COVER PAGE

PROJECT TITLE

Development of Improved Wheat Varieties for California 2024-2025

PRINCIPAL INVESTIGATOR

Xiaofei Zhang, Joshua Hegarty (80%)

OTHER INVESTIGATORS

Elmer Flores (90%), Xiaoqin Zhang (80%)

BUDGET TOTALS

7/1/24 - 6/30/25: $75,000 for the wheat breeding program

SUMMARY

The UC wheat breeding program is dedicated to developing improved varieties that excel in the diverse California environments and deliver on growers' specific needs. Aligning to this mission, our objectives include: 1) integrating new sources of disease resistance, improved yield, end-use quality, and nutritional value; 2) implementing modern breeding tools, such as drone-based observation and genomics for precise selection of complicated traits such as drought tolerance and biomass yield. 3) generating segregating populations through hybridization, evaluating them, and selecting the best for variety release; 4) producing Breeder Seed of lines targeted for variety release. One primary objective in our bread wheat program is the development of dual-purpose awnless varieties with high forage yield and grain yield, as well as robust drought tolerance. For durum wheat, we will continue selecting high-yielding lines with exceptional quality and will also prioritize introducing novel traits from ongoing research, such as enhancing nutritional values, including increased carotenoid and resistant starch and reduced allergenicity. Through these breeding efforts, we aim to advance the resilience, productivity, and quality of bread wheat and durum wheat in California.

CALIFORNIA CROP IMPROVEMENT ASSOCIATION
COMPREHENSIVE RESEARCH PROJECT PROPOSAL
July 1, 2024 to June 30, 2025

B. OBJECTIVES

The overall objective of the UC Wheat Breeding Program is to develop new varieties that adapt to various California environments and deliver excellent end-use quality. Our focus lies on improving traits crucial to growers, such as biomass and grain yield, disease resistance, and overall quality. Our wheat breeding efforts target broad market classes, such as dual-purpose awnless hard white and hard red bread wheat and high nutritional durum wheat. The varieties are primarily planted in the Central and Imperial Valley, with a supplementary effort for spring-planted materials in the Klamath Basin. To achieve our breeding objectives, we are dedicated to genetic enhancement through the introduction and discovery of new germplasm and genes, implementation of modern breeding tools for increased gains, optimization of breeding schemes for process excellence, and increase of breeder seed for the accessibility of superior varieties to California wheat growers. The Specific objectives for the 2024-25 growing season are:

Objective 1: Introduce and evaluate new germplasm from CIMMYT and Dubcovsky Lab's basic science research. CIMMYT germplasm will bring new variations for disease resistance, drought tolerance, and grain yield. The Dubcovsky Lab's research provided the favorable alleles for key traits needed by growers and customers, such as *Yr78* and *Yr36* combination for enhanced stripe rust resistance, new genes for high resistant starch and increased carotenoid in grains, and gliadin deletion for reduced gluten allergenicity.

Objective 2: Implement modern breeding tools to accelerate breeding selection gains. These tools include drone-based observations and genomewide marker-based prediction (i.e., genomic selection). Drone-based imaging enhances the evaluation of early-stage vigor and drought tolerance, and genomic selection enables us to leverage historical data to predict the performance of new breeding populations. Leveraging these advanced tools ensures the rapid development of superior wheat varieties to meet growers' needs.

Objective 3: Generate segregated populations through hybridization, evaluate them, and select the best for variety release. Our objective includes continuous improvement of breeding by annually creating crosses between elite parents and evaluating breeding populations across various generations, from F_2 and head row to preliminary and elite trials. Moreover, we advance candidates into variety trials every year. Complementing conventional breeding, we routinely employ marker-assisted selection to accelerate the introgression of key traits into new variety development.

Objective 4: Producing Breeder Seed of promising lines targeted for variety release and test these candidates for release with industry partners under testing agreements. After identifying promising lines, we will collaborate with stakeholders to select new varieties and partner with the Foundation Seed Program to produce and maintain foundation seeds. To ensure stakeholders' engagement, we offer elite lines under testing agreement for further evaluation. This approach enhances a strategic, collaborative, and transparent process of wheat variety development.

C. PROCEDURES

PROCEDURES FOR OBJECTIVE 1. Integrating New Sources of Disease Resistance, Improved Yield, End-use Quality, and Nutritional Values. Increasing the genetic diversity of our breeding program is crucial for making continued genetic gains and releasing new resilient and productive varieties for California growers. To achieve this, we are collaborating with breeding programs worldwide to evaluate breeding lines. We will receive 800 advanced lines of both common wheat and durum wheat from CIMMYT. After the field evaluation at Davis, the most promising lines will be selected for integration into our breeding population through hybridization.

Stripe rust and stem rust: In response to the evolving threat of pathogens, especially concerns about stripe rust, we will continually seek new sources of resistance. While our varieties currently heavily rely on resistant genes, *Yr5* and *Yr15*, we have been proactively searching for new stripe rust resistance. Recently, we have identified two new resistance genes, *Yr48* and *Yr78*, and developed linked molecular markers to identify them. These genes will be introgressed into our top-yielding varieties, alongside *Yr36*, to protect our wheat varieties against emerging stripe rust races. In addition, to be prepared for the potential threat of stem rust Ug99, we are introgressing *Sr13* and *Sr35* into our best varieties.

Biomass and grain yield: Increasing grain yield remains a top priority, and we are combining the genes crucial for spike development, including genes for grain size (*gw-A2*) and those associated with maximizing grain number per spike (*WAPO-A1b* and *FT-A2*). To align with growers' needs for dual-purpose varieties, we also intensify the breeding for increased biomass production and reduced awn length. By harmonizing biomass accumulation and spike development, we anticipate achieving more substantial increases in overall wheat production.

Quality and nutritional value: For improving wheat breadmaking quality, we will combine favorable glutenin gene ($Glu\text{-}B1_{Bx7OE}$) with *wbm1* alleles to increase dough extensibility while also incorporating *gli-D2* deletion of gliadin genes and *sbeII* mutations with improved water absorption. In durum wheat, we focus on integrating the low cadmium allele, *Cdu1*, and favorable alleles, *PSY-A1*, *PSY-B1*, *PSY-E1*, and *Lpx-B1.1* deletion, to enhance yellow pigment levels and stability in pasta. In addition, we are introgressing five *sbeII* mutations into elite backgrounds to develop additional varieties with high content of resistant starch.

PROCEDURES FOR OBJECTIVE 2. Implementing Modern Breeding Tools, Such as Drone-based Observation and Genomics, for Precise Selection of Complicated Traits Including Drought Tolerance and Biomass Yield. Benefiting from the ongoing WheatCAP grant from the USDA, we are implementing cutting-edge breeding tools to increase our efficiency in developing new wheat varieties. By leveraging genome-wide markers and drone-based high-throughput phenotyping, our primary objective is to optimize tools and integrate them into our breeding workflows.

Genomics-assisted breeding: Genomic selection has emerged as a transformative tool in both plant and animal breeding. By leveraging the power of genome-wide markers and statistical models, genomic selection empowers breeders to design more informed hybridizations and maximize the likelihood of producing superior progeny. Supported by the WheatCAP project, we will develop and validate genomic selection models that predict which lines will be the best parents for future generations.

Speed breeding: Using cutting-edge speed breeding technology, we will optimize the early-stage evaluation process and significantly reduce the variety development cycle from 10 years to 5-6 years. This accelerated timeline enables our breeding program to quickly respond to the ever-changing market and address the evolving demands of growers. We will renovate one greenhouse using the Startup funds, installing an advanced LED lighting system and temperature control to support 3-4 generations per year, a significant increase compared to the current pace of one generation per year in the field. By integrating genomic selection and speed breeding, we will dramatically accelerate the development of superior varieties and ensure our wheat breeding program effectively addresses the dynamic challenges growers face.

Drone-based high-throughput phenotyping: In March 2023, supported by an HHMI equipment grant, we purchased an advanced drone equipped with dual cameras. The high-resolution RGB camera enables detailed analysis of ground cover and canopy height. Our weekly flights facilitate the evaluation of early-stage vigor and canopy growth dynamics. Moreover, the multispectral camera provides NDVI data for relative biomass assessment and captures thermal imagery data for canopy temperature measurement. A low-temperature canopy suggests deeper soil moisture access and drought tolerance. With two years of experience, we will continue screening breeding populations, enhancing our capacity to develop drought-tolerant varieties, aligning with growers' demands and technical advancements.

PROCEDURES FOR OBJECTIVE 3. Generating Segregated Populations Through Hybridization and then Evaluating and Selecting the Best Lines for Variety Release. Small grains crop breeding is a long-term, multiple-stage, and continual process. We use a modified bulked pedigree breeding scheme across all small grains crops, including bread wheat and durum wheat. Each winter, we conduct 10-100 crosses, varying depending on the crop, in the greenhouse, producing F_2 seeds in spring. These F_2 populations are grown in Davis where we select the plants of the correct stature, without disease, and with superior spikes, which are harvested together to form bulk populations by families. The bulk evaluation and selection continue until the F_4 generation. Selected F_4 spikes form the $F_{4:5}$ head row, and 4 spikes are selected for observation plots in the $F_{5:7}$ generation. The selection of observation plots will be focused on agronomic traits like disease resistance, height, lodging resistance, and yield potential. Markers associated with these traits will be used to increase the selection efficiency. Around 50-200 lines will be advanced to Preliminary, Advanced, and Elite Yield Trials for multi-year and multi-location evaluations, including rainfed trials for drought tolerance evaluation. Following these evaluations, we advance 2-10 best lines to the Variety Trials supported by CCIA. Complementing conventional breeding, we employ marker-assisted selection to accelerate the integration of key traits in new variety development.

Strip rust resistance: We have combined two adult-plant resistant genes, *Yr36* and *Yr78*, in individual lines, and we will evaluate their stripe rust resistance by collaborating with USDA-ARS, Washington. At the same time, we will complement these resistant genes with *Yr5* and *Yr15* genes for added protection.

Yield components: The favorable alleles of three yield-related genes, *WAPO-A1b*, *FT-A2*, and *gw-A2*, will be introgressed into elite varieties to validate their effects on grain yield and other agronomic traits. These alleles will also be integrated into durum wheat through the bridge lines Kronos-WAPO-A1b and Kronos-FT-A2. Awnless is also a critical trait we select to meet the growers' demands for dual-purpose wheat varieties.

Breadmaking quality: We have observed four genes or loci that improve breadmaking quality: the *Bx7OE* allele, *Gpc-B1*, *gw-A2*, and *wbm1*. We will continue to use linked markers to select for selection to improve breadmaking quality.

Reduced gluten allergenicity: The alpha-gliadin deletion in the D genome reduced gluten allergenicity but did not affect breadmaking quality. We have introgressed the deletion into the released variety UC-Central Red. Their agronomic performance and quality will be evaluated in the upcoming season.

Carotenoid: In durum, we will improve color in semolina and pasta by a targeted selection of the favorable *PSY-B1* allele, and the *Lpx-B1.1* mutation allele. In common wheat, we are combining *PSY-A1*, *PSY-B1*, and *PSY-E1* alleles to develop a Triple Yellow variety. The lines will be evaluated for agronomic and quality performance during the 2024-2025 season.

Resistant starch: The high-amylose alleles have been introgressed into UC-Central Red. We are performing multi-environment yield trials to validate its performance. Durum wheat lines with resistant starch are in preliminary yield trials.

PROCEDURES FOR OBJECTIVE 4. Producing Breeder Seed of Lines Targeted for Variety Release. As our breeding program progresses and we identify promising lines through yield tests, we focus on increasing pure seeds for potential release. We carefully select 1000 spikes from uniform rows of the most promising common and durum wheat, triticale, barley, and oat lines. These selected spikes are used to produce breeder seeds. Once varieties are approved for lease by the UC Genetic Release Committee, seeds from their head rows are sent to the Foundation Seed Program for multiplication and distribution. Additionally, we also seek Plant Variety Protection (PVP) for all our released common and durum wheat varieties.

D. JUSTIFICATION

Common Wheat and Durum Wheat:

The UC Davis wheat breeding program plays a critical role in enhancing wheat production in California. While private breeding companies focus on areas with higher profitability, UC Davis has a long-term objective to improve bread wheat and durum wheat, meeting California growers' specific needs.

The program takes higher risk to evaluate a broader range of germplasm, novel genes, and variants. Once validated, these germplasm and beneficial gene alleles are shared with private companies operating in California. With active collaboration with Arizona Grain Inc., LimaGrain, Syngenta, Bayer, and Baglietto Seeds to address local challenges, UC Davis wheat varieties, along with those developed in partnership with private companies, represent a significant portion of wheat acreage in the state.

Moreover, the breeding program serves as a valuable backup for private efforts, helping to maintain stability in wheat breeding despite market fluctuations. Overall, UC Davis wheat varieties have played a crucial role in sustaining and enhancing wheat production in California, particularly in disease resistance and quality and nutritional improvement.

E. WHEAT BREEDING BUDGET 2024-2025

Table 1. Combined cost of the breeding program and distribution of requested resources among small grains crop breeding, variety testing program, and information distribution.

	Total Costs			This proposal Wheat Breeding		Triticale Breeding		Barley Breeding		Oat Breeding		Variety Testing	
Small Grains Breeding and Testing	Base	#	$	#	$	#	$					#	$
Personnel Costs													
Joshua Hegarty Project Sci.	$ 81,800	80%	$ 65,440	15%	$ 12,270	5%	$ 4,090					15%	$ 12,270
Benefits	$ 31,820	80%	$ 25,456	15%	$ 4,773	5%	$ 1,591					15%	$ 4,773
Isabel Alicia del Blanco	$ 107,029	96%	$ 102,748					5%	$ 5,351	5%	$ 5,351		
Benefits	$ 41,634	96%	$ 39,969					5%	$ 2,082	5%	$ 2,082		
Specialist (Elmer)	$ 64,946	90%	$ 58,451	15%	$ 9,742		$ -					30%	$ 19,484
Benefits	$ 25,654	90%	$ 23,089	15%	$ 3,848		$ -					30%	$ 7,696
Xiaoqin Zhang Lab Assistant III	$ 66,960	80%	$ 53,568	5%	$ 3,348		$ -						$ -
Benefits	$ 33,145	80%	$ 26,516	5%	$ 1,657		$ -						$ -
Undergraduate Technician -$600/ week	$ 600	32	$ 19,200	5	$ 3,000		$ -					5	$ 3,000
Farm Labor - $1,360/week	$ 1,360	40	$ 54,400	4	$ 5,440		$ -					1	$ 1,360
People Total	**$ 526,588**		**$ 468,837**		**$ 44,078**		**$ 5,681**		**$ 7,433**		**$ 7,433**		**$ 48,583**
Field Costs													
Davis - per acre	$ 3,000	20	$ 60,000	4	$ 12,000	1.5	$ 4,500			0.5	$ 1,500	1.5	$ 4,500
Westside REC - per acre	$ 4,000	4	$ 16,000	1	$ 4,000		$ -					1.5	$ 6,000
Intermountain REC - per acre	$ 5,000	2	$ 10,000	1	$ 5,000		$ -					0	$ -
Total Field	**$ 86,000**		**$ 86,000**		**$ 21,000**		**$ 4,500**				**$ 1,500**		**$ 10,500**
Equiptment													
Vehicle - $675/ month	$ 675	15	$ 10,125	3	$ 2,025	1	$ 675			1	$ 675	3	$ 2,025
Forage Harvester $100/ hr	$ 100	25	$ 2,500	10	$ 1,000	6	$ 600					6	$ 600
Plot Combine rental $300/ hr	$ 300	30	$ 9,000	10	$ 3,000	3	$ 900	1	$ 300			8	$ 2,400
Plot Combine Service	$ 8,000	1	$ 8,000	0.25	$ 2,000		$ -					0.1	$ 800
Greenhouse - per year	$ 4,000	2	$ 8,000	0.20	$ 800		$ -					0.1	$ 400
Consumables - bags, tags, tubes, diesel	$ 8,000	1	$ 8,000	-	$ 1,097		$ 644		$ 267		$ 392		$ 692
Website and Database maintenance													$ 10,000
Total Equiptment	**$ 45,625**		**$ 45,625**		**$ 9,922**		**$ 2,819**		**$ 567**		**$ 1,067**		**$ 16,917**
Grand Total	**$ 658,213**		**$ 600,462**		**$ 75,000**		**$ 13,000**		**$ 8,000**		**$ 10,000**		**$ 76,000**

Table 2. Distribution of requested CCIA funds across crops and research areas.

CCIA Funding	**2024-25**		**%**
Breeding	**$**	**106,000**	**58% of Total**
Wheat	$	75,000	
Triticale	$	13,000	
Malting Barley-2Row	$	8,000	
Oats	$	10,000	
Extension	**$**	**76,000**	**42% of Total**
Variety Testing	$	76,000	
Agronomic Exp.	$	-	
Total	**$**	**182,000**	**100%**

Table 3. Sources of funding which support the Small Grain Breeding and Testing Program

Sources of funding		
CWC Wheat Breeding - anticipated	$	100,000
CCIA Wheat Breeding	$	75,000
CCIA Triticale Breeding	$	13,000
CCIA Testing	$	76,000
Wheat Royalties	$	20,000
Triticale Royalties	$	15,000
USDA - Triticale	$	65,000
CCIA Barley Breeding	$	8,000
AMBA request	$	26,000
NACA-USDA - Barley -- anticipated	$	85,000
TTKSK SCA - Barley	$	29,000
BPI (USDA-ARS) - Barley	$	20,000
Ug99 Sentinel plots	$	10,000
CCIA Oat breeding	$	10,000
NACA-USDA - Oat - anticipated	$	48,000
Total	$	600,000

Budget Justification

We have coordinated with Dr. Mark Lundy to align our budget requests, ensuring the sustained operation of all the small grains programs. This year, we present a consolidated budget for the wheat, triticale, barley, and oat breeding and testing programs. **Table 1** outlines the detailed budget requests for the small grain breeding and variety testing programs. **Table 2** provides an overview of the allocation of requests among small grain breeding and extension efforts.

Our 2024-25 budget for the wheat, triticale, barley, and oat breeding and field operation of the testing program aims to maintain essential breeding and testing activities on the small grains crop breeding program. The total cost is $600,000 (as detailed in **Table 3**). The California Wheat Commission (CWC) is anticipated to allocate $100,000. We request CCIA support for breeding activities, $106,000 ($75,000 + $13,000 + $8,000 + $10,000), covering 18% of the cost of the small grain breeding program. The rest will be covered with a combination of wheat and triticale royalties ($35,000), support from a federal Triticale grant to Josh Hegarty ($65,000), collaborative projects with USDA-ARS scientists on barley and oat breeding and testing ($192,000) and support from American Malting Barley Association ($26,000).

The support of the CCIA is crucial for sustaining our core small grains crop breeding program. This support enables us to leverage additional research support and maintain a dynamic and internationally recognized program dedicated to serving California small grains crop growers.

Additional support to the breeding activities:

The small grains crop breeding program collaborates closely with Dr. Jorge Dubcovsky's lab, sharing personnel resources. Joshua Hegarty, Elmer Flores, and Xiaoqin Zhang also participate in the basic research activities of Dr. Dubcovsky. Part of their salaries are covered by the WheatCAP, Celia Disease Foundation, and USDA-NIFA projects.

F. APPROVALS

Xiaofei Zhang
Principle Investigator

Dr. Daniel Potter
Plant Sciences Dept. Chair