One-Half Century of Hop Research by the U.S. Department of Agriculture[1]

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ABSTRACT

U.S. government support for hop research started at Oregon State University in 1930 when most American hops were grown in that state. Research was aimed at finding genetic resistance to downy mildew by breeding and germ plasm introduction and at developing chemical control measures against the disease. Later, work expanded to include agronomic, physiological, and chemical investigations. U.S. Department of Agriculture scientists independently, and in cooperation with state scientists in Idaho and Washington, released several new hop varieties that now account for about 35% of total U.S. hop production. Significant contributions to hop growing and utilization also came from research in hop pathology, chemistry, agronomy, and physiology.

Key words: Breeding, Germ plasm, Hop diseases, Physiology, Varieties

Hops have been grown commercially in the United States since the first settlers arrived. The flourishing hop industry in the eastern United States climaxed in 1879 when New York reached an all-time production high of 21.6 million pounds (27). New York ceased producing hops in 1916 primarily because of poor yields and increased cost of production (28). Today all U.S. hops are grown in four western states: Washington, Oregon, Idaho, and California (Fig. 1). Hops are grown in only a few areas of each state that are ideally suited to production of this labor-intensive, high-value crop. Total 1983 production on 36,900 acres was 68.1 million pounds with a farmgate value of $132.3 million (29).

Despite recent increases in hop production worldwide, the U.S. share has been fairly constant since 1965, averaging about 25% of the annual world production (Fig. 2). Historically, 40–50% of U.S. production was exported, a pattern that has held to this day.

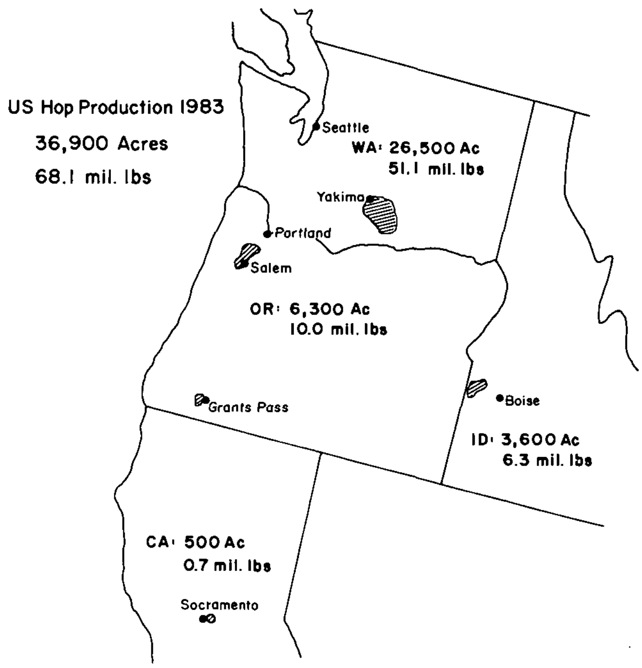

Fig. 1. U.S. hop growing areas and production in 1983.

HISTORICAL PERSPECTIVE

Efforts to improve hop production scientifically started in the United States after the turn of the century (27) but were abandoned with the advent of Prohibition. Following repeal of Prohibition, the hop industry recovered quickly, only to be threatened again by the invasion of downy mildew, *Pseudoperonospora humuli*, a disease that had never before been reported in the western United States. More than 96% of all American hops at that time were the variety Clusters, which was extremely susceptible to the downy mildew pathogen. Furthermore, most American hops were then grown in Oregon's Willamette Valley (28), a high-rainfall area, ideally suited to downy mildew infection.

The U.S. Department of Agriculture (USDA) initiated a hop research program at Oregon State Agricultural College (now Oregon State University) on September 3, 1930, with the appointment of E. N. Bressman. A plant pathologist, G. R. Hoerner, was appointed one year later. Both served as "agents" of the Bureau of Plant Industry, Soils, and Agricultural Engineering of the USDA and held faculty appointments at the college, which was the land-grant institution of Oregon.

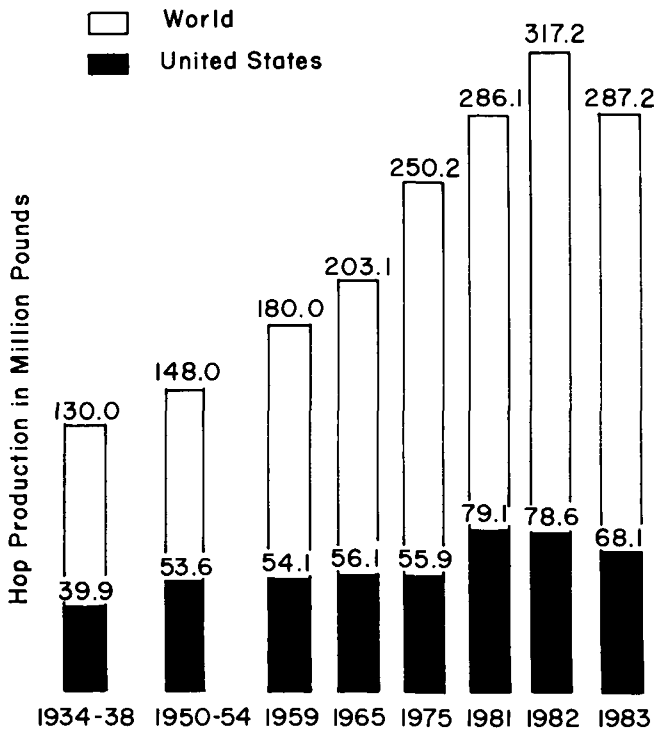

Fig. 2. U.S. and world hop production since 1934.

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[2] Research geneticist, chemist (retired), plant pathologist (retired), agronomist (retired), and former plant physiologist (now President, Sunny Hops Inc.).

Initial research efforts were mainly directed toward finding genetic sources of resistance to downy mildew to use in hop breeding and toward controlling the disease by chemical means. In the early years, there was a rapid turnover of hop breeding and agronomy research personnel (Fig. 3). Dr. Bressman resigned in January 1934 to be replaced by Dr. D. C. Smith, who served until May 1936. Dr. R. E. Fore held the position of hop breeder from 1936 until January 1944, when he was replaced by J. D. Sather. Illness prevented Sather from active research in 1947, and Dr. Fore, who was still at Oregon State University (OSU), headed the project again on an interim basis. Dr. K. E. Keller was appointed to the position in the spring of 1948. By that time it had become clear that Cluster hops had no future in the Willamette Valley of Oregon. Gradually Cluster cultivation, and with it the bulk of U.S. hop production, shifted to Washington. Clusters grew very well in the dry climate of the Yakima Valley where downy mildew was rarely a problem. Oregon lost its position as the leading hop producer of tne nation but retained responsibilities for regional hop research now conducted by the Agricultural Research Service (ARS) of the USDA.

Until 1948, USDA chemist, Dr. Frank Rabak, worked part-time on hops in the early part of the century. In 1949, a federal position was established at OSU for a hop chemist to work in cooperation with the hop breeder in developing new varieties and parental germ plasm lines. The first USDA hop chemist, R. A. Magee, served five years and actively cooperated with D. E. Bullis, a chemist in the Department of Agricultural Chemistry at OSU. USDA hop chemistry research continued until the retirement of S. T. Likens in July 1982 (Fig. 3).

The hop breeder, Dr. Keller, left in 1955 and was replaced by Dr. S. N. Brooks, who headed the project as investigations leader until June 1968, when he was transferred to Beltsville, MD. The first author (A.H.) initially was hired in August 1965, to study the genetics of disease and pest resistance of hops to supplement the breeding program. He assumed additional responsibilities for hop breeding and agronomic research after the departure of Dr. Brooks.

Research in hop physiology was conducted from 1959 until 1970 by C. E. Zimmermann, a USDA scientist at Corvallis. After his transfer to Prosser, WA, the scope of his research expanded to include agronomic research and variety development for the semiarid hop growing areas of Washington and Idaho in cooperation with the USDA hop breeder at Corvallis, OR, and state scientists at Prosser, WA, and Parma, ID. Zimmermann resigned in the spring of 1979, and his work is now being continued under a USDA Cooperative Agreement with Washington State University.

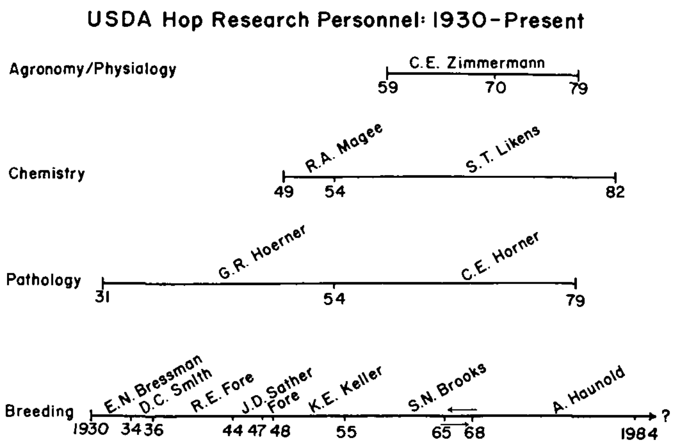

Fig. 3. U.S. Department of Agriculture scientists and their times devoted to hop research.

Other research areas, such as machinery and mechanical research, irrigation, or entomology, were undertaken to solve specific problems by state scientists or private organizations. Occasionally, USDA support was provided on a cooperative basis but was never expanded into full-time research.

Some reasons for the rapid turnover of personnel in the early phases of hop research were the difficulties of starting a new research project on a unique specialty crop. Trained scientists were unavailable and professional advancement appeared limited. This seems not to have affected hop pathology or chemistry research because two scientists each covered these areas from 1931 until 1979 and 1982, respectively, when the USDA began to deemphasize hop research following the retirement of the incumbents.

State scientists in each of the hop-growing states actively cooperated with the USDA scientists on various research projects over the years. This effort continues, with substantial financial support from hop growers, dealers, and brewers.

CONTRIBUTIONS AND ACCOMPLISHMENTS

Breeding

Initially, considerable effort was devoted to the introduction of germ plasm and varieties from abroad as sources of downy mildew resistance (11). Sometimes, progressive growers introduced foreign varieties for their own experimentation (9). Most foreign varieties, however, were poorly adapted to U.S. hop growing areas and quickly disappeared from commercial production (27).

Fuggle, an early maturing aromatic hop originally introduced from England, was sufficiently resistant to downy mildew to be grown commercially in western Oregon and western Washington (2,9). Later introductions, such as Bullion and Brewer's Gold, which became known as "English hops," were sufficiently resistant to downy mildew to be grown successfully in Oregon since the 1950s with careful disease monitoring and chemical control measures. Numerous crosses were made between Clusters and mildew-resistant male plants. However, the first successful U.S. hop variety came from Dr. Robert Romanko, an Idaho cooperator, who released Talisman in 1968 as an improved Cluster type (23). Talisman cultivation expanded to about 4% of U.S. hop acreage by 1974 but has since declined to less than 2% (Table I). Another cooperator, C. B. Skotland, initiated a mass selection program in the late 1950s at Prosser, WA, which resulted in several improved Cluster hops, such as E-2 (an Early Cluster selection), Yakima Cluster (a medium-early hop first known as L-1), and L-8, a high-yielding Late Cluster selection (26). These selections are still widely grown today (Table I). Fuggle-H, an improved Fuggle released in 1972, originated from a USDA mass selection program at Corvallis started in 1961 (14). Most Fuggle hops now grown in the United States are of the improved type.

The first new hop variety from the USDA breeding program, Cascade, was selected by S. N. Brooks in 1956 and released 16 years later (4). Cascade, an aroma hop adapted to Washington, Idaho, and Oregon hop growing areas, occupied nearly 13% of U.S. hop growing areas in 1983 and accounted for more than 8.5 million pounds of production (Table I). Recently, Cascade acreage has decreased somewhat because of reduced domestic demand and lack of export markets.

Two additional aroma varieties, Willamette and Columbia, were released in 1976 (5). They are seedless triploids and originated from a USDA polyploid hop breeding program initiated in 1965. Both are closely related to Fuggle but have better yields (Table I) and grow best in such areas as the Willamette Valley of Oregon where Fuggle is also well adapted. Curiously, Willamette, with a lower α-acids content similar to Fuggle, is now preferred over Columbia, which has a higher α-acids content and better keeping qualities. In 1983, Willamette occupied 3.4% of U.S. hop acreage, nearly all grown in Oregon (Table I). In 1984, Willamette acreage rose another 600 acres and now accounts for more than 6% of total U.S. hop production (29).

TABLE I
1983 United States Hop Production, Average Yield, and Quality Potential by Varieties[a]

Variety	Acres	% of Total	Yield (lb/acre)	Quality α-Acid (%)	Quality β-Acid (%)	Quality Cohumulone (%)	Production (× 1,000 lb)	% of Total
Fuggle	1,882	5.1	1,107	4–6	3	26	2,083	3.1
*Willamette[b]	1,244	3.4	1,576	5–7	3–4	28	1,961	2.9
*Columbia	204	0.6	1,529	8–10	3–4	33	312	0.5
*Cascade	4,763	12.9	1,790	5–7	6	32	8,526	12.5
*Galena[b]	3,847	10.4	1,479	12–15	8–9	40	5,690	8.3
*Eroica[b]	1,459	3.9	2,062	11–14	5	40	3,008	4.4
*Nugget[b]	232	0.6	1,478	12–15	4–5	27	343	0.5
*Olympic	84	0.2	1,800	11–15	5–6	30	151	0.2
Clusters[c]	17,210	46.6	2,005	5–7	6	38	34,506	50.7
*Talisman	573	1.6	2,000	8–9	6	45	1,146	1.7
English[d]	4,541	12.3	2,066	8–11	5	37	9,382	13.7
*Comet	288	0.8	1,800	8–11	4–6	38	518	0.8
Others[e]	573	1.6	846				485	0.7
Total	36,900						68,111	

[a] Yield data compiled by U.S. Hop Administrative Committee (29).
[b] Includes first year's production of new plantings: * = new variety.
[c] Includes 3,072 acres Late and 14,138 acres Early and Yakima (medium early) Clusters, respectively.
[d] Bullion and Brewer's Gold (mostly Bullion).
[e] Hallertauer M.F., Tettnanger, and seven experimental varieties at various stages of testing.

One of the early efforts of the USDA hop breeding program finally brought fruit in the early 1970s when it was shown that high α-acids content and good storage stability could be combined in a single genotype. Although lacking in yield potential, this genotype, USDA 21055, was later released as a parental breeding line (6) (Table II).

Other research which was started ten years earlier at Corvallis, OR, and Parma, ID, resulted in new varieties with very high α-acids content. Galena and Eroica, two new high-α-acid hops from open-pollinated Brewer's Gold seed were developed by R. R. Romanko at Parma, ID, in a cooperative effort with the USDA and the Oregon and Washington Agricultural Experiment Stations (24,25). Nugget and Olympic, two additional hops high in α-acids originated from USDA breeding efforts at Corvallis, OR, and Prosser, WA (7,16). All have high yield potential and an α-acids content considered to be among the highest of commercial hops anywhere in the world (Table I). Galena, Eroica, and Nugget are adapted to the major hop growing areas of the Pacific Northwest. Olympic thus far has not been tested adequately to draw definite conclusions. Most of the new hops high in α-acids, referred to as "super-alpha" hops by the trade, also have good storage stability of their soft resins, a trait that is of particular importance to hop processors. New American high-α-acid varieties occupied 5,622 acres (15.2%) of U.S. hop acreage in 1983 (Table I) and 7,415 acres (23.7%) in 1984 (29). This expansion came largely at the expense of established varieties, such as Bullion, Brewer's Gold, and Clusters that cannot adequately compete in α-acids content.

In addition to breeding new varieties, efforts continue to introduce and develop new hop germ plasm, the necessary parental material for breeding new varieties. Twenty germ plasm lines developed by the USDA scientists at Corvallis have been released for public use since 1971 (Table II). Outstanding features of these lines range from the doubled chromosome number in tetraploid Fuggle to downy mildew resistance, early maturity, good aroma potential, good storage stability of the soft resins, high α-acids content, high lupulin content, and high yield potential in various other lines (Table II). More than 100 germ plasm introductions have been acquired from abroad and integrated into the USDA hop breeding program in recent years.

TABLE II
Public Release of USDA Hop Germ Plasm

Year	Genotype	Advantage
1971	Tetraploid Fuggle	Polyploid breeding, noble aroma, downy mildew resistant female
1974	64032M 64033M 64037M	Downy mildew resistant male, noble aroma, low cohumulone
1978	21055	High alpha female, good storage stability of soft resins
1979	21102M 21104M 21105M 21106M 21175M 21176M 21177M 21178M	Triploid pollinator for yield stimulation without seed production
1982	21189M 21190M 21191M 21192M	Triploid pollinator, early maturity, yield stimulation without seed production
1983	63015M	Male, high α-acids, good storage stability of soft resins, low cohumulone
1984	65009	Female, high α-acids, high lupulin content, high yield potential
	64035M	Male, downy mildew resistant, noble aroma, low cohumulone

Pathology

Most of the 19,500 acres of hops grown in the United States in the early 1930s were Clusters, a variety extremely susceptible to downy mildew. Today, Clusters is still the predominant variety (Table I) but its importance has diminished somewhat.

To combat downy mildew, new varieties and germ plasm lines were introduced from abroad to find genetic resistance to downy mildew and initiate a breeding program (11). Early efforts also heavily emphasized chemical control of downy mildew to save the predominant Cluster variety. By 1950, however, most hop growing had shifted to the Yakima Valley, and Washington became the leading hop producing state.

Downy mildew control measures were initially based on copper or sulfur fungicides, and methods were adapted from other agricultural crops that had faced similar difficulties. Bordeaux mixture or copper dust formulations (8,10,20) eventually gave way to new organic fungicides, such as Zineb and related compounds (13). All, however, were only preventive measures that had to be applied before infection. Streptomycin, an antibiotic, looked promising as a control for systemic downy mildew (12), even after infection had already taken place. This compound, however, was slightly phytotoxic to hops and never received a permanent label. Recently, new systemic compounds, such as Ridomil, Aliette, and others, have appeared on the market (15). Despite the fact that some of these compounds are now widely used in other hop growing areas of the world, they have not yet been approved for general use by American hop growers.

Recent pathology research also includes work on Verticillium wilt and hop viruses. Fortunately, however, none of these diseases present the threat to the U.S. hop growing industry that downy mildew did in the 1930s.

Hop Chemistry

From the early beginnings, USDA hop chemistry research was designed to assist the breeding program. During the past one-half century, however, significant advances were made in hop chemistry and instrumentation. New methods and equipment were adapted for hop analysis. Work on analysis of male flowers (3,17), studies of soft resin composition, and characterization of hop oil constituents (18), the varietal characterization of α-acid analogs (21), and the elucidation of soft resin storage stability (19)—which led to an official method for hop storage stability adopted recently by the ASBC (1)—were of significant help in charting the direction of hop breeding efforts.

Following Likens' retirement in 1982, the USDA discontinued hop chemistry research. This work is now being continued by G. B. Nickerson, a chemist at OSU, and is largely supported through industry grants.

Agronomy and Physiology

Despite the relatively short duration, USDA agronomy and physiology research has made important contributions to the efficiency of commercial hop production. Development of a copper naphthanate/diesel mixture (30) enabled growers to use biodegradable Kraft brand paper strings as training material for hop plants. A comprehensive herbicide testing program, in cooperation with university weed research, resulted in registration of Dinoseb and Paraquat for weed control in hops and chemical suckering and stripping to remove unwanted basal growth (22). Treflan and Norflurazone were tested and approved for weed and grass control in existing hop yards. Gibberellic acid as GA-3 formulation was found to significantly increase flower and cone production in Fuggle, a notoriously low-yielding hop (31).

FUTURE OUTLOOK

New hop varieties developed during the past 25 years now account for about 35% of total U.S. hop acreage (Table I). This acreage will increase further, largely at the expense of older varieties. For example, from 1983 to 1984 the actual U.S. hop acreage dropped 6,000 acres but acreage of the Willamette variety increased by 885 acres, and that of the super-alpha varieties (Galena, Eroica, and Nugget) increased by 1,892 acres (29). However, despite an efficient and modern hop industry that combines favorable growing conditions and modern production and processing methods, some U.S. brewers still purchase substantial quantities of hops abroad to achieve the desired balance of flavor and aroma in their beer because they do not think domestic hops alone are capable of providing this.

The emphasis of USDA programs has recently turned away from commodity-oriented research and, therefore, vacancies in hop pathology, chemistry, and physiology have not been filled. Hop breeding and germ plasm development, however, will continue, with some change of emphasis.

Current breeding efforts center on developing additional aromatic varieties similar to those being imported from abroad. Germ plasm development now focuses on: identification of additional sources of downy mildew and Verticillium wilt resistance; incorporation of superior storage stability into additional high α-acid lines; evaluation of the interaction between soft resin storage stability and noble aroma characteristics; and combination of high yield potential with early maturity and suitable α-acids content.

To encourage expanded research efforts, industry now provides additional financial support to researchers in the three principal hop growing states through the U.S. Hop Research Council, an organization of growers, brewers, and hop merchants formed in 1979. In future years the role of state scientists will expand in research on problems of the brewing, hop growing, and processing industries. Cooperative research between the USDA and the four hop growing states, particularly with regard to germ plasm and variety development, will continue to benefit the American hop industry.

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