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BREEDING AND GENETICS

Jacob Osborne Ware, an Early Cotton Breeding Giant

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ABSTRACT

Jacob Osborne (J.O.) Ware (1888-1977) was an early leader in United States (US) cotton breeding and contributed significantly to the U.S. and Arkansas cotton industries. Dr. Ware bred cotton at the University of Arkansas (UA) from 1920 until 1934, when he became the senior United States Department of Agriculture (USDA) cotton agronomist at Beltsville, MD. He returned to UA in 1950 with a joint UA and USDA appointment. During his tenure, cotton occupied up to 10% of the land area of Arkansas, but state yield never exceeded 545 lb a^{-1}. Essentially all Arkansas cotton production was rain fed with little fertilizer added and with limited insect and disease control options available. Cotton production relied heavily on hand labor, management knowledge was limited, travel was difficult, communication was restricted, and no computers existed. In this environment, Dr. Ware made significant advances in variety development, variety testing, trait evaluation (inheritance and relationship studies), writing extensive cotton breeding reviews, and became an early leader of U.S. cotton breeding. Compared to today's program, Dr. Ware encountered similarities (geography, the cotton plant, pests, breeding objectives and procedures); disadvantages (low understandings of genetics, production practices, fiber testing, and test procedures; near absence of specialized equipment and methods to document plant releases; poor transportation; and no computer technology); and advantages (less complex traits, more state support, fewer labor and government restrictions; better public relations and less administrative demands). Dr. Ware was not the first cotton breeder at UA but was the first to establish a legacy that remains today.

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The science of cotton breeding made great strides in the early 20th century after the rediscovery of Mendel's laws. At that time, cotton breeding programs were initiated by many southern land grant universities including the University of Arkansas (UA). The earliest note of any UA cotton breeding effort was in a 1908 annual report indicating that "careful selection" had been made from cotton and other crops – but the person(s) who made these selections was not named (Bourland, 2018). Individuals conducting cotton breeding research at the UA from 1912 to 1920 included W.C. Lassetter, M.S. Baker, W.E. Ayers, and E.A. Hodson. Most of their efforts were associated with direct selection from established varieties but crossing of some varieties occurred. Hodson (1920) documented the degree of variation associated with seven years of pedigree selection by different breeders from one 'Trice' plant. He noted that the variation may have been attributed to the different breeders, cross-pollination, and environmental effects. Although some cotton breeding efforts existed prior to the 1920's, the first substantial UA cotton breeding program was led by Dr. Jacob Osborne (J.O.) Ware (Figure 1).

Figure 1. Photograph of Dr. Ware taken ca. 1960's.

Jacob Osborne Ware was born at Kings Mountain, NC, in 1877. He received his B.S. and M.S. degrees from North Carolina State University, and his Ph.D. degree from Cornell University. He married Melba Francis French and they had one daughter, Patricia, born ca. 1930. Dr. Ware joined the faculty in the Agronomy Department at UA as a cotton breeder in 1920. In 1934, he became senior cotton agronomist in charge of cotton breeding in the Cotton Division of the USDA Bureau of Plant Industry, Beltsville, MD. (According to the 1940 U.S. census, he lived at 4000 Cathedral Ave NW Apt 131, Washington, D.C., earned approximately $5,000 per year and paid monthly rent of $97.) Dr. Ware returned to UA in 1950 and served in a joint appointment with the UA and USDA. After retiring in 1958, he was granted emeritus status at UA until his death in 1977. In this presentation, I will summarize his career and make comparisons and contrasts to our current breeding program.

HIGHLIGHTS OF DR. WARE'S WORK

A summary of cotton production in Arkansas during his active career (1920-1958) provides a background for appreciating Dr. Ware's work. Comparable Arkansas cotton production statistics prior to 1927 were not available. In Arkansas, a record high of 3.577 mil acres of cotton was planted and a record low yield of 119 lb a^{-1} occurred in 1930 (Fig. 2). This record high acreage of cotton occupied 10.5% of the total area of the state. The record low yield was due to cotton planted in areas not well suited to the crop and was compounded by a very hot and dry summer – as evidenced by 71 consecutive rainless days and a high temperature of 113°F recorded in northeast Arkansas (Dyess, AR). Cotton acreage in Arkansas steadily declined from the high in 1930 through 1958 due to government programs, prevailing low cotton prices, and competition of other agricultural commodities. During this time, average state yields steadily increased from the low in 1930 to a high of 545 lb a^{-1} 1955. The average price of cotton lint was a record low of $0.055 lb^{-1} in 1931 and peaked at $0.398 lb^{-1} in 1950. Arkansas cotton production over the period ranged from 0.853 mil bales in 1935 to 1.982 mil. bales in 1948 with no apparent yearly trend. The production in 1948 has been surpassed in only three years – 2004, 2005 and 2006.

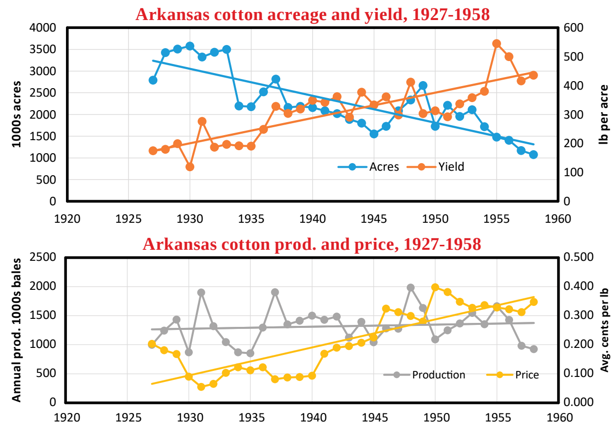

Figure 2. Arkansas cotton statistics during Dr. Ware's tenure at UA, 1920 to 1958 (no statistics available for 1920 through 1926).

During Dr. Ware's career, essentially all of Arkansas cotton was rain fed with little fertilizer added and limited insect and disease control options available. The boll weevil (*Anthonomus grandis* Boheman) became the dominant insect pest, and Fusarium wilt (caused by *Fusarium oxysporum* f. sp. *vasinfectum* (Atk.) Snyd. and Hans.) was the primary disease issue. Typically, producers planted fuzzy seed, and subsequent stands were hand thinned with hoes. Through much of his career, cultivation was performed with mule-drawn equipment, weeds were mechanically controlled (cultivation and hand chopping), and cotton was harvested by hand. Toward the end of his career, he helped to develop cotton lines adapted to mechanical harvesting (Ware, 1952a). In this environment, Dr. Ware made significant advances in variety development, variety testing, trait evaluation (inheritance and relationship studies), writing extensive cotton breeding reviews, and became an early leader of U.S. cotton breeding.

Variety development. Release status of a line (i.e., whether it was a public variety or simply evaluated as an advanced line) is often difficult to discern for materials developed in the first of half of the 20th century. Varieties apparently released by UA in the late 1920's included 'Arkansas Rowden 40' and 'Arkansas 17' (Express) from Rowden and Express materials, respectively, and 'Arkansas Acala 31', 'Arkansas Acala 34' and 'Arkansas Acala 37' from Acala material (Brannen, 1934). Arkansas Rowden 40 became very popular and was estimated to have occupied 50% of Arkansas's cotton acreage in the mid-1930's (over 1 mil acres) and spread to adjacent states. Arkansas 17 appeared to be particularly adapted to the "lowlands". 'Arkansas Rowden 2088', selected out of Arkansas Rowden 40, began to rapidly replace its parental variety (Ware, 1937). Arkansas Rowden 40 was earlier and more uniform than the old parental Rowden variety, and had high fiber quality (staple length of 1 to 1 1/16 inches), big bolls, storm resistance, hardiness to drought, considerable wilt resistance, and produced high yields.

UA released four additional Rowden varieties in 1939 – 'Rowden 41A', 'Rowden 41B', 'Rowden 42A', and 'Rowden 42C' (Anonymous, 1940). Although not stated, Dr. Ware would likely have been associated with the development of these varieties. Rowden 41B was the most popular of these releases and provided an important variety for rain-grown areas. Recognized for its high quality, this large stalk variety was dominant until the 1950's (Bourland and Waddle, 1988). The advent of mechanical harvest and the improved ability to control insects by organic pesticides caused the more prolific, later maturing delta type cottons to become preferred over Rowden 41B. Reports prior to 1934 mention various cotton materials including numerous Rowden and Acala lines, as well as multiple Trice, Lone Star, Dixie and Sweepstakes lines. Ware likely developed the Rowden, Acala, and Trice lines, but the originator of the other lines is unclear.

Variety testing. Dr. Ware was responsible for cotton variety testing at UA from 1920 through 1934. He also reported on variety testing from 1946 through 1950 (Ware, 1952b). The size of this testing program varied over years, but the 1923 and 1924 tests provide an example of the magnitude of his variety testing program (Ware, 1925). In both years, variety tests were conducted at Scott (central AR), Burdett (northeast AR), Lake Village (southeast AR) and Homan (southwest AR). Distance from Dr. Ware's base station in Fayetteville to Scott and Homan is over 200 miles and to Burdett and Lake Village is over 300 miles. The number of entries varied from 36 at Lake Village to 51 at Scott in 1923, and from 46 at Burdett to 91 at Scott in 1924. In 1923, number of replications varied from three at Homan to 10 at Scott. All tests employed four replications in 1924. Data reported included number of final plants, first pick and total seed cotton yield, percent lint (based on 100 boll samples), total lint yield, total seed yield, bolls per pound, and staple length. Boll samples were taken from all replications at most locations. These plots were likely planted and cultivated with mule-drawn implements and were definitely hand weeded and hand harvested. The extent of physical labor and logistics associated with conducting these tests was certainly challenging, particularly since UA had not yet established any branch experiment stations.

Inheritance and relationship studies. During his career, Dr. Ware published extensively on inheritance and relationships of various cotton traits including red leaf color (Ware, 1927; 1929b; 1933), fiber length (Ware, 1929b), leaf shape (Ware, 1929b; 1933; 1934), sparse/naked seed (Ware, 1941), and cotton varieties (noted above). Ware also conducted pioneering work in host-plant resistance traits of cotton. He cooperated with V.H. Young, a plant pathologist, to verify resistance to Fusarium wilt (Ware and Young, 1934; Ware et al., 1932). Dwight Isley, an entomologist, and Ware demonstrated that boll weevils preferred green leaf cottons over red leaf cottons (Anonymous, 1927). Bourland and Waddle (1988) suggested that this might be the first documented account of insect resistance in cotton. A primary goal of his plant spacing research was to engender early maturity to escape boll weevil damage (Ware, 1929a, 1929c; 1930),

Extensive reviews of U.S. cotton breeding. Dr. Ware published extensive reviews on the history of cotton breeding in the US and co-authored a reference book on cotton (Brown and Ware, 1958). In a chapter of the 1936 United States Department of Agriculture Yearbook, Dr. Ware (1937) reviewed the origin of the species and chronicled private and public cotton breeding programs. In 1952, he wrote an extensive review (188 pages) on the origin and development of American Upland cotton varieties (Ware, 1952b). Some information from that document was published in an experiment station bulletin, along with charts showing the early development of Deltapine and Stoneville cottons, and a key to identify nine common varieties of cotton grown in Arkansas (Ware, 1952c). These reviews illustrate the scope of Ware's knowledge and experience.

Cotton breeding leader. It is not clear what administrative duties Dr. Ware had as USDA senior agronomist in charge of cotton breeding. His obituary (Northwest Arkansas Times, March 19, 1977) stated that, "He established a national system of cotton variety testing, and assisted in the development of superior varieties to meet needs of cotton communities across the cotton belt." In a review of the 50-year history of the Cotton Improvement Conference, Miller (1998) referred to Ware as a key early leader of the cotton breeding community. Dr. Ware's obituary noted that, "He was recipient in 1963 of the "Man of the Year" award from the Southern Seedsmen's Association and his research in cotton genetics won him membership in the National Academy of Science and honor societies of the profession. He is the author of many technical papers, two textbooks, and numerous popular articles on cotton and was recognized internationally as one of the foremost cotton authorities of his time." Additionally, his obituary indicated that, "In 1951, he made possible the establishment of the Ben J. Altheimer Chair of Cotton Research, the first Chair in the division of agriculture at the University." This chair is currently held by F.M. Bourland and was previously held by B.A. Waddle and J. McD. Stewart. Dr. Ware was not the first cotton breeder at UA but was the first to establish a legacy that remains today. Arkansas and the cotton industry are heavily in debt to early researchers, like Dr. Ware, who paved the way for us.

UA COTTON BREEDING – THEN AND NOW

Similarities. Five similarities between UA cotton breeding during the tenure of Dr. Ware and today include:

1. Geography. The UA campus is still 200 to over 300 miles from major cotton growing areas of the state. This distance has always hindered campus-based UA cotton breeding by restricting daily interaction with the crop and producers. Today, interstate highways, modern vehicles (with air-conditioning and cruise control), restaurants and motels have eased travel discomfort. Yet, time occupied in travel still can impede productivity. After being located on campus for 10 years, Bourland negated this hindrance by moving the program to northeast Arkansas. However, this move lessened interaction with other cotton researchers and with students.
2. The cotton plant. Development and genetics of the cotton plant has not changed significantly. The plant originated in tropical/subtropical regions and was not adapted to grow in Arkansas, particularly northern Arkansas. Obtaining uniform and vigorous stands of cotton continues to be a challenge. Breeding efforts have certainly increased yield, earliness and pest resistance, but the plant still grows in an indeterminate fashion with similar vertical and horizontal flowering internals. Although genes have been introgressed into Upland cotton from other cotton and non-cotton (transgenes) species, the Upland cotton karyotype (allotetraploid with 52 chromosomes) remains unchanged. The plant itself still imposes many similar challenges to cotton breeders today.
3. Similar pests. We continue to battle similar cotton pests in Arkansas, namely seedling disease, Fusarium wilt, aphids, thrips, and worms. Notable differences today include the eradication of the boll weevil and enhanced problems with Verticillium wilt and nematodes. Herbicides have lessened problems with grasses, but many dominant broadleaf weed species continue to persist.
4. Overall breeding objectives. Breeding objectives of the UA cotton breeding program in 1936 listed in order of their importance included: 1) early maturity, 2) high yield, 3) medium to large bolls, 4) medium staple length for upland, longer staple for bottom land, 4) generally good fiber quality, 5) high lint percentage, 6) wilt tolerance or resistance, and 7) storm resistance (Ware, 1937). Today, we do not differentiate between upland and bottom land regarding stable length; we have added additional host plant resistance and fiber quality traits; and the importance of boll size has declined with mechanical harvest.
5. Breeding methods used. Development of segregating populations, number of plants selected, number of lines evaluated, selection criteria, and test terminology employed by Ware are curiously similar to those currently used in the UA Cotton Breeding Program (Table 1). Selection intensity in our current program appears to be similar to that employed by Ware.

Table 1. Numbers[z] associated with the UA cotton breeding program when headed by Dr. J.O. Ware compared to those used today

Ware (1929c)		Bourland (2004, 2013)	
Test designation	**Number**	**Test designation**	**Number**
Crosses	Not specified	Crosses	24 combinations
Individual plants	~1,000	Individual plant selections	~1,200
Progeny	~250	1st year progeny	~750
Increase blocks	~60	Advanced progeny	~220
		Preliminary strain tests	80 entries
Newest strain test	~30 entries	New strain test	20 entries
Advanced strain test	Not specified[y]	Advanced strain test	20 entries

[z] Number of entries in replicated tests include check cultivars.

[y] Ware (1929c) indicated that "The advanced strain test is much larger than the variety test and is made up of more recent strains developed by the Arkansas Experiment Station, other experiment stations, and commercial breeders, with some standard commercial varieties included for comparison".

Today's advantages. Advances in various technologies and knowledge provide significant advantages for today's cotton breeders. These advances include:

1. Increased understanding of genetics and related disciplines. During Dr. Ware's career, knowledge of genetics and gene action was mostly limited to Mendelian inheritance of qualitative traits. Understanding of plant development and interactions with pests was mostly derived from painstaking observations. Today, a much more comprehensive understanding of the plant, pests, nutrition, environmental effects, and interactions is available.
2. Improved production practices. Methods and understanding of cultivation, fertilization, pest control, and irrigation has advanced greatly. From a breeding perspective, perhaps the addition of irrigation has been the most important improvement. With irrigation, the likelihood of obtaining useful, repeatable data from a field trial is greatly enhanced.
3. Improved fiber quality analyses. During Dr. Ware's tenure, fiber analyses readily available to breeders was primarily restricted to visual evaluation of staple length. Now, HVI (High Volume Instrument) and AFIS (Advanced Fiber Information System) measurements can routinely provide detailed analysis of fibers.
4. Improved testing procedures. Testing methods and procedures including advanced statistical approaches and the availability of branch stations and regional tests greatly enhance ability of breeders to identify, evaluate, and describe plant materials.
5. Development of specialized equipment for packaging seed, planting plots, harvesting plots, ginning, and weighing samples. All of this equipment has greatly increased the efficiency of today's cotton breeder. Work now accomplished in a few hours by one to three persons might have required weeks of several workers to accomplish in Dr. Ware's day. Electronic weigh systems have replaced slow, mechanical analytical balances and bagging/weighing of harvested samples.
6. Formal release of varieties and lines. The Plant Protection Act of 1973 and subsequent procedures have enhanced records associated with formally releasing plant materials. Permanent records of materials now provide genetic and selection backgrounds, how they perform, and how they may be available. Availability of materials (seed) has been facilitated by USDA National Laboratory for Genetic Resources Preservation. These efforts provide a sustaining genetic bank of all released lines.
7. Transportation. Great advances have been made in transportation, which eases travel to research plots and meetings, and facilitate movement of seed, fiber, and plant samples.
8. Computer. Perhaps the greatest advantage that cotton breeders have today is the computer, which facilitates data handling, word processing, and communication. Additionally, almost all of today's machines and instruments utilize computer technology. Modern computers have greatly enhanced the speed and efficiency of breeding operations.

Today's disadvantages. Today's rapid-paced, high technology, interwoven society presents some obstacles to cotton breeders compared to the Dr. Ware's time. Some of these disadvantages include:

1. Increased complexity of traits. While early breeders and geneticists often evaluated simply inherited traits, we now focus on more complex traits and multiple levels of interactions.
2. Less state support. Public support of agriculture in general (and cotton breeding specifically) has steadily declined as the percentage of voters directly associated with agriculture has declined. I suspect that Dr. Ware spent little or no time seeking extramural funding.
3. Restrictions on labor. Since Dr. Ware's days, availability of labor has steadily declined and labor costs have increased. Additionally, labor skilled at performing tasks such as thinning plant stands and hand picking is now scarce in the US. Assuming 50 weather-permitting days with each person averaging 150 lb seed cotton day^{-1}, 56,755 hand pickers (3.0% of Arkansas' 1948 population) would be needed to harvest the 1948 record cotton crop in Arkansas. Undoubtedly, experienced people to hand pick research plots at that time were readily available.
4. Increased government regulations. We now deal with various government regulations on how we move and apply materials (planting seed, pesticides, and various chemicals), how we exchange germplasm, and how we manage employees. Although usually intended for the public good, these regulations can sometimes unnecessarily restrict and hinder breeding operations.
5. Diminished public relations. Through much of the 20th century, public cotton breeders were often the cotton authority in each state. They were usually generalists, adept in many disciplines. Today, cotton breeders are often more specialized, and countered with competing sources of information (consultants, industry, extension, press, internet, etc.). Additionally, the role of public varieties has diminished – particularly since the introduction of transgenic varieties.
6. Increased administrative demands. Requirements associated with various reports, evaluations, publishing, and general paper work has certainly increased and can restrict cotton breeders' time.

Would I prefer to be a cotton breeder in Dr. Ware's day or today? Although more complicated and perhaps more frustrating, I think that today's advantages outweigh today's disadvantages. Early in my career, I experienced cotton research without computers, electronic weigh systems, automated seed counting and packaging machines, cone planters, and mechanical plot pickers. I would not wish to breed cotton without these and other modern conveniences.

FINAL CONSIDERATION

Three UA cotton breeders having the longest active careers are J.O. Ware (1920-1958, 38 years, 22 at UA), B.A. Waddle (1951-1985, 34 years, all at UA), and F.M. Bourland (1978-present, 41 years, 31 at UA). They combine for 113 years of cotton breeding research including 87 years at UA. These three breeders are connected by their breeding interests (yield components, fiber quality and host plant resistance), their breeding focus (Arkansas and the Mississippi River Delta), and by overlapping time. Drs. Ware and Waddle shared office space in the UA Agronomy Department from 1951 until Dr. Ware's death in 1977. Bourland worked with Dr. Waddle during his M.S. degree program from 1970 to 1973. During that time, these three generations of UA cotton breeders met once in the office shared by Drs. Waddle and Ware. Dr. Waddle learned much from Dr. Ware and passed this on to Bourland. Hence, much of the breeding terminology, methods, and philosophy established by Dr. Ware are still used in the UA cotton breeding program.

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