Grafting Manual:
How to Produce Grafted Vegetable Plants

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Synopsis:
Grafting is an old and new technology to enhance the sustainability of vegetable crop production. The history of introducing this practice is summarized.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

History of vegetable grafting

Grafting of vegetable seedlings is a unique horticultural technology that is used worldwide to overcome soil- borne diseases and pests and/or to increase plant vigor under various environmental stress conditions. Today, grafting is used especially when there are limited rotation or soil fumigation options. For example, almost all watermelon produced in Japan, Korea, southern Spain, southern Italy, Turkey, and Greece are grafted, and there are increasing numbers of grafted tomato, eggplant, pepper, cucumber, and melons worldwide. In hydroponic greenhouses, grafting has become a standard practice to increase plant vigor and yield. In high tunnels, heirloom cultivars are grafted onto modern rootstocks to overcome soil-borne disease. Grafting is also used to mitigate environmental stress such as salinity, drought, flooding and low temperature. This article summarizes the history of the development of vegetable grafting and its use worldwide.

The beginning – innovation by a small farmer

The oldest record of grafting vegetable plants is in 500 AD in China (Lee and Oda, 2003) when farmers joined together multiple gourd plants to develop a greater root system to increase the size of gourd fruit (Fig.1). However, vegetable grafting using two different species or cultivars for disease and pest management was not documented until the early 1900s. Koshiro Tateishi published an extension research journal article in Japan (1927) indicating that vegetable grafting can be a revolutionary technology for future vegetable production, and encouraging scientists to further develop the technology so that it would become a common practice among farmers. This article was briefly featured in a Korean extension newsletter (Ashita, 1927), which is often mistakenly cited as the first modern report of vegetable grafting. In his article, Tateishi reported that a small watermelon grower named Ukichi Takenaka in Hyogo, Japan, grafted watermelon onto

pumpkin (or squash) and successfully, and easily overcame Fusarium wilt. Based on Takenaka's success, Tateishi set up various experiments to test watermelon grafting, compared grafting methods and recommended cleft grafting over approach grafting. He also noted possible issues of early female flower abortion of grafted plants in the field, as well as impact of grafting on watermelon fruit quality. Tateishi reported that while grafting was theoretically possible between these two species, it was not until farmer Takenaka did it, that grafting was considered to be a viable technology. Many research and extension efforts followed to use grafting at various agricultural experiment stations starting in 1929 (Oda, 1990).

By the 1950s, plastic tunnels had become popular to extend the production season of high value crops in Japan; however, the intensive production using the same land intensified the issue of soil-borne diseases, thereby accelerating the use of grafting (Fig. 2). During this era, seed companies made tremendous gains in breeding rootstocks for disease resistance, and they introduced grafting to many countries through their international marketing efforts.

Israel was one of the early adapters of commercial vegetable grafting. Crops other than cucurbits were grafted in the 1950s and 1960s. For example, eggplant was grafted onto scarlet eggplant (*S. integrefolium*) as a disease management strategy, In the 1960s commercial use of tomato grafting was introduced in Japan and Korea ((Lee and Oda, 2003). During the 1980s and 1990s, milestone grafting innovations were made, including the development of tube grafting, one-cotyledon grafting and healing methods suitable for commercial nursery operations (Itagi, 2009).

These methods integrated vegetable grafting into modern commercial nursery systems that used plug trays introduced from the United States. Tube grafting increased the speed of solanaceous grafting by 2-3 times (Itagi et al., 1990). One-cotyledon grafting was first developed by a watermelon grower (Saito, 1981) and was later introduced as the baseline method to mechanize grafting due to its simplicity compared with other grafting methods used for cucurbit plants (Onoda et al., 1992; Suzuki et al., 1995). Automation for grafting was studied intensively during this era and various grafting ro-

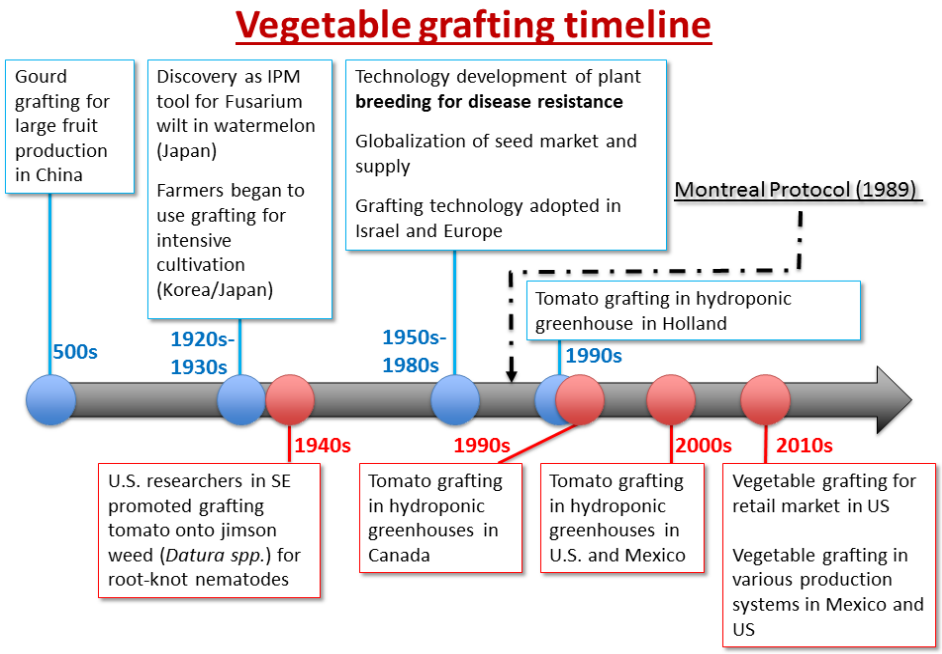

Figure 1. Timeline showing milestones in history of vegetable grafting in the world (upper part, blue) and in North America (lower part, red).

bots were invented and commercialized (Kurata, 1994). However, only a small number of robots were effectively used in commercial operations due to the precision required for preparing scion and rootstock plants suitable for machine use. In the early 1990s, indoor healing systems with environmental control were developed for mid to large-size nurseries (Itagi, 2009). An international symposium focused on transplant production technologies held in Yokohama, Japan (Hayashi et al., 1992) was a showcase of these technologies, and attracted many international scientists and engineers. After the Montreal Protocol identified methyl bromide as one of the substances to phase out and the protocol became effective in 1989, much effort by academia, commercial sectors and international organizations, including rootstock breeding and development, was made to introduce vegetable grafting as an alternative tool for soil-borne disease management in various countries.

History in North America

The U.S. developed one of the earliest innovations in grafting tomato. During the 1930s and 1940s, tomato was grafted onto jimson weed (*Datura stramonium*) and the technique was recommended to gardeners (Isbell, 1944). Southern growers used this technique to overcome root-knot nematodes (Lowman and Kelly, 1946); however, this practice was discontinued partly due to the possible transport of alkaloids to fruits from the rootstock (Lowman and Kelly, 1946). Similarly, germplasm that is considered as weeds have been introduced as rootstocks for other vegetable crops. A good example is Turkey berry weed (*Solanum torvum*) collected from Puerto Rico and Thailand, which are now widely used as rootstock for eggplant.

Commercial grafting used in today's North American vegetable industry was introduced

Figure 2. Bottle gourd rootstock seedlings and watermelon scion seedlings prepared for grafting in a rural village Shimohara in Nagano, Japan in 1967 (dated on April 5, Showa- 42 Year). Bottle gourd seedlings (rootstock) are at the stage of fully unfolding first true leaf inside a bamboo-framed tunnel. Watermelon seedlings (scion) are grown at a high density inside a small wooden tray filled with soil and are just about at the beginning of emerging cotyledons. The particular growth stage of young scion seedlings suggest that grafting would be done with the insertion method. (*Photo credit: Mountainlife, Wikimedia Commons*; Link http://www.wikiwand.com/ja/%E4%B8%8B%E5%8E%9F%E3%82%B9%E3%82%A4%E3%82%AB)

by Dutch growers in the 1990s. In the Netherlands, Dutch greenhouses were using grafting in the 1960s in their intensive cultivation systems; however, in the 1970s and 1980s, their use of grafting declined because other means such as resistant cultivars and chemical fumigants (i.e., methyl bromide) became available (L. Benne, personal communication). In the 1990s, grafting was re-introduced as the increased plant vigor was suitable for the long production cycle in modern greenhouse tomato production. Use of the tube grafting method contributed to making grafting more suitable for the production of large volumes of plants for commercial operations.

Grafting was also introduced in Canada in the 1990s to support the rapidly growing greenhouse industry in Canada and the U.S., and later in Mexico. Canada has been the primary supplier of grafted plants to the U.S. and Mexico, and long distance shipping has been a common practice in distributing grafted plants throughout North America.

In addition to the use of grafted plants in the greenhouse industry, various small growers and extension personnel in land-grant universities have contributed to the transfer of grafting technology. A commercial nursery in Oregon began introducing grafted heirloom tomato plants to retail markets in 2011. Seed retailers started selling small packages of rootstock seeds. This made grafting known to a wider range of stakeholders including home gardeners and professionals.

In Mexico, in the 2000s, grafting was introduced partly through a United Nations effort to reduce the use of methyl bromide in open fields and in tunnels (Martinez, 2015). However, the rapid development of the tomato greenhouse industry was another primary reason for the expanded use of vegetable grafting and its adoption as a standard practice in the greenhouse industry. More recently, grafting watermelon was introduced to mitigate the risk of intensive cultivation.

Vegetable grafting today and tomorrow

In the U.S., the vegetable grafting market has rapidly expanded in recent years despite the concern associated with the cost of grafted plants. More seed companies in the U.S. are now carrying commercial cultivars of solanaceous and cucurbit rootstocks. Today, plants are grafted in commercial nurseries in several states, targeting various markets including retailers, greenhouses, high tunnels, and open fields, of various production scales. New nursery operations are currently being built in collaboration with various sectors of the fruiting vegetable industry. The number of rootstocks available in the U.S. increases each year. Experimentation with grafted processing tomato is underway as a means to overcome issues associated with cultivation in marginal land.

While the exact number of grafted plants used in the U.S. is difficult to document at present, grafting is now recognized as a sustainable cultivation technique in most regions, and use is expected to increase as the grafting industries mature and growers learn how to use grafting technology more effectively and efficiently, with enhanced economic viability.

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