spinach-is-wilting>)

7. **Publications and Scientific Presentations**

- Six peer-reviewed journal articles were published.
- Three manuscripts were submitted.
- Eleven abstracts and presentations were delivered at the 2024 International ASHS Conference and other regional and national meetings.

What do you plan to do during the next reporting period to accomplish the goals?

Field Evaluation: Spinach lines will be evaluated under field conditions for resistance to downy mildew (DM) in Yuma, AZ, and Salinas, CA; and for resistance to white rust (WR), Stemphylium leaf spot (SLS), and Anthracnose leaf spot (ALS) in Crystal City, TX.

Greenhouse/Growth Chamber Evaluation: Spinach lines will also be evaluated under controlled conditions for DM resistance at the University of Arkansas; for ALS resistance at Texas A&M; and for Fusarium wilt (FW) resistance (races 1 and 2 separately) at Washington State University.

Disease Resistance Genetics: Quantitative trait locus (QTL) mapping, genome-wide association studies (GWAS), and genomic prediction (GP) will be conducted to analyze resistance to five key pathogens: ALS, DM, FW, SLS, and WR.

Spinach Line Development: Breeding and selection of new spinach lines will continue for:

- DM resistance at the USDA facility in Salinas, CA, and at the University of Arkansas, Fayetteville;
- ALS, SLS, and WR resistance at both the University of Arkansas and the Texas A&M AgriLife Research and Extension Center in Weslaco, TX;
- FW resistance at Washington State University and the University of Arkansas.

Outreach: Field days will be organized and held in Crystal City, TX; Salinas, CA; and Yuma, AZ to share findings and progress with stakeholders.

Publications and Conferences: Five or more articles will be submitted to peer-reviewed journals, and more than ten presentations will be delivered at international, national, and regional conferences, as well as field days.

Changes/Problems

Describe major changes/problems in approach and reason(s) for these major changes. If applicable, provide special and/or additional reporting requirements specified in the award Terms and Conditions.

None.

Estimated Project FTEs for The Project Duration

Role	Non-Students or Faculty	Students with Staffing Roles			Computed Total by Role
		Undergraduate	Graduate	Post-Doctorate	
Scientist	6	3	2	2	13
Professional	2				2
Technical	2				2
Administrative					
Other					
Computed Total					
	10	3	2	2	17

Activities

Research	80 %
Extension	10 %
Education	10 %

Research Effort Categories

Basic	20 %
Applied	60 %
Developmental	20 %

Classification

Knowledge Area (KA)	Subject of Investigation (SOI)	Field of Science (FOS)	Percent
201	1430	1080	25
202	1430	1080	25

Knowledge Area (KA)	Subject of Investigation (SOI)	Field of Science (FOS)	Percent
201	1430	1081	25
202	1430	1081	25

Knowledge Area

201 - Plant Genome, Genetics, and Genetic Mechanisms; 202 - Plant Genetic Resources

Subject Of Investigation

1430 - Greens and leafy vegetables (includes endive, lettuce, spinach, turnip-greens, celery, rhubarb, parsley, asparagus)

Field Of Science

1080 - Genetics; 1081 – Breeding