California Tomato Research Institute is committed to playing the long game: 50 years and counting of asking and answering questions in the field

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ABSTRACT

The primary function of the California Tomato Research Institute (CTRI) is to identify production challenges and opportunities and to fund projects which research and development can address. Funding is through tonnage assessments from its voluntary grower members. Decisions are governed by its Board; made up of growers. With the aim of building and maintaining an effective, robust and dynamic research agenda CTRI management promotes durable coalitions between growers, allied industry and researchers. Since 1968, when the CTRI was founded, over 600 research projects have been supported with a total direct funding expenditure of over 11 million USD. These projects have primarily focused on improving field production, particularly in the areas of: pest management (250+ projects); variety development, pre-breeding and variety evaluation (150+ projects); agronomics (100+ projects); market development and process quality (75+ projects); and automation (25+ projects). With the impetus of a semicentennial and a new managing director the CTRI has taken a deep dive into our historical results to help guide our path to continued success. The discussion will include examples of past successes as well as future opportunities. While some observers speculate that tomato yields in California have plateaued, the CTRI is positioned to continue to support the science to advance our industry.

Keywords: processing tomato, California tomato growers, CTRI, grower-funded research

INTRODUCTION

California processing tomatoes: can't stop, won't stop

Records dating back to the early 20th century concerning the production of processing tomatoes in California tell the story of a competitive collaboration of growers, processors and allied industry with a complete and total disinterest in complacency. With an average yield of 13.5 metric tons per hectare (t/ha) across a harvestable area of less than 10,000 ha in 1920 the industry today yields an impressive 107.1 t/ha across a 108,500 ha (five year average) harvestable area (Horwath and Geisseler, 2013; California Tomato Growers Association, 2018). The average yield of processing tomatoes in California is eight times more productive today as compared to one hundred years ago. In more recent history, utilizing only 2% more land area in 2017 than in 1968, the California processing tomato industry has more than doubled its output through the slow but steady work of increasing yields an average of 1.2 t/ha/year over the same period (see Figure 1).

The grinding persistence of this innovation has not come on its own. Major advancements along the way have taken the form of more targeted and efficient use of mineral fertilizers and crop protection products, improved varieties through breeding programs both public and private, the invention of the mechanical harvester, the transition from direct seeding to transplanting and the utilization of sub-surface drip irrigation (Hartz et al., 2008; Johannessen et

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al., 2018). Grower investment in research, although certainly not the only driver, has played an outsized role in these advancements and the industry scale adoption thereof. Given here is a summary and explanation of historical grower investment in research in the processing tomato industry of California with the expectation that this exploration of past focus and results will inform future direction and investment.

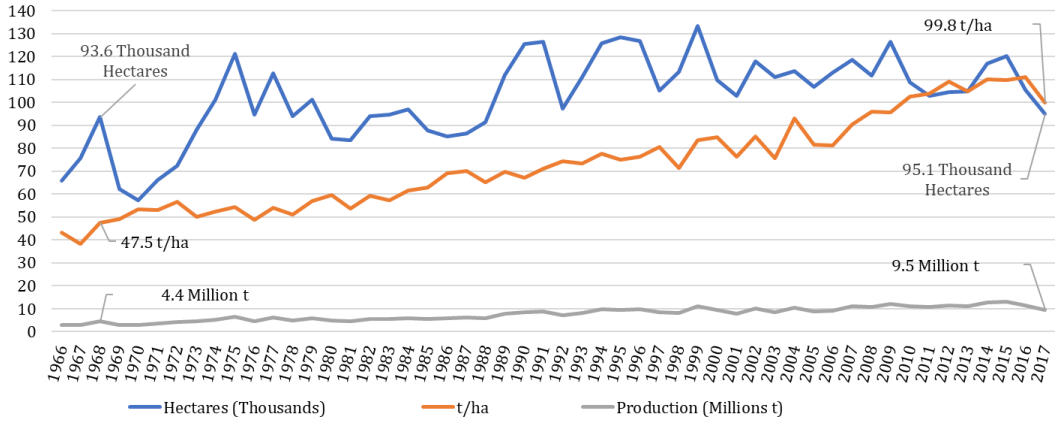

Figure 1. California Production: Totals, Area and Yield Through Time (1966-2017)

MATERIALS AND METHODS

The records of the CTRI, from the inception of the organization to date, were reviewed and analyzed. These records included annual reports, Institute newsletters, individual project reports, and yearly calls for proposals (Johannessen et al., 2018). A database was created to understand the past trends in research expenditure and to track the future progress towards organizational goals. Highlighted in particular here are Figures 2, 3, and 4 representing financial allocation through time to the research program as a whole and to the particular project areas which make up that program. In addition, Table 1 was created showing those projects or project areas with more than five years of funding; years of funding being a proxy for long-standing commitment, formidable research challenge, or both.

RESULTS & DISCUSSION

Historical research expenditure

At its beginnings, outside of the branched broomrape (*Orobanche ramosa*) eradication efforts which accounted for over $100,000/year alone through the mid-1970s, the CTRI funded an average of five projects per year with an average annual cost per project of ~$15,000. The cost per project remained relatively flat through the late 1990's while the number of projects which the organization chose to fund increased incrementally during that time, reaching a peak in 1998 with 34 funded projects. Through the early 2000's the number of projects funded on an annual basis stabilized at a moving average of between 15 and 20. In 2018, the CTRI is actively funding 16 projects with an average annual cost per project of $19,551. Although projects are reviewed annually and funding is made available only on a year by year basis the average lifetime of a given project over the entire history of funding has been 2.6 years. Total annual research expenditures (Figure 2) have ranged from a low of $100,246 in 1983 to a high of $565,975 in 2016; accumulating to a total of over 11.6 million USD in 2018. A trend which is not made immediately obvious in Figure 2 is the more or less lockstep movement in the moving average of total research expenditure with the growth or contraction of the industry as a whole. As a funding body deriving 100% of its available dollars for research from its member base in the form of voluntary assessments ($0.07/paid short ton since 1986), and representing an industry with no lack of challenges, this matching of available resources with worthy projects should be of no surprise.

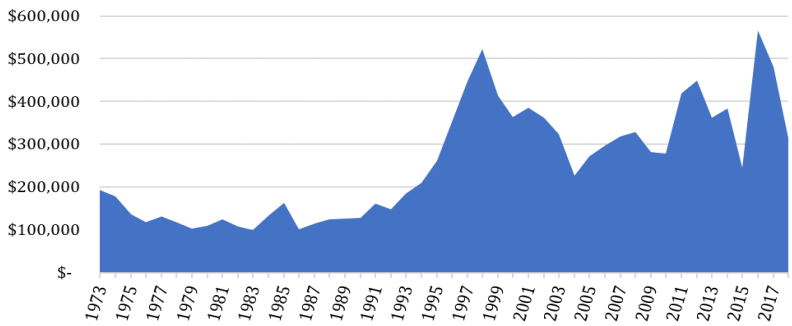

Figure 2. Annual Research Expenditure: 1973-2018. These are USD spent directly on research projects and funded by the CTRI.

The commitment which these accumulated dollars represent by the voluntary membership (representing 70% of the paid tons in 2017) of the CTRI is truly significant. That said, this dollar value does not fully account for: the in-kind donation of labor, fields for test plots, and other resources provided by this grower membership; the in-kind donation of materials (crop protection products, fertilizers, seed, etc.) and general collaboration provided by allied industry; and the time and understanding of processor harvest and field staff in the harvesting of variety trials and test plots and in discussion of in-field problems and future need as related to process quality. Lastly, it is understood that the attention and commitment to the processing tomato industry by our research collaborators at UC Davis, UC Cooperative Extension, UC ANR, UC Riverside, CSU Fresno, CSU Chico, Cornell, and the Ohio State University is a resource which could have been allocated to other cropping systems. In addition, although we do not have a historic record of funding which these research collaborators have attained by leveraging the industry support which a funded project from the CTRI represents we do know that in the past three years alone this has accounted for over five million USD. These are grants coming from the USDA, the California Department of Food and Agriculture, the California Department of Pesticide Regulation, the Curly Top Virus Program, etc. which are going directly towards research efforts which will ultimately and directly benefit the processing tomato industry.

Where did the dollars go?

Over the last fifty years, research expenditures can be broken down into eight major categories. Listed from highest to lowest in total expenditure: topics in pest management, individual genetic projects outside of the official UC breeding and variety trialing program, the UC breeding and variety trialing program, agronomic topics, topics of processor interest - product development and process quality, a long standing annual commitment to the Tomato Genetics Resource Center, topics in automation, and finally the control of branched broomrape. Figure 4 charts these eight categories over time in relation to the other categories and total funding. Those project areas which received CTRI funding for five or more years, beginning with the longest running research initiatives, can be found in Table 1.

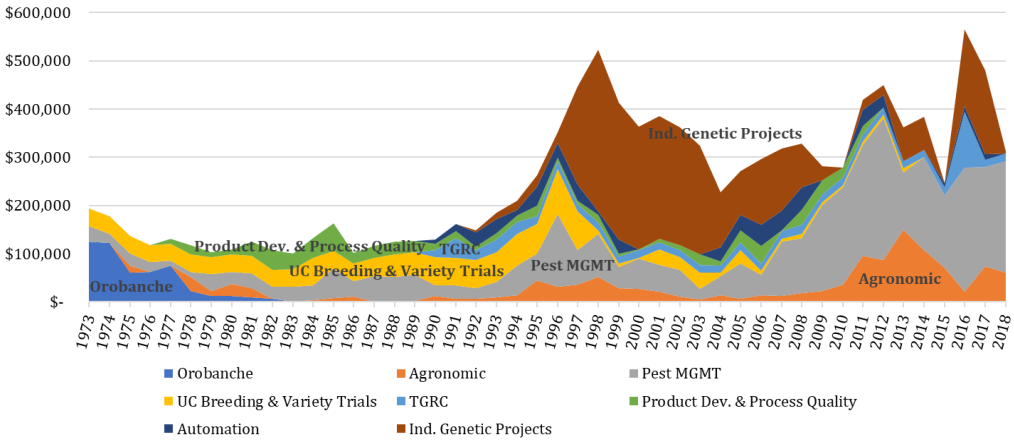

Figure 3. Expenditure by category through time (1973-2018)

1. Topics in pest management.

In total expenditure, total project number, and year-over-year consistency through CTRI history, pest management has been the chief concern. A full 32% of the total research expenditure has gone towards projects related to pest management. The earliest projects funded by the institute include those related to: bacterial speck (*Pseudomonas syringae*), Verticillium wilt (*Verticillium dahliae*), and black nightshade (*Solanum nigrum)*. The prevalence of these same pests (or some genetic variant thereof) in grower fields today reminds us that our work in this area is ongoing. Figure 4 breaks down the scale and persistence of funding by area which has been directed towards differentiated pest groups throughout the history of the CTRI.

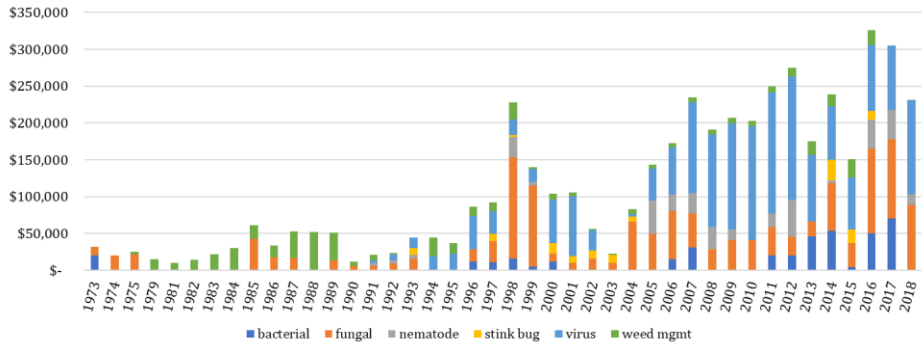

Figure 4. Pest management: persistence through time (1973-2018)

A cogent example of success in this funding and research category is the work done by Dr. Frank Zalom of UC Davis from the 1980's through the early 1990's in the development of an IPM strategy for tomato fruitworms (*Helicoverpa* zea) and armyworms (*Spodoptera praefica*). This research and extension effort brought IPM as a utilitarian tool into the mainstream for growers by working in commercial fields to effectively reduce insecticide applications by more than 50% while also controlling these pests. This example highlights the significance which targeted sampling and predictive forecasting of pest populations holds, when combined with effective applications of available crop protection products, in the successful implementation of IPM programs.

Other pests which the CTRI has funded the development of sampling protocols and forecasting models for include: seedling insect pests, powdery mildew (*Leveillula taurica*), blackmold (*Alternaria alternata*), *Tomato spotted wilt virus* and *Beet curly top virus*. In 2018 we are actively funding updates to the *Tomato spotted wilt virus* model and developing protocols and testing resources for the detection of Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*) in soils. Sampling protocols and forecasting models being ineffective over time without control options, the CTRI has consistently been supportive of side-by-side product testing of crop protection products. A recent example of product testing, which UC Cooperative Extension Advisor Joe Nunez has been championing, is an on-going multiple year evaluation of alternative nematicides in rotation for the control of Root-knot nematode (Meloidogyne spp.).

In addition to the support of research projects in the pest management category the CTRI has been active throughout its history in the collection of user data and member grower perspectives for support and registration of proven and effective crop protection products. A few examples of products which the CTRI has supported the registration of include: Dual (S-metolachlor) and Matrix (rimsulfuron).

2. Individual genetic projects.

Although there exists significant diversity within the genomes of wild tomato species (*Solanum pimpinellifolium, Solanum chilense*, *Solanum habrochaites*, etc.) the available commercial varieties of today, primarily developed from *Solanum lycopersicum,* utilize only a

small fraction of that diversity. Through the 1990s the CTRI recognized that pre-breeding efforts in the evaluation of wild tomato species would be necessary for the continued flourishing of the industry – particularly with concern to the discovery of novel sources of resistance to common pests, diseases and environmental stressors such as heat and drought. Since that time the CTRI has funded pre-breeding efforts in the areas of: aphid (*Macrosiphum euphorbiae*) and whitefly (*Bemisia tabaci*) resistance, bacterial speck (*Pseudomonas syringae)*, *Beet curly top virus*, blackmold (*Alternaria alternata*), corky root rot (*Pyrenochaeta lycopersici)*, root-knot nematode (Meloidogyne spp.), Verticillium wilt (*Verticillium dahliae*), and is currently working with *Solanum habrochaites* to pinpoint the chromosome region within its chromosome 9 which holds the genes for this species' water stress tolerance.

3. UC breeding and variety trials.

From their very beginnings, both the California League of Food Producers research committee and the CTRI, committed to long term annual funding of the tomato breeding program at UC Davis and to variety trialing by UC Cooperative Extension County Farm Advisors. By the late 1990's the private tomato breeding industry had significantly matured, staying quite competitive to the present time, and funding of these efforts were halted. Although public breeding efforts were stopped, in-field variety trialing of private, commercial varieties by Farm Advisors at the county level continued through 2013, when that work achieved sufficient scale by a now mature private seed dealer network.

4. Agronomic topics.

Starting with the work of UC Cooperative Extension Farm Advisor Mel Zobel in 1976 to develop a heat-units model to better predict and schedule harvest dates, improving not only field yield and quality but also processor facility utilization, the CTRI has from its earliest beginnings understood that research into the agronomics of the processing tomato cropping system is at its very core. The projects funded in this category can be broken down into fertility, water, and soil management respectively, and physiology. A specific project with significant impact in the category of fertility management is UC Extension Specialist Tim Hartz's work in 2000 to develop baseline NPK levels (a level of fertility which would not detract from higher yields) in soils pre and post-planting and the protocols around testing for this. This work allowed growers to target fertilizer applications in season to only those fields which were below baseline levels. Of note in water management: the adaptation of sub-surface drip irrigation (SSDI) to the California processing tomato cropping system done by UC Cooperative Extension Farm Advisor Don May, demonstrating the significance of this technology in its ability to provide yield gains as well as in its allowance for water savings in conjunction with this yield boost. In the area of soil management: UC Cooperative Extension Farm Advisor Gene Miyao performed a series of studies ending in 2016 evaluating the impact of composted manure on plant health and yield which, in its complicated results, reminded the industry that we have much work to do in understanding the complex relationships which exist in the soil – a component of our cropping system that we have from time to time mistaken as simply a medium for plant growth.

5. Product development and process quality.

Although the major emphasis of the institute remains on improving grower productivity while reducing costs and maintaining environmental stewardship in the field, beginning with funding the development of a sampling procedure for bulk loads in 1975 the CTRI has had an understanding that supporting projects which would co-benefit both growers and processors is a net positive for the entire industry. A particularly successful project in this category is one championed by Tim Hartz in the early 2000s to develop strategies to maintain soluble solids while at the same time protecting yields with the use of SSDI. This initiative provided further evidence to both growers and processors that this technology shift was positive.

6. Tomato Genetics Resource Center.

In 1990, the long running Tomato Genetics Resource Center, which since the 1950s has been the de facto seed bank for the global tomato industry, recognized it's need to buffer increasingly uncertain State and Federal funding with industry commitment. The CTRI answered that call and has upheld that commitment. In addition to its annual support the CTRI has responded to endowment funding requests in 1991, 1992, 1993, 1994, 2008 and 2016.

7. Topics in automation.

As UC Agricultural Engineering Professor Dr. David Slaughter tells it, the first representatives from any industry to approach him about research collaboration when he was hired by UC Davis as an Agricultural Engineering Professor in 1990 were UC Cooperative Extension Farm Advisor Gene Miyao and a CTRI Board Member. Since that time the CTRI has been working with Dr. Slaughter to develop labor saving technologies in the areas of cultivation and transplanting. His technology was the pre-cursor to the Blue River Group lettuce thinner and is currently being used by others in private industry towards the in-field development of cultivating and thinning equipment.

8. Branched broomrape control:

With an initial 10 years of aggressive funding, the goal being eradication of a rapidly spreading, invasive pest, this area has received no project funding since 1982. Although eradication was practically achieved during this period of aggressive research, surveying and fumigation there has been a small number of isolated cases of branched broomrape infestation reported in the last 5 years. This is an area of concern which the entire industry is watching very closely.

Table 1. Project topic areas with greater than 5 years of funding.

Project Area	# of Years with Funded Projects	Span of Years
UC breeding & variety evaluation	46	1968-2013
Tomato Genetics Resource Center	29	1990-Present
Root-Knot Nematode management	24	1991-2017
Automation of cultivation	23	1991-Present
Soil health management	23	1996-Present
Adaptation to SSDI	20	1996-2015
Product development & process quality	17	1978-1995
BCTV analysis & MGMT	16	2002-Present
Broomrape analysis & eradication	15	1968-1982
TSWV analysis & MGMT	14	2005-Present
Fertility MGMT & recommendations	14	1989-2016
Dodder control & MGMT	12	1991-2009
Stink Bug monitoring & MGMT	12	1993-2016
Aphid/Whitefly analysis & MGMT	10	1999-2008
Evaluation of Bacterial Speck TMNT & controls	9	1996-Present
Evaluation of controls for Southern Blight	8	2011-Present
F3 analysis & MGMT	8	2011-Present
Powdery Mildew analysis & MGMT	7	2006-2012
Field Bindweed MGMT	7	2010-2016
Strategies to increase high temp. fruit set	6	1996-2001
Forecasting model for Blackmold control	5	1996-2000
Adaptation to transplanting	5	1998-2003

Industry trends/future research considerations

1. When there has been an industry need growers, processors and allied industry have come together to solve for that need. With the significant consolidation which has continued to occur throughout the last 50 years, a general maturation of the players involved into specific areas of core competency, and the current competitive market for tomato products globally these forms of whole industry collaborations with mutual benefit will have to be managed carefully. Considerations for future work which would require such collaborations include:
    a. The potential of an invasive pest or disease entering the Central Valley of California and developing extensive populations prior to discovery. Examples here could be: the Brown marmorated stink bug (*Halyomorpha halys)*, branched or Egyptian broomrape (*Orobanche aegyptiaca*), or *Tuta absoluta.* With the volume of agricultural production and trade being conducted in California, the speed at which known pest and disease issues are becoming established in new regions, and the favorable climactic conditions the potential of this risk is high.
    b. Regulatory concerns around water (availability and quality), crop protection products, labor, and the availability of Federal and/or State resources explicitly for research. As not only the population of the state of California but also of the U.S. trends more urban an understanding of the needs, priorities and importance of these topics as it relates to agriculture and our food systems will require the continued efforts of the CLFP, the individual actions of growers, processors and allied industry and also a concerted collective effort in the court of public opinion; as well as in the halls of government.
2. Disruption happens. An average 1.2 t/ha/year yield gain over the last 50 years is only possible in the context of a dynamic industry. To continue the long run trend of gains in yield, quality and resource use efficiency there should be an expectation of change. The California industry will never stop making incremental gains. Areas of production where more than incremental gains are more likely include: the genetics of wild tomato (through traditional breeding and eventually through some iteration of CRISPR cas9), the microbiome of the soil, automation of particularly labor intensive tasks (cultivation, transplanting and to an extent irrigation and scouting), the positive quality and traceability impacts which forced technology use will bring (only if these characteristics are effectively leveraged in the global market).
3. As the 2017 season reminded the California industry, with its combined caused crop losses of over one million tons due to early rains and sustained heat, even the most up to date varieties and cultural practices do not fully protect the individual grower or the industry as a whole from significant shocks. Because of this fact the CTRI will continue its funding and advocacy efforts to understand and mitigate against seemingly the same pest and disease issues which have been historically funded. At the top of that list is fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici)*, the resistance breaking strain of the *Tomato spotted wilt virus*, and *Beet curly top virus*. Although the yield, vigor and disease resistance of even the average commercial variety today has the potential for tremendous results, after over 60 years of commercial cultivation of tomatoes in the major production areas the litany of pest and diseases now prevalent in these regions is incrementally depleting this tremendous yield potential. Staying ahead of the resistance curve on many fronts is of absolute priority.
4. Robots may come for our weeds; it will be a long time before they can understand our data. A persistent in-field challenge has been the connection of geospatial data to attributes such as yield, fertility and irrigation requirements, let alone soilborne disease severity. With fierce competition for this data it is exciting to imagine the possibilities. One tremendous opportunity with significant scale - a host of pest and disease issues with the ability to break current resistance could be significantly slowed down if growers were enabled by technology to manage areas of higher disease and pest pressure differently than surrounding areas in the same field. To assist in these efforts the CTRI will continue to fund both tissue and soil predictive assays and virus vector movement models.

CONCLUSION

The CTRI's express purpose is to identify, fund and direct research to maintain and enhance the economic viability of California's processing tomato industry with emphasis on production, product quality and the environment. As evidenced by a membership which represents 70% of the paid tons in 2017 and fifty years of historical expenditures, the CTRI has invested significantly (over 11 million USD) into the future of the processing tomato industry in California. These investments have come not only in the form of short term projects with results which can be immediately implemented in commercial fields (side-by-side crop protection product testing as an example) but also in the form of long term projection of industry need (continued annual TGRC commitment). Past experience highlights the reality that there is significance in not only what the CTRI chooses to fund from year to year but also in how we leverage those findings in two key ways: 1. To make the in-field changes which will continue to drive the industry forward incrementally and 2. To maintain and build the network of growers, processors, allied industry and researchers globally to cultivate and extend the next idea which will give us more than incremental change. As the original Director of the CTRI, Dr. George Johannessen commented to a New York Times reporter in 1987, ''We've got some very, very serious problems in the processing tomato industry; but we have the ability to fight and survive in the world market. Research is a major factor of the successes in the past and will be in the future.''(Lindsey, 1987).

ACKNOWLEDGEMENTS

In a world which seems too often content to give up on hard things the contributing growers of the CTRI continue to dive headstrong into the challenges whose outcomes will determine the future of this industry. Without the foresight, vision, sacrifice and tenacity of these growers the significant long run gains in yield, resource use efficiency and product quality would have never been imagined, let alone achieved. To fulfill this vision, for the last 50 years and into the future, the CTRI is reliant on the skills, connections, and intellect of countless others from both within and outside of the processing tomato industry. These individuals work in the seed industry, for processors, as PCAs, as researchers, and in many other allied industries. For their cooperation and support we'd like to particularly thank and recognize the dedicated service of University of California Cooperative Extension Farm Advisors, Extension Specialists, and Professors.

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