Melon Crop Vulnerability Statement 2020

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Summary of Key Points

Melon (*Cucumis melo*) is a remarkably diverse group of herbaceous, annual plants of commercial importance worldwide. They are best known in the United States for their sweet, dessert fruit, notably orange flesh cantaloupe and green flesh honeydew, but recent immigrants from various countries of Asia have introduced types with bitter, or bland fruit used as vegetables. U.S. melon producers face constantly challenging disease and insect pressures along with climate change and water related challenges. The U.S. NPGS melon collection is the largest, freely available melon genetic resource in the world with 3,224 accession from more than 80 countries, of which about 2,000 accessions are available for distribution. The USDA SCRI CucCap project evaluated 2,084 accessions using genotyping-by-sequencing in order to characterize the collection and establish a 384-member core/functional panel. Distribution of U.S.NPGS germplasm is vital to U.S. and international melon researchers but is challenged by storage capacity and a seed borne pathogen. The U.S. public melon genetics and breeding research community has declined in numbers while the international community has increased over the past 30 years. The global melon research community collaborates through various means to address production-limiting challenges, and develop molecular based resources for future melon improvement.

1. Introduction to Melon

Melon is a remarkably diverse group of herbaceous, annual plants of commercial importance worldwide. Melons have, like other cucurbit species, a long history with human culture (Kistler et al., 2015; Robinson and Decker-Walters, 1997; Whitaker and Davis, 1962). They have been enjoyed in various forms worldwide; indeed, an Indian tribal person in Madhya Pradesh, India stated, in essence, that "A day without a melon is like a day without the sun." A major aspect of cucurbit–human interaction is the movement of cucurbits around the world, far beyond their centers of origin, through exploration and trade.

Melons are best known for their fruit, which may be bitter, bland or sweet. Bitter and bland forms are used immature, as a vegetable, and may be eaten fresh, cooked, or pickled. Sweet forms are typically eaten fresh, but may be dried (McCreight et al., 2010). Melon seeds are an excellent source of vegetable oil and the meal is high in protein.

1.1 Biological features and ecogeographical distribution. Melon is an Old World species, whose origin remains unsettled. A 2018 molecular analysis suggested that modern melon cultivars go back to two lineages, with one restricted to Asia (*Cucumis melo* subsp. *melo*), and the other restricted to Africa, *C. melo* subsp. *meloides* (Endl et al., 2018). According to this research the Asian lineage gave "rise to the widely commercialized cultivar groups and their market types, while the African lineage gave rise to cultivars still grown in the Sudanian region." The most recent molecular analysis suggested three domestication events, recognizing one in Africa (ssp. *meloides*) and two in India (ssp. *agrestis* and ssp. *melo*) (Zhao et al., 2019).

Various schemes have been proposed to organize the phenotypic diversity exhibited by melon worldwide (see Pitrat, 2000 and Whitaker, & Davis, 1962). Botanists arbitrarily established two subspecies based on ovary pubescence (Kirkbride Jr., 1993), ignoring the fact that the 16 botanical *varietas* (per Pitrat, 2000) in the two subspecies are fully cross-compatible with little or no sterility (Mallick and Masui, 1986; Whitaker and Davis, 1962). It may be further noted that Pitrat (2000, 2008) grouped var. *chito* and var. *tibish* in ssp. *melo* despite their short ovary hairs because their vegetative characters resembled ssp. *melo* more than ssp. *agrestis* (Esteras et al., 2013; Pitrat, 2008; Pitrat, 2016; Pitrat et al., 2000). Furthermore, the name of one of the two subspecies, *C. melo* ssp. *agrestis*, was confused with the putative "wild" form sometimes known simply as *C. melo agrestis* (Pitrat, 2012). Three recent revisions of melon classification recognized the two subspecies: *C. melo* ssp. *agrestis* and *C. melo* ssp. *melo* (Burger et al., 2010; Pitrat, 2008; Pitrat et al., 2000). The arbitrary nature of the two subspecies was questioned prior to the recent revisions (Stepansky et al., 1999). The subgroups in the two subspecies were subsequently recognized as Horticultural Groups (Burger et al., 2010) according to the International Code of Nomenclature for Cultivated Plants (Brickell et al., 2009) but grouped under the two subspecies. The most recent revision of melon classification (Pitrat, 2016) deleted the two subspecies, and recognized 19 Horticultural Groups of wild (formerly *C. melo agrestis*), feral and domesticated melons, and for some of them of Sub-groups (Appendix 1; doi: 10.1007/7397_2016_10). Ongoing analysis of the NPGS melon collection show close relationships between African and Asian accessions (Xin et al. unpublished).

1.2 Genetic base of crop production. The genetic base of melons is varied. Most U.S. melons and honeydews are of Indian origin via Central Asia and Europe. (Paris et al., 2012). India is an important center of genetic diversity (Endl et al., 2018; Esquinas-Alcazar and Gulick, 1983; Sebastian et al., 2010). Modern U.S. western shipping type (USWS) cultivars may be largely based on 'PMR 45', which was developed by USDA, ARS from a cross of 'Hale's Best' with California 525, a landrace from India, followed by one backcross to 'Hale's Best' and inbreeding for two generations (Dhillon et al., 2012; Pryor et al., 1946). The next "generation" of USWS were based on or similar to 'Top Mark' (TM), which was developed by a commercial breeder. Modern versions produce larger fruit that set and mature earlier than TM types. Long shelf life (LSL) cultivars, exemplified by the Harper type, have made significant inroads since the turn of the century as a means to reduce harvest costs, as the LSL character enables a wider harvest "window."

1.3 Primary products and their value (farmgate). The primary types of melons grown in the United States are the dessert type fruits: orange flesh muskmelon, commonly referred to as cantaloupe, and green flesh honeydew. Harvested acres, total production and total value of muskmelon (melon) far exceeded that of honeydew melon in the United States from 2004 through 2016 (Appendix 2). Yield per acre of melon exceeded that of honeydew 2004–2012, but by 2013 they were comparable due, in large part, to increased honeydew productivity (Appendix 2). Value of U.S. honeydew per hundred weight (cwt) increased in 2011 to exceed that of melon and remained higher than melon through 2016. Total value of U.S. produced melons declined from 2012 through 2016, while total value of honeydew, though far less than melon, showed a slight increase, due to increased productivity (yield per acre) and increased value per hundred weight. Yield gains in the United States have offset some of the production loss that could be attributable to reduced area harvested (Appendix 2).

California and Arizona dominate U.S. cantaloupe production; based on National Agricultural Statistical Service (NASS) statistics they produced 82 % of the harvested acreage and 88 % of the total yield in 2015 (Appendix 3), with the balance coming from seven other states. Their actual share is less, as production figures from some states were not included in recent NASS reports, most noticeably Florida, which is reported to be a source of early-season melons (Appendix 3). Cantaloupes grown in many north and northeastern states for local or regional markets are missing from the NASS reports; though they are important seasonal-component of Community Supported Agriculture (CSA) farmers.

Cantaloupes are produced in the United States from April through November, and honeydew is sourced from U.S. growers from February through December (Appendix 4). The United States imports cantaloupes grown in Central America from November through May, while Mexico is a source of cantaloupe and honeydew from November through July (Figure 4).

Open field, direct seeded production dominates in California and Arizona. Transplants in open field or under protection are used on small-scale in some areas for early and extended season production.

Honeydew melons and mixed types, e.g., 'Santa Claus', 'Casaba', constitute a small fraction of U.S. production. Melons are imported from five southern North American countries 10 months, July and August being the exception when U.S. melon production is at its peak (Appendix 4).

Global melon production has increased steadily since the 1990s for area harvested, yield, total production, and production per capita (Appendix 5). Global melon production is dominated by Asia in terms of area harvested (73.2 %) and total production (76.6 %) (Table 1); the United States accounts for 3 % and < 4 %, respectively, of global melon production (McCreight, 2017). U.S. melon growers export melons to some foreign markets, e.g., Japan and Canada.

Table 1. Global melon production in 2013, by continent.

Continent	Area harvested Hectares	%	Production Tonnes	%
Africa	88,570	8.0	2,067,995	7.4
Asia	815,786	73.2	21,296,561	76.6
Australia	3,475	0.3	89,855	0.3
Europe	101,835	9.1	2,006,706	7.2
Northern America	34,107	3.1	1,002,488	3.6
South America	70,100	6.3	1,329,997	4.8

FAO. 2015. FAOSTAT http://faostat3.fao.org (accessed 7 Dec 2015)
Adapted from McCreight (2017).

2. Urgency and extent of crop vulnerabilities and threats to food security

2.1 Genetic uniformity in the "standing crops" and varietal life spans. F_1 hybrids dominate the melon seed trade in the United States, though exact figures are unknown. There is room for specialty producers that emphasize consistent high quality, e.g., Savor Fresh Farms (https://www.facebook.com/savorfresh/). Melons for the major retail markets and foodservice are, by and large, bred to meet their standards for size, etc. The cultivars are grown for large-scale production, in large fields isolated or in proximity to other crops, including other cucurbits. There are no publicly available data on varietal life spans, but melon market types are stable, e.g. USWS. 'Caribbean Gold', bred by Rijk Zwaan, was the first LSL melon and has been in the market place since early 2000s even though the company has introduce with improved flavor and texture. Melon Groups predominant in East and Central Asia and the Middle East may be found in U.S. ethnic markets in response to recent immigration patterns. There is an active interest in open-pollinated, and heirloom varieties to many home gardeners, organic farmers producing for local market markets, and those interested in preserving genetic variation (Goldman, 2019).

USWS cantaloupe fruit are well known for their climacteric character, with harvest maturity indicated by development of an abscission layer at the juncture of the peduncle and the fruit that allows the fruit to be cleanly separated from the vine, and exterior color change of the fruit. Several harvests are often required to maximize yield. There has in recent years been gradual adoption of Harper-type melons, e.g., 'Caribbean Gold', in United States, Mexico and Central America. They were developed for long shelf life (LSL), which in practical terms gives growers increased latitude in harvest timing to approach once-over harvest at the perceived loss of culinary quality, i.e., chewy texture and excessive firmness. Some LSL hybrids have fruit which exhibit a subtle color change at harvest maturity and do not abscise, they must be cut from the vine. LSL cultivars introduced new genetic variation into melon production areas

Melons grown for local markets typically have short shelf life. They typically differ from USWS and LSL types for fruit shape (oval), less netting, presence of vein tracts that are often free of net, have softer flesh and often times a more "musky" flavor. Such fruit characteristics were common for fruit grown in eastern United States, but newer hybrids for eastern production areas are more like USWS.

Green flesh honeydew melons are shifting from a soft flesh to a firmer flesh which holds up to minimal processing.

2.2 *Threats of genetic erosion in situ.* Genetic erosion is a concern to the future of melon breeding; farmers in developing countries seek more productive, uniform and higher quality fruit, and so landraces or farmer varieties are gradually lost. Drought in some areas threaten loss, e.g., Rajasthan where melons are more or less naturalized, solely dependent upon Monsoon rains. In 1992, the Indo-U.S. *Cucumis* Expedition noted in northern Rajasthan the complete loss of cucumber landraces due to repeated drought (McCreight et al., 1993). Though melon germplasm was abundant in Rajasthan in 1992, it is endangered and could erode.

2.3 Current and emerging biotic, abiotic, production, dietary, and accessibility threats and needs. Melons are subject to a wide array of biotic stresses–bacterial, fungal, viral, insects, and nematodes. A summary in the form of a questionnaire to melon researchers (McCreight, 2011) listed 10 fungal and three bacterial diseases, 33 viruses that can be supplemented by two newcomers: *Cucurbit chlorotic yellows virus* (CCYC) and *Squash vein yellowing virus* (SqVYV), and eight insect pests (Appendix 6); their concise descriptions of were recently updated (Anonymous, 2017).

2.3.1 Biotic threats (diseases, pests). Cucurbit powdery mildew (CPM), incited by three fungal species, is the most ubiquitous pathogen in melons. Many races of one CPM pathogen, *Podosphaera xanthi* (Px), have been reported worldwide (Lebeda et al., 2016). USDA initiated research on host plant resistance to CPM incited by Px in 1925 (Jagger, 1926) and continues to do so at the U.S. Vegetable Laboratory, Charleston, SC and the U.S. Agricultural Research Station, Salinas, CA. Sweet potato whitefly (*Bemisa tabaci*) emerged as a major pest worldwide, including the United States over the past 30 years, as a vector of several viral diseases, e.g., CYSDV, and in southern Arizona and California can devastate melon crops through feeding damage alone (Riley and Palumbo, 1995; Wintermantel et al., 2019; Wisler et al., 1998).

2.3.2 Abiotic (environmental extremes, climate change). Water availability and increased salinity are potential long-term problems in the melon production areas of Arizona and California. Limited research has been done on traits to meet these challenges, e.g., salinity (Carvajal et al., 1998; Meiri et al., 1982; Shannon and Francois, 1978; Shannon et al., 1984)

2.3.3 Production/demand (inability to meet market and population growth demands). U.S. production is, in general, currently fully capable of meeting market demands for the USWS and GFHD. Demand has dropped to some extent in response to recent contamination events. Harvest of immature WSWS and introduction of LSL types may have weakened demand for whole fruit in retail channels. Increased popularity of lightly processed fruit products in restaurant as well as retail sales has increased in recent decades.

2.3.4 *Dietary (inability to meet key nutritional requirements)*. Melon contributes to a healthy diet in different ways around the world. Melon flesh is a source of potassium and *beta carotene* and Vitamin C but is low in other nutrient, e.g., vitamin E, folic acid, iron and calcium (Lester, 1997). Content of ascorbic acid, folic acid and potassium are influenced by environment, e.g., soil type, and there appears to be potential for improvement in orange flesh cantaloupe and GFHD (Lester, 1997; Lester and Eischen, 1996; Lester and Crosby, 2002; Lester and Crosby, 2004). Small fruited *agrestis* types are dried in some areas, e.g., India, for use in soups when food is scarce (Staub and McCreight, 1993). Flesh of Waharman type melons (Group Ameri) may be sliced and dried for consumption during winter months in Turkmenistan (McCreight et al., 2010). In some countries, e.g., India and Turkmenistan, seeds are eaten for their high quality oil and proteinaceous meal, and may be found in local markets as a component of "roaster mixes" along with other cucurbit seeds (McCreight et al., 2010; McCreight et al., 2013).

2.3.5 Accessibility (inability to gain access to needed plant genetic resources because of phytosanitary/quarantine issues, inadequate budgets, management capacities or legal and bureaucratic restrictions). Restricted interchange of melon germplasm among genebanks is a concern for publicly funded breeding programs, as countries have become more protective of their genetic resources. USDA, NPGS is the model for free exchange for most crop species. Germplasm from India has proven to be a treasure trove of biotic and abiotic stress resistance, e.g., host plant resistance to downy and powdery mildews, Alternaria, Anthracnose, and aphid- and whitefly-transmitted viruses. (Dhillon et al., 2015; Dhillon et al., 2012; Malik et al., 2014)

CCYV was recently found in the New World (Imperial Valley, CA) for the first time (Wintermantel et al., 2019). Resistance sources were reported by a group in Japan (Okuda et al., 2013). A request for the materials from the genebank in Japan could not be filled due to lack of an agreement between the U.S. and Japan for germplasm exchange. In contrast, international seed companies have access to germplasm in countries worldwide, wherever they are present and actively breeding, and such resources may be moved around the world via normal trade. Overtime, genes could thus move among countries, and eventually into public breeding programs, as well as into programs of other companies where utility patents are not used for intellectual property protection or have expired.

3. Status of plant genetic resources in the NPGS available for reducing genetic vulnerabilities

3.1 Germplasm collections and in situ reserves

3.1.1 Holdings. The USDA, National Plant Germplasm System (NPGS) *Cucumis melo* collection conserved at the North Central Regional Plant Introduction Station (NCRPIS) currently includes 3,224 accessions from 80 countries. The National Laboratory for Germplasm Resources Preservation (NLGRP) has 214 accessions (cultivars, breeding lines) and the backup collection of accessions from the NCRPIS. The wild *Cucumis* species collection conserved at the NCRPIS currently includes 318 accessions (representing 22 species) from 31 countries. The NLGRP has six wild species accessions and the backup collection of the NCRPIS.

3.1.2 Genetic coverage and gaps. The NPGS melon collection is the largest, publicly available melon germplasm resource in the World. There are known duplicates, e.g., PI 313970 and PI 315410 are identical accessions that originated in India via the Vavilov Institute (accession VIR 5682) on two dates in 1966. Melons of African origin are under-represented in the NPGS melon collection.

3.1.3 Acquisitions. New *Cucumis* acquisitions have been extremely limited due to difficulties securing permission for plant exploration and collecting in the regions of interest, and acceptance of the Standard Material Transfer Agreement (SMTA) stipulating the NPGS policy of freely distributing germplasm in its collections. Most new acquisitions have been from discontinued breeding programs, expired PVPs, or old cultivars no longer being conserved by seed companies.

3.*1.4 Maintenance.* NCRPIS is rapidly running out of space in both the 4° C and -20° C storage rooms, but construction of additional -20° C storage is planned. *Cucumis* distribution lots are stored at 4° C, RH 28% and the original/parent seed lots are stored at -20° C. Regular viability testing is performed on distribution seed lots and accessions are regenerated when the viability percentage is low.

3.1.5 Regeneration. Regenerations are accomplished using field or greenhouse cages with insect pollinators (honey bees, alfalfa leaf cutting bees, bumble bees) or hand pollination in the greenhouse. Basic characterization data and images are taken as part of the regeneration/maintenance process to document accessions and verify taxonomy. NCRPIS pathology personnel survey plots to monitor plant/seed health during the regeneration process. This disease monitoring is critical to meeting import requirements for distribution of international germplasm requests.

Regeneration activities for *Cucumis melo* germplasm at the NCRPIS was significantly scaled back in 2015 due to concerns about bacterial fruit blotch (*Acidovorax citrulli*) contamination of seed lots in the NPGS collection, and the regeneration of melon germplasm continues to be extremely limited. We do not have a good accounting of the level of infestation of affected seed lots, and limited seed quantities do not allow for such assessments as these seeds are necessary for regeneration efforts. Measures implemented previously to screen and isolate plants prior to transplanting to field regeneration cages and treatment of suspected infested seed increases have not been effective. NCRPIS pathology personnel are actively working with the curatorial team to investigate other options to address the bacterial fruit blotch issue as well as to develop strategies to address other potentially seed-transmitted cucurbit diseases.

3.*1.6 Distributions and outreach. Cucumis* seeds are distributed freely worldwide for breeding, scientific research, and educational uses. A five-year distribution summary of *Cucumis melo* and wild *Cucumis* species, excluding *C. sativus* germplasm is found in the table below. Germplasm requests are submitted via the Public GRIN-Global website (https://npgsweb.ars-grin.gov/gringlobal/search.aspx) or directly to the collection curator.

Table 2. NCRPIS 5-Year Order Summary

		Number of			
Sitecrop	Year	Orders	Recipients	Items Distributed	Accessions Distributed
NC7-cucumis.melo	2015	45	40	1,000	744
	2016	43	37	2,310	2,048
	2017	35	32	1,113	867
	2018	57	48	2,880	2,020
	2019	56	46	1,454	991
Subtotal		236		8,757	
NC7-cucumis.wilds	2015	10	9	124	82
	2016	10	10	513	208
	2017	8	8	103	93
	2018	13	13	260	204
	2019	13	13	249	168
Subtotal		54		1,249	

3.2 Associated information.

3.2.1 Genebank and/or crop-specific web site(s). Passport, phenotypic and evaluation data, and images of *Cucumis* germplasm can be obtained from the GRIN-Global website (https://npgsweb.ars-grin.gov/gringlobal/search.aspx).

3.2.2 Passport information. Passport data include information on collection date, location, collector, donor, donor date, taxonomic classification, etc. GRIN-Global also allows for bibliographic citations of research papers to be added with links to lists of accessions included in the publication, so it is important for the germplasm user community to provide copies of publications to the appropriate NPGS germplasm curator for entry into GRIN.

3.2.3 Genotypic characterization data. There are currently no genotypic data in GRIN-Global for *Cucumis melo*.

3.2.4 Phenotypic evaluation data. Evaluation data sets available on GRIN-Global for *Cucumis melo* include: Anthracnose (*Colletotricum lagenarium*), Bacterial Wilt (*Erwinia tracheiphila*), Downy Mildew (*Pseudoperonospora cubensis*), Fusarium Rot (*Fusarium solani* f. *cucurbitae*), Leaf Blight (*Alternaria cucumerina*), Leaf Spot (*Cercospora citrullina*), Macrosporium Leaf Blight (believed synonymous with *Alternaria cucumerina*), Powdery Mildew (*Podosphaera xanthii* [syn. *Sphaerotheca fuliginea*]), Stem Blight (*Mycosphaerella citrullia*), Verticillium Wilt (*Verticillium dahlia*), Gummy Stem Blight, Root Knot Nematode (*Meloidogyne incognita acrita*). Characterization data, primarily fruit descriptors, are also available on GRIN, but much of these data (as well as fruit images) await uploading to the database.

3.3 Plant genetic resource research associated with the NPGS.

3.3.1 Goals and emphases. The global melon research community has extensively used the NPGS melon collection. Great emphasis has been on resistance to diseases, insects and abiotic stresses. The main goals are to maintain quantities of viable seed to meet the need of the research community. This has become complicated in recent years with the contamination of the collection with the bacterial fruit blotch pathogen. It is vitally important to develop means for disinfecting the seed stocks for distribution.

Other goals:

- correctly identify accession as to Horticultural Group
- increase inclusion of evaluation data in GRIN
- document research on accessions with inclusion of publications

3.3.2 Significant accomplishments.

3.4 Curatorial, managerial and research capacities and tools.

3.4.1 Staffing. The NCRPIS Vegetable Project is comprised of one full-time Iowa State University Research Scientist III (Curator), one part-time Iowa State University Agricultural Assistant III, and one half-time Iowa State University Agricultural Specialist I (position shared with NCRPIS Farm Management team) which is responsible for the NCRPIS cucurbit collections (*Cucumis melo*, *C. sativus*, wild species of *Cucumis*, and *Cucurbita*), as well as the

NPGS *Cichorium*, *Daucus*, *Ocimum*, and *Pastinaca* collections (almost 8,000 accessions). They are assisted by three to four full-time-equivalent Iowa State University student employees, and supported by NCRPIS administrative, farm management, plant pathology, information technology, seed storage, order processing, and seed germination personnel. Germplasm management includes germplasm preservation and regeneration, viability testing, plant and seed health assays, characterization and evaluation, taxonomic verification, distribution, and record keeping. Collection sizes and workloads continue to increase, but resources to accomplish the work do not.

3.4.2 Facilities and equipment. The Ames location is rapidly running out of space in both the 4° C and -18° C seed storage rooms. A request has been made for support for a 2500 sq. ft. -20° C storage building. A -20° C cold room could essentially double the longevity of viability of many of the taxa maintained at the NCRPIS. Greenhouse space is inadequate, and the facilities are outdated. We upgrade as funding becomes available, e.g., purchase and installation of LED lighting fixtures in order to improve plant productivity and reduce energy costs. A few germplasm regeneration cage frames and screens are purchased annually to replace old and damaged equipment that cannot be repaired.

3.5 Fiscal and operational resources. NCR of the North Central Regional Plant Introduction Station (NCRPI) are supported by the USDA-ARS Plant Introduction Research Unit CRIS Project, Hatch Multistate Project NC-007, and in-kind support from Iowa State University, its host institution. These funding sources support NCRPI farm and facilities operations, scientific, technical and administrative personnel responsible for curation, maintenance and distribution of more than 1700 plant taxa, including melon. NCRPIS activities include phytosanitary practices, and seed production, and software development focused on improved genebank information workflow.

4. Other genetic resource capacities (germplasm collections, *in situ* reserves, specialized genetic/genomic stocks, associated information, research and managerial capacities and tools, and industry/technical specialists/organizations) (2 pp. maximum)

International research groups in public institutions, i.e., national research centers and universities, and private companies have long-term and working collections of melon germplasm. These resources are not readily available to U.S. researchers. Six public "genebanks" may be found via Worldwide Web search (Table 3). The World Vegetable Center has no melons listed publicly though it is engaged in melon related research in southeast Asia. India which is notable for its wealth of melon germplasm does not publicly list the number of melon accessions. Siregal (France) lists 102 accessions, yet its melon research group, Génétique et Amélioration des Fruits et Légumes, Montfavet, is a major center for melon related genetics, pathology and entomology research (https://www6.paca.inra.fr/gafl). The European Cooperative Programme for Plant Genetic Resources (ECPGR) website (ecpgr.cgiar.org) provide a glimpse of a large array of multi-crop database, many of which are not readily accessible. Melon databases in Spain and Turkey are notably inaccessible, as both countries have numerous, significant melon research efforts, public and commercial.

Table 3. International Melon Germplasm Collections

Country	# accessions	Names, Institution and URL
France	102	Siregal, the Plant Genetic Resources Information System of the National Institut for Agronomical Research (INRA) URL: urgi.versaille.inra.fr
India	–	ICAR–National Bureau of Plant Genetic Resources (NBPGR), New Delhi URL: nbpgr.ernet.in
Japan	611	Genebank Project, NARO URL: gene.affrc.go.jp
Taiwan	0	WorldVeg Genebank, World Vegetable Center URL: avrdc.org
The Netherlands	79	CGN, University of Wageningen URL: cgngenis.wur.nl
Uzbekistan	1330	Uzbek Research Institute of Plant Industry, the Uzbek Research Institute of Vegetables, Melons, and Potato, the Karakalpak Research Institute of Agriculture, Tashkent. (Mavlyanova et al., 2005)

Genotyping-by-sequencing (GBS) was carried out on 2,084 accessions from the germplasm collection through the USDA SCRI CucCap project (Grant Number: 2015-51181-24285). About 400 accessions were selected for a core/functional panel through this project. These accessions are being selfed and a single plant will be re-sequenced as part of the same project. Progeny from these single plants will be available for public distribution.

The Cucurbit Genomics Database (CuGenDB; http://cucurbitgenomics.org) was developed as a resource for the Cucurbitaceae family (cucurbit) which includes such as melon, cucumber, watermelon, pumpkin, squash and gourds. This resource provides a central portal for the cucurbit research and breeding community (Zheng et al., 2019).

5. Prospects and future developments

Access to unique germplasm resources is essential to meet the dynamic challenges of emerging and chronic pathogens and insect pests. Climate change presents unique combinations of challenges on top of pathogens and insect pests. Water resources are inextricably with climate change and population growth with its attendant encroachment on agricultural land. For example, Imperial Valley enjoyed abundant use of Colorado River water, essential for soil salinity management, for much of the 20th century. Increased demand for more water by largely coastal communities from Los Angeles to San Diego has resulted in demand for efficient water use by Imperial Valley farmers with the savings being sent to the urban coastal areas.

The U.S. NPGS serves as a major resource for the increasingly global research and development community. Commercial partners play a key role in accessing unique genetic resources that, though they may intellectual property protections serve the U.S. melon industry and ultimately the American Public.

The U.S. public melon genetic and breeding community is small. It is essential that federal projects at Charleston and Salinas be maintained. There are part-time efforts in two programs at Texas A&M and Cornell University.

Global efforts in the area of melon genetics have increased over the past 30 years and have developed molecular resources (see CuGenDB). Melon researchers interact through various disciplines based professional societies, e.g., American Phytopathological Society, and through periodic (4- to 5-year intervals) of international, cucurbit-focused meetings sponsored by Eucarpia, International Society for Horticultural Science, and Cucurbitaceae, heretofore organized by U.S. researchers. The Cucurbit Genetic Cooperative serves to disseminate cucurbit research and other information of interest to the cucurbit research community (https://cucurbit.info/home/reports/).

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7. Appendices

Appendix 1. Melon Horticultural Groups[a,b]

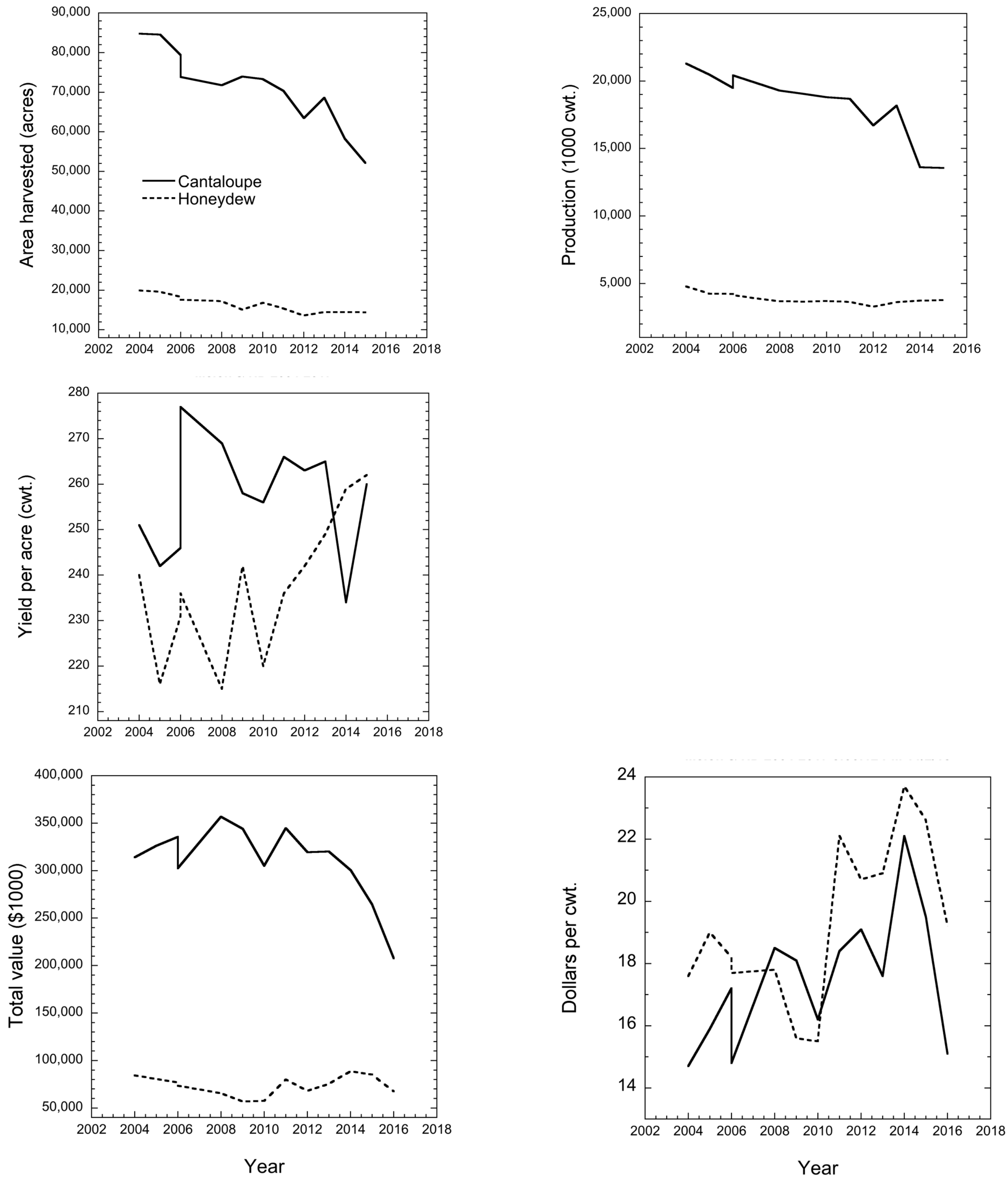
Group	Areas where commonly grown and examples	Uses	Flower and fruit characteristics[c]	Notes
Monoecious, short or long hairs on the ovary (as noted), not sweet, no aroma, small seeds (0.4 to 3.0 g per 100 seeds) in a gelatinous sheath				
Agrestis	Africa, Asia, from Turkey to Japan, not cultivated; in India they are sold in street markets	Consumed in soups and stews; may be sliced open and dried for later use	Short or long hairs on the ovary; very small fruits (20-50 g); round, oval or elliptic; light-green skin, uniform or with dark-greens spots or stripes; some dehiscent; very thin exocarp; light-green flesh; long shelf life	Very small seeds (0.4 to 0.9 g for 100 seeds)
Kachri	Rajasthan (India); heterogeneous "large agrestis;" e.g., AHK 119	Consumed in soups and stews	Short or long hairs on the ovary; small fruits (100-200 g); round, oval or elliptic; some with vein tracts; some slightly netted; light-green, yellow or cream uniform color or with dark-greens or orange spots or stripes; some dehiscent; thin exocarp, thin light-green (some slightly orange) flesh; long shelf-life	Small seeds (0.5 to 2.0 g for 100 seeds)
Chito	Feral in Central America and Caribbean Islands	Consumed in soups and stews	Short hairs on the ovary; very small fruits (50-100 g); round to ovoid fruits; smooth; yellow skin; thin exocarp, light-green, thin flesh; ong shelf-life	Very small seeds (0.4 to 0.7 g for 100 seeds)
Acidulus	Cultivated mainly in India and Sri Lanka, e.g., PI 313970 (90625), PI 164323, PI 164723, Kekiri	Consumed in soups and stews	Short hairs on the ovary; small fruits; oval or elliptic, yellow or orange or ochre skin with stripes; non-dehiscent; thin exocarp, white very firm flesh; long shelf-life	Small seeds (0.9 to 2.3 g for 100 seeds)
Momordica	Cultivated in India and southeast Asia, e.g., PI 124111 (MR-1), PI 414723	Consumed in soups and stews	Short hairs on the ovary; small to medium fruit; flat to oval to elongated; uniform color or with speckles, spots or stripes; dehiscent; very thin exocarp which can sometimes be easily peeled off, splitting at maturity; light-green, sometimes white or slightly orange, mealy flesh; early maturing; very short shelf-life	Small to medium seed; Group is quite heterogeneous– some sub-groups could be defined (see Dhillon et al., 2015)
Andromonoecious, short hairs on the ovary, not sweet or sweet, no aroma, small seeds (0.5 to 3.0 g per 100 seeds) in a gelatinous sheath				
Tibish	Cultivated and endemic Sudan	Eaten raw in salads like cucumber, seeds are also eaten (known as "seinat")	Small fruit weight; elliptical or pyriform; smooth; light-green with dark-green stripes or spots (or the opposite: dark-green main color with light-green spots or stripe); thin exocarp, thin light-green flesh; no aroma; long shelf-life	Small seeds (1.7 to 3.0 g for 100 seeds)
Conomon	Cultivated in the Far-East (China, Japan), but of decreasing importance, e.g., Tokyo Wase Shiro Uri, Ko Shiro Uri, PI 266935 (Hyogo Shiro Uri)	Fruits harvested before maturity and eaten raw or as pickles, like cucumbers and gherkins	Oval or elongated; light-green or white, sometimes dark-green; thin exocarp; light-green or white flesh; long shelf-life	Small seeds (1.2 to 2.2 g for 100 seeds)
Makuwa	Cultivated in the Far-East (China, Japan), but is declining, e.g., Ogon, Kanro, Ginsen	Sweet fresh fruit	Some hermaphrodite; medium fruit weight; round, oval or pear; some with vein tracts; usually green flesh, sometimes white or orange; medium sugar content; early maturing; short shelf life	Small seeds (0.5 to 2.3 g for 100 seeds) Six sub-groups according to the exocarp color, presence/absence of vein tracts, and seed shape
Chinensis	Far-East (China, Japan), e.g., PI 161375, PI 255479, PI 266934	Vegetable	Medium fruit weight; pear shape; ribbed; prominent light-green vein tracts (facets); uneven fruit surface; light-green exocarp color with dark-green spots; non-dehiscent; thin exocarp; orange-green flesh; long shelf life	Small seeds (0.8 to 1.7 g for 100 seeds)
Monoecious, long or short hairs on the ovary, not sweet, no aroma				

Flexuosus	Morocco to India, sometimes on the northern Mediterranean shore (Spain, Italy, Greece), e.g., Fqus, Armenian cucumber, Snakemelon, Snake cucumber, Kakri;	Fruits harvested before maturity (ca. 8-10 days after flowering) and eaten raw in salad or pickled	Long (usually) or short (sometimes) hairs on the ovary; very long ovary and fruit (up to 2 m); cream (Sometimes orange) exocarp, sometimes with spots or stripes; light-green or slightly orange mealy flesh; very short shelf life	Long ivory seeds with a gelatinous sheath Three sub-groups according to fruit surface (smooth, wrinkled or ribbed (see Pitrat, 2016)
Chate	Mediterranean basin and in western Asia; e.g., Carosello, Dolmalik	Fruit harvested about 10 days after flowering and eaten raw as a cucumber,	Long hairs on the ovary; medium fruit weight; round to oval; ribs and vein tracts usual; dehiscent; thin exocarp; light-orange (sometimes white or light-green) flesh; medium size yellow seeds without a gelatinous sheath; early maturing; short shelf life	Medium seeds size Some carosello accessions produce very early female flowers and present very short first internodes resulting in the "bird-nest" phenotype.
Andromonoecious, long hairs on the ovary, not sweet, strong aroma in the skin (exocarp) but not in the flesh, medium size yellow seeds in a gelatinous sheath				
Dudaim	Cultivated from Turkey to Afghanistan, and north to Turkmenistan; e.g., PI 177362, Queen Anne's Pocket Melon	Not eaten but used for its fragrance	Size of an orange; round to ovoid; yellow epicarp with orange/ochre spots or stripes; dehiscent; thin exocarp; white thin flesh; short shelf life	
Andromonoecious, long hairs on the ovary, medium sweet, low aroma, large seeds in a gelatinous sheath				
Chandalak	Cultivated from Central Asia to India	Sweet fresh fruit	Medium fruit weight; round or flat fruit; some slightly ribbed; vein tracts usually but sometimes absent; netting present or absent; uniform cream to orange/brown or with speckles, green vein tracts (when present); dehiscent; often large blossom scar; thin exocarp; usually green (but sometimes orange or white) flesh; thin mesocarp; fibrous flesh texture; early maturing; short shelf life	Four sub-groups defined according to presence/ absence of netting and vein tracts
Andromonoecious, long hairs on the ovary, sweet, aromatic, large seeds in a gelatinous sheath				
Indicus	Cultivated in central India (Maharashtra, Telangana, Andhra Pradesh), e.g., landraces from Nagpur, Aurangabad, Hyderabad, Cuddapah	Sweet fresh fruit	Medium fruit weight; elliptical; smooth to slightly netted; dark-green vein tracts; dehiscent; large protruding blossom scar; grey/orange/brown/cream exocarp; orange (rarely green) flesh; thick flesh, juicy firm flesh	
Andromonoecious, long hairs on the ovary, sweet, low aroma, large seeds with no gelatinous sheath, long shelf life				
Ibericus	Mainly cultivated in Spain, but is also popular in all the Mediterranean area, and in North and South America, e.g., Amarillo, Negro	Sweet fresh fruit	Medium to high fruit weight; elliptical or acorn, sometimes round, more or less wrinkled; non-dehiscent; thick skin; thick light-green (sometimes light-orange) juicy flesh; late maturing	Five sub-groups defined according to exocarp color
Casaba	Cultivated in western and central Asia, e.g., Kirkagac 1, Hasan Bey, Golden Beauty Casaba	Sweet fresh fruit	Medium to high fruit weight; pear shape and more or less wrinkled; non-dehiscent; thick epicarp; thick light-green flesh; late maturing, long shelf life; three sub-groups can be defined according to the fruit skin	

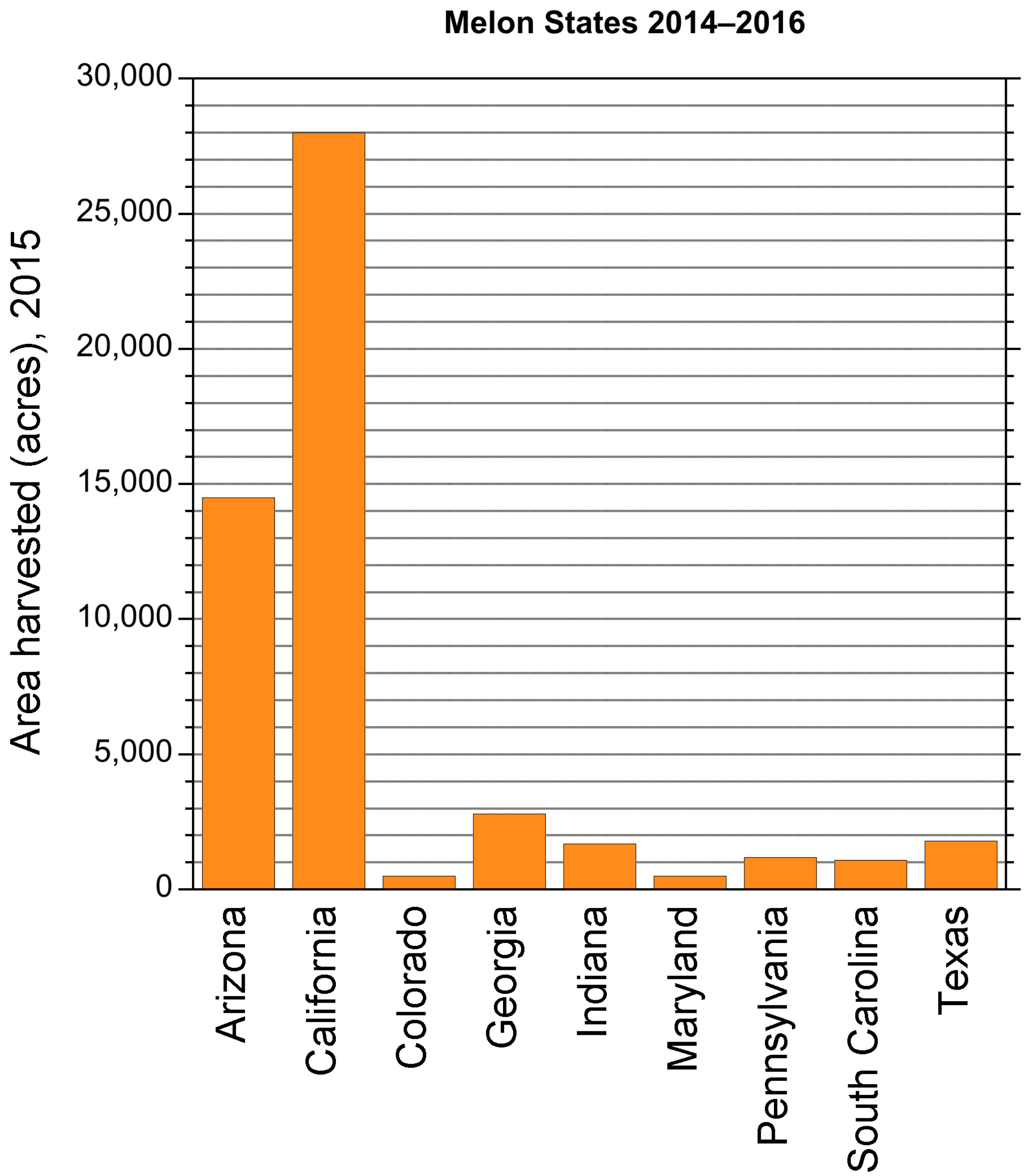
			color; sub-groups within Cassaba offer parallel variation with the Ibericus Group for skin color	
Inodorus	Includes accessions with low aroma and long shelf life that do not belong to the Groups Cassaba or Ibericus, e.g., Green Flesh Honeydew, TAMDew, Earl's Favourite	Sweet fresh fruit	Medium fruit weight; round; non-dehiscent; thick skin; thick light-green flesh; late maturing; long shelf life	
Andromonoecious, long hairs on the ovary, *sweet, aromatic, medium to large seeds with no gelatinous sheath, short to medium shelf life*				
Ameri	Cultivated in Asia from Turkey to western China, e.g., Ananas Yokneam, Ak Uruk, Evankey 2, Ghasri	Sweet fresh fruit, or dried	Medium to high fruit weight; oval or cylindrical; presence or absence of netting; dehiscent; white, light-green or light-orange flesh; medium shelf life, some with very long shelf life, e.g., Waharman; four sub-groups according to exocarp color and presence/absence of vein tracts	
Cantalupensis	First developed in Europe, probably from accessions from eastern present-day Turkey; later, diversification and selection in the USA led to the American cantaloupes, e.g., Prescott à Chassis, Ananas d'Amérique, Védrantais, Noy Yizre'el, Rocky Ford, Hale's Best, PMR 45, Iroquois	Sweet fresh fruit	Some monoecious; medium fruit weight; flat to round to oval, light to medium ribs; more or less netted, warts may be present; white to light-green to dark-green skin; dehiscent; orange, sometimes green flesh; strong aroma; short to medium shelf life	Six sub-groups defined according to shape, ribs, vein tracts, netting, dehiscence, shelf life, etc.

[a]Adapted from Pitrat (2016).
[b]Subset by sex expression, ovary hair, sweetness, aroma and seed characteristics.
[c]General order of flower and fruit characteristics: fruit shape, exocarp and flesh features, shelf life

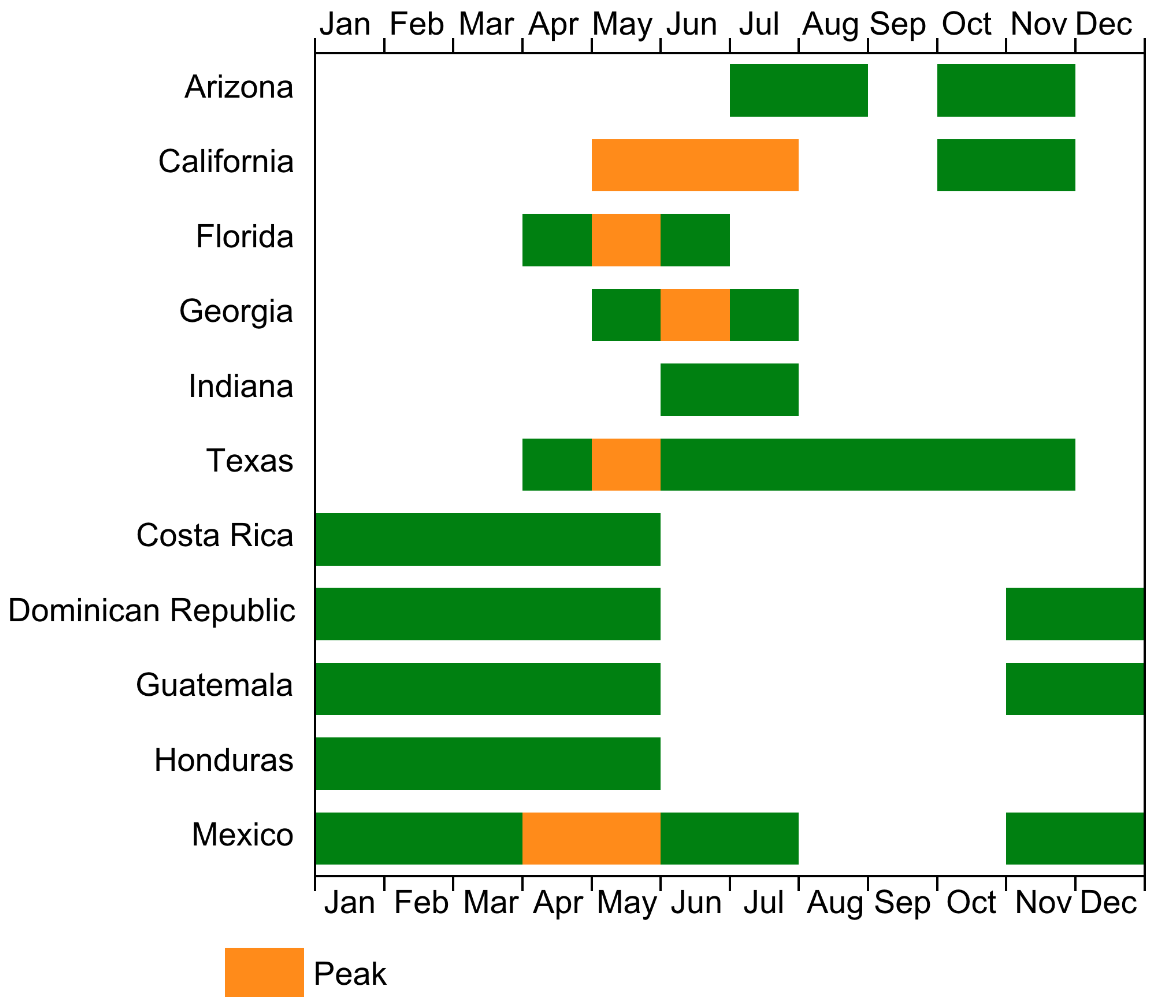
Appendix 2. Muskmelon and honeydew U.S. trends for area harvested, yield, total production, dollars per cwt., and total value, 2004–2016; Source: NASS (Accessed 2 Nov. 2018).

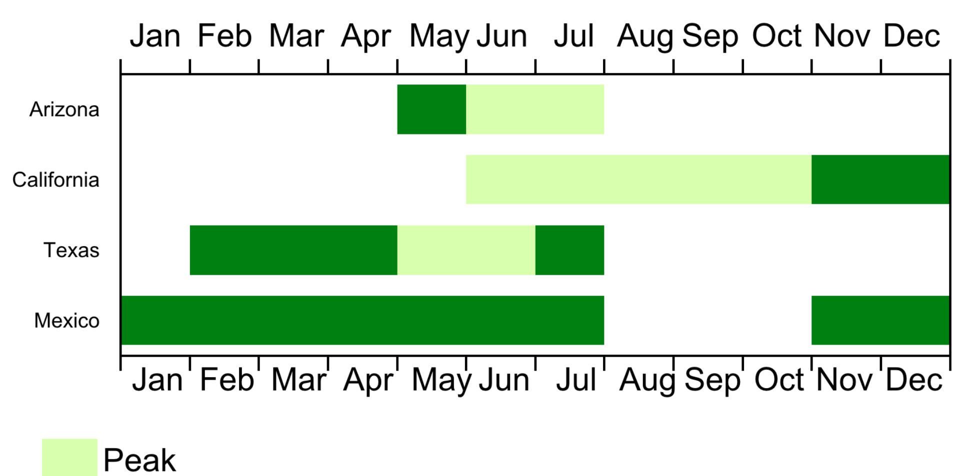


Appendix 3. Harvested area (acres) of cantaloupe, by state in 2015; Source: NASS (Accessed 2 Nov. 2018).

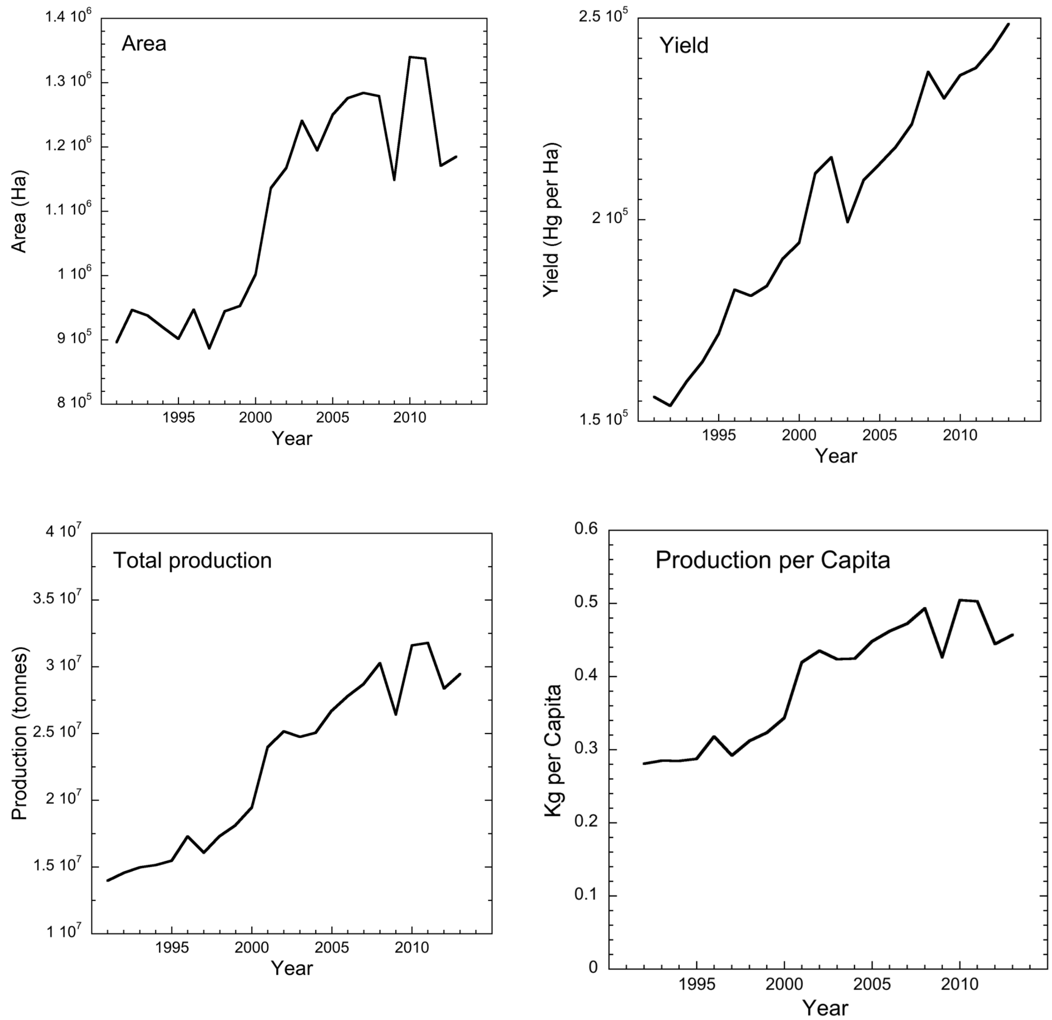


Appendix 4. Melon (top)and honeydew (bottom) availability from U.S., Mexico, and Central America sources; adapted from The Packer Produce Availability & Merchandising Guide: the 2011 Guide.





Appendix 5. Melon global trends for area harvested, yield, total production, and production per capita from 1991 through 2013; FAO. 2015. FAOSTAT http://faostat3.fao.org (Area, yield and production-Compare Data link accessed 4 Sept. 2015; Population data for per capita estimate accessed 27 Nov. 2015).



Appendix 6. Reported abiotic stresses, fungal and bacterial diseases, viruses, and insect and nematode pests of melon (McCreight, 2011).

Fruit traits

___ Increased shelf life
___ Lightly processed characteristics
___ Increased yield
___ Nutritional value
___ New market types
___ Other: ______________________________
___ Other: ______________________________

Abiotic stress

___ Temperature
___ Salt excess
___ Mineral deficiency
___ Water
___ Other: ______________________________
___ Other: ______________________________

Disease: Fungal

___ Powdery mildew
  ___ *Podosphaera xanthii*
  ___ *Golovinomyces cichoracearum*
___ Downy mildew (*Pseudoperonospora cubensis*)
___ Anthracnose (*Colletotrichum lagenarium*
___ Fusarium wilt (*Fusarium oxysporum* f.sp. *melonis*)
___ Verticillium wilt (*Verticillium dahliae* and *V. albo-atrum*)
___ Phytopthora crown rot (*Phytopthora capsici*)
___ Pythium (*Pythium* spp.) root and crown rot
___ Alternaria (*Alternaria cucumerina*)
___ Gummy stem blight (*Didymella bryoniae*)
___ Vine decline (*Monosporascus cannonballus*)
___ Other: ______________________________
___ Other: ______________________________

Disease: Bacterial

___ Fruit Blotch (*Acidovorax avenae* subsp. *citrulli*)
___ Bacterial wilt (*Erwinia tracheiphila*)
___ Angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*)
___ Other: ______________________________
___ Other: ______________________________

Disease: Viral

Aphid-transmitted

___ Cucumber mosaic virus (CMV)
___ Cucurbit aphid borne yellows virus (CaBYV)
___ Muskmelon yellow stunt virus (MYSV)
___ Papaya ringspot virus (PRSV) watermelon strain (= WMV 1)
___ Watermelon mosaic virus (WMV) (= WMV 2)
___ Watermelon mosaic Virus-Morocco
___ Zucchini yellow mosaic virus (ZYMV)

Disease: Viral (continued)

Whitefly-transmitted

___ Beet pseudo yellows virus (BPSYV)
___ Cucurbit leaf crumple virus (CuLCrV)
___ Cucurbit yellow stunting disorder virus (CYSDV)
___ Lettuce infectious yellows virus (LIYV)
___ Melon chlorotic leaf curl virus (MCLCV)
___ Melon leaf curl virus (MLCV)
___ Squash leaf curl virus (SLCV)
___ Watermelon curly mottle virus (WCMoV)
___ Other ______________________________
___ Other: ______________________________

Soil-borne/ Seed-borne

___ Muskmelon necrotic spot virus (MNSV)
___ Squash mosaic virus (SqMV)
___ Other ______________________________
___ Other: ______________________________

Other

___ Cucumber green mottle mosaic (CGMMV)
___ Cucumber vein yellowing virus (CVYV)
___ Cucurbit latent virus (CLV)
___ Curly top virus
___ Eggplant mottled dwarf rhabdovirus
___ Kyuri green mottle mosaic virus (KGMMV-YM)
___ Melon rugose mosaic virus (MRMV)
___ Melon vein-banding mosaic virus (MVbMV)
___ Melon yellow spot virus
___ Melon yellowing-associated virus (MYaV)
___ Melon yellows virus
___ Muskmelon yellow spot virus (MYSV)
___ Ourmia melon virus
___ Tobacco ringspot virus (TrSV)
___ Tomato leaf curl virus
___ Zucchini yellow fleck virus (ZYFV)
___ Other ______________________________
___ Other: ______________________________

Insects and Nematodes

___ Sweetpotato whitefly, *Bemisia tabaci* Biotypes: A/B/Q
___ Greenhouse whitefly, *Trialeuroides vaporariorum*
___ Cucumber beetle, *Acalymma trivittatum*, *Diabrotica undecimpunctata undecimpunctata*, and *D. balteata*
___ Leafminer, *Liriomyza sativae* and *Liriomyza trifolii*
___ Green peach aphid, *Myzus persiceae*
___ Melon aphid, *Aphis gossypii*
___ Melon fly, *Myiopardalis pardalina*
___ Root knot nematode, *Meloidogyne* spp.
___ Other: ______________________________
___ Other ______________________________