BLACK CURRANT

(*Ribes nigrum* L.) – AN INSIGHT INTO THE CROP

A synopsis of a PhD study




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List of contents

Abstract

There is an increasing interest in the inclusion of berries, especially the black currant in the human diet mainly for the health benefits associated with their consumption. Black currant (*Ribes nigrum* L.) belonging to the genus *Ribes* is widely cultivated across temperate Europe, Russia, New Zealand, parts of Asia and to a lesser extent North America. Besides high content of tasty juice, black currant is a valuable source of bioactive compounds like vitamin C and polyphenols, acting as antioxidants, with a potential to protect against disorders such as cardiovascular events, cancer and other degenerative symptoms. Industrially, black currant fruits are considered to be of importance; however other anatomical parts like buds and leaves are also excellent sources of phenolic compounds. The leaf and bud extracts are of relevance as raw material for the food and health industry thereby making black currant a lucrative product for use as functional food ingredient. Research until now has investigated the content of different polyphenolic fractions of the fruits and to lesser extent on content of these fractions on plant parts like buds and leaves.

The breeding of black currant is mainly focussed on national and international requirements, as related to specific quality desired from the processing sector alongside with important agronomic characters. Black currant cultivation is in different areas limited by a lack of climate adaptation in the existing cultivars as well as susceptibility of these cultivars to different pests and diseases. Also, the levels of bioactive compounds in black currant like content of ascorbic acid and polyphenols are influenced by genotype, environment and genotype x environment interactions. Durable resistance towards damaging pest and diseases together with an increase in content of health promoting compounds and adaptability to local climates remain to be of high priority for breeders. Additionally flavour, mouth feel, aroma and after taste are important primary quality factors for the fresh fruit market and juice industry.

This introductory paper focuses on the history of development and biology of black currant; their ecology and environmental adaptability; crop utilisation; bioactive compounds, genetic, biochemical and phenotypic diversity. The breeding objectives and important pest and diseases are also presented. This paper is an attempt to review important work that has been done so far and the background literature, whilst providing the scope for the current PhD study.

1. Introduction

In recent years there has been an increased scientific interest toward the crops belonging to the genus *Ribes*, not only due to their desired taste but also for the health benefits associated with their consumption. *Ribes* is an economically important small fruit crop, 99% of world's production originates from Europe where the production figures have increased by 24% between 1998 and 2007. (Mitchell et al., 2011). In countries like USA that did not previously cultivate the crop, there is a growing interest in expanding *Ribes* production (Hummer and Dale, 2010).

The *Ribes* genus consists of nearly 150 diploid species of spiny and non-spiny shrubs (Brennan, 1996). The edible forms of *Ribes*, being commercially propagated, are the black (*Ribes nigrum* L.), red and white currants (*R. rubrum* L., synonyms = *R. vulgare* Jancz. and *R. sativum* Syme.) and gooseberry (e.g. European gooseberry: *R. uva-crispa* L., synonym = *R. grossularia* L., and American hairystem gooseberry: *Ribes hirtellum* Michx.).

Black currant is a commercially important soft fruit crop with an annual turn over of 160,000 tonnes in Europe and 185,000 tonnes worldwide (Hedley et al., 2010). Black currants are widely cultivated across temperate zones of Europe, Russia, New Zealand, parts of Asia and to a lesser extent North America, where most of the fruits are primarily cultivated for juice and beverage production. The fruits are eaten raw or processed for production of jams, purées, jellies, liqueurs and imparting colour and flavour to yoghurt and other dairy products.

In Sweden black currant is cultivated on approximately 350-400 ha mainly for juice production (Jenson, 2009). A significant commercial black currant production takes place in northern Sweden. Black currant is also a popular Swedish home garden bush.

One reason mainly for black currants being heavily marketed at present is the content of bioactive compounds such as vitamin C (ascorbic acid) (AsA) and polyphenols including flavonoids such as anthocyanins, procyanidins, flavanols and phenolic acids with potential health promoting properties (Slimestad and Solheim, 2002; Määttä et al., 2001; Tabart et al., 2007; Brennan and Graham, 2009). A number of scientific studies using *in vitro* models have demonstrated that the above mentioned bioactive compounds exhibit anti-inflammatory, vasomodulatory and anti-haemostatic activities (Hollands et al., 2008; Brennan and Graham, 2009; Karjalainen et al., 2009).

Commercial breeding of black currants is mainly focussed towards quality (nutritional and sensory components), and agronomic traits such as yield, fruit size and resistance to pests and diseases to fulfil national and international requirements.

The steadily increasing fresh fruits market for black currants presents a challenge for the breeders in order to develop naturally sweet cultivars with big berry size, dry pick (less bruised) and long green strigs suitable for harvesting by hand (Brennan et al., 2008)

Additionally, development of resistant cultivars towards foliar pathogens, especially the black currant gall mite (*Cecidophyopsis ribis* Westw.) and *black currant reversion nepovirus* (BRV), adaptability to local climatic conditions and enhanced bioactive compounds contents are main priorities due to increased interest towards integrated crop management systems (Brennan, 2008).

2. Origin and history of development of the crop

2.1 Taxonomy

The genus *Ribes*, was classified to the *Saxifragaceae* family originally, but was later placed within the *Grossulariaceae* family on the basis of morphological traits such as the presence of inferior ovaries, syncarpous gymnosperm and fleshy fruit (Cronquist, 1981; Sinnot, 1985). Black currants belong to the sub genus *Coreosma* (Table 1). The other species of *Ribes* of commercial importance are the red currants belonging to sub genus *Ribesia* and gooseberries belonging to *Grossularia*.

Table 1. The scientific classification of black currants

Kingdom Plantae	**Division** Magnoliophyta
Class Magnoliopsida	**Order** Saxifragales
Family Grossulariaceae	**Genus** *Ribes*
Sub genus Coreosma	**Species** *Ribes nigrum* L.

2.2 Origin, distribution and domestication

The word “currant” is originating from the ancient Greek word for the city Corinth and was used to illustrate grapes grown in the region. Earlier English texts described the cultivated varieties with words like ‘corinthes’, ‘corans’, ‘currans’ and ‘bastardecorinthes’ (Hederick, 1925; Brennan, 1996).

Black currants have been cultivated in northern Europe for more than 400 years and records were first described by the 17th century herbalists, e.g. Gerard (1636), referring to the use of black currants as ingredients in tea and medical concoctions (Barney and Hummer, 2005). John Tradescant imported black currants to the United Kingdom in 1611 from Holland and by 1800, they were popular shrubs grown in home gardens in the UK (Brennan, 1996; Hederick, 1925). The Royal Horticultural Society recognised five black currant cultivars in the UK in 1826: 'Black Naples', 'Black Grape', 'Common Black', 'Wild Black' and 'Russian Grape'. Among these cultivars, 'Black Naples' and 'Black Grape' of unknown origin were popular for over 100 years (Roach, 1985). By 1920, 26 additional cultivars of *Ribes nigrum* descent were identified in the UK by Hatton (1920).

In the UK, the most important cultivar from the late nineteenth century was 'Baldwin', which is of unknown origin. A number of more recent cultivars have been derived from 'Baldwin' and incorporation of germplasm from the Nordic cointres such as 'Brödtorp' (Finish), 'Öjebyn' (Swedish) and 'Sunderbyn II' (Swedish). The mentioned crosses have led to the development of late flowering and frost tolerant cultivars across Europe.

In Russia, the black currant breeders used wild germplasm *R. nigrum* var. *sibiricum* (gall mite resistant), *R. pauciflorum* and *R. dikuscha* for crosses resulting in development of cultivars such as 'Primoskij Cempion' (Brennan, 2008).

Black currants were introduced in the USA along with red currants in the seventeenth century, but received little interest in terms of their domestication and cultivation (Barney and Hummer, 2005). In Canada, wild germplasm of *R. ussuriense* was used for breeding of black currants in the 1930's led to development of series of rust resistant cultivars including 'Consort'. During the World War II, citrus fruits were difficult to cultivate and expensive to import into Europe, and as black currants had exceptionally high levels of vitamin C their cultivation was encouraged for production of healthy juice. From this time on, several breeding programs by plant breeders, gardeners, common people and government-funded institutes have led to a steady increase in the number of cultivars across Europe (Brennan, 2008).

2.3 Cultivar development in Sweden

In Sweden, the majority of black currants cultivated have traditionally been from Great Britain and other Nordic countries. Some of the imported varieties grown during 1900 to 1950 were 'Boskoop Giant', a Dutch variety and 'Bang up' from England. The results of harsh winters led to a shift away from the use of non-nordic germplasm to the incorporation of 'Brödtorp' and 'Åström' from Finland, which were known to be mildew resistant, winter hardy and high yielding (Hjalmarsson and Wallace, 2007).

The first Swedish cultivar trial was established in 1940 at 12 different locations around Sweden, the plants were subjected to cold winters and the outcome was that European cultivars were not hardy enough to be cultivated in the north. Among the evaluated cultivars, 'Wellington' and 'Silvergiester' were suitable for southern Sweden, and 'Wellington X' and 'Brödtorp' for central Sweden. For the northern climatic conditions 'Brödtorp', 'Janslunda' and 'Östersund' were favourable. Also several local varieties from Norrland were collected and evaluated at the research station in Öjebyn, the most suitable ones were chosen and named after home villages. The most prominent local varieties being 'Öjebyn', 'Haparanda', 'Sunderbyn' and 'Östersund' (Hjalmarsson and Wallace, 2007).

The modern black currant-breeding programme was conducted in southern Sweden at Alnarp and Balsgård. Cultivars that have resulted from the breeding in Alnarp are 'Stella I', and 'Stella II' introduced in 1967 and 'Stellina' introduced in 1979 sharing the parentage between 'Boskoop Giant' and 'Erkiheikki' (Hjalmarsson and Wallace, 2007).

The breeding programme at Balsgård applied the ideas of state horticulturist V. Trajkovski, who had incorporated the use of local germplasm from northern Sweden (Norrland) and Russian germplasm as source of genes for resistance to mildew and gall mite respectively. Trajkovski also used the Canadian variety 'Consort' as a source of resistance for rust and hardiness. The success of this approach resulted in a new generation of black currants cultivars such as 'Stor-klas', 'Polar' and 'Intercontinental' with high disease resistance against fungi, hardiness, yield and berry size (Trajkovski, 1986; 1992). These ideas were further taken by P. Tamás at Tollarp in southern Sweden leading to the development of the cultivars 'Titania' and 'Triton'. 'Titania' was of special interest in the USA due to its resistance to white pine blister rust (*Cronartium ribicola* Fisch.), a pest that has caused serious problems in pine plantations in North America (Brennan, 1996). However, none of these cultivars are resistant to gall mites.

Figure 1. Plots of black currant plantations at Balsgård, Sweden (Pictures by the author)

At present, a breeding programme is ongoing at Balsgård to develop new cultivars with an increase in content of polyphenols and resistance to pests and diseases (notably leaf diseases, gall mite and BRV) for organic farming and to provide cultivars for northern Sweden. Also advanced selections and foreign cultivars (Scottish) are being evaluated in comparative trials at both Balsgård and Öjebyn.

3. Biology of black currants

3.1 Phenotypic characteristics

Black currant is a deciduous, unarmed, aromatic shrub (Figure 2) that can grow as tall as 2 m (Rehder, 1986). The plants attain maturity and start yielding in about 3-4 years. Shoots are straight, firm, long and thick at the base, slightly pubescent and markedly brown in colour (Wassenaar and Hofman, 1966).

Buds are aromatic and can vary from short and thick to long and slender, fusiform or conical in shape, reddish or yellowish in colour. The colour of the buds becomes more intense (reddish) as the winter months progress. The strongly perfumed leaves are pale green, alternately paired, lobed and glabrous above, a little pubescent with many sessile and aromatic glands on the lower leaf surface. The racemes hang down and bear about ten flowers, composed of reddish or brownish campanulate hypanthia, curved sepal and white petals. Flowers bloom during spring, held together on a drooping, delicate stem called the strig. In the very northern latitudes, during extreme long days, flowering commences in late June/July and completes by the end of August, and a day length of *ca.* 16 hours for floral initiation is prescribed for the crop (Brennan, 2008).

Figure 2. Images of a blackcurrant bush and fruits (Pictures by the author)

The fruit which usually is about 1cm or more in diameter is an edible berry and shiny black or purple in colour when ripe, containing large number of seeds (Hummer and Barney, 2002). Also green cultivars are available. Depending on the cultivar, the fruits begin to ripen 70 to 100 days after blossoming (Brennan, 1996).

3.2 Cytology, mode of pollination and cropping

Black currants have a chromosome number of 16 and, like all species of *Ribes* are diploid (2x=2n=16), with natural polyploidy rarely seen (Brennan, 1996). The chromosomes are 1.5-2.5mm in diameter, with both mitotic and meiotic processes being highly uniform (Zielinski, 1953). The karyotypes and chromosome compliments are consistent in this crop (Sinnot, 1985).

Although most of the black currant cultivars are to at least some extent self-fertile, cross-pollination is essential in achieving optimum yields (Denisow, 2003). The bloom duration of the flowers is directly related to the temperature the plant is exposed to, and pollinizers are selected based on the same bloom time as the main cultivar. Basal flowers bloom much earlier than the terminal flowers on the same strig (Harmat et al., 1990; Hummer and Barney, 2002). Insects like bumble bees are important pollinating agents. Flowering usually takes place in the months of April and May and last up to 3-4 weeks depending on the choice of cultivar and environmental conditions. In controlled pollination the flowers are emasculated using a scalpel and a forcep upto 5 days before anthesis.

For breeding of black currants in most countries, berries are collected as they ripen. The berries are then stored at 4^{o}C until the seeds are extracted in water using a blender. The seeds are thereafter dried on a filter paper and put in compost, covered with a layer of moist vermiculite that is then followed by stratification at 2^{o}C for a period of 13 weeks in dark. Later the seed trays are brought into the greenhouses for germination, which completes within 2 to 3 weeks. Seedlings are normally raised in the glasshouses and then planted in the field (Brennan, 2008). Planting takes place through the months of October to March preferably in dry and crumbly soils, which do not impede the roots of the plant when they start to grow (Hummer and Barney, 2002). The plants are planted in a row spacing of 0.6 m either in the form of rooted bush or cuttings in deep furrows. Black currants can also be propagated clonally by cuttings of the hard wood during autumn or soft wood during early summer or by single bud cuttings (Thomas and Wilkinson, 1962) The first year after their planting, pruning is done to initiate further strong and vigorous growth; a sparse crop of 0.202 tonne per hectar is produced in the second year with no pruning required followed by exceptionally high crop yield in the third year or 30 months (Blackcurrant foundation, 2011).

3.3 Ecology and environmental adaptability

Black currant does best on deep organic soils with good water retention capacity and aeration. Black currant grows best at a soil pH ranging between 5.5 and 7.0 (Hummer and Dale, 2010).

3.3.1 Location

Site selection is an important factor to be considered for growing a healthy crop. The planting sites must be accessible to sunlight for good yields and in warmer climates the plants should be grown in shade or on north facing slopes or in high elevations so that they could perform better agronomically (Barney and Hummer, 2005).

3.3.2 Climate

Black currants are noted for their winter hardiness and adaptability to temperate growing conditions. The crop performs best in climates with cold winters and mild summer conditions. High mid summer temperatures, especially intense sunlight induce a greater risk to foliar damages. Insufficient chilling requirement during the dormancy period can have a serious impact on the phenological traits like bud break, time and duration of flowering and fruits quality at the time of harvest (Hedley et al., 2010). In recent years late spring frost and drought in summer have been known to cause problems in black currant cultivation (Kahu et al., 2009). In terms of biochemical compounds warm weather conditions increases the soluble solids content and accumulate less acids in the fruits, and environmental conditions have been reported to have more impact on acids than of sugar content (Brennan, 1996).

3.3.3 Temperature

Black currants can survive minimum temperatures of -40^{o}C or lower. It has been estimated that black currant cultivars normally require about 800 to 1600 hours of chilling (0 to 7^{o}C), 1300 hours in case of New Zealand and over 2000 hours for Nordic germplasm, before buds will break in the spring (Barney and Hummer, 2005; Brennan, 2008). To reach blooming black currants require a base temperature of 5^{o}C and the fruits require a time of 120-140 frost-free days (Harmat et al., 1990). Cultivars growing at 5^{o}C for several weeks have been reported to result in reduced leaf appearance and leaf expansion and greater photo-inhibition. In cultivars like 'Ben More' a low temperature of 5 or 12°C for several weeks delayed bud break by 33 days (Jefferies and Brennan, 1994).

3.3.4 Light

The growth and development of black currant is affected by day length. Some influence of light on the quality traits of the fruits such as content of ascorbic acid (AsA) levels has been reported. Fruits from the plants grown in south facing slopes were found to contain 20% more AsA than the ones grown in north facing slopes at the same location. The increase in content of AsA in fruits from bushes grown in south facing slopes was found related to higher solar radiation (Walker et al., 2010). Also, the spectral quality as well as abiotic stresses are known to effect the regulation of flavonoid biosynthesis (Jenkins, 2008).

3.4 Genetic diversity, molecular characterization and chromosomal mapping

Characterization of genetic diversity can be an effective tool to determine the genetic relatedness among cultivars and can be used for selection in black currant breeding programs. Mostly dominant markers (such as RAPDs, AFLPs, ISSRs) have been used to assess the diversity in black currants (Lanham et al., 1995; 2000; Lanham and Brennan, 1998; 1999). The material present at the Scottish crop research institute (SCRI), also representing a broad cross section of the available genetic base from Scandinavia, Europe and Russia, have been evaluated using the mentioned dominant markers. Unique accessions were distinguished including sister seedlings (RAPDs) and genetic relatedness between three wild species (ISSRs). Furthermore, using AFLP markers Lanham and Brennan (2001) separated closely related genotypes, indistinguishable from each other when using RAPDs or ISSRs.

The use of co-dominant markers like SNPs and SSRs have been mostly associated with construction of genetic linkage maps in black currants (Brennan et al, 2008). Furthermore, SSRs have been used to examine the genetic diversity within the black currant material (Brennan et al., 2002). The first linkage map for black currants was based on a mapping population (designated 9328) obtained from a cross between a seed parent SCRI S36/1/100 and a pollen parent B1834–110. This population segregated for several important characters, which included agronomic factors, developmental stages and fruit quality components, with the map consisting of 8 linkage groups constructed from 116 AFLPS, 47 SSRs, and 18 SNPs (Brennan et al., 2008).

3.5 Phenotypic diversity

There is a wide phenotypic diversity among black currants. This morphological variation is exhibited in plant growth, habit and several characteristics, which include bud position in relation to shoot, bud shape of apex, bud bloom and the opening of leaf blade base and floral features (UPOV TG/40/7).

The growth habit (Figure 3) varies from upright, semi upright to spreading of the canes. In terms of height an upright variety is taller than broad, a semi upright variety is approximately the same height as the width and a spreading variety is broader than tall.

Figure 3. Images of upright and spreading black currant bushes (Pictures by the author)

For bud position in relation to shoot some varieties show a depressed or slightly held out position, while others moderately held out or strongly held out. As regards to shape of apex of the buds, the diversity spreads from narrow acute, broad acute to rounded. The blooming of the vegetative bud differs based on the level of glaucosity. Variation in the base of the leaf blade is characterised from strongly open, moderately open, weakly open, touching through to overlapping. The floral morphological variation is observed on the number of inflorescence per axil, the length of peduncle, infructescence type and fruit size range. Polymorphism is also observed in time of bud burst, beginning of flowering and beginning of fruit harvest.

Results from a recent study conducted in Poland divided forty black currant cultivars into five distinct clusters based on the contribution of traits such as ripening time, fruit size and firmness, number of basal shoots, fruit yield of the plant, as well as susceptibility of pests and diseases to the overall phenotypic diversity (Madry et al., 2010).

3.6 Biochemical diversity

The genus *Ribes* offers an excellent gene pool for fruit quality, diversity and improvement in black currant breeding. The levels of AsA among black currant breeding lines are highly variable, but normally contain 130–200 mg/100 ml juice from ripe berries although even higher levels (400 mg/100 ml juice) have been detected (Brennan, 1996; 2008). There is a rich diversity with respect to phenol compound classes and content (Määttä et al., 2003). The total anthocyanins content may vary about eight times in the *Ribes* gene pool and western European cultivars contain a higher amount of cyanidin derivates whereas Scandinavian cultivars seem to contain a higher amount of delphinidin derivates (Karjalainen et al., 2009). The content of flavonols also varies and a three-fold variation has been found in the levels of myricetin and quercetin contents among black currant cultivars (Mikkonen et al., 2001). The high variability in flavonol content offers possible avenues for identification of cultivars rich in certain flavonols for production of black currant products with health benefits.

Significant differences were observed in the content of polyphenols and vitamin C in commercial European black currant juice products. The vitamin C content was highest in British (70 mg/2.5 dl) and lowest in commercial Finish (15 mg/2.5 dl) juice products. Higher levels of individual polyphenol groups have been reported in German (94.0 mg/2.5 dl) and Polish (79.5 mg/2.5 dl) juice drinks than the Finish and British drinks (Mattila et al., 2011). Rumpunen et al. (2012) observed a large variation for every specific phenolic compound among 21 accessions evaluated. The coefficient of variation was 28% for epicatechin, 39% for epigallocatechin, 40% for catechin, 12% for cyanidin-rutinoside, 22% for delphinidin-rutinoside, 39% for delphinidin-glucoside, 45% for cyanidin-glucoside and 56% for peonidin-rutinoside.

In terms of black currant grown in two different latitudes, the berries grown in the southern latitude of Finland had higher content of glucose, fructose, sucrose and citric acid and lower content of malic acid, quinic acid and vitamin C in comparison to the berries grown in northern Finland (Zheng et al., 2009). Considerable variation has been reported in the levels of fatty acid contents in the seeds among cultivars (Castillo del Ruiz et al., 2002).

4. Crop utilisation

Black currant bushes are in the majority of European countries cultivated mainly for the juice-processing sector, but also for ornamental purposes. Industrially, fruits are considered to be of importance due to high content of tasty juice; however other anatomical parts like buds and leaves are also excellent sources of total phenols with antioxidant ability (Tabart et al., 2006; 2007). Health related products such as black currant tea are gaining popularity. Leaves of black currant when reduced to powder by micronisation and glycerinate extracts of buds when macerated in glycerin are of application as raw material for food, health and cosmetic industry. The characteristic pleasant flavours and colour that the buds and leaves impart, is reminiscent to that of the fruits (Dvaranauskaite et al., 2008; Tabart et al., 2006; 2011). Furthermore, the health benefits associated with consumption of black currant related products are one key reason for the continuing and growing scientific interest in black currants (Brennan, 2008).

4.1 Buds

Black currant buds are rich sources of aroma volatile compounds, the majority of them being hydrocarbons and oxygenated fractions of terpenes (Dvaranauskaite et al., 2009). The buds accumulate large amounts of essential oils liberating a strong terpenic aroma, which is inundated by a “catty note” (Le Quere and Latrasse, 1990; Piry et al., 1995). The essential oils isolated from dormant buds are used in applications as aroma enhancers in cosmetics and ingredients for fragrance in perfume manufacture (Piry et al., 1995; Castillo del Ruiz and Dobson, 2002). Studies conducted on buds report them as a possible source of total phenolics and antioxidants to be extracted and used in a number of applications (Tabart et al., 2006; 2007; 2011; Dvaranauskaite et al., 2008).

Vagiri et al. (2012) determined the detailed composition of polyphenolic compounds in buds and the variations of these compounds during different stages of ontogenetic development over a season and found that swollen buds collected in March had highest content of phenolics with rutin, epicatechins and kaempferols being dominant, whereas the content of chlorogenic acid was very low through out the season. Studies (Opera et al., 2008) have demonstrated that essential oils of black currant buds showed significant antimicrobial activity against pathogenic bacteria and the buds can therefore be used as a natural alternative for treatment of infectious diseases. Studies by Hedley et al. (2010) provided insight into the genetic control of dormancy transition in black currant buds identifying important changes in gene expression around bud dormancy release. The genes identified might have a possible role for the release of dormancy and hence could provide a basis for the development of genetic markers for future breeding purposes.

4.2 Leaves

Traditionally the leaves from black currant have been used in European folk medicine to treat rheumatism, arthritis and respiratory problems (Stević et al., 2010). The leaves are beginning to get considerable amount of scientific attention due to the anti-inflammatory activity reported using *in vitro* and *in vivo* models (Declume, 1989; Garbacki et al., 2005). The culinary uses of leaves include the refreshing 'louhisaari' drink in Finland prepared preferably using the young leaves of early summer. Infusion of black currant leaves to sweetened vodka makes a deep yellowish green beverage with characteristic sharp flavor and astringent taste.

Recent phytochemical studies report black currant leaves as a remarkable source of total polyphenols. The content of polyphenols in the leaves is considered to be five times higher than in the fruits or any other black currant part (Tabart et al., 2006). The leaves might therefore be of interest to the health and functional food industry for preparation of extracts with high antioxidant ability. The polyphenol composition of black currant leaves has been reported by Raudsepp et al. (2010) and includes flavonoid derivatives like kaempferol, quercetin and phenolic acids. Also, composition and antimicrobial activity of the essential oil of the leaves have been reported recently (Stević et al., 2010).

Although the leaves are rich in biochemical compounds they can be prone to damaging pests and diseases, therefore breeding efforts are focussed on developing cultivars with healthy leaves that could be used in preparation of diverse food supplements.

4.3 Fruits

The fruits of black currant are regarded as a natural high value raw material for juice and beverage production. The fruits are favoured for their organoleptic properties like rich colour, taste and flavour and they are used in diverse food applications (Piry et al., 1995; Brennan et al., 2003). Fruits also are suitable for freezing and can be processed into concentrates, jams, jellies, fillings on pies, ice creams, flavoured mineral water, candies and desert toppings. In various countries fruits are of use in production of liqueurs like 'crème de cassis' and for converting white wine to rosé (Brennan, 1996).

In Sweden, there are some black currant 40% alcohol drinks, such as absolute vodka and "svarta vinbärs brännvin". The fresh fruit market for black currants is steadily increasing with the requirement of sweeter fruits and high content of soluble solids (Brennan, 2008). Scientifically the fruits are regarded to have significant antioxidant activity mainly attributed to the relatively high vitamin C content and over the last few decades vitamin C has been the main driving force for the marketing of black currants. However, the health effects can also be attributed to the exceptional levels of polyphenolic compounds contained in the fruit, including flavonoids, mainly anthocyanins. Apart from anthocyanins the fruits contain other phenolic compounds like phenolic acids, flavonols, flavan-3-ols (catechins) and tannins with potential health promoting properties making black currant fruit a lucrative product to be used as a functional food ingredient (Macheix et al., 1990; Lister et al., 2002; McDougall et al., 2005; Anttonen and Karjalainen, 2006).

Additionally, the juice obtained from black currants has a distinct aroma profile, comprising more than 120 volatile aroma compounds that include terpenes, esters and alcohols (Varming et al., 2004). In comparison with other fruits (Table 2), black currants are low in calories and sodium with significant levels of pro-vitamin A (carotenoids), vitamin B1 (thiamin), vitamin B3 (niacin), vitamin E (tocochromanols), iron, potassium and calcium (Hummer and Barney, 2002).

Table 2. Nutritional data of raw black currants in contrast with other fruits per 100g edible portion.

Fruits	Water (%)	Calories^{Y}	Protein (g)	Fat (g)	Carbohydrate (g)	Vitamins				
						A	B1 (mg)	B2 (mg)	Niacin (mg)	C (mg)
Black currant	81.96	63	1.4	0.41	15.38	230	0.05	0.05	0.3	181
Red currant	83.95	56	1.4	0.2	13.8	120	0.04	0.05	0.1	41
Gooseberry	87.87	44	0.88	0.58	10.18	290	0.04	0.03	0.3	27.7
Apple	83.93	59	0.19	0.36	15.25	90	0.017	0.014	0.077	5.7
Strawberry	91.57	30	0.61	0.37	7.02	27	0.02	0.066	0.230	56.7
Orange	82.3	40	0.3	0.3	15.5	250	0.10	0.05	0.5	71

* I.U. International units; 28.35 g = 28,350 mg = 1.0 oz, ^{Y} Food calorie – 1000 g calories of heat

4.4 Pomace

Black currant pomace, a by-product of juice production contains seeds and peels. The seeds of black currant are a rich source of γ-linolenic acid and other fatty acids of nutritional significance and can also be used as a herbal concentrate and in functional food products. Apart from the seeds, the peels are enriched with beneficial polyphenols especially the anthocyanins, ending up as a residue instead of in juice during processing. Recent studies conducted by Holtung et al. (2011) showed that phenolic compounds could also be extracted from press residues by simple water extraction at 90^{o}C and that the extracts obtained at this temperature exhibited a strong inhibition of cell proliferation for cancer cell lines.

4.5 Black currant as a raw material

The majority of the black currants are cultivated for the processing sector, mainly to be used in the production of juice and nectars. The crop is considered to be a high value food raw material and a source of many nutritionally important bioactive compounds (Anttonen and Karjalainen, 2006). Also, the products processed form black currants are considered to have intense taste and aroma and therefore are desirable market products (Sojka and Krol, 2009; Brennan et al., 2003). However, during the enzymatic depectinisation process of the mash and pasteurisation of the juice, Shahidi and Naczk (2004) have reported a reduction in the level of polyphenols with considerable loss in vitamin C, which may affect the bioactivity. With the technological advances in the food production sector, a lot of progress has been made in enhancing the nutritional and sensory characteristics with increased production, but this might affect the by-product composition.

The press-cake which is a by-product during juice production presents a major problem for its disposal. However the press cake could be of use as a functional raw material because of the nutritional properties (Larrauri, 1999; Krede et al., 2000; Sojka and Krol, 2009). Extracts prepared from industrial black currant by-products have been found to have high antioxidant activity and the extracts were also a good source of phenolic compounds especially anthocyanins (Kapasakalidis et al., 2006; Sojka et al., 2010). These antioxidants are abundant in the flesh of the fruits, and thereby they mostly end up as residues during juice processing. However, the raw material cost is an important factor to be considered for the functional food industry. Thus, for profitable business in this area there arises a need for inexpensive sources of phenolic compounds that simultaneously can bring extra income for the juice processors and the health industry. The black currant raw material could be an important element due to its high content of polyphenols for use in black currant based diverse food applications.

5. Crop production and breeding

5.1 World black currant production (in tonnes and hectares)

From the production figures it could be inferred that Germany, Poland and the United Kingdom contribute to about 80% of the total production. The total world black currant production averaged about 205,150 tonnes in 2006. Production figures (Table 3) have then fluctuated from 166,320 t (2007) to 185,535 t (2008) and then to 136,446 t (2009). In global terms, Poland is by far the largest producer of black currants, with the UK in second place. Among the non-European countries New Zealand is the main producer followed by Canada and the United States. In Sweden, the commercial production covers approximately 350-400 hectares and there is still a great potential for increase in cultivation due to favourable climatic and soil conditions preferably in the south. Production figures for the Russian federation and China are not available, although black currants are an important soft fruit crop of increasing economical importance in these regions.

Table 3. Global black currant production 2006-2009, showing cropping area (ha) and yield (tonnes)

Country	2006		2007		2008		2009	
	Hectares	Yield	Hectares	Yield	Hectares	Yield	Hectares	Yield
Denmark	1.700	9.000	1.600	6.800	1.600	9.200	1.600	8.500
Estonia	-	-	300	500	300	150	300	350
Finland	2.000	1.800	1.900	1.500	1.860	1.500	1.860	2.000
France	2.060	11.300	2.200	7.500	2.200	8.000	2.200	9.000
Germany	1.400	7.000	1.000	4.500	1.100	5.500	1.100	5.500
Hungary	445	1.300	400	1.400	375	1.575	-	-
Lithuania	3.900	10.000	5.000	5.000	5.000	4.000	-	-
Netherlands	557	4.400	500	2.200	500	2.600	450	3.000
Poland	28.000	130.000	25.000	95.000	25.000	115.000	25.000	85.000
Sweden	350	1.200	400	1.200	350	800	300	1.200
United Kingdom	2.060	14.050	2.300	13.200	2.300	13.500	2.300	14.250
Europe Total	**40.772**	**190.050**	**40.600**	**138.800**	**40.585**	**161.825**	**35.110**	**128.800**
Australia	-	-	110	340	78	560	78	496
Canada	-	-	125	500	140	-	140	650
China	4.300	15.100	4.000	16.600	4.000	14.100	-	-
New Zealand	-	-	1.500	9.940	1.600	9.050	1.600	6.500
U.S.A	-	-	65	140	85	-	85	-
Non E.U total	**4.300**	**15.100**	**5.675**	**27.520**	**5.903**	**23.710**	**1.903**	**7.646**
World total	**45.072**	**205.150**	**46.275**	**166.320**	**46.488**	**185.535**	**37.013**	**136.446**

*(-) Production records not available **Source** 15th European Black currant conference, Nyborg, Denmark

5.2 The organic and conventional black currant

In recent years, a number of scientific studies have testified whether organically grown fruits and vegetable contain higher content of biochemical compounds with superior antioxidant properties than the ones produced through conventional farming. There is also a perception among consumers that organic foods are healthier and better tasting than the ones grown conventionally (Shepherd et al., 2005). However no keen evidence support the assumptions that organic food is healthier than the ones produced through conventional farming. Evidence supporting both organic and conventional farming is present. Reports indicate e.g. that organically grown corn had 52% more AsA and significantly higher polyphenol content in comparison to conventionally grown corn (Asami et al., 2003). Tomatoes grown organically were also found to contain high levels of flavonoids than those produced conventionally (Mitchell et al., 2007). Wang et al. (2008) reported that blueberries grown organically had higher content of phytonutrients than those produced conventionally. Studies by Hussain et al. (2011) indicate that organically grown wheat had similar content of tocochromanols as previously found in conventionally grown wheat.

Over the last 10 years there has been a rapid increase in organically grown black currants solely due to the demand and assistance provided to the growers by the European Union (Anttonen and Karjalainen, 2006). The organic cultivation in Europe is closely aligned to the EU council regulation (ECC) 2029/91. In Sweden there is an increasing demand for organically grown black currants and the demand is likely to increase even more in the near future due to the benefits attributed to its consumption.

According to U.S regulations organic cultivation involves ecological friendly production that promotes bio diversity and biological activity of the soil unlike conventional farming which permits the usage of mineral fertilizers and synthetic plant protection agents (Winter and Davis, 2006). Organic farmers use animal and crop waste, certified organic fertilizers, botanical or biological pest control and permitted synthetic material that could be broken down by sunlight and oxygen (Winter and Davis, 2006).

There are few studies conducted on black currants bringing out the comparison between organic and conventional cultivation in terms of biochemical compounds and agronomic characteristics. Studies by Anttonen and Karjalainen (2006) did not confirm any impact of the farming system on flavonol content between organic and conventional black currants. However other studies conducted by Kazimierczak et al. (2008) presented that flavonol content (Figure 4) was 25% higher in black currants grown through organic farming as compared to fruits grown conventionally. AsA and anthocyanins levels were higher by 35%

and 40% respectively in organically grown fruits as compared to conventionally produced ones. In connection to agronomic characteristics, fruit drop was found to be higher in organic farms where no fertilizers (or plant protection sprays) were used and higher fruit yield were obtained from both organic and conventionally cultivated black currants (Kahu et al., 2009).

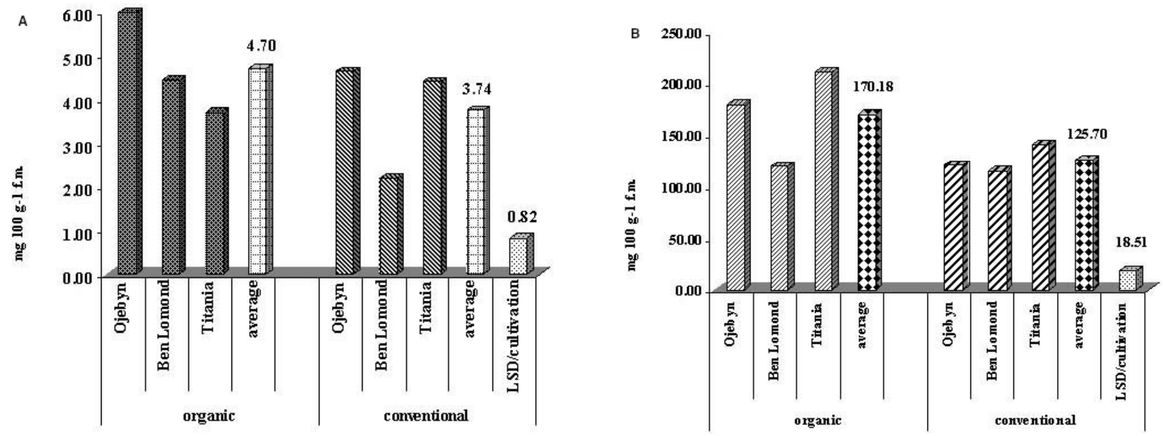


Figure 4. Flavonol content (A) and AsA content (B) among black currant germplasm from organic and conventional cultivation. (*Reprinted with permission from Kazimierczak et al., 2008).*

The higher content of phenolic compounds in organically grown black currant fruits is speculated to be due to increase in disease pressure due to non-use of pesticides. However, in some genotypes phenolic compounds are present in high level even though they are not attacked by pathogens (Howard et al., 2003).

As black currant performs best in deep, well drained and organic soils; fertilization and nitrogen supply are the key factors in organic cultivation where differences in fertilization treatments could have an impact on the level of phenolic compounds (Anttonen and Karjalainen, 2006). The cultivar choice with resistance to leaf diseases and pests is also a more important factor to take into consideration than in conventional farming (Kahu et al., 2009). Hence, increased demand arises for development of economically valuable cultivars with resistance to damaging pests and diseases.

5.3 Breeding objectives (Agronomic and quality traits)

Over the past 40 years, the breeding of black currants has undergone significant changes solely due to demands by the processing sector mainly for juice production. This sector has become a lucrative industry in Europe. The breeding targets are therefore focussing to satisfy the processors leading to development of cultivars with fruits high in AsA but moderate levels of acidity, good flavour and other sensory characteristics (Brennan and Gordon, 2002). Also, there is an increasing interest for cultivars with enhanced levels of polyphenols, including anthocyanins, due to the high antioxidant capacity (Anttonen and Karjalainen, 2006; Tabart et al., 2006; 2007). Although the main emphasis is given to the processing and nutritional quality of the fruits; breeding for better agronomic traits is equally important. The agronomic traits are not least important in the breeders and growers perspective, as the consumer prefer residue free fruit and therefore is a important move towards integrated crop management system that restricts the usage of insecticides (Brennan and Graham, 2009). Cultivars that flourish under a low input system are becoming an important factor in selection of desired genotypes (Brennan, 2008).

Modern black currant breeding programmes consider several plant characteristics. Breeding for resistant cultivars to damaging pest and disease is paramount to breeding of black currants especially for organic cultivation. The primary concern of black currant plantations in Europe are infestation by gall mite (*Cecidophyopsis ribis*), a vector for the *black currant reversion nepovirus* (BRV) that makes organic and integrated growing very risky. Resistance has been achieved by introgression of the *Ce* gene from gooseberry into *R. nigrum* followed by an extensive back crossing programme (Knight et al., 1974). PCR-based markers linked to resistance to the black currant gall mite have been developed (Brennan et al., 2009). Breeding at Balsgård, Sweden is ongoing to find other complimentary possible sources of resistance towards infestation to gall mite.

Significant damages are also caused by foliar pathogens such as mildew (*Sphaerotheca mors-uvae* (Schwein.) Berk & Curtis), septoria leaf spot (*Mycosphaerella ribis* (Fuckel) Lindau), anthracnose (*Drepanopeziza ribis* (Kleb) and the rust fungi *(Cronatium ribicola* Fisch.). Breeding is aimed for the introduction of cultivars suitable for organic cultivation for the production of healthy leaves to be used in preparation of diverse food supplements.

Another important goal in black currant breeding is the development of cultivars with good physical characteristics like upright and vigorous growth habit, long strigs, big berry size, firmness and fruits with dry pick characteristics in case of fresh fruit, increased yields and ease for mechanical harvesting.

Changing climatic conditions is a major concern for the present day black currant breeding. Climatic data suggest that there have been significant changes in temperature in the past 100 years with an increase by 1^{o}C, greater than the global average. Temperature projections in Europe suggest that by 2080 there could be an increase in temperature by 2.5^{o}C (Jones and Brennan, 2009). Altogether, climatic modelling shows that cold temperatures will decrease significantly in the future. Because black currant is an early spring blooming shrub, the risk of spring frost is a matter of serious concern due to floral damages leading to poor yield. In addition to this, mild winters and insufficient winter chilling have profound effects on time and evenness of bud break, time and duration of flowering thereby leading to considerable yield loses in susceptible cultivars (Jones and Brennan, 2009). For this reason efforts are being made to develop late flowering, spring frost tolerant and low-chill requirement germplasm with better adaptability to varying climatic conditions. The content of bioactive compounds including sugars, vitamin C and acids might be affected by latitude, temperature, day length, UV radiation and total precipitation. As black currant is cultivated under contract farming for commercial juice production, it is essential for the processors that the composition and sensory characteristics of the juice remain constant. Hence there arises a need to develop cultivars that is less affected by weather conditions; the more stable a cultivar is, the more amenable for commercial processing (Zheng et al., 2009).

In recent years, characters linked to sensory parameters, such as flavour intensity, colour, sourness, mouth feel and aroma have received considerable attention in determining the product quality leading to increased consumer acceptability. Hence, need arises to screen and select germplasm with superior sensory attributes. The identification of cultivars with good sensory characters and with a balanced sugar/acid ratio is important for juice processing. There is a steady increase in demand for fresh fruit and dessert quality black currants with high concentration of soluble solids; so breeding programmes are focussed to produce new varieties with sweeter fruits thereby leading to the increase in relatively low fresh fruit market (Brennan, 1996; 2008).

Currently, there are several active breeding programmes established in Scotland, Denmark, Sweden, Poland, Baltic countries (Lithuania, Latvia and Estonia), Norway, Finland and New Zealand to develop cultivars with enhanced nutritional composition in combination with field resistance to damaging pests and diseases, suitable to be grown in local climatic conditions. It is estimated at present about 15 breeding programmes is ongoing in the world.

5.4 Heritability studies

The genetic analysis in black currants has been fairly restricted till date, and most information is linked to agronomic traits. Zurawicz et al. (1996) using a 5 x 5 diallel cross focusing on variation and heritability of some agronomic traits like fruit yield, leaf spot resistance, plant habit etc., showed that additive genetic effects were mostly higher than non-additive genetic effects for some traits studied. Non additive effects were greater than additive effects for the traits such as plant vigour, bush size etc. Narrow sense heritability was mostly dominating for all these traits, suggesting breeding would be difficult and costly. An early identification of the best parental genotypes would therefore be highly desirable. Pluta et al. (2008) identified promising parents for the development of 'dessert quality' black currants among six black currant genotypes, which differed phenotypically and genetically. The clone 'SCRI C2/15/40' (now released as `Big Ben') and the Swedish cultivar 'Storklas', were found the most suitable dessert quality parental types due to their stable and reasonable GCA (General combining ability) effects (Pluta et al., 2008).

Inheritance of quality traits in black currants was not well known, until recent studies on heritability and breeding values for nine antioxidant traits performed by Currie et al. (2006) using a six parent half diallel cross. For most of the antioxidant traits additive gene action was the main effect with heritability estimates being moderate to high (0.46-0.80).

An initial full 6 x 6 diallel experiment during the authors MSc. project at SCRI revealed that some traits like AsA, have large components of genetic variance. AsA content had a high narrow sense heritability indicating that it is highly heritable. Traits like anthocyanin had significant reciprocal effects suggesting that the right parental combination should be chosen for creation of crosses, hence amenable to future breeding. However the data needs to be confirmed as limited information is available on genotype-environment interactions.

6. Bioactive compounds

6.1 Phenolic compounds

Phenolic compounds are secondary plant metabolites, present mostly in consumed foods of plant origin. These compounds are reported as bioactive components having health benefits against cancer or cardiovascular diseases (Shahidi and Naczk, 1995; Scalbert et al., 2005; Karjalainen et al., 2009). They have also been attributed to play an important role against microbial attacks (Mikkonen et al., 2001). Reviews have indicated that many phenolic compounds are epicuticular and thus give quick response to infections and injury (Witzell et al., 2003). The molecules range from simple individual hydroxylated aromatic ring to complex polymeric molecules (Harborne and Williams, 1995).

The polyphenol molecules are separated into different classes according to their number of phenol rings and to the structural elements connecting these rings. The berry fruits are known to contain a wide array of phenolic compounds (Figure 5) such as flavonoids, phenolic acids, tannin, lignans and stilbenes. The diverse array of phenolic compounds present in the berry fruits, especially black currants contribute to their astringency, bitterness, colour, part of flavor and also for the oxidative stability of their derived products.

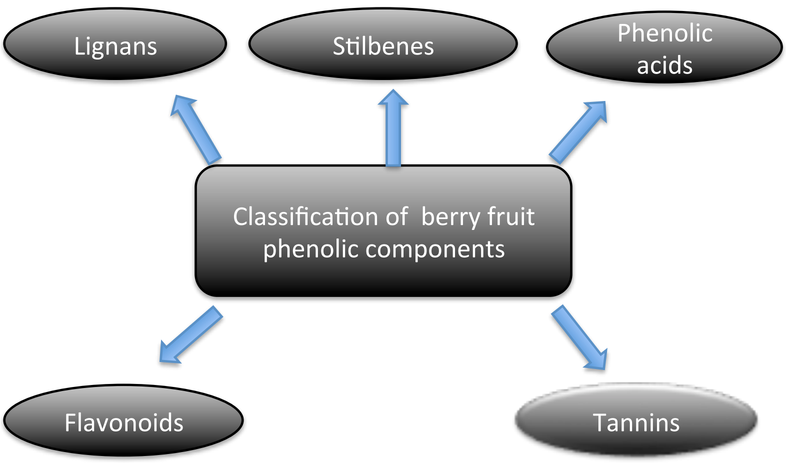
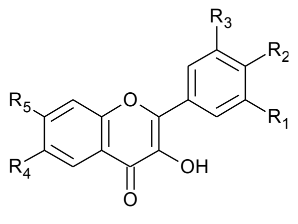


Figure 5. The classification of phenolic compounds found in berry fruits (Paredes-López et al., 2010).

Generally black currants contain high levels of polyphenols (500-1342 mg/100g of fresh weight) especially anthocyanins, phenolic acid derivatives (both hydroxybenzoic and hydroxycinnamic acids), flavonols (glycosides of myricetin, quercetin, kaempferol and isorhamnetin) as well as proanthocyanidins as compared to other berries (e.g., strawberry and raspberry) making them an interesting target for the functional food sector (Karjalainen et al., 2009; Mattila et al., 2011). Many studies report about the high concentrations of phenolic compounds in black currants; a number of investigations have evaluated the different polyphenolic fractions of the fruits and to a lesser extent other plant parts like buds and leaves (Mikkonen et al., 2001; Määttä et al., 2003; Anttonen and Karjalainen, 2006; Tabart et al., 2006, 2007; Sojka et al., 2009; Raudsepp et al., 2010). The phenolic extracts from black currant have been demonstrated to provide effective neuroprotection against oxidative stress induced by neuronal damages in human cell cultures (Karjalainen et al., 2009). McGhie et al. (2007) in a recent intervention showed that plasma antioxidant capacity to be significantly increased in response to black currant juice intake compared with a placebo control, providing evidence that black currants may offer protection against oxidative stress-related health-conditions.

Black currants contain a wide range of flavonols (Figure 6) with high levels of myricetin and relatively high amount of quercetin. Both myricetin and quercetin have been reported to possess neuroprotective activity. Recently, isorhamnetin was found in black currants which is also of interest in terms of neuroprotective effect (Anttonen and Karjalainen, 2006). Myricetin also inhibits the formation and extension of beta-amyloid fibrils in a dose dependent manner and destabilise the performed amyloid beta *in vitro.* Furthermore, quercetin and isorhamnetin are known to reduce blood pressure and improve blood flow evoking a potential protective function against development of vascular type of dementia (Karjalainen et al., 2009).



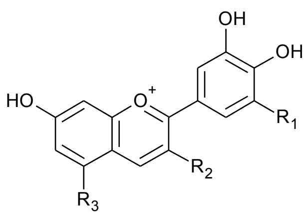
Compound	R_1	R_2	R_3	R_4	R_5
Quercetin	OH	OH	H	OH	OH
Kaempferol	H	OH	H	OH	OH
Myrecetin	OH	OH	OH	OH	OH
Isorhamnetin	OCH_3	OH	H	OH	OH

Figure 6. Image depicting the structures of major flavonols present in black currant.

The above mentioned therapeutic effects of black currant polyphenols, increase its importance as a natural functional food product. Hence breeding and selection of high total and individual polyphenolic content among germplasm available, raises the possibility of breeding for improved antioxidant activity.

6.2 Anthocyanins

Anthocyanins are naturally occurring water-soluble pigments responsible for imparting colour to fruits, vegetables and other plant parts. They play a crucial role in attracting animals to carry out pollination and to disperse seeds in plants. The most common anthocyanins found in plants include pelargonidin, cyanidin, delphinidin, penonidin, petunidin and malvidin, their classification is based on the number and position of hydroxyl and carboxyl groups on the flavinium nucleus. Anthocyanins belonging to the flavonoid class of phenolic compounds are the most important, with a mean content in fresh fruit of approximately 250 mg/100g, constituting about 80% of all the flavonoids. The common anthocyanins in blackcurrants (Figure 7) have been found to be cyanidin-3-O-β-glucoside, cyanidin-3-O-β-rutinoside, delphinidin-3-O-β-glucoside and delphinidin-3-O-β-rutinoside and the proportions of these compounds vary between different cultivars (Anttonen and Karjalainen, 2006).



Compound	**R_1**	**R_2**	**R_3**
Cyanidin-3-O-β-glucoside	H	O-glucose	OH
Cyanidin-3-O-β-rutinoside	H	O-rutinose	OH
Delphinidin-3-O-β-glucoside	OH	O-glucose	OH
Delphinidin-3-O-β-rutinoside	OH	O-rutinose	OH

Figure 7. Image depicting the structures of anthocyanins present in black currant.

The anthocyanin content may vary from one fruit to the other and the reason for this might be variation in the action of internal and external factors including genetic and agronomic ones. Thus intensity of light and temperature might influence as might processing and storage. The stability of anthocyanins might be improved by microencapsulation techniques such as spray drying (Ersus and Yurdagel, 2007). Barczak and Kolodziejczyk (2011) used maltodextrins as a coating or cell wall material resulting in the highest content of anthocyanin and polyphenol content at the end of the spray drying process. Earlier anthocyanins have not been studied and recognized as a physiological functional food factor. However, recent studies demonstrate that anthocyanin extracts display a wide range of biological activities, including antioxidant, antimicrobial and anticarcinogenic activities; maintaining eye health and vision and neuroprotective effects (Han et al., 2007; Ramos 2008). Anti-inflammatory activities of anthocyanins have also been reported recently (Seeram et al., 2001). Matsumoto et al. (2006) demonstrated in animal models that black currant anthocyanins were absorbed in ocular tissues. The oral administration of anthocyanins in the same animal models prevented a myopic refractory shift partially through relaxing effect on bovine ciliary smooth muscles. Although anthocyanins have been shown to exhibit a protective effect against human diseases *in vitro,* there is a need for further research to be done on the low and partial bio availability demonstrated in many studies (Karjalainen et al., 2009).

From breeding point of view, cultivars with enhanced levels of anthocyanins are now in demand from juice processors and consumers due to an increasing interest in the antioxidant activity and potential health benefits of fruits (Lister et al., 2002). Black currants have high anthocyanins levels especially of delphinidins which are highly stable. Breeding programmes in Scotland have preferentially selected on delphinidins levels in black currants for over 15 years, which are now favoured by the processing market and breeders have included it among the breeding objectives because of the deep colour it imparts. Processors are particularly interested in the dark coloured fruits as the quality of the juice depends on the fruit which have rich colour (Brennan, 1996). To satisfy these requirements breeding programmes regularly screen cultivars which possess high anthocyanin levels and thereby enabling the feasibility of breeding cultivars with enhanced levels in combination with other quality and agronomic traits.

6.3 Ascorbic acid (vitamin C)

Ascorbic acid (vitamin C), also known as ascorbate (Walker et al., 2006), is a water-soluble antioxidant present in plant tissues (Smirnoff, 2000). AsA plays an important role in cellular metabolism like photoprotection, cell cycle control, expansion of cells, cell loosening, stress perception and response to pathogens in plants (Hancock and Viola, 2005). Vitamin C is easily absorbed by the human body due to its active transport in the intestines as it is a water-soluble compound, but it is not stored. Hence a natural intake of vitamin C can be obtained from a diet that involves the consumption of fresh fruits and green leafy vegetables.

Black currants are considered to be a rich source of AsA (Table 4). In particular the proven high AsA levels in the fruits are an important attribute of the crop. Also, the high concentration of AsA in the fruit is also an important marketing tool and an important breeding target (Brennan and Gordon, 2002). Commonly grown black currant cultivars contain AsA levels ranging from 130-200 mg/100ml juice to over 350-450 mg/100 ml juice in some breeding lines (Brennan, 2008).

Even higher levels have reported in sub species of *R. nigrum* in particular *R. nigrum* var. *sibricum* (Volunez and Zazulina, 1980). In Scandinavian cultivars it has been reported that the content of AsA in fruits was found to be lower in comparison with the western European types (Kuusi, 1965; Heiberg et al., 1992). The AsA content in black currants is found more stable than that of most other sources, solely due to the protective effect of anthocyanins and other flavonoids present within the berries (Hooper and Ayers, 1950; Morton, 1968). Sugars act as substrates for the biosynthesis of AsA. The AsA accumulation in the black currant fruit occurs during the early berry expansion phase after flowering. The AsA content established at this early stages remain stable thereafter (Hancock et al., 2007). The inheritance of high AsA levels in black currants is known to be strongly connected with the maternal influence but there are reports of variation due to environmental factors (Brennan, 2008). The actual content of AsA was shown to vary in between years although cultivar rankings remained stable (Walker et al., 2010). Hence, breeding of cultivars that are high in AsA is an achievable objective.

Table 4. AsA content (mg 100g^{-1} fruit) in black currant in comparison with other fruits (Belitz et al., 2004).

Fruit	AsA content	Fruit	AsA content
Apple	3-35	Black currant	177
Apricot	5-15	Orange	50
Cherry	8-37	Grapefruit	40
Peach	5-29	Lemon	50
Strawberry	75	Pineapple	25
Raspberry	25	Blackberry	17
Red currant	40	Melons	6-32

6.4 Sensory components

Sensory properties of black currants are of considerable importance to the processing sector and ultimately to the consumers. Sensory components like sugars and organic acids are among the important drivers that contribute to the quality of the juice. Additionally flavour, mouth feel, aroma and after taste are important quality factors of fruits and juices (Brennan et al., 2003). Very little information is available about the evolution of sugars and organic acids in blackcurrant fruits. However, recent work by Hancock et al. (2007) brought some light towards understanding the accumulation of ascorbic acid and other constituents such as sugars, during fruit ripening and development.

Fruits with pleasant sensory characteristics are often considered to have high content of sugars with relatively low amount of acids (Zheng et al., 2009). Sugars and organic acids play an important role in the normal metabolism, e.g. during maturation and senescence of the fruit, and are therefore important parameters at harvest. Sugars impart sweetness to the juice thereby increasing its palatability; organic acids on the other hand regulate the pH within the fruit and affect the formation of off-flavours that might affect the product quality during processing. Black currant berries might be prone to rejection if they are too acidic and astringent. The content of sugars and sugar/acid ratio contribute to the overall sensory quality of the fruit. Glucose, fructose and sucrose are the major sugars found in blackcurrant fruits (Pérez et al., 1997). Citric acid is the major organic acid of the fruits (about 44.08 mg·g$_{-1}$ fw) with minor concentrations of succinic, malic and quinic acid. The content of different acids considerably varies between genotypes (Zheng at al., 2009).

Brennan et al. (1997) reported high level of variation in sensory profile (flavour, mouth feel, aroma, after taste) within blackcurrant and further research showed that the sensory attributes associated with particular genotypes endure in processed juice products even at juice concentrations of only 25% (Brennan et al., 2003). Utilization of other *Ribes* species in breeding for pest and disease resistance can severely affect the sensory characters of the fruit, at least in the early generations - for instance, off-tastes have been noted in the flavour profiles of genotypes developed from *R. ussuriense* and *R. petiolare* (Brennan and Graham, 2009).

As the fresh fruit market for dessert quality black currants is steadily increasing, there is a need to develop naturally sweet cultivars. Additionally, the juice processing industry wants to reduce the addition of sugars to the processed fruit. Hence breeding programmes are focused on screening the cultivars with high level of sugars and relatively low acid content to produce new varieties with sweeter fruits, thereby leading to increase in sales of relatively low fresh fruit market for black currants.

6.5 Essential fatty acids

The presence of a high content of γ-linolenic acid (GLA) and of other nutritionally important fatty acids like α-linolenic acid (ALA) in black currant seeds, impact positively on the marketability of its oil as a health supplement. Over 20% variation in the content of GLA has been reported among black currant genotypes (Ruiz Del Catillo et al., 2004). The other minor nutritionally important fatty acids, stearidonic acid and α-linolenic acid, varied in a range of 2-4% and 10-19% among genotypes respectively. The breeding for high GLA content in seeds is achievable with possibilities of integrating other fruit quality characteristics (Brennan, 2008).

6.6 Volatile compounds

The volatile fractions of black currant constitutes of more than 150 compounds responsible for the characteristic flavour and aroma impact from black currants (Varming et al., 2004). Black currants possess glandular trichomes containing characteristic terpenoids on the surface of leaves, buds and fruits (Iversen et al., 1998). The aroma compounds of black currant are composed of a complex mixture of saturated and unsaturated aldehydes and ketones, esters and alcohols (Varming et al., 2004). Oxygenated compounds which include linalool, citronellol, isodiosphenol, diosphenol, p-mentha-1,8-dien-4-ol, m-cymen-8-ol, ciscarverol, isopulegol and perillyl alcohol are responsible for the characteristic ‘floral’, ‘minty’, ‘coniferous’ and ‘terpene’ like aroma of fresh black currant fruits (Dvaranauskaite et al., 2009). Unripe fruits lack the characteristic flavor; hence it has been assumed that volatile components of fruits are developed during the ripening process. In addition, the essential oils of black currant buds accumulate large amounts of volatile compounds where the monoterpenes that include α-and β-pinene, sabiene, δ-3-carene, limonene, phellandrene and terpinolene make up the major part. The rest of the volatile compounds in the black currant buds are sesquiterpenes (Le Quere and Latrasse, 1990). Remarkable variation in the content of total and specific essential oil volatile components has been found in the buds of black currant cultivars at different developmental stages (Dvaranauskaite et al., 2009).

Changes in volatile compositions have been reported during the processing of black currant fruits (Iversen et al., 1998). Thermal treatment on black currant juices decreases the intensity of aroma and quality (Varming et al., 2004). The effects of heating were correlated with a decrease in concentration of terpenes and a general increase in concentration of aldehydes (Boccorh et al., 1999). During the process of concentration of juice an overall deficit of some esters, alcohols, carbonyls and terpenes have been seen, with recovery of some volatiles (Varming et al., 2004). Variations in the aroma compositions have been found to be affected by several factors like genotypes, length of growing season, climatic factors, ripeness at harvest, and post harvest storage conditions (Boccorh et al., 1999; Kampuss et al., 2008).

7. Pests and disease resistance

7.1 Black currant gall mite (*Cecidophyopsis ribis* Westw.)

One of the biggest problems encountered in commercial black currant plantations in the majority of the European countries is the infestation by arachnid gall mite (*Cecidophyopsis ribis* Westw.). De Lillo and Duso (1996) describe *Cecidophyopsis ribis* as a cigar shaped Eriophyid mite comprising of four functional legs. Gall mites cause galling of the buds leading to a damaging condition known as "big bud" (Brennan et al., 2008; 2009). Furthermore, the gall mite is the sole vector of *black currant reversion virus* (BRV) which could render the plant sterile within two years thereby leading to severe yield losses (Jones, and McGavin, 2002). In Sweden this pest is a matter of concern for many black currant growers and the most efficient pesticides for mite control have been withdrawn due to environmental reasons.

Gall mites disperse rapidly between the bushes and start to infest new buds (Smolarz, 1993). Egg laying by female mites starts in January in the buds when the temperature is over 5^{o}C and mites population begin to rapidly increase by late March (Mitchell et al., 2011). The infestation commences during the time of flowering and later during the vegetative season at temperatures between 13-14^{o}C. Low temperatures and rainy weather hinder the chances of its transmission (Rubauskis et al., 2006). The mites disperse from the infected buds and migrate to the branches to infect new buds. The common agent for mite dispersal is wind, although some of them maybe carried by insects and birds that visit infected bushes (Thresh, 1996). The adult and larvae cause damage by feeding inside buds (Figure 8) leading to malformation and irregular growth. The drying of the galled buds has a negative impact on the development of leaves and flowers. The damage caused depends on the percentage of galled buds per bush and an infected bush can contain over 100-galled buds (Mitchell et al., 2011).

Figure 8. Image of galled buds (picture by the author) and electron microscopic image of a gall mite feeding on the cells within a galled bud. Image accessed from Fruitgateway, 2011) (http://www.fruitdisease.co.uk/EntomologyResearchPage6.asp)

Control ingredients such as endosulfan and amitraz have been used to control gall mite but permitted plant protection sprays are now restricted to sulphur sprays. The two mentioned chemical agents have been withdrawn from the EU countries due to environmental and health risks and growing interest towards promoting integrated and organic production systems. Hence the best strategy to support organic and sustainable black currant growing would be to breed and introduce resistant cultivars. Resistant germplasm is available within the *Ribes* genus, derived notably from gooseberry (*R. grossularia*) (Knight et al., 1974). The introgression of the resistant single dominant gene *Ce* from *R. grossularia* into black currant to give resistant cultivars have been successful through development of resistant F_1 allotetraploids followed by an extensive back crossing programme (Brennan, 2008). Another useful sources of resistance determined by a dominant gene, *P* has been transferred from *Ribes nigrum* var. *sibiricum, R. pauciflorum*, *R. petiolare* and *R. ussuriense* (Anderson, 1971). In the genotypes containing the gene *P*, the mites can infest the buds and transmit the reversion virus even though they don't survive long enough inside the buds (Jones et al., 1998). In contrast mites cannot infect the buds in bushes carrying the resistant gene *Ce* proving that resistance conferred by the *Ce* gene is far superior than that by the gene *P* in preventing mite infestation.

In Scotland, breeding programmes have led to the development of numerous gall mite resistant cultivars with commercial quality. One such cultivar is 'Ben Hope' preferably developed for integrated growing. However, recently indications of mite symptoms were observed in this cultivar leading to the assumption that the resistance might have been broken down by the mite (Brennan et al., 2009). Inspite of all this, the use of cultivars containing *Ce* gene seems so far to be the best mean of control against the mites. The development of a PCR-based marker linked to the *Ce* resistance gene now facilitates the screening of a large number of germplasm already in the seedling stage (Brennan et al., 2009). The newly released commercial cultivar 'Ben Finlay' has resistance to gall mite as well as to reversion virus solely due to the *Ce* gene (Mitchell et al., 2011). However other alternative sources have to be investigated with comprehensive sources of resistance to gall mite as well as to reversion virus which it transmits, especially if virulence develops for the gene *Ce* in the future.

7.2 Black currant reversion disease

Reversion disease, which affects both black and red currants is the most important viral disease and it was described over 100 years ago in Netherlands (Jones, 2000). Immunity to the disease has been reported in gooseberry (Adam and Thresh, 1987). The severity of the disease is marked by the crop loss it causes and its occurrence worldwide except in North America. In the plants affected by reversion, symptoms usually take 2-3 years to develop but only on few branches which is later followed by infection which is fully systemic causing substantial losses in production (Adams and Thresh, 1987; Jones and McGavin, 2002). Attempts to identify the casual agent of reversion disease were made for several years with no success. However Lemmetty et al. (1997) was able to isolate the virus from the black currants infected with the R form of the reversion disease by transmitting the virus through mechanical inoculation of sap. The virus has been characterised as the *black currant reversion virus* (BRV), genus *Nepovirus*, family *Comoviridae* (Jones and McGavin, 2002).

Two distinct strains of reversion disease are distinguished, the common European form (E) and a more severe (R) form found through Scandinavia and the former Soviet Union (Jones et al., 1998). The two forms differ based on the degree of severity expressed among the affected black currant plants (Adams and Thresh, 1987). Effective control of this disease is difficult because the virus is spread through the feeding of the buds by the Eriophyid mite in the genus *Cecidophyopsis* within the buds (Jones, 2000; Jones and McGavin, 2002).

The disease causes changes in plant physiological state, mostly on the leaf appearance and reduction in the density of hairs on flower buds followed by increase in pigmentation of the buds. In black currants the disease is characterised by a decrease in the leaf number and size, with reduced marginal serrations and number of veins. Furthermore, a less clearly defined sinus at the petiole is observed (Jones and McGavin, 2002). The flowers infected by either E or R forms are usually sterile leading to severe yield losses in production. In contrast, the leaf and flower symptoms are much less noticeable in red currants making it the most difficult *Ribes* material to detect BRV reliably (Adams and Thresh, 1987).

Previously, the detection of reversion disease was difficult by the use of biological techniques. Normally the disease could not be evaluated until 2 years after the transmittance. Two years was the time it took for the symptoms to clearly develop after mite infection. In breeding mite infection took place by graft inoculating material to susceptible black currant cultivars (Adams and Thresh, 1987; Jones, 1992). However, new molecular methods like the improved RT-PCR technique to analyse BRV, allows early infection to be conclusively and rapidly detected in 1-2 days thereby enabling efficient screening and a means to follow disease development accurately (Jones and McGavin, 2002; Dolan et al., 2011).

7.3 Mildew (*Sphaerotheca mors-uvae* (Schwein) Berk & Curtis)

Powdery mildew is a common foliar problem caused by *Sphaerotheca mors-uvae* (Schwein) currently known as *Podosphaera mors-uvae* (Schwein.) Braun & Takam. (Braun and Tackamatsu, 2000). The fungus overwinters on shoot twigs and during the spring and summer it infects leaves, shoots tips and fruits. First recorded on gooseberries (*R. grossularia*) in 1900 in Ireland, the fungus has been a major limiting factor for successful production of gooseberries. The disease also spread in an alarming rate throughout Europe on black currants by 1960 (Brennan, 1996). On susceptible cultivars, the symptoms of the disease (Figure 9) are characterized by white powdery growths on surface of leaves and young green shoots. Scorch like symptoms appear on the leaves that become deformed and dry out. The infected leaves may fall off during warm weather and infected plants have a stunted growth. The severely affected fruits develop a dark brown, felt-like coating that renders the fruits unmarketable (Hummer and Dale, 2010).

A range of resistance genes for powdery mildew has been identified in black currant varieties: the *Sph* series comprising *Sph1* from gooseberry species (*R. oxyacanthoides)* and *Sph2* from the Swedish cultivar 'Öjebyn'. Two complimentary genes M_1 and M_2 control the resistance in the Finish cultivar 'Brödtorp'. The *Sph2* is among the best know resistance genes against mildew (Brennan, 1996). However, the resistance to mildew seems to be broken down at least in parts as 14 different races of *Sphaerotheca mors-uvae* were identified by Trajkovski and Pääsuke (1976). Trajkovski and co-worker identified two black currant cultivars from northern Sweden, 'Sunderbyn II' and 'Matkakoski' as resistant cultivars with high fruit quality. The identification of these cultivars had a great impact on breeding of mildew resistant genotypes in Sweden. 'Sunderbyn II' has remained resistant for over 50 years and the resistance is thought to be associated with epidermal cell developmental factors (Temmen et al., 1980). This resistance appears to be operated by a single dominant gene or a block of closely linked genes. According to Trajkovski (1976), durable resistance in the genotypes is characterized by accumulation of low levels of ascorbic acid in the newly developed shoots with the concentration of o-dihydroxy phenols being relatively high.

Figure 9. Picture of mildew affected leaves of black currant (Picture by the author)

Furthermore, the content of certain polyphenols in black currant shoots has been associated with resistance to mildew, thus indicating that the defense mechanism involves biochemical reactions between the host tissues and the invading pathogen (Trajkovski and Pääsuke, 1976). Further the breeding of interspecific black currant hybrids by utilizing *R. americanum* as a potential source of resistance against mildew and other leaf diseases has been reported (Siksnianas et al., 2005).

Control of mildew is otherwise dependent on the use of chemical sprays, but continued breeding for durable resistance in black currant cultivars could successfully limit the possibility of the disease and thus lower production costs.

7.4 Septoria leaf spot (*Mycosphaerella ribis* (Fuckel) Lindau)

Septoria leaf spot is an important disease of black currants in Scandinavia, east European countries, Russia and New Zealand. The disease causes premature leaf fall, stunted growth in shoots and reduced crop yield. The disease (Figure 10) appears as small dark spots with a pale brown centre surrounded with a dark brown margin, making them easy to differentiate from anthracnose (Berrie, 2011).

Figure 10. Picture of septoria affected leaf of black currant (Picture by the author)

In bushes affected by septoria, reduced photosynthetic activity and increased respiration and transpiration were observed (Lebedeva and Ivanteeva, 1975). The fungus survives during winter periods in the form of sclerotia and sexual fruiting bodies (perithecia). The ascospores mature during springtime and are dispersed from the perithecia infesting the leaves. This is linked with bud burst. The conidia appear on the leaf spots in June and are spread by rain splash during summer. The favourable conditions for fungal development ranges from 20-25^{o}C.

Resistance to septoria leaf spot has been found in *R. americanum, R. dikuscha* and *R. nigrum sibiricum* (Brennan, 2008).

7.5 Black currant leaf spot (Anthracnose) (*Drepanopeziza ribis* (Kleb.) Höhnel)

Anthracnose occurs throughout Europe and North America affecting the leaves (Figure 11) causing small, dark brown necrotic lesions leading to premature defoliation in severe cases. Small greyish disc like fruiting bodies (acervuli) developing in the center of the spots characterize the disease. The disease can also be found on fruits, where in severe cases the fruits crack open and develop bad taste. Further, the disease may lead to loss of crop in subsequent years. Infection levels are increasing in rainy conditions, due to splash dispersal of spores. The fungi over winters in the sexual state on fallen leaves affected by the disease and subsequently infect newly emerging leaves the following spring (Berrie, 2011). Xu et al. (2009) suggest that infection by conidia takes place on old leaves on extension shoots and that wet conditions are favorable for the disease to develop. Field monitoring has revealed that significant disease infestation occurs only by late July in Sweden.

Figure 11. Image showing black currant leaves affected by anthracnose (Picture by the author)

Resistance sources identified are *R. nigrum* var. *sibricum* and *R. dikuscha*. The robust resistance of *R. dikuscha* is controlled by two complementary genes, *Pr1* and *Pr2* (Anderson, 1972). Other sources of resistance that relate to black currants are *R. americanum, R. pauciflorum* and *R. glutinosum* (Brennan, 2008).

The majority of new black currant cultivars have reasonable resistance to anthracnose and screening for resistant germplasm is a routine in most breeding programs.

7.6 White pine blister rust (*Cronartium ribicola* Fisch.)

The two species of rust identified on black currants are *Cronartium ribicola* Fisch. (white pine blister rust) and *Puccinia ribesii-caricis*. European black currants are more susceptible to white pine blister rust than red or white currants. In gooseberries *Puccinia ribesii-caricis* is the most common rust than in currants generally (Hummer and Dale, 2010). Rust occurs in Asia, Europe and North America. The emerging *Ribes* industry in North America was brought to a halt with the introduction of white pine blister rust on timber stocks imported from Europe in the 1920s (Barney and Hummer, 2005).

Black currant bushes have a significant role in the lifecycle of this disease and as a result there is a need for resistant cultivars in areas where susceptible pines are grown, often resulting in death of the trees or young plantations. In North America, where pine is an important crop, eradication programmes for *Ribes* were introduced as a strategy for disease control. Nowadays quarantine procedures are still severe for the germplasm to be introduced into the U.S (Brennan, 2008).

Figure 12. Typical symptoms of rust on black currant leaves (Picture by the author)

The rust disease is not noticeable until late summer. After infection the symptoms (Figure 12) appear as lesions, with small yellow cup like spots on leaf upper surface and developing uredinia on the leaf abaxial surfaces formed from minute orange hair like structures. The infected plants are weakened and may defoliate prematurely with a negative impact on yield the following season (Hummer and Barney, 2002).

In black currants, resistance to *C. ribicola* was achieved by incorporating of the dominant gene *Cr* from *R. ussuriense* which lead to the development of the resistant cultivars 'Consort', 'Coronet' and 'Crusader'. Further breeding efforts in Sweden produced the rust immune cultivar ‘Titania’, with ‘Consort’ in its parentage. The resistance conferred by the *Cr* gene is fairly robust and research is being carried out currently to align *Ribes* resistance with resistance in *Pinus* spp. (Brennan, 2008).

7.7 Aphids

The most important aphids (Homoptera, Aphididae) that commonly infest *Ribes* are the permanent currant aphid (*Aphis scheneideri* Börne), the red currant blister aphid (*Cryptomyzus ribis*), the currant-sowthistle aphid (*Hyperomyzus lactucae*), and the European gooseberry aphid (*Aphis grossulariacae*) (Mitchell et al., 2011). These pests feed on the underside of the leaf (Figure 13) causing a characteristic blistering and distortion of the leaves. The leaf damages caused by aphids ranges from cosmetic to severe. The colour of the blistering is purple to red in red currants while yellowish green in black currants. During spring, infestation can cause the curling down and yellow mottling of leaves, preferably on shoot tips. In some cases the growth of the shoot may be stunted.

Figure 13. Images showing the European currant aphid (*Aphis schneideri* Börne) and distorted leaves caused by feeding. (Pictures by the author)

Differences in susceptibilities of aphids between *Ribes* species and cultivars towards ahpids have been reported by Keep and Briggs (1971). Currently not much additional information is available about resistant cultivars to aphids, as the aphid resistance has not been included in most breeding programmes (Mitchell et al., 2011). Aphid damage to black currant plantations can be controlled by application of pesticide or soap treatment before flowering and after harvest (Hummer and Barney, 2002; Hummer and Dale, 2010).

7.8 Black currant leaf curling midge (*Dasyneura tetensi* Rübsaamen)

First recorded as a pest in Kent, England in 1928, the black currant leaf-curling midge subsequently spread through the UK and parts of Europe. The pest is most noticeable during the white larval stage. The larvae turn orange and grow to a length of about 2.5 mm. The adult stage is a short-lived period characterised by a small, dark brown to orange body and pale stripped abdomen (Mitchell et al., 2011). The life cycle of the midge has been extensively studied by Cross and Crook (1999), where they describe the larvae to overwinter in cocoons in the upper soil surface under the black currant bushes. In spring the midges pupate and appear as adults, which begin to mate and lay eggs in the folds of young leaves and growing points of green shoots. After the eggs begin to hatch, the larvae feeding on the surface of the leaves causes a crinkled and folding like appearance. The crinkling and folding has a direct impact on the expansion of the leaves. The midge attacks young shoots causing stunted growth and temporary death of shoots, the effects of the pest on yield has not been quantified (Hellqvist, 2005). The damaged buds at the base of the plant that break earliest during the season are the first parts of the bush that show signs of damage. In black currant nurseries, this pest is a matter of concern where in severe infections the young plants have to be discarded or completely destroyed.

There is a large variation in susceptibility to this pest between black currant cultivars (Brennan, 2008). Resistance has been reported from the species *R. americanum* and *R. dikuscha* controlled by a dominant gene *Dt* within the wild species of *Eucoreosma* jointly with cultivars such as 'Ben Connan' (Keep, 1985). Antibiosis resistance has been observed in some genotypes, ranging from no gall formation and high larval mortality, to complete galling and slow development of the larvae (Hellqvist and Larsson, 1998). In Sweden, two strains of the midge have been recorded: a virulent biotype adaptable to the resistant host (with the *Dt* gene) and an avirulent biotype that is not adaptable (Hellqvist, 2001).

8. The current study on black currants

The present PhD project is an attempt to study the ontogenetic and genetic effects on the health-promoting compounds in black currant material.

8.1 Overall objective

The objective of this project is to study and estimate the ontogenetic effects, effects of genotype, and genotype-environment interaction on health-promoting compounds (single polyphenols and ascorbic acid) in black currant buds, leaves and fruits. Additionally organic acids and individual sugars will also be determined in the fruit. This entails the determination of biochemical variations in different plant parts of advanced plant material established in comparative organic trials in the south (Balsgård) (56°06' N, 14°10' E) and north (Öjebyn) (65°21' N, 21°23' E) of Sweden. In parallel, the project will investigate possible association between content of polyphenols in leaves and different major leaf diseases and pests in black currant seedling populations. This study takes place for three years thereby making it possible to detect the yearly variation.

On completion, the project will provide valuable information of the phenolic compounds in different plant organs that could be used to enhance the nutritional content in the black currant material and support the development of resistant cultivars for sustainable cultivation. The information will thus (i) aid black currant breeders to develop new cultivars, adaptable and hardy enough for the changing climate, (ii) provide organic growers with information on cultivars resistant to severe pests and diseases, and with enhanced nutritional content, (iii) provide cultivars to north of Sweden with increased ascorbic acid and polyphenol content, (iv) support the health industry in preparation of functional food ingredients from different black currant parts with high antioxidant capacity, (v) support the processing sector with the introduction of fruits with high quality and sensory attributes, (vi) support researchers investigating the health properties of single polyphenols identified in this study, and finally, (vii) benefit consumers and the nation on the whole due to health benefits associated from consumption of antioxidant and polyphenol rich black currant products.

The specific objectives are to:

- Optimize the conditions for extractions, identification and analysis of single polyphenols in buds, leaves and fruits by HPLC-DAD and HPLC-ESI-MS

- Evaluate performance and field resistance towards pests and diseases in comparative organic field trials in the north (Öjebyn) and south (Balsgård) of Sweden
- Study genetic effects, G-E interactions and reveal the role of ontogenetic stage of buds, leaves and fruits on the content of specific polyphenols
- Study AsA, organic acids and sugars in fruits following their ontogenetic development
- Study possible association between polyphenols and leaf diseases and pests
- Investigate the effect of yearly variation, latitude and growing seasons on the content of AsA and specific polyphenols

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