Apple Scab (*Venturia inaequalis*) and Pests in Organic Orchards

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Doctoral Thesis
Swedish University of Agricultural Sciences
Alnarp 2003

Abstract

Sandskär, B. *Apple Scab (Venturia inaequalis) and Pests in Organic Orchards*
Doctoral Dissertation
ISSN 1401-6249, ISBN 91-576-6416-1

Domestication of apples goes back several thousand years in time and archaeological findings of dried apples from Östergötland in Sweden have been dated to *ca* 2 500 B.C. Worldwide, apples are considered an attractive and healthy fruit to eat. Organic production of apples is increasing abroad but is still at very low levels in Sweden. This study deals with major disease and pest problems in organic growing of apples. It concentrates on the most severe disease, the apple scab (*Venturia inaequalis*). Resistance to apple scab was evaluated during three years in over 450 old and new apple cultivars at Alnarp and Balsgård in southern Sweden. There were significant differences between the cultivars and years. About ten per cent of the cultivars had a high level of resistance against apple scab. The correlation between foliar and fruit scab was stronger when the scab infection pressure was high (1998-1999), compared to when it was low (2000). Polygenic resistance is a desirable trait since such resistance is more difficult to overcome by the pathogen. A common denominator for polygenic resistance among the cultivars assessed was 'Worcester Pearmain'. The leaf infection of apple scab was compared at three locations: Alnarp, Kivik and Rånna (Skövde) in an observation trial for 22 new apple cultivars. The ranking of the cultivars was similar at the three locations. The best cultivars, 'McShay' and 'Sansa', are unfortunately not suitable for growing in Sweden, due to climatic conditions. However, several other cultivars might be useful in organic growing. The incidence of apple scab races was investigated for the first time in Sweden. Races 1-4 and 6 were reported from different geographical locations in Sweden (1999-2001), and tested in growth chamber/greenhouse trials. Race 1 was present at all sites and race 7 was reported on *Malus floribunda* 821 for the first time in a field trial at Kivik in 2002. Apple scab lesions were also found on the ornamental species *Malus baccata jackii*. In an experimental organic orchard with 'Amorosa' and 'Discovery' interplanted with ornamental shrubs, the insect and spider fauna was investigated. Codling moth was considered to be a key pest in the orchard. Winter moth and apple sawfly damaged the fruit to a significantly higher extent in 'Discovery' than 'Amorosa'.

Key words: Apple cultivars, apple scab races, resistance biology, rosy apple aphid, sanitation practices, interplanting

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Fig. 1. Leaf scab (*Venturia inaequalis*). Photo: Boel Sandskär.

Fig. 2. Fruit scab (*V. inaequalis*). Photo: Boel Sandskär.

Contents

List of papers

Papers I-V

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Sandskär, B. & Gustafsson, M. 2002. Susceptibility of twenty-two apple cultivars to apple scab in Sweden, *J Plant Diseases and Protection* 109(4), 338-349.
II. Sandskär, B. & Gustafsson, M. 2003. Classification of apple scab resistance in two assortment orchards. *Genetic Resources and Crop Evolution, In press.*
III. Sandskär, B. Abundance of spiders, beneficial insects and pests in an organic apple orchard. *Submitted*
IV. Sandskär, B. & Liljeroth, E. Incidence of apple scab races in Sweden. *Manuscript*
V. Sandskär, B. 2002. Apple scab infection in three differently managed orchards. *Organic production of Fruit and Berries*. NJF Meeting, Oct 22. Web-publishing.

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Introduction

Apple growing in Sweden

Apple is a highly appreciated fruit and commercially grown in many parts of the world. It has a great ability to grow in different climatic conditions and is cultivated in temperate climates such as Siberia or the Mediterranean and in subtropical climates such as Brazil or South Africa. The chilling requirements are very different among cultivars. Cultivation of apples has been known for 3 000 years in Greece and Persia. The Ancient Greeks and Romans had the knowledge about the techniques of grafting and budding of fruit trees. The Vikings used apples in their diet and archaeological findings of dried, probably wild apples from Östergötland in Sweden are dated to 2 500 B.C.

During the Middle Ages, monasteries were important as centres for fruit growing in Europe and Sweden. The monks introduced new varieties from abroad and early nurseries were established, for example in Alvastra monastry. In the 16th and 17th Centuries, Swedish kings such as Gustav Vasa promoted fruit growing in Sweden. The noblemen followed the king's example and planted orchards around the castles and manor houses. As an example, apple growing has been documented for nearly 400 years in Grönsöö, Uppland county in the middle of Sweden. Later the knowledge of fruit growing was spread via the church and priests to the peasants and other parts of the society (Nilsson, 1986).

Swedish pomologies

In the middle of the 19th Century, Olof Eneroth dedicated his life to apple cultivation and experiments in the county of Sörmland and Stockholm. He was author of the first Swedish Pomology (Eneroth, 1864-66). Thirty years later, a second revised edition was published by Alexandra Smirnoff (Eneroth, 1896-1902). A detailed pomology was published by Carl G. Dahl, Alnarp in 1929, followed by a second edition (Dahl, 1929, 1943). The most recent pomology, in which over 350 cultivars are described, was written in 1986 by Anton Nilsson (Nilsson, 1986).

Organic farming

Organic farming is a term used for several growing systems. The most important systems are: biodynamic, nature like and organic-biologic farming, all having an ideology and theory as a base for growing. They have in common the condition that pesticides and inorganic fertilizers not are used. An international organization, IFOAM (International Federation of Organic Agricultural Movements) is working on establishing guidelines and basic standards for organic growing. A definition of organic farming adopted by a Nordic IFOAM meeting in Denmark in 1989 was: The term organic farming is used for a self-sustaining, durable agro-ecosystem in balance. The system is based on local and renewable resources. In organic farming the holistic perspective is considered and factors such as ecological, economic and social aspects of agriculture are looked upon in a local and global perspective (Granstedt *et al.*, 1998).

The Swedish control association for organic farming is called KRAV (accredited by IFOAM). The association checks that organic produce is grown according to the rules set by KRAV. The rules are updated regularly and are published yearly. The member growers may use the symbol and name KRAV as a trademark, when marketing their products. In Sweden, there are about 3 500 organic growers and the area is roughly 10% of the total farm area. In the sector fruit and berries, the numbers are considerably lower but the official goal is set to 5% of the cultivated area. Furthermore, a committee within the European Union is promoting an increase of the acreage of organic growing in the member countries (Sandskär, 2001).

The interest in organic fruit growing has increased in Europe lately. Countries like Switzerland, Germany and Great Britain are investing in research and often subsidize organic production. However, there are many obstacles in organic production that involves cultivar choice, pest and disease problems, weed control and tree nutrition. The market conditions are crucial for the success of organic fruit production, *i.e.* good possibilities for selling the products at prices that compensate for a lower productivity (Weibel, 2000).

Domestication of apples

The apple (*Malus* x *domestica* Borkh.) belongs to the rose family (Rosaceae, subfamily Maloideae or formerly Pomoideae, x=17) and is a functional diploid (Brown, 1992). Other genera are *Pyrus* (pear) and *Cydonia* (quince). There are about 25 to 30 species in the genus *Malus* and a number of subspecies of crabapples. Self-incompatibility is common among apples. The fruits are characterized by two to five carpels situated in a fleshy cover. The main ancestor of the cultivated apple is probably *Malus sieversii* (Lodeb.) M. Roemer, a species with a high degree of diversity found on the boundary between western China and the former Soviet Union. The centre of origin for this species is Kazakhstan in Central Asia, and collections of seeds were recently performed (Forsline, 2000; Geibel *et al*., 2000). Other species thought to have contributed genes to domestic apples are *M. orientalis* Uglitzk. ex Juz., the European crab (*M. sylvestris* Miller) and Asian species such as the Siberian crab [*M. baccata* (L.) Borkh.] (Janick & Moore, 1996).

Breeding of apples

Breeding of fruit is very time-consuming and costly. It takes at least 20 years from the first crossing to a commercial apple cultivar. The flower is emasculated and pollen from a known parent (father) is transferred. The selection of parents is very important. The flower is protected in a small bag after the pollination and later the fruit is collected. The next season the seeds are sown, and thereafter selection are made among the seedlings. The juvenile period is long, at least 4 years and sometimes up to 7-8 years. Sometimes backcrossing is necessary to obtain the right characteristics. If the desired trait is under polygenic control, there will be a range of variation. As an example of how difficult it is to combine several characters, theoretical calculations were made of breeding for five characters. In this case a progeny of several thousands of seedlings would only yield one seedling with a combination of these characters (Janick & Moore, 1996).

Traditionally, breeders produce new varieties for professional growers and home gardens. Fruit quality (size, shape, colour, taste, aromatics, russet, acidity, sugar content, firmness *etc*), winter hardiness, pest and disease resistance and tree architecture are important traits. In the final analysis, factors such as flavour and texture could mean failure or success of a new variety on the market. Breeding for industrial purposes is not so common apart from to the cider industry. Breeding for disease resistance is becoming inceasingly important, in particular for organic growing, and that is discussed in more detail below. Other future breeding strategies could involve using marker assisted selections as a tool.

Another possibility for utilizing the potential of a variety is to explore different characteristics when it comes to cultural practices among the new cultivars. For example, to optimise fertilizing, pruning and timing of harvest for the individual cultivars might be more economic than starting a new breeding programme (Janick & Moore, 1996).

Cultivars

There are some very old cultivars that are still being grown. Since the propagation of apple trees is vegetatively (asexual) performed by budding or grafting, it is a fascinating thought that we in some cases have the same genetic material today as 400 years ago. Gene banks are important in order to preserve cultivars that are no longer planted and to serve as a basis for research. The trees could be useful for purposes other than fruit production, for example as ornamental trees and in landscape shaping. The fruit may have desirable properties as a raw material in the food industry. In the following some examples of apple cultivars are given.

Old cultivar. As with many old cultivars there are lots of theories about their background. The cultivar 'Gravensteiner' has its origin in the castle of Graasten, Denmark back in the 17th Century. It was distributed to Germany where it was recommended for planting by the German Society of Pomology in 1853. It is a triploid plant and not suitable as a pollinator.

Most popular cultivars worldwide. 'Golden Delicious' is probably the most planted cultivar today. It derives from Western Virginia, USA (1890) and the pedigrees are probably 'Grimes Golden' and 'Golden Reinette' (Mühl, 1999). Newer varieties that are gaining territory are 'Gala', 'Fuji' and 'Braeburn'.

Most popular cultivars in Sweden. 'Ingrid Marie' is the most planted cultivar grown in Sweden at the moment. It originates from Denmark (1910). The total area of Swedish apple orchards is around 1 600 ha producing roughly 20 000 tons of apples. Besides 'Ingrid Marie', the most frequent cultivars are 'Aroma', 'Cox´s Orange', 'Discovery' and 'Gravensteiner'. 'Alice', 'Kim' and 'Katja' are quite common as well (Anonymous, 2001). Cultivation in home gardens is quite extensive, but no figures are available. The cultivars sold in most Swedish nurseries in 1983 were: 'Transparente Blanche', 'Ingrid Marie', 'Lobo', 'Alice', 'Aroma', 'Gyllenkroks astrakan', 'Oranie', 'Sävstaholm', 'James Grieve', 'Katja', 'Cox´s Orange', 'Åkerö', 'Cox´s Pomona', 'Gravensteiner', 'Signe Tillisch', 'Maglemer' and 'Silva' (Nilsson, 1986). Since the importation regulations regarding apples were removed in 1989, apple imports account for roughly eighty per cent of the marketed amounts.

Cultivars for organic growing. The option is either to convert an existing orchard with tradional varieties to organic growing, or to plant a new orchard. Not all varieties are suitable for organic growing, for example the most scab susceptible cultivars. Few of the new cultivars possessing the *Vf* resistance gene are tested in Sweden but interest in them is growing. Breeding and evaluating of new scab resistant cultivars are in the final stages at Balsgård, Sweden but to date no new cultivars have been released. In Germany, the cultivar Topaz (*Vf* gene) from Czech Republic is quite common in organic orchards. Kühn (2001) has tested several scab resistant cultivars in Denmark. Based on these experiments, she recommends the cultivars 'Prima', 'Retina', 'Initial' and 'Topaz' for organic commercial growing.

Rootstock

The rootstock plays an important role for growth and development of the apple tree. It influences the growth (tree size), juvenile period, fruit quality, yield, life length and pest and disease resistance of the grafted cultivar. The most commonly used rootstocks in Europe come from East Malling, Great Britain. They are named with the letter M and a number. The most common rootstocks are: M 9 – gives very weak growth (dwarfing); M 26 – gives stronger growth than M 9, is more winter hardy and gives early, even and high yields; MM 106 – middle sized growth suitable in different climates and soils, gives early and even yields and possesses resistance to woolly apple aphids (*Eriosoma lanigerum*); and A 2 – a Swedish selection from Alnarp that gives very vigorous growth and tolerance against frost, but is at the moment not utilized for commercial growing (Janick & Moore, 1996).

Apple diseases

The most important fungal disease is apple scab, which is described in detail further ahead in the text. Other diseases are powdery mildew (*Podosphaera leucotricha*), monilia (*Monilia laxa*) and apple stem canker (*Nectria galligena*). Storage diseases are also a problem and apart from apple scab, *Gloesporium* and *Monilia fructigena* cause damages. Other common fungi like grey mould (*Botrytis cinerea*) and green mould (*Penicillium* spp.) may occur during storage of the fruit.

Several diseases caused by viruses or Mycoplasma-like organisms (MLO) were common earlier. Nowadays all plant material is taken from healthy, controlled sources. Examples of virus diseases are: apple mosaic, flat limb, rubbery wood, horse-shoe wound, star crack, green crinkle, russet ring and chat fruit. The bacterial disease fire blight (*Erwinia amylovora*) mainly infects pears, but apples can also be infected (Nilsson & Åhman, 1991).

Apple pests

There is a range of insects and mites that attack apples. Common insects are aphids, such as green apple aphid (*Aphis pomi*) and rosy apple aphid (*Dysaphis plantaginea*). The latter insect is very serious and can cause distortion of the young shoots. The apple sucker (*Psylla mali*) can do some harm. Another important group of pests is the moths, whose larvae can damage both leaves and fruit. Examples of lepidopterans are: codling moth (*Cydia pomonella*), winter moth (*Operophtera brumata*), *Hedya nubiferana*, fruit tree tortrix moth (*Archips podana*) and apple fruit moth (*Argyresthia conjugella*).

The hymenopteran pest apple sawfly (*Hoplocampa testudinea*) damages the fruit, both in early and late stage of its development. The mites come mainly from the families spider mites, gall mites and rust mites (Alford, 1984).

Control of pests and diseases

In conventional growing, chemical treatments of the orchard are recommended during the growing season. In Sweden 2-4 sprayings against insects with compounds such as pyrethroids or organophosphates and several sprayings against fungal diseases with fungicides such as Candit, Euparen M 50 WG, Baycor 25 WP, Scala or Topas C 50 WP are common (Table 1).

Table 1. Number of sprayings in early or medium-early cultivars, *e.g.* 'Transparent Blanche', 'Alice', 'Katja', 'Summerred' and 'Gravensteiner'. IPM=Integrated Pest Management (Tornéus, 2002).

Problem	Low input of extension, not IPM	'Normal' IPM-orchards	High input of extension, IPM-orchards
Fungal diseases	3–8	2–6	1–4
Spider mites	1–2	1	0–1
Pests	2–4	2–3	0–2

In Integrated Pest Management (IPM), the use of some pesticides is not recommended, due to environmental concerns. Forecasting systems should be consulted and thresholds should be fulfilled/used before applying an insecticide or acaricide. The threshold is sometimes very low, for example one rosy apple aphid in the field in the springtime is enough to have 'permission' to spray. For apple scab, weather stations and scab warning system should be consulted before spraying. As a consequence, if the weather is unfavourable to scab, then the number of sprayings should be low (Table 2).

Table 2. Number of sprayings in late cultivars for storage, *e.g.* 'Ingrid Marie', 'Cox´s Orange', 'Aroma' and 'Mutsu'. IPM=Integrated Pest Management (Tornéus, 2002).

Problem	Low input of extension, not IPM	'Normal' IPM-orchards	High input of extension, IPM-orchards
Fungal diseases	7–15	7–12	5–10
Spider mites	1–2	1	0–1
Pests	3–4	2–3	0–3

Synthetic pesticides are not allowed in organic growing and the goal is to avoid usage of all pesticides. However, soap products, *Bacillus thuringiensis* and neem-products (from the Indian neem-tree) are allowed according to the rules set by the organization KRAV. Natural enemies are very important in organic orchards. Anthocorid bugs are general predators of small insects. Earwigs (general predators) and ladybirds are often found in fruit trees. Two-spot ladybird (*Adalia bipunctata*) and seven-spot ladybird (*Coccinella septempunctata*) are common predators of aphids. Some mirid bugs (capsids) are predators. The syrphid larvae are predators of aphids and other insects. Larvae of the midge *Aphidoletes aphidimyza* feed on aphids. Common green lacewing (*Chrysoperla carnea*) prey on mites, aphids and a number of other insects. Parasites are found in the families Ichneumonidae, Braconidae and Aphiidae. Most of them are endoparasites where the larva feeds within the host (Alford, 1984). Spiders are reported as general predators in orchards (Bogya, 1999). The fruit tree red spider mite predator (*Typhlodromus pyri*) and *Amblyseius finlandicus* are examples of species feeding on mites.

Microorganisms such as entomopathogenic fungi do occur but in most cases biological control methods are not developed for outdoor use. The insect pathogenic bacterium *Bacillus thuringensis* is marketed as a control method of lepidopteran larvae. The minimum temperature has to exceed 13 ^{o}C before it is effective. Birds are great insect eaters and feed on a large number of pests, especially lepidopteran larvae.

Sulphur is recommended for scab control in organic orchards, see *Control with sulphur* under Apple scab.

Apple scab

Biology

The apple scab disease has probably evolved over a long time along with the apples. The disease is caused by the fungus *Venturia inaequalis* (Cke.) Wint., anamorph *Spilocaea pomi* Fr. (Hughes, 1953). The summer stadium of the disease was first described by a Swedish botanist (Fries, 1819), with later additions (Fries, 1832). The winter stadium was illustrated by Cooke (1866). The two stadia were not considered to belong to the same fungal species until Goethe (1887) described them together. In an old painting from 1600 by Caravaggio the subject is a fruit basket with scabbed apples, which implies that scab has been closely associated to apples since historic times (Olsson, 1962). The fungus is placed in the division Ascomycota, order Pleosporales and family Venturiaceae. The major characteristic is the one-septate green, yellowish, or olivaceous-brown ascospore (Barr, 1968). The perfect state involves formation of a pseudothecium, which is seen as black pin-point heads on the over-wintering apple leaves. Within this pseudothecium the asci are formed; each ascus contains eight ascospores. Sivanesan & Waller (1974) state the size of ascospores as 12-15 x 6-8 µm.

Early in the spring the ascospores start to mature and when weather conditions are suitable, *i.e.* after rain or dew and when the temperature is high enough, the spores are ejected. The spores are airborne and infect newly sprouting apple leaves. High humidity alone is not enough to trigger an infection; leaf wetness for a certain number of hours is required. The concentration of spores is also important since not all spores are able to penetrate the cuticle. The life cycle of the fungus is demonstrated in Fig. 3.

After penetration, the mycelium forms a subcuticular radiating plate (stroma) wherein the conidiophores are formed in acervuli. The conidia are produced one by one at the tip of the conidiophores and the size is 12-30 x 6-10 µm. (MacHardy, 1996).

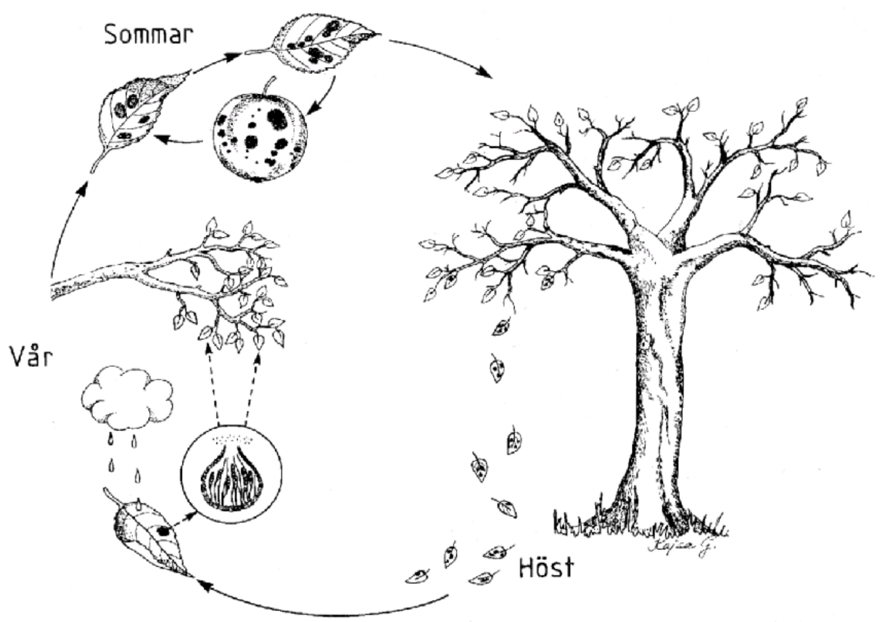


Fig. 3. Life cycle of apple scab (*Venturia inaequalis*) Summer=sommar, autumn=höst, spring=vår. Drawing: Kajsa Göransson, reprinted by permission (Åkesson & Norin, 1999).

Leaf scab

The symptoms are dark olive-green lesions (Fig. 1) which later darken and become necrotised and eventually fall out. Both sides of the leaves can get infected, a common place is along the leaf nerves. The sepals can be infected early, and from these parts the young fruit can be infected by conidia.

Fruit scab

The young fruit can get infected early in the season and the lesions expand with the growth of the apple (Fig. 2). The lesions become necrotic and can crack later during the growth period. A late infection gives smaller but numerous lesions on the fruit. It is also possible for the apples to develop scab symptoms during storage.

Wood pustules

The fungus can also overwinter as a mycelium on twigs where new conidiophores are formed. The conidia are then released very early in the season for a period of several weeks. The climatic conditions determine whether or not the conidia from wood pustules have any significance for disease development or not. Kennel & Moosherr (1983) found significant apple scab infection in a research plot in Germany where the leaves of the orchard floor were removed indicating that conidia from wood pustules can cause the disease. Becker & Burr (1990) made histological investigations of the wood pustules. They described a host defense mechanism whereby periderm was formed below the fungal tissue which thereby weakened and stopped the growth of the fungus by the following spring.

Apple scab races

The interest in different apple scab races started early, even though the first authors were more concerned about morphological differences and infection patterns (Schmidt, 1935). Shay & Williams (1956) identified three physiological races of *V. inaequalis*. They defined race 1 as the race commonly found in the USA and other countries; race 2 infected three cultivars: Dolgo, some segregants of the Russian variety R12740-7A and Geneva; and race 3 infected Geneva. It was also discussed whether the origin of race 2 was through import of plant material from Russia. Race 4 was detected in scab resistant seedlings (*M. pumila* R12740-7A) in Purdue, USA (Williams & Kuć, 1969). Evidence of a new physiological race (race 5) was presented by Williams & Brown (1968) and it was characterised by the capacity to infect plants, giving the pit type of reaction in *M. micromalus* and *M. atrosanguinea*. Supposedly scab resistant selections from the USA were sent to England, but some selections of *M. micromalus* developed sporulating lesions.

Race 6 was first described by Parisi *et al*. (1993). Scab symptoms on Prima (*Vf*) had been noted in Ahrensburg, Germany since 1984. The isolates from Germany proved to infect other *Vf*-selections but the progenitor *M. floribunda* 821 remained resistant. The pathogenicity of race 6 was further investigated by Parisi & Lespinasse (1996) on apple clones. Race 6 gave symptoms on nearly all of the thirty-seven *Vf*-cultivars tested, but 'Granny Smith' and three cultivars with another type of resistance (*Vbj, Vr* and *Va*) were not infected. They found that much of the genetic background for resistance to *V. inaequalis* in wild species had been lost in the breeding process. The importance of finding polygenic sources of resistance was stressed. The defined scab races 1-7 in *Malus* are shown in Table 3. For more details, see also Table 4 (p. 20).

Table 3. Definition of apple scab races 1-7. Sources: Janick & Moore (1996); Roberts & Crute (1994).

Race	Source	Susceptible material
1	Worldwide	Most of the world´s cultivars
2	South Dakota, USA	*M. baccata*, 'Dolgo', 'Alexis', 'Bittercrab' segregates of R12740-7A, 'Geneva'
3	Nova Scotia, Canada	'Geneva'
4	Lafayette, Indiana, USA	Segregates of R12740-7A
5	Norwich, England	*M. micromalus* pit type resistance, *M. atrosanguinea* 804
6	Ahrensburg, Germany	'Prima' (*Vf* cultivars) but not 'Evereste', *M.* x 'Perpetu' and *M. floribunda* 821
7	Great Britain	*M. floribunda* 821

The last race to be discovered was the English race or race 7, which was described by Roberts & Crute (1994). An isolate from a naturally infected *M. floribunda* tree gave lesions on *M. floribunda* 821 and some *Vf* cultivars while some other *Vf* cultivars were not infected. Later a second dominant gene was discovered in *M. floribunda* 821 (*Vfh*) and the host-pathogen relationship was discussed. It was confirmed that 'Golden Delicious' (*Vg*) was resistant to race 7 (Bénaouf & Parisi, 2000).

Pathogenicity and virulence

There is a controversy regarding nomenclature in the complicated interactions of pathogens and their hosts. Shaner *et al.* (1992) go through the terms pathogenicity and virulence from several points of view. They start with the definition from an English dictionary, where **pathogenic** means causing or capable of causing disease, and **virulence** means the quality or property of being virulent; the relative capacity of a microorganism to overcome the body defences of a host. They suggest the term parasitic fitness instead of aggressiveness and list several definitions for this term, for example: synonym for virulence, description of the rate at which an amount of disease is reached and the reproductive fitness of a pathogen when growing in a host.

I try to avoid using these terms without explanation. In some of my studies I have been recording whether or not the disease is prevalent on certain cultivars. In such cases, I have quantified the disease according to a defined scale or counted the number of scabbed leaves at a certain time.

Control methods in organic growing

There are both indirect and direct control methods for scab. Since apple scab is dependent on humid and cool climate to develop, some locations are better than others for establishing an orchard. The choice of cultivar is also very important. A mixture of cultivars, avoiding the most susceptible ones, can reduce the infection pressure of the fungus.

Pruning and fertilizing are two important factors for disease development. If the trees are well pruned the leaves dry up more quickly and the fungus has less chance of infecting the tree. The level of nitrogen fertilization during the growth period is also of importance. Apple trees do not need high amounts of nitrogen and excess may result in loose growth of the shoots, which are then more susceptible to the disease.

Sanitation procedures, such as removal of the overwintering leaves, were used before the modern fungicides became available. Shredding of the leaves after leaf fall and keeping the grass short between the tree rows enables earthworms to break down leaf litter. A method of flaming the overwintering leaves, was described by Desilets *et al.* (1997). If the timing is right, *i.e.* not too early since the ascospores are not developed yet and not too late since there could be a fire risk, this might be a feasible method for growers.

Different sources of nitrogen compounds were tested on apple leaves in the autumn, in order to investigate their role in pseudothecial production. It was found that nitrogen application at leaf-fall (October 31) was better than on November 22, and in this case the number of pseudothecia was reduced by 75-90% (Cook, 1969).

Scab warning systems

Considerable progress has been made in developing prediction systems for sceduling treatments for scab control. Mills & LaPlante (1951) introduced a model for scab infection periods. Basically, a combination of length of leaf wetness periods and temperature was used in the model (Fig. 4). It was based on data from growth chamber experiments reported by Keitt (1927). Mills & LaPlante collected field data during 20 years with the help of Extension Service agents in the USA. Mills (1944) stated that ascospores need 3 hours more than conidia to infect the leaves. Over thirty studies were conducted in many countries all over the world to validate the model, *e.g.* Schwabe (1980). The model has been revised by MacHardy & Gadoury (1989) and was designated as the 'Mills/a - 3' infection curve. The name refers to the three hour discrepancy between Mills´ curve and the findings in other studies.

Mills´ revised curve is used in combination with data from weather stations in the field. Values of temperature, relative humidity, rainfall and leaf wetness are collected during the growing period. The computer programme then indicates if there is a light, medium or severe infection risk. It can also be used for recommendations of timing of sulphur sprays in organic growing.

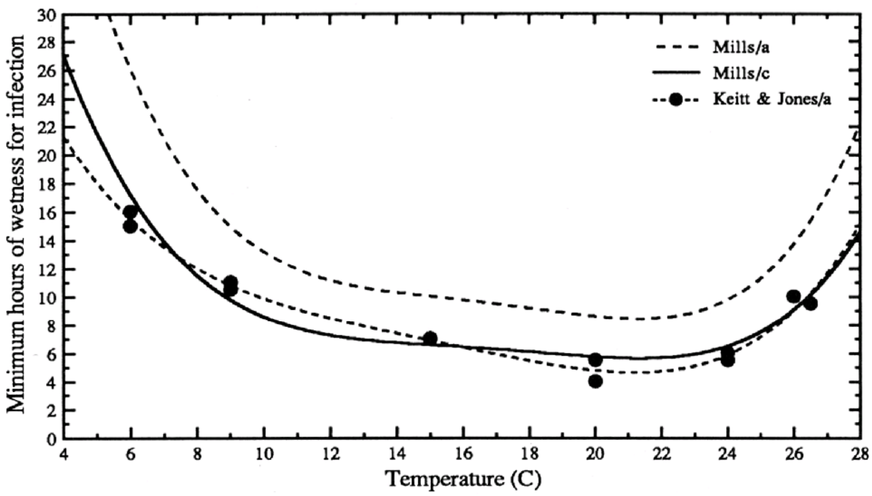


Fig. 4. Curves identifying the minimum hours of wetness required for ascospores and conidia of *Venturia inaequalis* to infect apple leaves at different temperatures, developed from data reported by Keitt & Jones (1926) for infection by ascospores under controlled environment conditions (Keitt & Jones/a; solid circles, dotted line), from data reported by Mills (1944) and Mills & LaPlante (1951) for infection by ascospores under field conditions (Mills/a; dashed line), and from Mills´statement that conidia infect in two-thirds the time required for ascospores to infect (Mills/c, solid line) (MacHardy, 1996, reprinted by permission).

The refining of this model still continues. Stensvand *et al.* (1997) investigated ascospore release and infection of apples at temperatures below 8 ^{o}C. They proposed further revisions of the infection model with shorter minimum infection times for ascospores and conidia at these low temperatures. Moreover, the minimum infection time for ascospores and conidia seems to be similar for both spore types. Discontinuous wetness is another area of research. Moore (1964) performed glasshouse experiments and the results show that dry periods of 32 to 96 h gave 40-83% fewer foliar lesions. Other factors such as sunlight, wind, temperature and phylloplane microorganisms might influence the apple scab infection. However, these have only been investigated in a few reports.

Control with sulphur

The beginnings of a scab control programme took place during the period 1880-1920. The chemicals used were Bordeaux mixture, lime-sulphur solution and sulphur-lead dusts. Some of these mixtures, for example lime-sulphur, were phytotoxic. This compound was popular until the mid-1930s when it was replaced by sulphur which was less effective and had no eradicative capability compared to lime-sulphur. Mills´ warning system was originally designed to time the applications of sulphur-lime and sulphur and to maximize their effects (MacHardy, 1996).

Biological control

Fifty years of research reports on biological control of apple scab were reviewed by Carisse (2000). The fungus *Microsphaeropsis* sp. (strain P130A) is an antagonist of *V. inaequalis*. It can penetrate directly through the cell wall and hereby reduce the growth and induce cell death of the apple scab fungus. Ascospore production has been shown to be reduced by 85 to 98% under controlled conditions and 75 to 85% under field conditions (Carisse *et al*., 2000). This might be a successful method in the future.

Resistance biology

The terms used in resistance biology are relevant for most pathogens. The groundwork was carried out by Flor (1955, 1956), when the host-pathogen interactions between flax and flax rust (*Melampsora lini*) were described. Major resistance genes in the host interact with corresponding avirulence genes in the pathogen. This so called gene-for-gene relationship is valid for many diseases, but not for all (Johnson, 1992). Gene-for gene interactions have also been shown to occur between apple and *V. inaequalis* (Bénaouf & Parisi, 2000). Resistance to apple scab can be either polygenic, which means that several genes are involved, or monogenic, when one gene is involved in the resistance reaction. Race-specific resistance (or vertical resistance) is mostly monogenic and determined by major genes. The resistance works against certain isolates but is ineffective against others. Host resistance can also be race-nonspecific (horizontal) or partial, where several minor genes are involved. In the field several types of resistance reactions can be observed, such as 'pin-point' spots (hypersensitivity), sparsely and few sporulating lesions, chlorotic or necrotic spots.

Variability in the fungus

V. inaequalis has a high degree of genetic variability. The fungus recombines genetically every year, thereby increasing the possibility to overcome host resistance. Breeding for disease resistance is nowadays aimed at combining several sources of disease resistance or using polygenic sources.

Ontogenic resistance

Aderhold (1900) observed that young leaves get more easily infected than old leaves. As a rule the first two or three unfurled leaves and the last developed leaf are the most susceptible for scab infection. Schwabe (1979) found a negative relationship between the number of lesions and leaf age. The leaves develop fully in 13 days. Already when the leaves were 8-9 days, hardly any lesions were found. My own observations are that only the 2-3 youngest leaves are infected on the same occasion.

However, older leaves can lose their resistance later in the season. The build up of scab in the autumn has been explained by a physiological change in the leaves (Olivier & Lespinasse, 1981). The resistance might be an inhibition of fungal growth which can be overcome later.

Pest resistance

Breeding for pest resistance has not been a prime concern. Some efforts have nevertheless been made and major resistance genes have been identified against several insect species such as rosy apple aphid (*Smh*), rosy leaf-curling aphid *(Sd1, Sd2, Sd3*) and woolly aphid (*Er*) (Knight & Alston, 1974). Resistance against apple sawfly and red spider mite has been reported from wild *Malus* species. Differences in susceptibility to pests have also been observed in commercially grown cultivars. Some of the new German apple cultivars possess resistance against several of the following factors: apple scab, powdery mildew, apple wood canker, fire blight, fruit tree red spider mite and frost hardiness (Fischer, 1999).

Breeding for resistance

The aim is to introduce into the crop plant resistance genes to various diseases, in order to reduce the number of chemical sprays. Since there are a number of diseases it is difficult to obtain resistance to all diseases in one cultivar. Breeders are nowadays, however, trying to combine different resistance genes (Fischer, 2000). Breeding programmes for resistance against apple scab were started at the discovery of an apple scab resistant clone of *Malus floribunda.* Hough (1944) evaluated hybrid seedlings, which were a cross between 'Rome Beauty' and *Malus floribunda* Sieb. clone 821 in the field. He found a segregation of 1:1 ratio for resistance versus susceptibility. Later it was found that the *M. floribunda* 821 resistance was determined by a dominant gene (*Vf*) (Hough *et al.*, 1953). The breeding was intensified in the 1940s and as a result over 70 new varieties were produced over a forty-five-year period (Crosby *et al.*, 1992). It was thought to be durable for a long period of time (over forty years). The first cross was made with 'Rome Beauty', and the segregate F_2 26829-2-2 has been used as crossing parent in many cases. Parisi & Lespinasse (1996) have analysed the pedigree and incidence of race 6 on each susceptible clone in a number of crosses. A pedigree of the cultivar 'McShay' is shown in Fig. 5 as an example (Mehlenbacher *et al.,* 1988).

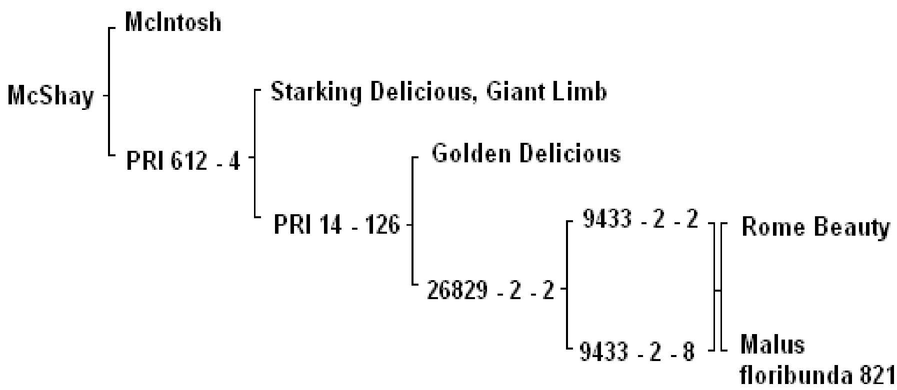


Fig. 5. Pedigree of 'McShay' apple, which possesses the *Vf* gene originating from *Malus floribunda* 821 (after Mehlenbacher *et al.,* 1988).

A number of other resistance genes against apple scab have been identified and several sources for polygenic resistance are known (Table 4). The Russian cultivar 'Antonovka' (*Va* gene) has been included as a scab resistant parent in breeding for a long time (Visser *et al*., 1974).

Table 4. Apple scab resistance genes and plant sources for resistance genes. Sources: Lespinasse, 1989, 1994; Bénaouf & Parisi, 2000; Hemmat & Brown, 2002.

Monogenic		Polygenic
Symbol	Species/selection	Species/selection
Vf	*M. floribunda*	*M. baccata*
Vfh	*M. floribunda*	(selected seedlings)
Vm	*M. micromalus*	*M. sargentii* 843
Vr	*M. pumila* R12740-7A (stellate necrotic)	*M. sieboldii* 2982-22
		M. x *zumi calocarpa*
Vbj	*M. baccata jackii*	*M. toringo* 852
Vb	Hansen´s baccata #2	Old European cultivars
Va	'Antonovka' PI 172623	
Vg	'Golden Delicious'	
Vx	*M. pumila* R12740-7A (pit type)	

Unfortunately the *Vf*-cultivars have so far had limited commercial success. One reason is that the acid taste from *M. floribunda* is still present in the final cultivar. The taste and overall quality have not been high enough to compete on the market.

The Russian apple R12740-7A (*Malus pumila*, *Vr* gene) was also recognised as a source of resistance to apple scab (Dayton *et al*., 1953) and recently a second gene (*Vx*) was described (Hemmat & Brown, 2002). Other main major resistance genes are *Vm* from *M. micromalus*, *Vb* from *M. baccata*, *Vbj* from *M. baccata jackii* and *Vg* from 'Golden Delicious' (Bénaouf & Parisi, 1998). A review of breeding scab resistant apples was given by Kumar & Sharma (1999).

Example of polygenic resistant cultivars are 'Discovery' and 'Antonovka'.

Genetic diversity

Since the research on molecular markers of the fungus is quite young, there are few reports on the diversity so far. However, the genetic diversity of *V. inaequalis* was investigated recently in eleven populations in Europe, using RAPD markers (random amplified polymorphic DNA). The diversity within each population was high. The difference between north and south of the Alps was not as high as expected, a discrepancy explained by human activities such as export of plant material (Tenzer & Gessler, 1999). Microsatellite markers of the fungus have been identified in Switzerland (Tenzer *et al.*, 1999). A genetic map of *V. inaequalis* was constructed by Sierotzki & Gessler (1998).

Nybom & Schaal (1990) used RFLP (restriction fragment length polymorphism) and RAPD to study genetic variation in apples. About ten years ago, the work of defining molecular markers associated with scab resistance genes was initiated for apple. The *Vf* gene has been studied in several papers (Yang *et al.*, 1997) and PCR markers are now available (King *et al*., 1998; Tartarini *et al.*, 1999). Tightly linked markers were described by Hemmat *et al.* (1998). Other resistance genes have been less studied, but DNA markers for the *Vm* gene were developed by Cheng *et al.* (1998). Ninety-eight *Malus*-accessions were studied with respect to presence of the twelve DNA markers in the *Vf* linkage group (King *et al.,* 1999). Some of the genotypes possess all markers, for example 'Prima', Priam', 'Dayton' and 'Novamac', but many accessions lack one to seven markers, for example 'Florina', 'Reanda', 'Priscilla', 'GoldRush' and 'Baujade'. However, the loss of resistance versus race 6 could not be explained as a loss of genes close to the *Vf gene,* since a large part of the original *M. floribunda* genome was still present after several back-crossings. Previous work had indicated that the genes in two cultivars were wrongly determined from the beginning. The cultivars were checked with the DNA markers by King *et al.* (1999), and earlier findings were confirmed, that the resistance in 'Nova Easygro' is caused by the *Vf* gene and not *Va* gene (first described by Fischer *et al.*, 1999). Likewise the resistance gene found in 'Reglindis' was *Vf* and not *Vr*, confirming earlier results by Tartarini (1996).

Objectives and methods in this study

The objectives of this study were:

- To identify apple cultivars suitable for organic growing in an observation trial for new apple varieties, with respect to apple scab susceptibility.
- To classify apple scab resistance in a number of old and new apple cultivars.
- To identify and record major pest problems and natural enemies in an experimental organic orchard interplanted with ornamental shrubs.
- To investigate the prevalent apple scab races in Sweden.
- To study natural scab infection pressure in three differently managed orchards.

The experiments were conducted and assessed as follows:

1). Three fruit observation trials of new varieties were assessed for apple scab. They were located at Alnarp (south-west), Kivik (south-east) and Rånna/Skövde (central) in Sweden and planted in 1991-1994. Twenty-two apple genotypes were evaluated for susceptibility to apple scab in 1999-2000. The number of scabbed leaves per annual shoot was counted three times per season. Furthermore, the degree of infection by fruit scab was evaluated utilizing an apple scab index from 0 to 4. A sample of harvested fruit from five cultivars was classified into four classes, corresponding to the size of their apple scab lesions (Paper I).

2). Leaf scab was evaluated at two locations in Sweden during 1998-2000: Alnarp and Balsgård (south-east), using an apple scab index from 0 to 4. At Alnarp fruit scab was also evaluated. The assortment orchard at Alnarp and parts of the Fruit Gene Bank at Balsgård comprised 339 and 165 cultivars or selections, respectively (Paper II).

3). An experimental organic orchard was planted in 1994 at Alnarp with 'Amorosa' ('red Aroma') and 'Discovery', and interplanted with the ornamental shrubs: Tartarian Bush Honeysuckle (*Lonicera tatarica*), American Arborvitae (*Thuja occidentalis*), Snowberry (*Symphoricarpos rivularis*), Rugosa Rose (*Rosa rugosa*) and European Cranberry Bush (*Viburnum opulus*). The insect and spider fauna was investigated through beating samples, performed in 1997-1999. Treatments against apple scab with sulphur and fatty acids, were carried out in 2000-2001 and the harvest was classified with respect to major pests and diseases (Paper III).

4). One set of apple scab race indicators was planted in the field at Kivik Experimental Station (year 2000) and one set was used in greenhouse/growth chamber trials at Alnarp (1999-2001). The apple scab races were recorded at Kivik during 2001-2002, and in a portable potted set with indicators at Alnarp in 2002. A special scale ranging from 0-4, for evaluating apple scab was used, see Paper IV for details. Furthermore, the number of scabbed leaves per annual shoot was counted. A total of thirteen experiments were carried out in the greenhouse/growth chamber (Paper IV).

5). Apple scab was assessed on the leaves of the potted cultivars 'Aroma', 'Discovery', 'Gravensteiner', 'Ingrid Marie' and 'Summerred'. They were placed in three differently managed orchards in 2000 and 2001 at Alnarp. The places were: underneath unpruned fruit trees; in the organic orchard; and in the new varieties orchard (Paper V).

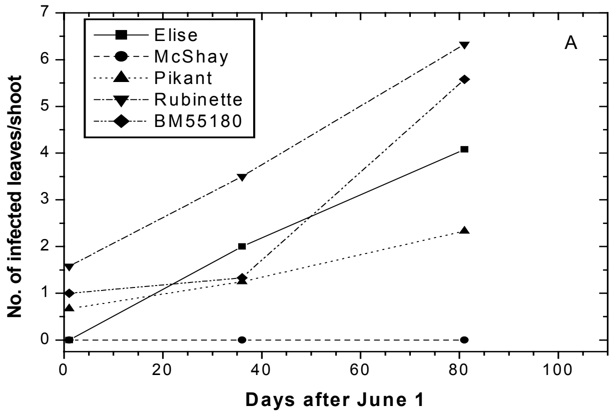
Summary of results

Apple scab resistance in some apple cultivars (Papers I and II)

Leaf scab. The susceptibility of twenty-two cultivars to apple scab was investigated at three locations in Sweden. The most resistant cultivars were 'McShay' and 'Sansa', but these cultivars are not suitable for growing in Sweden, since the climate is too cold. The cultivars were ranked similarly with respect to apple scab symptoms on their leaves at the three locations (Sandskär & Gustafsson, 2002). Three patterns of infection were defined; no or small infection as in 'McShay', slow or intermediate as in 'Pikant' or 'Elise', and rapid development of the infection as in 'Rubinette' and BM55180.

We found a significant correlation between foliar apple scab and fruit scab. The strength of the correlation depended on the year, location and cultivar in our experiments. Moreover, when the apple scab infection pressure was high, the average fruit weight was observed to be reduced to a greater extent among susceptible cultivars compared to resistant cultivars.

Five cultivars were selected for further studies. The differences between the cultivars and the years were large. The scab incidence was much higher in 1999 compared to 2000 (Fig. 6). These observations were in accordance with differences in the weather conditions. There were twice as many scab infection periods detected by the scab warning device with medium/severe strength in 1999 compared to 2000.



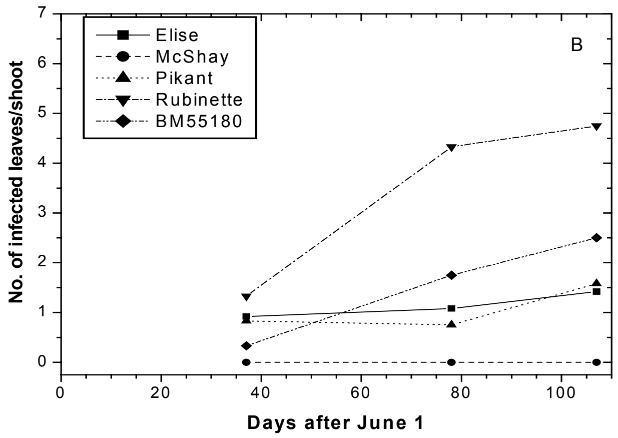


Fig. 6. Mean number of scabbed leaves per annual shoot in five cultivars in an unsprayed fruit cultivar observation trial at Alnarp, Sweden, during the growing seasons (A) 1999 and (B) 2000.

Fruit scab. The difference between the five cultivars and the two years in fruit scab lesion size were also large. As an example the three 'intermediate' cultivars ('Pikant', 'Elise' and BM55180) had large lesions (> 1 cm^2) in 1999 (Fig. 7a) but in the following year they were practically free from fruit scab (Fig. 7b). In 1999, fruit scab was confirmed on a 'McShay'-fruit for the first time at Alnarp, Sweden, indicating the presence of race 6.

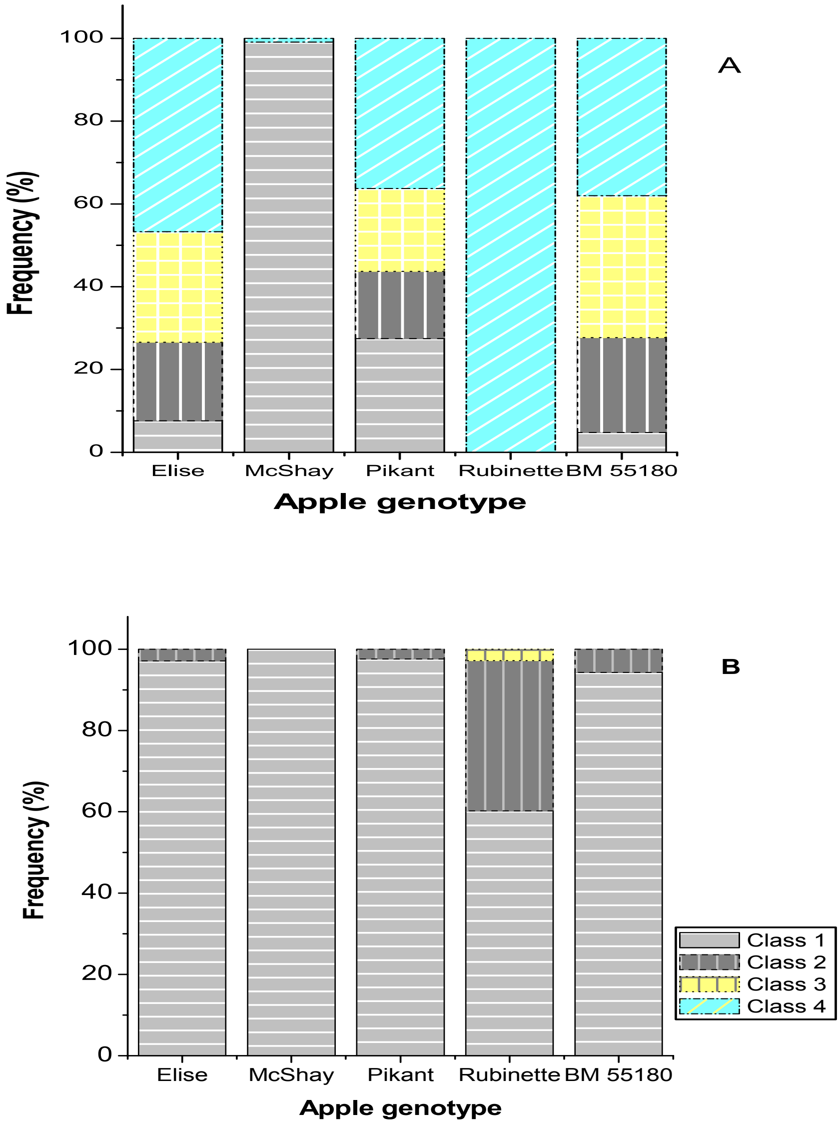


Fig. 7. Per centage of harvested apples in the different apple scab classes in an unsprayed fruit cultivar observation trial at Alnarp, Sweden, (A) 1999 and (B) 2000. *N* = 105 for all cultivars except 'Pikant', N = 80. Class 1 = No apple scab, Class 2 = 0.1-0.25 cm^2 lesions, Class 3 = 0.25-1 cm^2 lesions, Class 4 > 1 cm^2 scab lesions on the fruit.

In Paper II, the apple scab resistance was classified in over 450 cultivars or selections during 3 years. There were significant differences between the cultivars. The correlation between leaf and fruit scab was stronger in the two years with more apple scab symptoms (Sandskär & Gustafsson, 2003). The majority of the cultivars at Alnarp were placed in apple scab index groups 3 and 4 the first two years. In the last year the majority of the cultivars were instead found in scab index groups 1 and 2 (Table 5).

Table 5. The frequency (%) of apple cultivars sorted in an apple scab index, in an unsprayed fruit assortment orchard (Alnarp, Sweden, 1998-2000). The scab index ranged from 0 to 4, where 0 = no scab; 1 = small spots, no visible sporulation; 2 = apple scab symptoms, sporulating lesions on < 25% of the leaves/fruit; 3 = scab symptoms on 25-50% of the leaves/fruit, and 4 = scab symptoms on > 50% of the leaves/fruit. Both leaves and fruit were assessed.

Year	Leaves (%) Scab index					Fruit (%) Scab index				
	0	1	2	3	4	0	1	2	3	4
1998	4.5	5.1	20.0	35.2	35.2	6.3	9.5	20.4	31.2	32.6
1999	5.0	6.4	16.0	28.6	44.0	7.3	3.7	14.7	19.3	55.0
2000	4.0	30.3	48.2	12.4	5.1	60.4	7.6	23.3	6.3	2.4

The best cultivars at Alnarp with lowest mean scab index belonged to a group of 35 cultivars. Examples were: 'Priscilla', 'Nova Easygro', 'Prima', 'Akane', 'Remo', 'Co-op 23, 25 & 26', 'Liberty', 'McShay', 'Katinka', 'Reglindis', 'Antonovka Pamtorotuka', 'Vanda', 'Dayton', 'Hibernal' and 'Discovery'.

In a special study (1999), a part of the orchard at Balsgård was untreated with fungicides. One hundred and twelve cultivars, planted both at Alnarp and Balsgård, were compared and the mean leaf scab index was higher at Balsgård. There was a significant correlation between Alnarp and Balsgård for cultivar susceptibility to apple scab.

Another part of the Gene Bank at Balsgård was treated with fungicides. No scab was noted on the assessed *Vf*-cultivars, indicating that race 6 was not present at this location.

Some of the cultivars with no defined resistance genes had no or limited scab lesions, such as: 'Akane', 'Discovery', 'Alfa 68', 'Santa Brita' and 'Mio'. The common denominator was 'Worcester Pearmain' and this cultivar could be a candidate for further investigations of resistance genes.

Abundance of spiders, beneficial insects and pests in an organic apple orchard (Paper III)

This orchard was planned as an experimental organic orchard and has never been treated with pesticides. The most frequently found group in the beating samples was spiders (families Theriidinae and Araneidae). Among the shrubs, the rose harboured most arthropods (yearly mean 435), compared to *Thuja* (328), *Symphoricarpos* (224) and *Lonicera* (216). The *Viburnum*-shrubs died back due to damages by the pest *Pyrrhalta viburnii*. The number of spiders was highest in *Thuja*, followed by *Rosa*, while lower amounts were found in *Lonicera* and *Symphoricarpos*. The rose harboured more ladybirds and aphids compared to the other shrub species (Fig. 8).

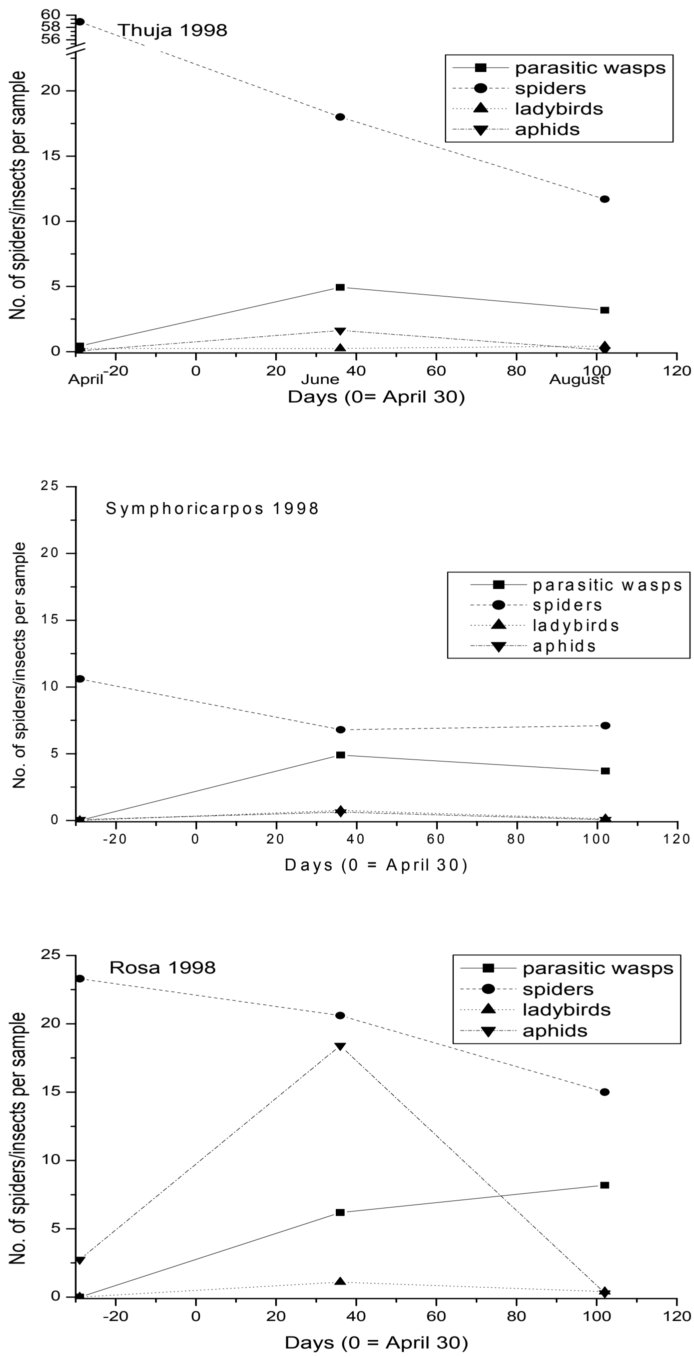


Fig. 8. Numbers of spiders and insects (parasitic wasps, ladybirds and aphids) per beating sample in an organic apple orchard interplanted with ornamental shrubs at Alnarp, Sweden in 1998. American Arborvitae (*Thuja occidentalis*), Snowberry (*Symphoricarpos rivularis*) and Rugosa Rose (*Rosa rugosa*).

The shrub species rose and *Thuja* can be recommended for interplanting, since they harboured a high number of natural enemies.

There were no significant differences between the cultivars 'Discovery' and 'Amorosa' in catches of spiders and selected insect groups (parasitic wasps, ladybirds, aphids, winter moths and mirid bugs). However, differences were observed between years. The harvested amounts are presented in Table 6.

Table 6. Total yield in an organic apple orchard inter-planted with ornamental shrubs at Alnarp, Sweden, 1997-2001. The number of trees per ha was estimated at 1 800, including ornamental shrubs.

Cultivar	Year	Yield per tree (kg)	Yield per ha (kg)	Marketable fruit (%)
'Discovery'	1997	1.9	3420	62.4
	1999	5.2	9360	38.0
	2000	4.9	8820	39.0[1]
	2001	6.0	10800	
'Amorosa'	1997	1.6	2880	–
	1998	4.8	8640	42.0
	1999	1.4	2520	–
	2000	11.5	20700	51.0[1]
	2001	7.1	12780	

[1] Average yield of the years 2000 and 2001

As shown in Fig. 9, there was a rather high catch of aphids in 1998. A type of hypersensitivity reaction towards the rosy apple aphid, was observed in 'Discovery' and the flowers were destroyed or produced only worthless 'aphid-apples'.

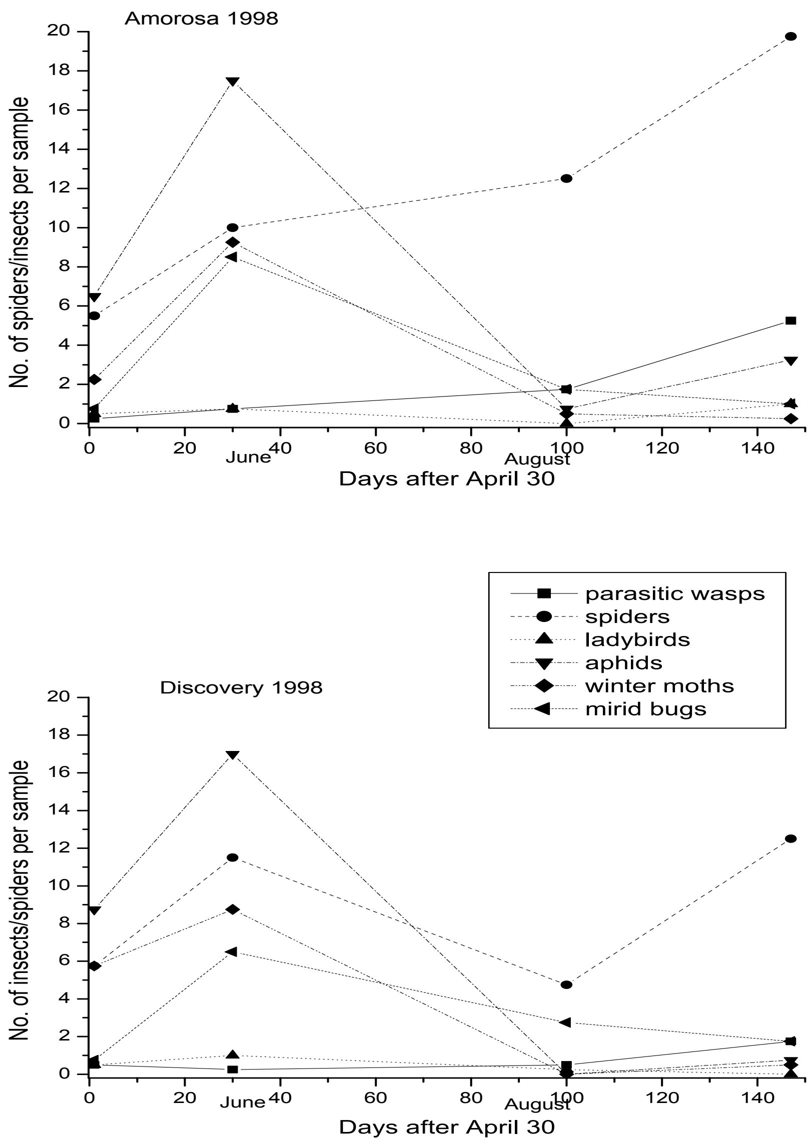


Fig. 9. Number of spiders and insects (parasitic wasps, ladybirds, aphids, winter moths and mirid bugs) per beating sample in the cultivars 'Discovery' and 'Amorosa' in an organic apple orchard inter-planted with ornamental shrubs at Alnarp, Sweden in 1998.

When sorting the apples a large proportion was found to be damaged by the codling moth which was considered to be a key pest. There was no difference in damage between the two cultivars, but the treatment against apple scab had an reducing effect on fruit damages by this insect. I found, however, great differences in fruit damages between the two cultivars both for apple sawfly and winter moth: 'Discovery' was attacked to a significantly higher extent than 'Amorosa'.

Incidence of apple scab races in Sweden (Paper IV)

The thirteen apple cultivars and selections or *Malus*-species used as scab race indicators in the experiments were: 'Gala', 'Golden Delicious', TSR34T15, 'Geneva', TSR33T139, 9-ART196, 'Prima', 'Florina', *Malus floribunda* 821, *M. pumila* R127.40.7A, *M. baccata jackii*, 'Generos' and 'Antonovka'. They were budded on B9, which is considered to be a hardy rootstock. One set of the plants was used in growth chamber/greenhouse experiments, one set was planted in the field and one set was potted and placed in the field. The recorded races are shown in Table 7.

Table 7. Apple scab races found in Sweden by testing isolates in growth chamber and greenhouse experiments (Exp. no. 1-13) or in field trials.
\+ indicates scab symptoms and *chlorotic spots.

Locality	Exp.	Race							*M. baccata*
	No.	1	2	3	4	5	6	7	*jackii*
Alnarp	1	+							
	2	+							
	3	+							
	5	+		+					
	7	+	+						+
	10	+	+	+			*		
	11	+	+	+					*
Balsgård	4	+	+	+	+				+
Kivik	8	+			+				
	13	+	+	+					
Stockholm	6	+	+						
Rånna	9	+	+						+
Hallstahammar	12	+	+	+			+	*	
Field trials									
Kivik	2001	+	+	+					
	2002	+	+	+	+			+	+
Alnarp	2002	+	+	+					+

This is the first investigation on apple scab races in Sweden. Race 1 was common and found in all collected samples. Race 5 was absent but all the other races were found in one or several samples or places. Race 7 was detected for the first time at Kivik in 2002, with abundant sporulation on the leaves of *M. floribunda* 821. Race 6 was still not present at Kivik or Balsgård, but probably at low levels at Alnarp. It was, however, found in samples from Hallstahammar, in the middle of Sweden.

Apple scab infected *M. baccata jackii* at several geographical sites and in the field trial at Kivik 'Antonovka' was also infected with scab in 2002.

The method of placing potted apple scab race indicators in an orchard was successful. It can quickly give valuable information about the apple scab race composition in the area.

Apple scab infection in three differently managed orchards (Paper V)

Five commonly grown cultivars in Sweden were potted and placed in three differently managed orchards at Alnarp, Sweden. I found significant differences in the number of apple scab infected leaves per shoot, between years, cultivars and orchards. Among the cultivars, 'Discovery' was the most resistant, followed by 'Ingrid Marie', 'Gravensteiner' and 'Aroma', while 'Summerred' was most susceptible to apple scab.

The sites also differed in infection levels; the unpruned orchard was highly infected while the new varieties orchard was less so and the organic orchard was least infected. This is an interesting aspect, that the grower might influence the scab infection by different management strategies.

Conclusions and future developments

The interest in organic production is growing both among consumers and growers worldwide. However, organic fruit growing is not developing in the same manner, although the organic proportion of the total cultivated area is steadily increasing in Sweden. There are over 3 000 cultivars of apples worldwide, but in practice just a few of these make up a large proportion of the cultivated area of apple orchards. Organic production of apples is a demanding task and there are many problems to solve. My study has focused on identifying and selecting apple varieties that have good apple scab resistance and therefore might be suitable for organic growing. I have also investigated the apple scab race composition, never investigated before in Sweden. Furthermore, I have identified the key pests in an organic orchard and their relative importance for fruit damages.

Apple scab. First of all, there were large variations in apple scab resistance in the old and new apple cultivars assortment at Alnarp and Balsgård in southern Sweden (Paper II). A correlation between leaf and fruit scab was observed, which was generally more pronounced at higher scab infection levels. Cultivars with low and high susceptibility were identified and about ten per cent of the cultivars assessed had a high level of resistance to apple scab. This study included a large number of cultivars and selections and the information about their scab resistance can be valuable for breeders and advisors in the future. Since many of the old cultivars possessed a high level of resistance it is very important that they are preserved as a gene bank. Among the investigated cultivars at Alnarp, Kivik and Rånna (Paper I), I found few obvious candidates for organic fruit production. The two best cultivars ('McShay' and 'Sansa') are unfortunately not suitable for growing in Sweden due to climatic conditions. On the other hand, several cultivars with medium high resistance should be considered for further in-depth studies and evaluation of other agronomic traits. The importance of knowing the experimental conditions such as scab infection periods, planting system *etc.* was stressed when evaluating new cultivars. However, additional intensive studies are needed to further evaluate suitable candidates for organic growing. For growers wanting to convert their orchards, it is very important to know the apple scab resistance of the cultivars in the orchard, since the most susceptible ones should be avoided.

As stated above, the incidence of apple scab races was investigated for the first time in Sweden (Paper IV). All apple scab races except race 5 were found, but they differed in occurrence between geographic locations and years. Race 7 was reported for the first time in the country. The ornamental species *M. baccata jackii* was infected at several locations, which might indicate the presence of a new race. There was a low incidence of race 6 in the south of Sweden. Many of the best cultivars in the assortment orchards possessed the *Vf* resistance gene from *M. floribunda* 821. Since the planting of *Vf* cultivars will probably expand, there is a risk of an increased spread of race 6. That risk can be reduced if these cultivars are protected by sulphur sprays during the ascosporic period, *i.e.* usually up to June.

Apple scab incidence was recorded in the experimental organic orchard, 2000-2001. There was a low level of scab in the orchard but nevertheless, significant differences were found between the cultivars, in that 'Amorosa' was more infected than 'Discovery' ($F = 1.5$, $p < 0.001$). The ornamental shrub rows probably act as a barrier against airborne conidia between the fruit rows. Other reasons for the low scab level could be the raking and removal of overwintering leaves, and the fact that grass between rows was kept short, thereby reducing ascospore inoculum in the orchard. Different management approaches to the orchard significantly influenced the level of scab infection (Paper V). There was a significant difference between natural scab infections in the three differently managed orchards. This means that the organic grower can efficiently reduce scab infection levels utilizing basic control and sanitation methods.

Pests. On the whole, insects caused more damage than apple scab in these experiments (Paper III). Codling moth was a key pest in the experimental organic orchard at Alnarp. In one of the years documented, the rose apple aphid caused a total harvest loss in 'Discovery'. This cultivar is more vulnerable to apple sawfly and winter moth damages, compared to 'Amorosa'. The ornamental shrubs used for interplanting in these experiments, harboured a number of natural enemies of apple pests, such as spiders, which were the most frequently detected group. The Rugosa Rose and American Arborvitae (*Thuja*) were recommended for interplanting, since a high number of natural enemies were found in these shrubs, compared to the other shrub species.

Future challenges in organic apple growing

There are a number of factors of a technical, biological and economic character that are important to the future development of organic apple growing in southern Sweden. Among the biological aspects apple scab plays a significant role, with serious economic consequences for the organic professional grower. If further positive development is to be achieved in the short-term, new cultural practices should be adopted. In the long-term perspective, new management techniques should be developed.

Some of these are:

- Resistance breeding of new varieties that combine resistance genes from different sources is desirable. The use of polygenic cultivars should be increased, so that the fungus has smaller chances of adaptation. Continued research is also needed on identifying resistance genes. Further studies of interactions between the fungus and the host are of great importance.
- Improved cultural practices such as interplanting with shrubs may reduce apple scab infection patterns within the orchard. Sanitation methods should not be overlooked as being old-fashioned, as they also work in modern orchards and particularly in organic orchards. Removal/shredding of overwintering leaves, thereby reducing the apple scab inoculum, is an essential orchard hygiene procedure. Pruning can be carried out in

August, a period when scab-susceptible new shoots do not develop as abundantly as after winter pruning.

- The grower should promote balanced growth of the tree between vegetative and fruiting parts. One link in achieving this is by routinely taking soil samples before N-fertilizing of the trees.
- Identification and management of key pests in the area is fundamental for a successful apple production. In our case, codling moth was a major pest but one that might be controlled by pheromone use. However, there is still no efficient means of controlling rosy apple aphid, other than by mechanical removal. Soap spraying is ineffective since the leaves curl up around the aphids and the solution cannot come in contact with the aphids. This study shows that there is still a great need for new and old methods and approaches for pest control in organic growing in southern Sweden in particular.

Acknowledgements

Working with apples over these past years has been really fun and demanding in many ways. To isolate a single spore from the fungus and make the thing grow on artifical medium has been a challenge. To manage an entire experimental orchard was heavy going sometimes (the fruit boxes weighed approximately 25-27 kg) but as a bonus, I got fit. To infect apple trees with apple scab in growth chambers for the first time was hilarious, it took some efforts before succeeding…

First of all, I want to thank my supervisor Mats Gustafsson for accepting me as a PhD student. The project was a collaboration project with Viktor Trajkovski, Balsgård and was funded by the Swedish Council for Forest- and Agricultural Research.

Erland Liljeroth joined as a co-supervisor over the last year, but has with great enthusiasm really been helpful with the writing part.

Hilde Nybom and collegues are thanked for the possibility of using parts of SLU Balsgård and for the supply of budding material.

Thanks also to:

Hanne Lindhard for sharing her apple scab experience with me; Luciana Parisi, INRA, Angers, France for receiving me for ten days and teaching me all techniques involved in inoculation of apple scab and sharing her knowledge of apple scab races; François Laurens, INRA, Angers, France for hospitality and budding material; Paul Ilg, the late Nils-Arthur Ericsson and personnel for excellent care of my trials at SLU Kivik; Birgitta Svensson for saving the trial at SLU Rånna one more year; Elna Sjöström, Stångby plantskola AB for supply of all the trees used in potted experiments and field trials; my true collegue, Gunilla Åhman for friendship and laughter; Åsa Johansson for good company visiting Gene banks in Julita, Stockholm, and Jönköping and friendship; Thomas Jonasson, Blago Begic and Christer Nilsson for collecting the insect and spider samples in the organic orchard; Britt Åhman for identifying the spider species in the organic orchard; Knut Sakshaug for pomology expertise and Jens Weibull for valuable comments on my third paper.

My nice 'fika' room friends: Monica, Malin, Pernilla, Shu-Chin, Helén, Lotta, Britt G., Claus, Stefan, Agnese, Ramune, Marisa, Salla, Tintin, Digby, Alaina and many others. From the other house, formerly Plant Protection Department which I used to be a part of: Miryan for brushing up Portuguese and amazing dinners, Ylva, Anna-Carin, Peter W., Marie, Elisabeth M., Elisabeth K. and Torbjörn.

Last but not least, I want to thank my parents Berit and Bengt for everything, my sister Metta and brothers Ola and Tomas with families for great support. My two sons Andreas and Sebastian helped in eating my apple pies and my husband Carlos showed patience, encouragement and cheering.

An apple a day – because you´re worth it!

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