Vegetable Hybrid Seed Production

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Abstract

The trend of F1 hybrid seed usage in vegetable is increasing globally in term of species, cultivars and volume of seed used. F1 hybrid vegetable seed can be categorized into hand-pollinated and gene-control pollinated species. The gene-controlled species can be due to the effect of self-incompatibility genes or male sterility genes. The vegetables with both F1 hybrid and open-pollinated cultivars were summarized to show their trend of adoption in the world and their F1 seed production method. The development of the hand-pollinated F1 vegetable seed production industry in the world was summarized and the contract production system described. A case study using tomato hybrid seed production in Taiwan was exemplified in details to illustrate the production steps from selection of site to actual growing of the male and female parents, emasculation of the male flowers and pollination, seed extraction and drying, and constraints facing the industry.

Introduction

Vegetables consist of many species and cultivars, and can be classified in many ways such as by botanical family and species, cultivar group, the edible part, climatic region, user ethnic origin, life cycle and nutrition. In seed production they can be categorized into open-pollinated, F1 hybrid and clonally propagated cultivars. The trend of F1 hybrid seed usage in vegetable crops is increasing globally in term of species, cultivars and volume of seed used. Most of the seed of our main vegetables including tomato, sweet pepper, eggplant, cucumber, squash, pumpkin, melon, watermelon, brassicas such as cabbage, cauliflower, broccoli, Chinese cabbage and radish, and onion in developed countries are of F1 hybrid cultivars. The popularity of F1 hybrid cultivars is due to their vigor, uniformity, disease resistance, stress tolerance and good horticultural traits including earliness and long shelf-life expressed and therefore giving consistent stable high yield. From the breeder point of view, it is a fast and convenient way to combine desirable characters of a vegetable together, for example fruit size and color, plant type and disease resistance, and as a mean to control intellectual property rights through control and protection of the parental lines by the breeders. The latter was the main reason Japanese seed companies applied to protect their cultivars in the 1940s and 1950s.

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In F1 hybrid vegetable seed production, vegetables can be divided into two groups: the hand-pollinated and the gene-control pollinated species. The genetic control system can be due to the self-incompatible system where pollen of the same plant or flower cannot pollinate itself or to the male-sterile genetic system where a female plant has no male organ, deformed organ or no functional pollen to pollinate itself. When no such genetic control system is found or when it is not introduced into inbred parental lines, tedious hand-emasculation and pollination have to be used to produce F1 seed. In both the gene-control system and hand-pollinated species sufficient field or female flower isolation have to be maintained to obtain high seed genetic purity. Table 1 gives examples of these two groups of species and the trend of F1 hybrid cultivars adoption in the world.

The gene-control pollination F1 vegetable seed production system

The vegetables with highly developed self-incompatibility system are those in the family Crucifereae. They include *Brassica oleracea* (Brussel sprouts, cabbage, cauliflower, broccoli, kohlrabi and kale), *Brassica rapa* (Chinese cabbage, turnip and a range of Asian leafy brassicas) and *Raphanus sativus* (Table 1). The genetics of the self-incompatibility system in the cruciferous crops are so well developed that they consist of a series of genes (loci) and alleles. Vegetable breeders have been very successful in using them for decades in F1 hybrid seed breeding. Hybrid seed production of sweet corn, carrot and onion are based on male sterility gene system and the genetic control can be either just clear-cut male sterility genes or the interaction of a male sterility gene with a cytoplasmic factor. In recent years, brassica breeders are trying to use male sterility system instead of the standard incompatibility system. Some of the difficulties encountered were the reduction in nectary gland size and decreasing function of these glands. Plants with male-sterility gene were therefore unable to attract insect pollinators which are required for pollination. The progenies of the male sterility progeny in *Brassica juncea* also gave rise to young leaf yellowing symptom.

The hand-pollinated F1 vegetable seed production system

Most of the seed of F1 hybrid vegetables are produced by hand-pollination as indicated in Table 1. The method in principle is simple as it involves the manual emasculation of the pollen-producing organ, the anthers, followed by hand pollination with pollen of the male parent and then preventing other pollen from contaminating the pollinated flowers. However, it is labor intensive and requires a team of skillful growers and many dedicate pollinators with good eye-sight, gentle hands, a lot of patience and commitment, and able to follow instructions accurately. The main task of a seed producer is the management of the production system and business. To be cost-effective, this system only works in species where a single pollination of a female flower will produce many seeds. This is the case for all the solanaceous crops and cucurbits. On the contrary, in legumes the small number of seeds per flower/pod prevents hand-pollination to be efficient and thus no hybrid beans to date have been produced. In this case the use of gene-control pollination has to be exploited. Similarly, if a good gene-control pollination system is available in say tomato and pepper their seed production could be transformed into less intensive large field production system as in the brassicas and sweet corn.

The distribution of F1 vegetable seed production in the world

The two systems of hybrid vegetable seed production have different production requirements. The gene-control pollination system requires suitable climatic conditions, good growers with mechanized farm and high standard of seed quality and seed health control. Many of these locations are in developed agricultural countries such as USA and Canada, Europe, and Australia and New Zealand. On the other hand, the intensive hand-pollination system demands in addition to suitable climate, good seed growers and high standard of seed quality and seed health control also efficient low cost pollination teams, small intensive fields with constant supervision, techniques to harvest and extract pollen from the male parent, efficient way and machinery to extract, clean and dry the valuable hybrid seed produced and also quarantine certification. These conditions are usually found in lesser-developed countries where horticulture is progressive and a contract agreement is respected and kept. The contracting seed company through stringent contract specifications and regular supervision of the seed production field and the harvested seed is able to control and maintain high seed quality.

The distribution of hybrid vegetable seed production in the world is therefore limited to some specific regions where the climate, weather and availability of good growers are the main deciding factors. Vegetables can be classified into three categories according to their temperature requirements as follows:

- Low temperature species such as brassicas, radish, carrot and spinach require a low temperature of 8°-15°C of vernalization to bolt, flower and seed set;
- Moderate temperature species such as tomato, sweet pepper and zucchini require a temperature of around 18°-20° with around 25°C in the day and 15°C at night for optimum seed production. The diurnal temperature difference is desire to obtain best result. Too low a temperature causes low seed set and pollen production, and too high a temperature flower abscission, low pollen production and viability, and pest and disease problem; and
- High temperature species such as okra, cucurbits, sweet corn and tropical vegetables require a temperature of 20°C and above.

This temperature requirement is attained at different latitudes by a combination of climatic season and elevation above sea level. For instance in tomato, a moderate temperature requirement vegetable, seed production can be carried out equally well in the winter season of a subtropical region as the case in Taiwan and Southeast Asia or in the summer season in temperate region as in Northeast and Northwest China, and in Chile. In the tropics seed production is sometimes achieved in highlands of 500-2000 m altitude where the cool temperature is suitable for the moderate temperature loving vegetables to produce seed. Photoperiodic reaction is not a concern as most of the modern cultivars of the moderate temperature requirement species are day-neutral plant and thus insensitive to photoperiod. The low temperature requirement vegetables often require a specific period of cold vernalization in their growth phase to induce bolting and flowering. Seed of these species are often produced in the higher latitudes. However, some of the heat tolerant cultivars of these cold loving vegetables e.g. some cruciferous crops and carrot require less vernalization time and also process shorter day photoperiod requirement and thus their seed production has been successfully carried out in subtropical areas.

The hand-pollinated F1 hybrid seed occurs mainly in East Asia (China and Taiwan) and Southeast Asian highlands (Northern Thailand and Northern Philippines), India (Karnataka and Andhra Pradesh), Mexico and Chile. The gene-controlled pollinated seed production is found largely in the USA (California – brassicas, onion and radish; Idaho – brassicas, onion and radish; Oregon – brassicas, onion, radish and turnip; and Washington State – brassicas, carrot, onion, radish and turnip), Canada (British Columbia – crucifers), Denmark (crucifers), Australia (Southeast Australia including Tasmania – crucifers and onion), New Zealand (crucifers) and in East Asia, China (Northeast, North and Northwest China - crucifers, Central China and Southeast China), Korea - crucifers, Japan – crucifers, and Taiwan – crucifers.

Development of hand-pollinated hybrid vegetable seed production in the world

I. Post Second War World Period. Following the success of F1 hybrid sweet corn breeding in the USA in the 1940s and 1950s other F1 hybrid vegetables were bred. The end of the Second World War could be said to mark the beginning of the global hybrid vegetable seed industry when the seed production technologies were spread from the US and Japan to other countries. Japan was already exporting hybrid tomato and eggplant in the 1950s. The main recipient of this technology was Taiwan which was to develop into one of the most successful countries in the world in producing hand-pollinated F1 hybrid vegetable seeds. The combination of both the US and Japanese know-how in Taiwan has resulted in an efficient production system. During the peak of the industry in the 1970s, Taiwan produced most of the world F1 hybrid tomato seed and also watermelon, melon, sweet pepper, eggplant and cucumber. Hot pepper and other lesser cucurbits such as luffa and gourds were also introduced during this period. Almost all of the hybrid seed produced were for the US, Japanese and European seed companies.

Some of the international companies decided to establish offices and research farms, or joint partnerships with local Taiwanese seed companies, for example Petoseed (presently, Seminis) acquired Wann Shiang to form Peto Wann Shiang which later served as Petoseed's technical base for its entry into other Asian countries like China, Thailand and India. On the other hand Sluis & Groot (presently, Syngenta) decided to enter into partnership with Ching Choung to form Fu Lan which then operated like other local seed companies. Sakata Seed of Japan decided to establish its own research farm there. The prominent local seed companies were Known-You Seed and Evergrow Seed and they are still the main vegetable seed companies there, presently. Known-You has been the winner of several All-America Selections awards in the past years including most recently in 2001 for its melon hybrids.

The production areas were concentrated in southern Taiwan in Kaohsiung, Pintung, Chaiyi and Tainan Prefecture with approximately 40%, 40%, 14% and 6% of the total production, respectively. There are several factors that contributed to this success and development, and the four main factors are:

1. The cool dry climate with plenty of sunshine hours and good irrigation water during the winter season is ideal for growing moderate temperature requirement crops such as tomato, melon and pepper and thus their seed production. In general, the day and night temperature difference at this period is optimal for good fruit-set. In addition, the dry climate allows the

soil moisture to be accurately controlled by furrow irrigation for optimal growth and seed development.

2. The seed crop fits well into the existing paddy rice based cropping system which ensures better farm land utilization and pest and disease control especially the soil borne pathogen such as bacterial and fungal wilt, root-knot nematode, viruses and others. This is important because some of the parental inbred lines due its inbreeding or polyploidy origin as in the case of seedless watermelon seed production are often not so vigorous and specific cultural techniques have to be used to grow them successfully. In addition, every new field has to be tried out to identify the species and best hybrid combinations that it can produce.
3. The general crop management skill of the seed growers was high such as skill in seedling raising, irrigating, fertilizing, pruning, staking and general field cleanliness and hygiene. The growers had the economical capability to invest in labor and farm inputs in this intensive undertaking. Skillful and patient pollinators with delicate and stable hands were available. Hence, a successful hand-pollinated hybrid seed production enterprise depends both on the availability of technical knowledge at the actual operational level of seed production, and the ability and willingness of the growers to participate in this high-risk high capital cost and slow turnover investment.
4. An efficient contract seed production system was developed and established between the international seed companies and specialized local seed contract production companies. Those international companies even after setting up their own offices in Taiwan continued to use some of the services of the local production companies and their area seed agents to implement their seed production targets. The contract system is summarized in Figure 1.

Both the local and overseas companies in Taiwan were equipped with modern appropriate machinery and had highly trained technical staff who worked directly with the growers or through their area seed agents. The responsibilities of the area agents and company staff were to recruit potential seed growers, to negotiate the production contracts, and to train and retain good growers. The contract covered agreement on the amount of seed to be produced, seed price, time of delivery, term of payment and seed standard including germination rate, genetic purity and moisture content. Sometimes, certain production inputs e.g. mechanized wet seed extractor had to be loaned to growers depending on the contract agreement. Once a contract was signed the company personnel issued seeds of the parental lines and provided expertise on seed production rangeing from crop management practices to pollination and seed processing techniques to the growers. The most important duty of the seed company staff and agents were to ensure the contract quality and quantity of the seed produced under their supervision. The seed standard of tomato was a genetic purity of at least 98%, germination rate of above 85% and moisture content of less than 8%. Normally, a grower would be paid around 45 days after seed submission to the seed company. Due to the close supervision of seed company’s staff and agents only occasionally a seed lot would be rejected. Through the contract production system the seed company technical staff could also plan and locate seed production fields to ensure sufficient isolation distances between species and that each company usually would develop its own production areas and respect those of another company. This contract production system has led to the development of the “seed village” concept where the whole village will be trained and developed to produce hybrid vegetable seed.

II. From early 1980s to present: The era from the 1960s to 1980s marked the beginning of large-scale hand-pollinated hybrid vegetable seed production in Taiwan and in the world. When the cost of production started to increase in the mid 1980s in Taiwan due mainly to its manufacturing industry competing for labor both local and international companies started to seek new production sites in other countries including China, Thailand, the Philippines and India. For example, Peto Wann Shiang was to dispatch and station its Taiwanese technicians in China and India for the entire seed production season.

In China several very successful production locations have been established in northeast, north and northwest China, some area of south and central China. It has positioned itself into one of the main hand-pollinated F1 hybrid vegetable seed production countries in the world. The expansion of Chinese domination is to a great extend the result of the Chinese government policy to commercialize its seed industry from a centrally plan operational system where seed production target were handed down from the top into a more open business and profit-orientated industry. The state-own seed companies are facilitated to operate in a reasonably independent manner and they seek outside funds such as the World Bank loans to modernize and to train a new class of market-orientated managers. They seek and forge corporation among themselves and with international companies to build competitive advantages in the market.

In Thailand vegetable hybrid seed production is concentrated in Northeast Thailand where the cool winter weather is drier and thus has less disease and pest problem as comparing to Northern Thailand. However, the cooler weather in the highlands of Northern Thailand continues to offer good suitable locations both for seed production and plant breeding station. This industry has shown sign of stabilization and consolidation due to the increasing wages of pollinators. In the Philippines production is concentrated in Northern Luzon and it is not expanding and has stabilized as in Thailand. In India, vegetable production is expanding at a rapid rate with an increase of three folds during the last 50 years. A large area is now planted with F1 hybrid cultivars and thus hybrid vegetable seed production is growing at a rapid rate. The production is mainly concentrated in Karnataka and Andhra Pradesh. All these new production locations in East, Southeast and South Asia are based on Taiwanese technology and the rice paddy based cropping system.

In the western hemisphere, Mexico due to its proximity to US and the availability of cheap pollinators the industry is also established in Baja California. In Chile the reverse season in the southern hemisphere and suitable climate have provided specific advantages that are not found elsewhere and a substantial hybrid vegetable seed production industry has been established.

F1 hybrid vegetable seed production: A case study on tomato in Taiwan

The goal of a seed grower is to produce good quality seed and to make a profit by increasing seed yield and reducing labor and other farm inputs costs. To achieve this, both the growers and the seed companies have developed their own specific techniques in order to be more competitive than the others. Many growers because of their experience in managing their own fields have modified the standard management recommendations to suit their fields. Some of the modified techniques are unsuitable for other fields and others have no obvious advantages over the standard methods.

The following are the standard techniques in use for commercial F1 tomato hybrid seed production in Taiwan:

1. Crop management practices:
   In tomato higher fruit yield generally gives higher seed yield but this applies only within each of the genetic types. For example, the Roma-type generally gives fewer seed per fruit as compared to medium-size globe fruit type. Most reciprocal crosses in tomato express almost the same hybrid vigor and therefore the better seed yielding line is always used as a female. Optimal crop management practices should therefore be adopted to grow a healthy vigorous crop with more and concentrated flowering period to reduce pollination days and to increase fruit set. The application of more phosphorus and potassium fertilizers is reported to increase seed filling and thus seed yield.

1.1. Planting season. The optimal planting season is from September to October at the on set of the cool season. This will allow the fruit to ripen in the cool dry month of February thus reducing disease occurrence and facilitate seed drying.

1.2. Soil and location. Well-drained sandy loam is selected but fields with deep sandy soil along the bank of rivers have been successfully used when fertilization and irrigation are well managed. Fields immediately after rice paddy are selected because they are relatively free of pests and diseases and they should be away from commercial tomato production areas.

1.3. Female to male parent ratio. The ratio of female to male parent is normally four to six females to one male depending on the flowering ability, pollen productivity and fertility of the male.

1.4. Synchronizing sowing and planting. Depending on the flowering date difference between the male and female sowing date are adjusted. However, the male is normally sown 1-2 weeks earlier in order to produce enough pollen for pollination when the females are ready. This also provides more time for the off-types to express themselves, thus more accurate roguing and better genetic purity.

1.5. Stagger planting. Stagger planting is commonly practiced to spread out the concentration of works at any one time. This eases the problem of shortage of experience pollinators.

1.6. Transplanting. Seedlings are raised in small plastic pots or flats. The male and female are planted in separate field or in difference section of the same field. They are usually planted in double rows per bed with within row spacing of about 0.40-0.45 m and between row if 0.80 m for the female. The bed height is normally about 0.25-0.30 m high. The wide spacing of the female rows allows easy movement for pollinators during emasculation and pollination.

1.7. Staking and pruning. Depending on the availability of labor and capital, staking of the female plants help to facilitate hand emasculation and pollination, and if the weather is wet it also reduces diseases. Seed yield will therefore increase. A comparison of the two staking systems – tee-pee over a raised bed and tee-pee over a furrow, and no staking is given in Table 2.

1.8. Purity of the parental lines. The parental lines are supplied by the seed companies and seed genetic purity is usually high. Optimum crop management is used to allow all the plants to express their full potential so that all off-types can be recognized easily during field inspection and roguing from the beginning of the production season before they contaminate the production. Extra precaution and effort are emphasized in the male parent because when contamination occurs it could be extensive as it is not limiting to an individual as in the case of a female plant. Several rounds of field inspection are done at different growth stages including seedling, transplanting, growing, flowering stage, etc. to rogue all suspected off-types and volunteer plants. Every plant is inspected because of the high demand in cultivar purity of better than 98%. In addition, non-emasculated flowers and selfed fruits on the female plants are removed during emasculation and pollination rounds, and at harvesting.

2. Emasculation and pollination:
   Tomato style and stigma are, normally, enclosed by the anther cone and the stigma is often at the same level or below as the tip of anther cone. As the result, tomato is predominantly self-pollinated with only about 2% of natural out-crossing. It is therefore safe to leave the female flowers uncovered after emasculation and pollination when isolation distance of at least 50 m between two lines is provided in hybrid seed production. However, usually greater isolation distance is planned for in the field.

2.1. Emasculation. The female flowers are emasculated usually starting from the second cluster up with a forcep at 2 days before anthesis. Too early emasculation can damage the bud and too late stage increases the chances of selfing. The whole anther cone can be taken out or each anther is removed individually. Chiou and Yu (1969) showed that the first cluster has lower rate of fruit setting, small fruits and fewer seed in a fruit. This also allows the young plants to have more vegetative growth before the onset of reproductive phase. Usually, emasculation is done in the afternoon after the emasculated flowers from the previous day were pollinated.

2.2. Pollen collection. Male parent flower buds that will open the following day are picked in the afternoon, the anthers are separated that night to dry and the pollen are extracted the following morning for pollination. Once the anthers split pollen can then be shaken out in a closed container and the pollen are separated from other flower parts by sieving through a 300-mesh screen. Alternatively, buds that will open that day are collected, allowed to open and the pollen extracted for pollination. Tomato pollen can be stored in a cool dry place for weeks e.g. in moisture-proof container with calcium chloride in a refrigerator.

2.3. Pollination. Pollination is done first thing in the morning. The emasculated flowers are pollinated on the day of flowering by either using the little finger dipped with viable pollen or with a special small vial that has a ring to be worn on the pollinator finger. It is important to introduce enough pollen onto the stigma to ensure high seed set because normally pollination is done only once in a flower and one pollen can give only one seed. Two to three sepals are cut with a small scissor to indicate that the flower has been pollinated and to identify the hybridized fruit during harvesting. Generally, setting of 4-5 fruits per cluster and 5-8 clusters are sufficient to give good yield. However, individual plants with up to 80 pollinated fruits are not uncommon in good season. Pollination 1-2 days before blooming gives low fruit set and seed yield whereas one day after blooming has no detrimental effect. The pollination period normally last about a month to a month and half with about 40-60 workers per hactare per day.

2.4. Post-pollination cultural management. Immediately after the final round of pollination the female plants are pruned to remove new growth firstly to prevent formation of new flowers and thus selfed fruits and secondly to reduce competition for nutrient with the pollinated fruits. The field is given another top-dressing and followed by furrow irrigation if needed. Pest and disease control are rigorously implemented until harvesting. All selfed fruits found are removed through out the season to avoid seed contamination.

3. Harvesting, seed extraction and processing:

3.1. Harvesting. Fully matured fruits with full color are harvested and any selfed fruits found should be discarded. The fruits can be immediate seed extraction or kept in a cool place for 3-4 days for post-harvest maturation before extraction. However, some crosses with no seed dormancy may have to be harvested a little earlier than full fruit maturity and should not allow for post-harvest incubation because seed could start to germinate in the fruit. A simple field test to determine seed readiness for harvesting is to cut a fruit with a sharp knife and if the seed are not being cut they are ready for harvesting.

3.2. Seed extraction and processing. Most of the growers use a mechanical "wet" seed extractor which can process about 2-3 t of fruits per hour. A "wet" seed extractor consists of a feeder, a cutting component, fruit pulp and seed separating cylinder, seed strainer cylinder and a network of water-jet flashing system to assist the seed and pulp separation. The seed with the mucilagous coating is separated from the pulp. This mucilagous coating can be removed by acid treatment or fermentation. The acid method consists of mixing thoroughly in proportion of 7 ml of commercial grade concentrated hydrochloric acid (19-21%) in every kg of wet extracted seed for 20 minutes. Washing is done immediately when treatment is completed using the decantation washing process. Alternatively, the fruits are squashed in the bags manually by stepping on them until all the fruits are broken and the seeds have come out of the fruits. The slurry of the squashed tomato in the bags is then allowed to ferment in a non-staining container away from direct sun and rain. No water should be added during squashing and fermenting. The fermentation process may take 2-3 days depending on the ambient temperature. Warm days allow faster fermentation. The fermentation is indicated by the bubbling CO_2 gas releases, and the slurry swells and produces heat. Fermentation completion is recognized by the reduced bubbling activity, cooling of the slurry, the swollen slurry subsiding to its initial volume and the clearing-up of the supernatant of the slurry. The seed may then be acid treated to disinfect the seed and to improve the seed color.

3.3. Seed drying. The washed seed are bagged into nylon netting bags and spin-dried with a standard laundry centrifuge before being spreading out into thin layer of less than 0.5 cm thickness on fine-mesh netting trays for drying. In solar drying partial shade is provided during hot midday hours with a layer of the clear fine-mesh netting. The seed are turned regularly to allow uniform drying and to break down the seed clumps into individual seed. Dried seed of about 7% seed moisture wet basis are packed in multiple layers of plastic bag for submission to seed companies.

3.4. Quality testing. The individual seed companies control their own seed quality. Seed germination is carried out following ISTA seed testing method and rules. In the field genetic purity is done in the greenhouse or field by observing for specific morpho-physiological markers, disease resistance markers and also DNA, isozyme and protein markers.

A well managed seed production field coupling with optimal climatic conditions will give seed yield of 140-200 kg/ha. The success of this seed industry depends on a set of complementary technical, environmental and social inputs and considerations. A lack of a single attribute will negate the others resulting in poor performance.

Future of the hand pollinated F1 vegetable hybrid seed production

The present state of the hand-pollinated F1 vegetable hybrid seed production industry is entering a stabilizing phase following the rush to look for new locations after Taiwan became to costly to be competitive in the early 1980s. This stabilizing phase will become even more settled in the coming years as both China and India, the current main production countries still process the flexibility and cushion in term of available new locations and human resources to provide for new expansion and cost-effective pollinators, respectively. As the adoption of F1 hybrid cultivars the vegetables is growing globally the vegetable seed industry will thus continue to explore and move to new, better and more cost-effective areas and countries.

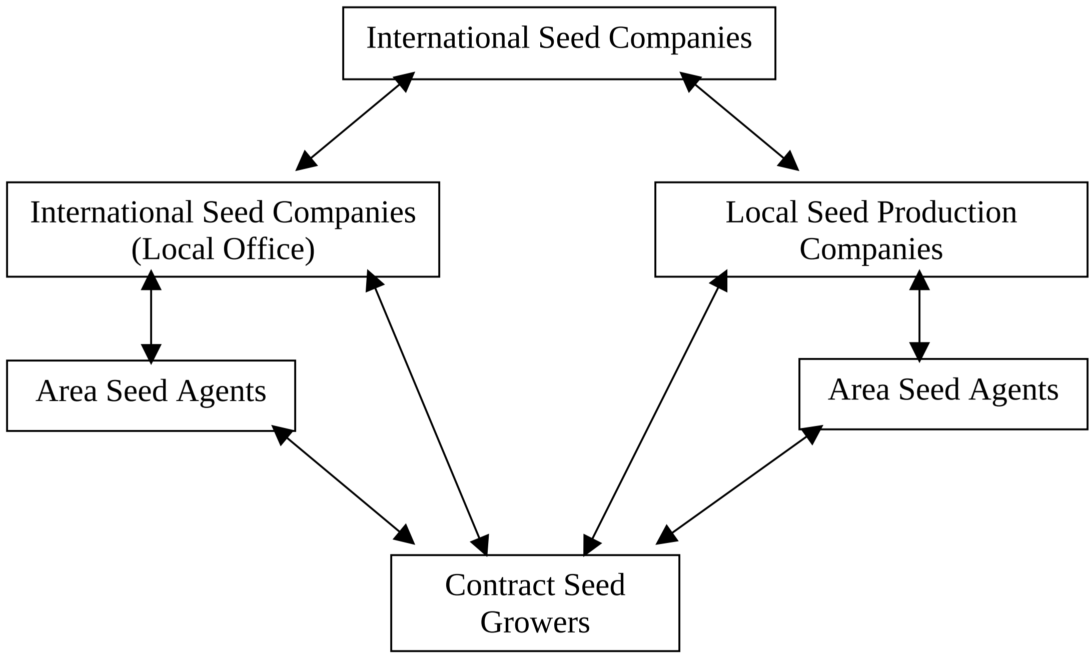

Figure 1. Summary of contract system of F1 hybrid vegetable seed production in Taiwan.

Table 1. Vegetables with both F1 hybrid and open-pollinated cultivars showing their adoption trends in the world and their F1 seed production method.

Vegetables	**F1***	**OP***
Asparagus (*Asparagus officinalis*)	Mainly (di)	Old cultivars
Beet and chard (*Beta vulgaris*)	Increasingly (di)	Constant
Bitter gourd (*Momordica charantia*)	Increasingly (h)	Local cultivars
Broccoli (*Brassica oleracea*)	Mainly (si)	Local cultivars
Cabbage (*Brassica oleracea*)	Mainly (si)	Local cultivars
Carrot (Daucus c*arota*)	Increasingly (cms)	Local cultivars
Cauliflower (*Brassica oleracea*)	Mainly (si)	Local cultivars
Celery (*Apium graveolens*)	New (gms)	Mainly
Chinese cabbage (*Brassica rapa*)	Mainly (si)	Local cultivars
Chinese mustard (*Brassica juncea*)	Increasingly (si)	Local cultivars
Cucumber (*Cucumis sativa*)	Mainly (h)	Local cultivars
Eggplant (*Solanum melongena*)	Mainly (h)	Local cultivars
Gourd (*Benincasa hispida*)	Increasingly (h)	Local cultivars
Leek (*Allium porrum*)	New (cms)	Mainly
Luffa (*Luffa angulata* & *L. cylindrica*)	Increasingly (h)	Local cultivars
Melons (*Cucumis melo*)	Mainly (h)	Local cultivars
Okra (*Abelmoschus esculantus*)	Increasingly (h)	Local cultivars
Onion (*Allium cepa*)	Mainly (cms)	Old cultivars
Pakchoi and Petsai (*Brassica rapa*)	Increasingly (si)	Old cultivars
Peppers (*Capsicum annuum*)	Mainly (h)	Local cultivars
Pumpkin (*Cucurbita moschata*)	Increasingly (h)	Old cultivars
Radish (*Raphanus sativus*)	Mainly (si)	Old cultivars
Spinach (*Spinacia oleracea*)	Mainly (di)	Local cultivars
Sweet corn (*Zea mays*)	Mainly (h & cms)	Local cultivars
Tomato (*Lycopersicum esculentum*)	Mainly (h)	Old cultivars
Turnip (*Brassica rapa*)	Mainly (si)	Old cultivars
Watermelon (*Citrullus lanatus*)	Mainly (h)	Old cultivars
Zucchini (*Cucurbita pepo*)	Mainly (h)	Old cultivars

* F1 – F1 cultivars; OP – open-pollinated cultivars; (di) – dioecious; (h) – hand-pollinated hybrids; (cms) – cytoplasmic male-sterile system hybrids; (gms) – genetic male-sterile system hybrids; and (si) – self-incompatibility system hybrids.

Table 2. Comparison of the three staking system in tomato F1 hybrid seed production.

Staking Method	**Advantage**	**Disadvantage**
Tee-pee over a raised bed	• Easier hand emasculation and pollination • Less diseases • No direct soil compaction on the plants	• Extra stake cost and labor for staking • Extra weeding of furrows • Wet working path in wet weather and after irrigation
Tee-pee over a furrow	• Easier hand emasculation and pollination • Less diseases • Dry working path in wet weather and after irrigation • No weeding of furrows once covered by the tomato	• Extra stake cost and labor for staking • Direct soil compaction on the plants
No staking	• Low capital cost and less risk • No direct soil compaction on the plants	• Emasculation and pollination more difficult • More diseases • Extra weeding of furrows • Wet working path in wet weather and after irrigation