BIOLOGY OF APPLES AND PEARS

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Apples and pears in the wild and in prehistory

The genus *Malus* has, according to most authorities, 25 to 30 species and several subspecies of so-called crab apples. These species are found in the wild almost continuously throughout temperate Eurasia and North America. The primary centre of diversity appears to be within a region stretching from Asia Minor to the western provinces of China (Janick *et al.*, 1996; Juniper *et al.*, 1999, 2001). Forests of wild apples are still found in this region (Roach, 1985), with fruits ranging from small and unattractive to ones similar to the traditional cultivated eating apples.

There is evidence that the fruits of apples were collected as food by prehistoric man. Carbonized fruits dating from 6500 BC were found at Çatal Hüyük in Anatolia and remains of both sour crab apples and a larger form, which may have been cultivated, were discovered in prehistoric lake dwellings in Switzerland. It seems likely that apples moved with human migration along the Old Silk Roads linking western China with the Near East and Danube valley even in Neolithic and Bronze Age times. These routes passed through Almaten (Alma Ata) in eastern Kazakhstan and the northern slopes of the Tien Shan Mountains, now thought to be the possible centre of origin of the domestic apple (Juniper *et al.*, 2001).

Cultivated pears appear to have arisen from three centres of diversity: a Chinese centre where forms of *Pyrus pyrifolia* and *P. ussuriensis* are grown, a centre in the Caucasus Mountains and Asia Minor where the domesticated forms of *P. communis* arose, and a Central Asian centre where *P. communis* and its hybrids occur (Vavilov, 1951; Bell *et al.*, 1996). Asian or Japanese pears are thought to have been domesticated in prehistoric times from wild *P. pyrifolia* and to have been cultivated in China for at least 3000 years (Lombard and Westwood, 1987).

Apples and pears in antiquity

Improved forms of apples and pears (*P. communis*) were spread through the civilizations of the Fertile Crescent, extending from the hills of Persia and south of the Caspian Sea to Turkey and through Palestine to Egypt. Apple trees apparently reached Palestine in about 2000 BC and feature in the Bible (Authorized King James Version) in the Song of Solomon. From Palestine they were taken to Egypt and apple plantations in the Nile Delta are mentioned in the Third Papyrus of Anastasi in the reign of Rameses II (1298–1235 BC). The Harris Papyrus of the time of Rameses III (1198–1166 BC) refers to 848 baskets of apples being delivered as offerings to the Temple of Ra in Heliopolis.

Both apples and pears were well known in the world of Ancient Greece. Homer, in the *Odyssey* written between 900 and 800 BC refers to a large orchard with both apples and pears; and Theophrastus spoke of the difficulty of propagating apples from cuttings, budding and grafting being the generally accepted methods.

Apple culture was well developed in the Roman empire. Columella described cleft- and rind-grafting and also a technique of propagation practically identical with modern patch-budding. Pliny described the apple as having the highest value among fruits. He noted that fruit cultivation was a very profitable enterprise, provided that the orchards were near to a town where the fruits could be sold, and that fruit cultivation in the villages near Rome was more profitable than any other form of farming. The Roman Varro (116–27 BC) described apple storage and the construction of an apple store so as to keep it cool and well ventilated. All the Roman writers included the names of a number of apple cultivars. Pears seem to have been favoured more for cooking and the Romans had many named cultivars, some already of considerable antiquity.

The earliest written record of cultivated Asian pear groves in Japan is in the manuscript of the Emperor Jito in AD 693 (Kajiura, 1994).

Apples and pears in medieval and pre-industrial times

Charlemagne, the Frankish king who was crowned Holy Roman Emperor in AD 800, introduced a law which laid down that crown lands in every city of the Empire should have a garden planted with herbs and fruits. The fruits included apples and pears. Over the ensuing centuries, both in England and throughout western Europe, the monasteries became major centres for apple and pear production. In England these monasteries were, from 1100, under the direction of Norman-French bishops and abbots and had the management not only of adjoining properties but also of lands allocated to them by the King. In Kent, in 1086, almost half of the entire county was owned by

Christ Church and St Augustine's priories at Canterbury. They grew apples and pears for eating and cooking and also apples for cider. The sale of cider was recorded at Battle Abbey in Sussex in 1275 and cider production was recorded in Yorkshire at around the same time. In the South Tyrol, also at around this time, apples were grown in the gardens of monasteries, castles and rural settlements to supply local markets, e.g. the Obstplatz (fruit square) in Bolzano (Oberhofer, 1981). In England two cultivars, the 'Pearmain' and the 'Costard' were grown extensively in the thirteenth century and there are records of apples and pears and their rootstocks being bought and sold. Pears were much planted in medieval England, with new cultivars brought over from the La Rochelle area of France. King Henry VIII ordered the importation of graftwood of the best available cultivars in 1533 and Richard Harris, Fruiterer to the King, imported many apple cultivars, especially pippins, from France and pear graftwood from the Low Countries (Netherlands). Subsequent to this Walloon refugees settled in Sandwich in Kent. Some of these Dutch settlers then moved to northwest Kent and Surrey to establish market gardens to supply London and later established apple and pear orchards for this purpose.

In the sixteenth century the use of dwarfing 'Paradise' rootstocks was described for the first time in Europe, by Ruellius in 1536. This 'French Paradise' probably had originated in Armenia as a form of *Malus pumila* or a *M. pumila* × *M. sylvestris* hybrid. 'Paradise' apple trees were grown and used as rootstocks to control the vigour of cultivars grafted on them in England in the late sixteenth and early seventeenth centuries. The first 'Paradise' rootstocks had been brought over from France but they were subsequently propagated in English nurseries.

The introduction of apple and pear culture in North and South America, South Africa, Australia and New Zealand accompanied European settlement. The first documented apple orchard in what is now the USA was planted near Boston in 1625, and this was almost certainly preceded by plantings in Latin America.

Apple and pear production in the modern era

The distinctively modern era, from the perspective of apple and pear production, dates from the development of cheap and rapid long-distance transportation by steamship, railway train and truck. It is characterized by the development of science-based technologies to improve the productivity of fruit trees in a wide range of environments and to enable apples and pears to be stored in good condition for many months.

Prior to these developments apple and pear growing for market was predominantly in areas close to large towns and cities, such as in villages near to Rome in the time of Pliny, and in Kent near to London in the Middle Ages and subsequently. There was some international trade, e.g. over the Brenner Pass

from areas south of the Alps and over the Channel from France to England, but the distances involved and the bulks transported were limited.

APPLE PRODUCTION

In 1867 the railway from Bozen (Bolzano) in what is now Italy was opened across the Alps, connecting the South Tyrol with many populous cities and towns in central Europe (Oberhofer, 1981). Subsequently there was a major increase in apple exports from what is now the Alto Adige region of northern Italy and by far the greater proportion of fruit grown there is now exported, especially to Germany and Austria.

Apple growing in the United States followed the extension of settlement westwards. Climatic conditions differed markedly from those in Great Britain and there was much practical trial and error to select appropriate cultivars. The native crab apples were largely discounted even as a source of breeding material and large numbers of seedlings were imported, especially for the production of cider. As populations moved into areas with colder winters many northern European cultivars were introduced and by 1872 more than a thousand cultivars were listed. Production in the eastern and mid-western states of the USA centred on New York, Michigan and the Shenandoah Valley area of Pennsylvania, West Virginia and Virginia, all within easy reach of major markets. Apple planting in Washington State, remote from large centres of population, began early in the nineteenth century primarily to supply apples for the settlers themselves. Commercial orchards were planted extensively near Yakima by the 1890s (Marshall and Steigmeyer, 1995). Most of the plantings were along the banks of the Columbia River and its major tributaries, the Okanagan, Snake, Wenatchee and Yakima rivers. Steamboats on the Columbia were a major means of freight, rail service became available from Wenatchee town in 1893 and car-lot shipping started in 1901. Further extension of the railway and heavy promotion of apple planting led to a rapid increase in production and by 1920 Washington had become the leading state for apple production in the USA. Expansion continued and in the 1990s there were extensive new plantings on virgin land in the central Columbia River Basin. In 1994 Washington State produced 2.540 million tons of apples out of a total production in the USA of 4.909 million tons, i.e. more than 50% of the US total. It should be noted that this production is totally dependent on irrigation, average annual rainfall in Wenatchee and Yakima being only 252 and 202 mm respectively (Elfving, 1997). The industry is dependent on markets outside the state, international exports rising to 33% of total shipments by 1994. Two thirds of the production is of the cv. 'Red Delicious', followed by 'Golden Delicious', 'Granny Smith', 'Gala' and 'Fuji'.

The apple industries of Australia, New Zealand and South Africa underwent major expansion in the early twentieth century to take advantage of the

Table 1.1 *Annual apple production by country 1948/50–1996 (1000 MT)*

Rank (1996)	Country	Year					
		1948/50	1960	1970	1980	1990	1996
1	China	133	298	801	2383	4332	16009
2	USA	2521	2231	2902	4000	4381	4773
3	Former USSR	1033	1950	5046	5090	5800	4716
4	France	3615	5693	4423	2930	2346	2445
5	Turkey	109	208	748	1430	1900	2100
6	Iran	39	50	89	800	1501	2000
7	Italy	642	1834	2062	1937	2050	1940
8	Poland	141	627	691	844	812	1700
9	Germany	1191	3142	1975	2395	4147	1594
10	India	85	180	277	658	1093	1200
11	Argentina	155	431	445	958	980	1147
12	Japan	366	876	1021	960	1053	963
13	Chile	86	101	140	245	632	910
14	Spain	184	262	484	931	657	811
15	Korean DPR	69	87	115	460	645	660
16	Brazil	6	10	15	42	543	653
17	Mexico	46	64	146	262	376	645
18	Korean Rep.	46	104	212	410	629	630
19	Pakistan	3	3	33	107	240	600
20	Canada	325	304	406	553	540	560
21	Belg./Lux.	271	197	252	327	223	515
22	South Africa	41	150	222	426	530	500
23	Netherlands	253	384	450	470	431	490
24	New Zealand	43	72	140	211	361	480
25	Hungary	121	290	661	1017	945	475
26	Romania	57	111	176	414	683	457
27	Egypt	2	4	4	14	62	455
28	Austria	369	702	309	330	338	368
29	Morocco	2	3	14	27	300	360
30	UK	561	686	596	357	311	350
Total	1–30	12 515	21 054	24 855	30 988	38 841	50 506
Total	World	14 576	23 497	27 502	34 104	40 518	53 672

Data from FAO (1987, 1997).

opportunities offered by the English market. Indeed research in England on apple rootstock breeding and on fruit storage during this period was partly to support production in and shipment from these southern hemisphere countries.

Over the period 1948/50, when annual world production averaged 14 576 000 tons, France was the leading producer of apples, followed by, in order, the USA, Germany, the [then] USSR, Italy and the United Kingdom (Table 1.1). These six countries between them produced 65% of the total world output. In 1996, by comparison, China was the leading producer followed by

the USA, the former USSR, France, Turkey, Iran and Italy, between them producing 59% of a world output of 53 672 000 metric tons (MT). In 2000 these were still the top six producing countries, but production in China had risen to 22.89 million MT out of a global total of 60.64 million MT (Belrose, 2001).

From 1948/50 to 1996 production in northwestern and central Europe (France, Germany, Belgium/Luxembourg, the Netherlands, Austria and the UK) was relatively constant, although that in the Netherlands increased and that in the UK declined. Output from Italy increased up to 1960 and then changed very little while production in Poland, Spain, Hungary and Romania increased substantially.

The modern era of apple production in Japan began in the 1870s, when more than 100 cultivars of apple were introduced from western countries and distributed by the government, mainly to prefectures in northern Japan (Fukuda, 1994). These replaced the poor crab-apple type of apples called 'Waringo' (*M. asiatica* Nakai) which had been grown in Japan from the fifteenth century. The cvs. 'Ralls Janet' and 'Jonathan' dominated until the 1960s when they were replaced by 'Fuji', which was bred in Japan, and by 'Delicious' strains, the latter then being largely replaced by newer, mainly locally-bred, cultivars.

Total production of apples in Japan remained relatively constant from 1960 onwards but elsewhere in Asia there were dramatic increases in production. In western Asia, production in Turkey increased steadily over the period, from 109 000 MT on average in 1948/50 to 2 100 000 MT in 1996, while that in Iran increased very rapidly from the 1970s onwards. In India expansion in production was fairly steady, while in Pakistan most of it came after 1990. In east Asia the increase in production in the two Koreas came well before that in China, where it was much greater in the 1990s than in any earlier period. Indeed, the increase in production in China was the dominant feature of world apple growing in the 1990s. The largest production was in Shandong province, across the Yellow Sea from South Korea and southern Japan, followed by Liaoning to the north, Hubei in central China, Hunan, Shaanxi and Shanxi (Shou-Chun, 1998). As has typically been the case where there have been large planned increases in production in 'new' areas, there was emphasis on production of new cultivars with high consumer demand. By the late 1990s approximately 50% of the apples grown in China were of the Japanese cv. 'Fuji', which returned twice the price per kilogram compared with the previously dominant 'Red Delicious'. Although the main market was within the country, apples were exported to Far East Russia, and to Hong Kong and Singapore from which they were re-exported to the rest of Asia.

In North America expansion of production was relatively moderate and steady in Canada and the USA, doubling between 1948/50 and 1996, whereas it increased 14-fold over the same period in Mexico with the greatest growth in absolute terms in the 1990s.

In South America most of the increase in production in Argentina was in the period up to 1980, whereas in Chile output continued to increase rapidly in the 1980s and 1990s and in Brazil the rapid increase in production was virtually confined to those two decades. Planting in Brazil was mainly in Santa Caterina province in the south, with emphasis on the relatively new cvs. 'Gala' and 'Fuji'.

In South Africa production increased 12-fold over the period 1948/50 to 1996, the rate of increase being fairly steady, while growth in apple production in Egypt and Morocco was much more rapid in the 1990s than previously. It is notable that in 1996 production in Egypt and Morocco together considerably exceeded that in South Africa.

Production in New Zealand expanded steadily, increasing 10-fold over the period considered, with a pattern of change very similar to those in the other southern hemisphere countries, Chile and South Africa, where apples are also grown mainly for export.

The figures given in Table 1.1 show dominance of a relatively few countries in apple production, but the concentration of output in relatively small favoured areas is even more striking. More than half of the total output of apples in the USA is from a small number of river valleys in Washington State, where the fruit trees are grown in irrigated semi-desert country in the rain shadow of the Cascade Mountains (Figure 1.1). Similarly, Italy is the world's seventh largest producer of apples and more than 40% of its production (Sansavini, 1990) and half of its exports (Oberhofer, 1981) are from a very small area of the Trentino and Alto Adige provinces. In Poland, another major producer, the area around Grojec, about 50 miles south of Warsaw, has one of the greatest apple orchard concentrations in Europe, accounting for 35% of Poland's fresh apple production in 1993 (Florkowski *et al.*, 1996).

PEAR PRODUCTION

Pear production, although on a much smaller scale than apple production, has followed a similar pattern of expansion in recent years. China was the leading country in 1996, having overtaken Italy by 1980. Italy, Spain, Argentina and Japan are all relatively higher-ranked for pear than for apple production although they each produce more apples than pears. Production in western and central mainland Europe (Italy, Spain, Germany, France, Belgium/Luxembourg, the Netherlands, Switzerland, Portugal and Austria) gave 46% of the world's output over the years 1961/65 but despite a slight rise in output by 1996 produced only 21% of the world output in that year. This relative decline was because of major increases in output in China, Argentina, Turkey, Chile, South Africa, Iran and others (Table 1.2).

There is a similar concentration of production within specific areas, as is found with apple. More than 70% of Italian output of pears comes from the

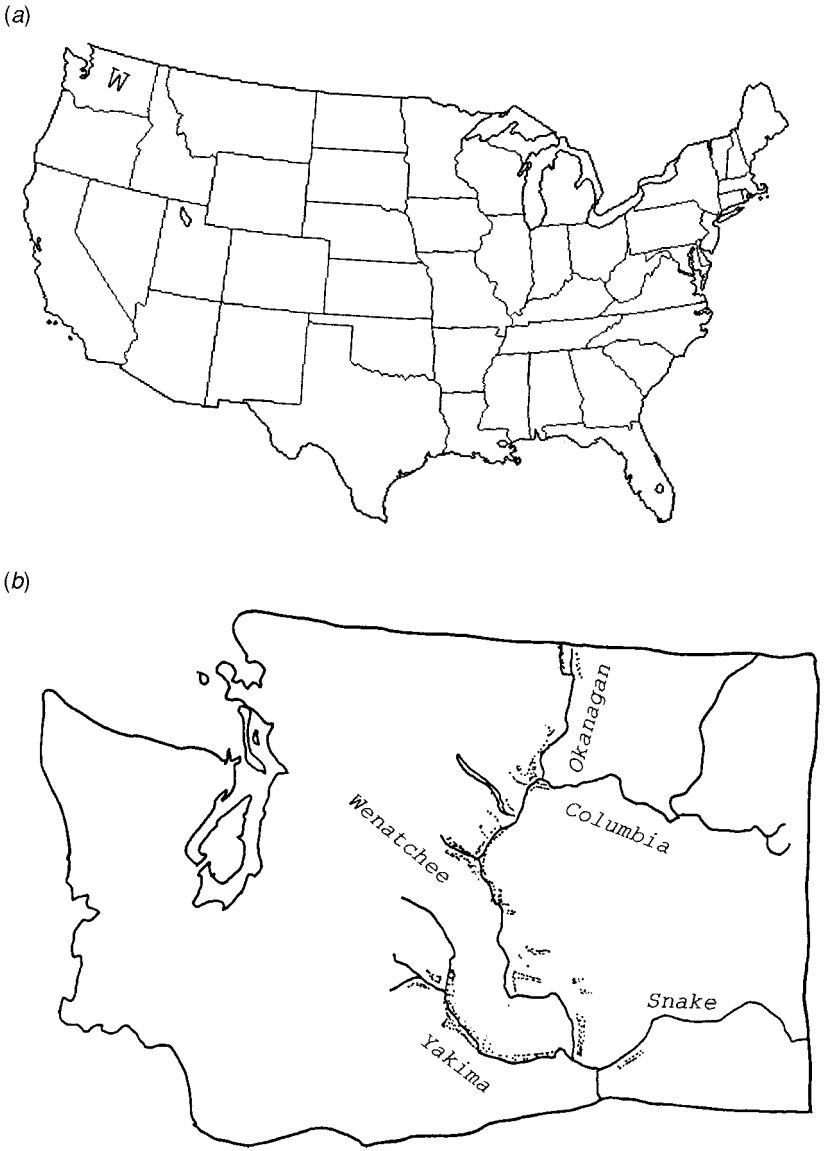

Figure 1.1 Concentration of apple production. More than half of all production in the USA is in Washington State (W on map(*a*)) and within that state is largely confined to the valleys of the Columbia, Okanagan, Snake, Wenatchee and Yakima rivers in the stippled areas on map (*b*). Map (*b*) redrawn from Marshall and Steigmeyer (1995).

Table 1.2 *Annual pear production of leading countries 1961/65–1996 (1000 MT)*

Rank (1996)	Country	Year				
		1961/65	1969/71	1980	1990	1996
1	China	826	1203	1645	2483	5615
2	Italy	934	1749	1318	968	937
3	USA	557	612	814	874	707
4	Spain	147	295	437	449	584
5	Argentina	96	90	155	210	513
6	Former USSR	N.A.	538	610	500	435
7	Japan	330	466	496	443	426
8	Turkey	141	172	330	413	410
9	Germany	499	536	452	380	370
10	France	410	551	445	331	350
11	Chile	20	31	39	140	250
12	South Africa	63	94	133	203	220
13	Iran	24	29	45	125	184
14	Korean Rep.	30	49	60	159	163
15	Australia	124	162	124	171	160
16	Belg./Lux.	55	73	76	59	158
17	Netherlands	111	120	115	90	130
18	India	40	52	64	105	130
19	Korean DPR	10	22	65	115	125
20	Switzerland	167	155	101	86	100
21	Egypt	12	17	51	75	95
22	Greece	96	112	111	51	90
23	Portugal	52	43	59	94	81
24	Austria	236	158	126	100	78
Total	1–24	4980	7330	7871	8624	12 311
Total	World	5655	8232	8726	9509	13 093

Data from FAO (1977, 1982, 1992, 1997).

lowlands of Emilio Romagna and Veneto (Sansavini, 1990). More than 35% of the output of pears in the USA comes from the irrigated valleys of Washington State, which overtook California in pear production in the mid-1990s (USDA, 1995–96).

In Japan there were more than 1000 named cultivars of Nashi (Japanese or Asian pears) by 1860 and commercial production began around the capital. This was boosted in about 1895 with the introduction of two high-quality chance seedlings ('Nijisseiki' and 'Chojura'), and the development of the railway network enabled Nashi fruits to be transported to the big cities from distant agricultural regions such as the Tottori prefecture (Kajiura, 1994). 'Chojura' remained the dominant cultivar until 1971 when it was replaced by the newly-bred cvs. 'Kosui' and 'Hosui'. In 1992 'Kosui', 'Nijisseiki' and 'Hosui' were cultivated on 36.1%, 21.8% and 21.2%, respectively, of the area growing Nashi

Table 1.3 *Apple exports. Exports in 1000 MT from the 12 leading apple exporters*

Country and rank in 1987	Exports			Country and rank in 1995	Exports		
	1987	1988	1989		1993	1994	1995
France (1)	762	707	681	France (1)	641	654	768
Hungary (2)	396	341	318	USA (2)	525	739	635
Italy (3)	347	340	280	Italy (3)	422	414	499
Chile (4)	331	347	326	Chile (4)	361	347	433
USA (5)	228	306	276	Netherlands (5)	366	401	412
Argentina (6)	202	208	215	Belg./Lux. (6)	276	271	368
Netherlands (7)	192	200	200	New Zealand (7)	225	201	302
South Africa (8)	190	221	225	Argentina (8)	145	147	243
New Zealand (9)	166	120	174	South Africa (9)	175	245	214
Belg./Lux. (10)	138	144	156	Iran (10)	216	190	190
Poland (11)	81	85	80	Poland (11)	175	115	139
China (12)	60	88	65	China (12)	119	107	109

Data from FAO (1990, 1996).

pears in Japan. 'Kosui' is an early-season pear and 'Nijisseiki' and 'Hosui' are mid-season pears.

Trade in fresh apples

Between 1980 and 1993 imports, which are a measure of between-country trade, averaged between 8% and 9% of production in most years (Belrose, 1996), i.e. most apples were consumed in the country of production. However, exports of apples are very important to a number of national economies and also, to at least some extent, provide an indication of the countries with comparative advantages in production. Exports are shown in Table 1.3.

Most exports are to nearby countries. In 1986 the major destinations of apples exported were as shown in Table 1.4. Exports from France, Italy, Poland, the USA, the Netherlands, Argentina and Belgium/Luxembourg were all to neighbouring countries; only those from Chile, New Zealand and South Africa were to distant countries. In these latter cases the need for long-term storage during transport is self-evident, though this is of course also true for apples sold within the country of production. The high level of exports from the Netherlands and Belgium-Luxembourg to some extent involves re-export of imported fruits, but in 1995 Dutch exports of 411 812 MT greatly exceeded imports of 284 851 MT and the corresponding figures for Belgium-Luxembourg were 368 337 MT of exports and 228 132 MT of imports (FAO, 1996). Imports into Poland in 1995 were only 18% of exports, no imports were recorded for

Table 1.4 *The major destinations of fresh apples from the top ten exporters in 1986*

Exporter	Rank	Major destinations
France	1	United Kingdom
Chile	2	Netherlands
Italy	3	West Germany
New Zealand	4	Belgium/Luxembourg
Poland	5	USSR
United States	6	Canada
South Africa	7	United Kingdom
Netherlands	8	West Germany
Argentina	9	Brazil
Belgium/Luxembourg	10	West Germany

From Vidyashankara and Wilson (1989). Credit Washington State University IMPACT Program.

Chile, Iran or South Africa, and those into New Zealand were only three hundredths of 1 % of exports.

Trade in pears

Whereas in 1987 France and Italy were ranked first and third, in terms of exports they were only ninth and seventh respectively in 1995, while Argentina, South Africa, Chile and the USA had improved their relative positions (Table 1.5).

Apple and pear products

Apples and pears have many uses: fresh fruits, fresh fruit juice, concentrated fruit juice, cider and perry, 'pop wine', and various canned and dried fruit products.

Fresh fruits are by far the most important in terms of total apple consumption (Table 1.6). They are even more so in terms of value: in the USA over the period 1962–72 the prices growers received for fresh apples averaged more than twice those received for apples for processing. Within the processing sector higher prices were paid for large apples suitable for peeling for canning and freezing; dried apples, from sound fruit, achieved about 80% of the canning and peeling price and apples for pressing for juice and cider averaged 60% of the canning and freezing price (Greig and Blakeslee, 1975). Prices of apples for

Table 1.5 *Pear exports. Exports in 1000 MT from the 12 leading pear exporters*

Country and rank in 1987	Exports			Country and rank in 1995	Exports		
	1987	1988	1989		1993	1994	1995
France (1)	117	70	94	Argentina (1)	142	142	222
Argentina (2)	97	116	142	South Africa (2)	115	99	150
Italy (3)	74	83	79	Belg./Lux. (3)	103	140	148
Netherlands (4)	70	90	87	Chile (4)	147	157	147
South Africa (5)	69	80	52	USA (5)	124	162	146
China (6)	53	127	59	Netherlands (6)	102	158	143
Spain (7)	49	32	43	Italy (7)	172	127	113
Chile (8)	45	63	76	China (8)	69	97	91
Belg./Lux. (9)	40	56	53	France (9)	50	82	80
USA (10)	39	54	83	Spain (10)	45	71	69
Australia (11)	36	40	21	Australia (11)	31	28	26
Japan (12)	13	12	9	Hong Kong (12)	18	21	23

Data from FAO (1990, 1992, 1996).

Table 1.6 *Major uses of apples in selected regions, 1989–90 (1000 MT)*

	Fresh consumption	Fresh exports	Processing	Withdrawal
EC	6414	1384	1521	276
USA	2229	340	1946	0
Turkey	1673	84	92	0
Argentina	223	225	620	0
South Africa	205	222	133	0

Data from O'Rourke (1994).

processing are declining and in the USA in 2000 were only about a quarter of the fresh apple price (Belrose, 2001).

Under many, perhaps most, circumstances the apples which are used in processing do not cover their full share of production costs. In Washington State in 1990 a typical orchard might produce 20 tons of apples per acre (50 t ha^{-1}) at a total cost of $4000, i.e. $200 per ton. The orchard would typically yield 15 tons of apples sold for fresh consumption at $309.44 per ton, 2 tons of apples suitable for canning or peeling at $108.47 per ton and 3 tons of apples suitable for juice only at $69.94 per ton (Hinman *et al.*, 1992). Although the fruit sold for processing does not appear to meet its cost of production, as long as the price per ton exceeds the costs of harvesting and transporting to the processor this processing fruit makes a net contribution to the grower's income because it does not affect his pre-harvest costs.

Fresh apples and pears are, as mentioned earlier, sold in categories, classes or grades which reflect perceived quality. The quality criteria are specific to types (e.g. red, partially coloured or green apples) and even to individual cultivars. In general larger fruits are preferred to smaller ones, bright red colour is preferred in red cultivars, and downgrading results from any surface blemish whether this is the result of pest or disease attack or a physiological or environmental cause. This quality grading has very important consequences in terms of tree management. Large fruits develop when fruits and leaves are well exposed to sunlight and fruit-to-fruit competition for assimilates is reduced by fruitlet thinning. The anthocyanin pigment which gives fruit skin its red colour is only formed, in most cultivars, under the direct influence of exposure to sunlight. Downgrading can thus result from fruit development under shady conditions. When, however, light intensities are very high, inadequate shade can lead to sunburn, which can result in the fruit being unsuitable for the fresh market.

Apple juice is the second most important apple product. The apples are ground, pressed and filtered to remove skins and pulp. The juice is then pasteurized. It may be sold as such, in un-concentrated form, or concentrated to give a 6 to 1 concentrate, i.e. a concentrate which is reconstituted to apple juice by adding six parts of water to one of concentrate. The ability to concentrate apple juice has greatly reduced its transportation costs and made it possible to ship it economically from areas of production to distant markets. In 1985 Argentina processed more than 40% of its apple production into juice concentrate and exported 97% of this to the USA (O'Rourke, 1994). Apple juice is the cheapest of all fruit juices: as well as being sold as such it is therefore also widely used in fruit juice blends which are marketed under the name of the other ingredient. In England and in Canada apples are fermented to make an alcoholic drink called cider (most American cider is non-alcoholic juice). In England this is produced from special cultivars giving characteristic aroma and flavour. Conventional apple juice can also be used as the sugar source for producing 'pop wines' as an alternative to using the more expensive grape juice.

The second most important processed apple product is apple sauce. The apples are peeled, cored and trimmed, chopped and cooked with sugar. The cooked sauce is then filtered, and water and sugar automatically added to ensure consistency of product prior to canning. Other products include dried apple and apple chips.

Pears are primarily grown for the fresh market and for canning. One cultivar, 'Bartlett', dominates the canning market. In 1995, out of a total US production of 944 250 tons of pears, 493 000 tons were of 'Bartlett' grown in the states of California, Washington and Oregon of which 390 040 tons (79%) was processed (USDA, 1995–96). Over the ten years 1986–95 an average of

51 % of the utilized pear production was for the fresh market, the proportion being greater in the more recent years. 'Bartlett' used in processing, mainly grown under contract for canning, averaged about 67 % of the 'grower price' of 'Bartlett' for fresh consumption in the USA over the years 1985 and 1990–98. Processed pears of other cultivars tend to be used in juice and other low value products and achieved only about 23 % of their fresh fruit price (Belrose, 2000).

Climatic conditions in major centres of production

It is clearly impossible to give any narrow description of the climatic conditions required for successful apple and pear production. Apples and pears are grown for export, i.e. to an internationally competitive level, in climates as diverse as those of the Netherlands and South Africa. They can be grown with varying degrees of success throughout the temperate zone and, increasingly, in the subtropics and even the tropics. Successful production depends both on the climate, especially the local microclimate, and on effective adaptations to this in terms of cultivar selection and cultural practice. This is discussed in detail later.

Table 1.7 illustrates the range of temperatures in which apples and pears are successfully produced. The dominant climatic constraints range from winter-freeze damage in Poland to inadequate winter chilling for fruit bud development of most cultivars in Egypt, and summer heat stress and fruit sunburn in Washington State. It should be noted that whereas the means of the daily minima and maxima (daily means) are useful in defining growing conditions, the means of the monthly minima and maxima (monthly means) are much more informative as the levels of potentially limiting stress factors which occur on a regular basis.

At a more subtle level, temperature effects on fruit set, fruit size, fruit colour and fruit shape determine where the leading apple cultivar, 'Red Delicious', is best produced.

Table 1.8 shows the incoming solar irradiation in a number of apple and pear growing regions. At higher irradiation levels a greater depth of canopy can receive light at any given level so potential photosynthesis of the canopy is increased.

Irrigation is practised in most of the major regions of apple and pear production. Rainfall is probably adverse in most areas, leading to increased incidence of fungal diseases, especially apple scab, and bacterial diseases, especially fire blight, on pears. The high cloud cover associated with rainfall is also a major factor in reducing the available solar radiation in many fruit-growing areas.

Table 1.7 *Daily and monthly mean maximum and minimum temperatures (°C) in different apple growing areas*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. *Netherlands*												
Daily max	5.0	5.1	8.5	11.9	15.9	19.0	20.6	20.9	18.7	14.1	9.4	6.3
Daily min	1.0	0.6	2.5	5.4	8.7	12.0	14.1	14.4	12.6	8.9	5.2	2.4
Monthly max	10.2	10.6	15.3	19.4	24.1	26.8	27.6	27.5	25.0	19.1	13.9	11.4
Monthly min	−5.0	−5.7	−2.5	0.9	3.6	7.5	10.0	10.5	7.9	2.8	−0.3	−4.0
2. *Poland*												
Daily max	−0.4	0.3	5.6	11.8	19.6	22.6	24.1	22.9	19.0	12.9	5.6	1.9
Daily min	−5.5	−6.0	−2.0	2.9	9.0	12.3	14.6	13.5	9.5	5.1	0.7	−2.5
Monthly max	6.7	8.3	14.5	21.3	28.4	30.1	31.2	29.6	27.9	21.0	13.0	8.5
Monthly min	−17.2	−16.3	−8.7	−2.7	2.6	6.3	10.1	9.0	3.1	−1.1	−5.5	−11.6
3. *Italy (1)*												
Daily max	4.8	8.7	14.5	18.8	23.0	26.0	28.2	27.3	24.5	18.8	10.6	5.6
Daily min	−4.5	−1.4	3.0	7.4	10.8	14.2	15.8	14.9	12.3	6.6	1.4	−2.7
Monthly max	11.5	15.9	21.9	26.4	29.4	32.1	33.6	33.1	29.5	25.1	17.1	12.1
Monthly min	−10.0	−6.4	−2.3	1.9	4.8	8.8	11.0	9.8	6.6	−0.4	−4.6	−8.5
4. *Italy (2)*												
Daily max	5.1	8.4	13.5	18.4	23.2	27.2	30.1	29.9	26.0	19.6	18.8	7.3
Daily min	−0.6	1.5	5.4	9.5	13.7	17.5	19.7	19.3	16.5	11.7	6.3	1.9
Monthly max	11.7	15.9	20.6	24.7	29.5	33.3	35.3	35.0	30.7	25.5	18.3	14.6
Monthly min	−6.0	−3.5	−0.3	4.1	7.8	12.0	14.4	14.8	11.4	6.4	0.8	−4.6

5. *USA*												
Daily max	2.5	7.1	12.9	18.8	23.4	26.7	31.6	30.3	26.0	18.7	8.9	4.3
Daily min	−7.5	−4.9	−1.8	1.8	6.0	9.3	11.7	10.3	6.6	1.9	−2.9	−4.8
Monthly max	12.1	14.9	20.4	27.4	32.6	35.4	38.8	36.8	33.8	26.6	16.8	13.2
Monthly min	−15.5	−11.9	−6.6	−2.3	0.8	4.9	7.8	6.8	2.0	−2.9	−7.9	−10.9
6. *Egypt*												
Daily max	19.4	21.7	25.6	30.6	34.4	36.1	36.7	36.1	33.9	30.6	26.1	21.1
Daily min	4.4	6.1	8.9	12.2	17.2	18.9	20.0	20.6	18.3	15.6	11.7	6.1
Monthly max	26.1	30.0	34.4	39.4	43.3	42.2	41.7	41.1	39.4	36.1	32.2	27.2
Monthly min	1.1	1.7	4.4	7.8	11.7	15.6	17.2	17.8	15.5	11.7	7.2	2.2

Sites: 1. Vlissingen, Netherlands. 51° 28′ N, 3° 35′ E, 1 m altitude
2. Warsaw, Poland. 52° 13′ N, 21° 03′ E, 110 m
3. Bolzano, Italy. 46° 30′ N, 11° 21′ E, 271 m
4. Bologna, Italy. 44° 30′ N, 11° 21′ E, 60 m
5. Yakima, USA. 46° 34′ N, 120° 32′ W, 323 m
6. Cairo, Egypt. 29° 52′ N, 31° 20′ E, 116 m

Data from Meteorological Office (1980). The figures for Cairo are taken from the 1958 edition.

Table 1.8 *Incoming global radiation during a 5-month growing season at weather stations in major fruit-producing regions*

Location	Year	Radiation (GJ m^{-2})
Davis, California	LT	4.13
Avignon, France	1971	3.23
Riwaka, New Zealand	LT	3.20
Ithaca, New York	1987	2.73
Wilhelminadorp, Netherlands	1986–89	2.50

LT, long-term average data.
From Wagenmakers (1995). Reproduced with permission.

Recommended reading

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