The best tasting pear in the world

is there a future for the cultivation of *Pyrus sinkiangensis* in Sweden?

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Abstract

Pears are next to apples one of the most important fruit crops of the temperate world but only a few cultivars are being produced. There is great genetic diversity within the genus *Pyrus,* and the wide dispersion of the species has created pears with many different traits and qualities. Commercially produced pears are divided into two groups, Occidental and Oriental pears, and production of the two groups is practically limited to each continent with few exceptions. The purpose of this study has been to explore through literature and research studies the characteristics and production methods of a Chinese pear with significant domestic importance, *Pyrus sinkiangensis* Yü. By comparing qualities with the common pear, *Pyrus communis*, the aim has been to identify arguments for an introduction of *P. sinkiangensis* Yü in commercial production in southern Sweden. The results of the study found evidence for disease resistance in the Oriental group, that may be advantageous in European cultivation. Another potential for *P. sinkiangensis* Yü in a European commercial environment may be the fundamental difference in ripening habits between the two groups. In comparison, the fruit of *P. communis* requires cold treatments to obtain optimum quality but *P. sinkiangensis* Yü is ready for consumption immediately upon harvest without loss in storability.

Keywords: Fragrant pear, Korla pear, Xiang li, *Pyrus sinkiangensis*

Sammanfattning

Päron är efter äpplen en av de viktigaste fruktgrödorna i den tempererade världen, men endast ett fåtal sorter produceras. Det finns en stor genetisk mångfald inom släktet *Pyrus* och artens stora spridning har skapat päron med många olika egenskaper och kvaliteter. Kommersiellt producerade päron delas in i två grupper, europeiska och asiatiska päron. Produktionen av de två grupperna är praktiskt taget begränsad till vardera kontinent med få undantag. Utgångspunkten med denna studie har varit att genom litteratur- och forskningsstudier utforska egenskaperna och produktionsmetoderna hos ett kinesiskt päron med betydande inhemsk betydelse, *Pyrus sinkiangensis* Yü. Genom att jämföra kvaliteter med det europeiska päronet, *Pyrus communis*, har syftet varit att identifiera argument för en introduktion av *P. sinkiangensis* Yü i kommersiell produktion i södra Sverige. Resultaten av studien fann bevis för sjukdomsresistens i den asiatiska gruppen, vilket kan vara fördelaktigt i europeisk odling. En annan potential för *P. sinkiangensis* Yü i en europeisk kommersiell miljö kan vara den grundläggande skillnaden i mognadsprocess mellan de två grupperna. Medan frukten av *P. communis* kräver kylbehandlingar för att erhålla optimal kvalitet, är *P. sinkiangensis* Yü redo för konsumtion direkt efter skörd utan förlust av lagringsbarhet.

Nyckelord: Fragrant pear, Korla pear, Xiang li, *Pyrus sinkiangensis*

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Abbreviations

ABA	Abscisic acid
ACO	1-aminicyclopropane-1-carboxylate oxidase
AFLP	Amplified fragment length polymorhism
CA	Controlled atmosphere
GLV	Green leaf volatile
NAA	Naphtalene acetic acid
PRD	Partial rootzone drying
RDI	Regulated deficit irrigation
'OH x F'	Old home x Farmingdale
SSC	Soluble solid content
XTH	Xyloglucan endotransglucosylase/hydrolase

Preface

There is a pear that has been cultivated for many centuries, some say thousands of years, in the Xinjiang Uygur Autonomous Region of China. Where it is grown, it is immensely popular, and it has been deemed the best-tasting pear in the world by some. Over the years there has been an increased demand for these pears internationally and a portion of the pears produced in Xinjiang every year is being exported to other parts of the world where they are sold at high prices. Yet this pear is practically unknown in Europe, let alone Scandinavia.

The fruit itself resembles the Occidental pear, Pyrus communis, with its pyriform shape and rosy-cheeked bright green skin completely lacking russet formations. These are morphological traits that set it apart from most of its Oriental relatives. The trait that is shared with Oriental pears like Japanese pears, sometimes named apple-pears in foreign markets, is a remarkably crisp texture. Another shared trait is the possibility to enjoy the fruit right after harvest without maturing it unlike most cultivars of P. communis yet still being able to keep a high-quality product after months of cold storage. This pear has many names, for example, Korla pear from the city in Xinjiang where there is a high concentration of orchards, Pyrus Sinkiangensis Yü, and locally, Xiang Li. However, the name that raises my curiosity describes the same attribute that also sets this pear apart from other Oriental pears. It is also called fragrant pear, due to its abundant floral aroma. A strong aroma is a quality that is usually paired with the European pear and it is believed to be inherited to P. sinkiangensis Yü due to the natural hybridisation between P. communis and Oriental species. The result is a pear with the most sought-after qualities from both parts of the world, the crisp and sweet freshness of the Oriental pear and the complex taste and bouquet of the fragrance of the Occidental pear.

The introduction of a new fruit or vegetable variety on the market is extremely valuable for both fruit and vegetable producers, for industry, the restaurant industry, and consumers. By studying high-quality varieties that are much appreciated in different parts of the world, new products can be added to the market. A prerequisite for success with domestic production is that it is possible to grow the varieties in Sweden and that it is profitable to do so. The Korla pear, P. sinkiangensis Yü, meets high criteria for being completely new on the market and of high quality and can be a future part of the fruit range in Sweden. Potatoes, tomatoes, and bananas are some early examples of new fruit and vegetable varieties for Swedish conditions and the Swedish market. One might think that the introduction of new fruits or vegetables is part of history and that everything has already been investigated and tried. But it is instead the opposite. The climate crisis is changing the playing field for fruit and vegetable production in the world today with, for example, earlier flowering, increased risk of frost, lack of water, or the fact that low-lying soils may be submerged in saltwater. Perhaps it suddenly becomes an advantage to grow wine in Sweden compared to production in traditional viticulture sites. It is against this background that this work should be viewed.

Finally, this text is dedicated to my daughter Isolde, expected the day after finishing the thesis. You were in my mind all the time.

1. Introduction

The Pyrus genus is of the Rosales order and Rosaceae family, wherein many species of great horticultural importance belong. Pears are divided into three classifications, based on the number of carpels and size of the fruit where Oriental pears have two and most Occidental pears have a larger size and five carpels. In between these two classifications, there are the hybrid species, having three to four carpels (Silva et al. 2014).

1.1 Origin of the genus *Pyrus*

It has been theorised and subsequently accepted that the genus Pyrus originated in the mountainous regions of southwestern China 65 to 55 million years ago, during the Tertiary period. The area is believed to be the centre of origin for vast numbers of species in the genders Pomoideae and Prunoideae and evidence has been retrieved suggesting that species of Pyrus was dispersed along the mountain ranges eastwards and westwards (Silva et al. 2014).

There are 69 species of Pyrus found in China alone, of these 13 are of Chinese origin. Within these species, P. sinkiangensis Yü is included (Korban 2019).

1.1.1 History of pear cultivation

The domestication of pears has been centred in two geographical areas, one being China and the other has extended from Asia Minor to the Middle East through the mountain ranges of the Caucasus. Domestication of pears is believed to have taken place later than other fruits, about 5000 years ago, due to the small fruit size of the wild species. The first record of pear cultivation in Europe was in Ancient Greece where it was mentioned by Homer in the Odyssey, almost three thousand years ago deeming pears "a gift of God". In ancient Greek pears were differentiated by two separate words, "acras" and "apios" with the latter referring to the cultivated pear (Silva et al. 2014). Ancient Greek philosopher Theophrastus (c. 371–286 BC), by some, is considered the father of botany (Negbi 2010) because of his two surviving botanical works Historia Plantarum and On the Causes of Plants described pear cultivation and vegetative propagation methods in ancient Greece. Also mentioned is the need for cross-pollination although without any further explanation in why this is beneficial for fruit set. Four cultivars are mentioned by name, 'Myrrha', 'Nardinon', 'Onychinon' and 'Talentiaion' (Korban 2019). Records have shown evidence of 35 pear cultivars grown in the Roman empire adjacent in time with Pliny the elder, 23-79 BC. Meanwhile, put into perspective against the richer genome and multitude of species in Asia, by the end of the Sung Dynasty (1279 BC) there were over a hundred pear varieties in cultivation. According to Pieniazek (1966), there were commercial pear orchards in existence for over 2000 years. According to Sun et al. (1983), there have been active commercial orchards of 200-300-year-old pear trees. Out of the 5000 known pear cultivars over the temperate parts of the world and Africa, 3000 of these are found in China. Pears are mentioned in the Chinese poetry anthology Shi Jing (1000 BC) as growing in "wet lowlands" (Teng & Tanabe 2004).

During the Middle Ages and following centuries, developments in early pear breeding took place in central Europe. France was the premier producer of pears and the centre of the development of new cultivars. Notably, most varieties had crisp flesh. The development of the buttery texture of the Occidental pears of today took place during the eighteenth century in Belgium (Stephan *et al.* 2003). However, one of the first to breed pears through controlled crosses was Gregor Mendel (Dondini & Sansavini 2012).

Snow pear, *Pyrus nivalis*, is a species that together with *Pyrus pyraster* is believed to be a progenitor for *P. communis*. A third species is also believed to have been involved, *Pyrus caucasica*, however, there is conflicting evidence suggesting that the undomesticated *P. caucasica* rather is a natural hybridisation of *P. communis* than the opposite relationship (Bell & Itai 2011). Wild trees are sparsely scattered through central Europe and there is a tradition of cultivation of *P. nivalis* in northern France and Britain. The scientific name *P. nivalis* is probably derived from the name *Schneebirne*, a name likely dubbed because of either the large snow-white flowers or the fact that the fruit was not soft for eating until there was snow. Snow pears are believed to be the ancestor of sage pears in France, named because of the silvery branches' resemblance with the herb sage. Named cultivars ('Sauger Cirole') were discovered in Champagne in the 1850s. The fruits of the 'Cirole' pears were not consumed until bletted, much like medlars in the Middle Ages. Snow pears are used for making pear spirit, *most,* in former Czechoslovakia and are essential in the traditional making of pear cider, *perry*, in France and Britain (Morgan 2015). Despite great compatibility between species, pears are typically self-incompatible. There is great morphological plasticity and a high frequency of hybridisation. Therefore, there is a low genetic distance between different taxa. Thus, it is assumed that *P. sinkiangensis* Yü is derived from hybridisation between *P. communis* and either the cultivated variant of *P. pyrifolia* or *P*. x *bretschneideri* Rehd. (Wu *et al.* 2018).

1.1.2 Challenges in European pear production

For the past decades, there has been a steady decline in European pear production, from a total production volume of just above 4,300k tonnes in 1970 to 2300k tonnes in 2020. Numbers are even bleaker in Sweden, with a production peak in 1974 of 28,800k tonnes and a dramatic decline in 1990 from 10,890k to 3,000k tonnes in 1991. From there on the development has been less prominent, however, with a steady downward trend and a total of 1,550k tonnes produced in 2020 (FAO 2022). Possible reasons for this decline are a higher dependency on imports, a difficult infectious pressure in cultivation, or mishandling of fruit in post-harvest or markets (Stiftelsen Lantbruksforskning 2016). The production in Italy also has met biotic adversities which compromises production. Pear breeding programs of the world generally focus on the development of different traits. In Europe, the focus has been set on fruit quality and sensory attributes while the goal with breeding in North America has been pest and pathogenic resilience and resistance (Dondini & Sansarini 2012). In Asia efforts have been made in breeding earlier maturing cultivars and fruit of larger size (Hancock 2008).

1.2 Purpose

The purpose of this thesis is to investigate the characteristics of *P. sinkiangensis* Yü, in what way it differs from *P. communis*, and if the fruit can be incorporated in the Swedish commercial production system as well as the market. The research question during this work has been that while exploring the nature of *P. sinkiangensis* Yü and its cultivation in Xinjiang, find out if any of the successful methods for cultivation could be translated into southern Swedish production terms.

1.3 Delimitations

In this thesis, there have been limitations imposed regarding the wide range of feasible methods for establishing the cultivation of P. sinkiangensis Yü. Focus has instead been on the methods that stand out as best suited given awareness of certain local circumstances that have arisen during the research for this thesis.

2. Method

As a method for this thesis, a literature study has been conducted to assay information through partaking of current research regarding the purpose and hypothesis of this thesis. Information has been collected through relevant books as well as databases Web of Science, Scopus, PubMed, and Google Scholar. Search terms have been "*Pyrus sinkiangensis*", "Korla fragrant pear" or "Xinjiang pear" in combination with search terms related to each section, such as "irrigation" or "pollination"

3. Result

According to Hjalmarsson and Trajkovski (2007) out of 138 varieties of pears traditionally grown in Sweden, only 17% of the studied varieties were of Swedish origin. The rest of the varieties were from countries with a much warmer climate, mainly in Europe. Of the imported varieties, ten percent were believed to be of non-European descent. Pears were established as a fruit crop in Sweden during the Middle Ages through cultivation by monks in monasteries. As a result, the popularity of pears grew when they became a horticultural interest of the nobility, and the import of nursery trees from southern European countries began (Hjalmarsson & Trajkovski 2007). Since then, pear trees have been a given feature of home gardens in the southern and central parts of Sweden but no species of Pyrus occur naturally in Swedish biomes (Stephan et al. 2003).

3.1 What is *P. sinkiangensis* Yü?

According to Wu *et al.* (2018), phylogenetic analysis has shown that the cultivated accessions of *P. sinkiangensis* Yü most likely is originated from natural hybridisation between Occidental pears and Oriental pears. Furthermore, as *P. sinkiangensis* Yü showed a lesser proportion of genetic make-up with wild European species like *P. pyraster* it is suggested that hybridisation has undergone between cultivated Occidental and Oriental pears. Due to the vast cultural connection between continents along Silk Road, which is set to be the believed site of origin of *P. sinkiangensis* Yü, assumptions can be made on how the hybridisation originated due to anthropogenic factors. A historical record of a cultivated Asian pear being brought to the Xinjiang region, made by a Han dynasty diplomat 2000 years ago, implies that possible ancestors of *P. sinkiangensis* Yü and its accessions of today could have been introduced to the region as a result of commercial exchange (Wu *et al.* 2018). There is also speculation in the whereabout of the origination of the hybrid, some evidence suggests the cross with *P. communis* might have taken place in the prominent trading city Isfahan of Iran (Abdollahi 2021; Morgan 2015).

In a study made by Pan *et al.* (2002), AFPL fingerprinting was used to investigate the genetic relationship between *P. sinkiangensis* Yü and *P. communis*. What was already assumed due to morphological resemblance between the two (Pu 1979) was then supported through the study. Also disclosed in the study was the discovery that three popular cultivars of *P. sinkiangensis* Yü showed evidence of being a further hybrid between Xinjiang pears (*P. sinkiangensis* Yü) and Chinese white pears (*P.* x *bretschneideri* Rehd.). The cultivars 'Kuerle Xiangli', 'Sha-01' and 'Lanzhou Dadongguo' appear to have inherited the fruit size of the Chinese white pear and the ability to withstand drought from *P. sinkiangensis* Yü (Pan *et al*. 2002).

The genetic distance between the five groups of Oriental pears has been discussed, concerning potential genetic influence from closely existing species as well as the true origin of *P. sinkiangensis* Yü. Niu *et al.* (2019) conducted a study where the genetic relationship of local varieties of Xinjiang was researched by examining floral organ characteristics. Based on the previous conclusion that cultivar 'Lüli' was part of the Xinjiang group (*P. sinkiangensis* Yü) and the close resemblance of floral organs of 'Lüli' and 'Korla fragrant pear', it was suggested that the famous variety 'Korla fragrant pear' should be classified as belonging to *P. sinkiangensis* Yü. Also evident in this study was the fact that *P. sinkiangensis* Yü shared pollen morphology with *P. communis* thus indicating a close genetic distance. Research made by Chang *et al.* (2017) discovered that the most commercially produced cultivar 'Korla' pear shares chloroplast haplotypes with Chinese white pears, *P.* x *bretschneideri* Rehd. This finding supports the theory that Chinese white pears are involved in the hybridisation that resulted in *P. sinkiangensis* Yü. As evident in dendrograms depicting the phylogenetic relationships within the group of Oriental pears, *P. sinkiangensi*s Yü, and *P.* x *bretschneideri* Rehd. likely shares the same progenitor in *P. pyrifolia*. Due to the variation of characteristics of cultivars within the Xinjiang group, it is also likely that accessions occurred as interspecific hybridisations with the involvement of multiple parents (Bao *et al*. 2008).

The cultivar 'Korla', *P. sinkiangensis* Yü, also goes by 'fragrant pears' and refers to a multitude of cultivars of pear that has been grown for 1300 years in Xinjiang, northwestern China (Volk & Cornille 2019). Its fruit is yellow-green, sometimes slightly blushing, medium-sized, and egg-shaped. The pears have a high content of fructose and a well-balanced relationship of acidity and sweetness. The peel is thin, the flesh juicy and crunchy with a unique aroma that is sometimes described as floral or rose-like. Some of the aroma is credited to ethyl decadienoate, the pear ester familiar to those who enjoy the common pear, *P. communis.* as described in an article in The New York Times, commenting on the onset of the 2006 introduction in North American supermarkets (Karp 2006). 'Korla' pears are traditionally and extensively grown in the area around the city of Korla in Xinjiang and then transported further inland and around the world. Its fruit is highly esteemed within the country and in its foreign markets (Specialty Produce no date).

3.1.1 Botany and habit

Akin to most other *Pyrus* species, *P. sinkiangensis* Yü is a deciduous woody plant of medium size. Trees grow about 6-9 meters tall having purplish to grayish-brown branchlets bearing white lenticellate. Leaves alternately arranged, elliptic to broadly ovate, reddish-green in colour with fine serration. Young leaves are either glabrous or white tomentose. Trees flowers typically in April, in umbel-shaped racemes. Four to seven white flowers in each raceme. Pome fruit ovate and small with long, slender pedicel of 4-5 cm. Four cartilaginous carpels and few to no stone cells, sclereids. Some cultivars of *P. sinkiangensis* Yü produce fruit with a persistent calyx that needs ripening, similar to *P. communis.* Fruit maturation occurs in July-September (eFloras 2008; Korban 2019).

Figure 1: Korla fragrant pear, *Pyrus sinkiangensis* (Shutterstock 2022).

3.1.2 Traditional uses for pear

Historically there have been records of ancient medicinal usage of pear fruits reaching back two millennia. Recent findings through various studies demonstrate evidence of therapeutic functions beneficial for reducing obesity, diabetes, inflammation as well as being anti-carcinogenic and a cardio-protective agent to mention a few (Hong *et al*. 2021). Traditional use of pears as folk medicine has taken place in China for two thousand years in consideration of their anti-inflammatory, -hyperglycemic properties as well as being a diuretic agent. Other remedial uses of pears in folk tradition consist of the usage of pears in treating alcohol hangovers, constipation, and coughing (Reiland & Slavin 2015).

3.1.3 Market in China and worldwide

While the cultivation area for pears is steadily declining in Sweden, the production of Korla pears in China increased by 20% in 2020 (Henry 2020). China has the highest share of production area in the world, 72.3%. China produces 17 million tons of pears per year. Approximately 4% of the total production is exported and the export consists of only two cultivars, closely related genetically, Yali, *P*. x *bretschneideri* Rehd., and the 'Korla' pear (Teng 2011). The volume of Chinese pear production represents nearly 70% of the world's entire production (Hussain *et al.* 2021), Japanese production accounted for 2.1%. The dominant producer of pears in Europe is Italy with a 4.9% share of the world production in 2004 (Hancock *et al.* 2008). In Europe, only eight cultivars of the common pear constitute 80% of the total production, 'Conference', 'William'/'Bartlett'/'Bon Chrétien' and its red sports, 'Abbé Fétel', 'Blanquilla', 'Doyenne du Comice', 'Kaiser', 'Dr. Jules Guyot' and 'Coscia'. In the USA, only four cultivars dominate the production however due in part to a larger population of Asian ethnicity, there are also Oriental cultivars in production (Dondini & Sansavini 2012).

3.2 How does Oriental pears differ from Occidental?

The main sensory differences between Occidental and Oriental pears are texture and in most cases aroma, whereas *P. communis* showcases a soft buttery texture when ripe, accompanied by a characteristic aroma. Oriental pears in general have less of an aroma and an apple-like, juicy and crisp texture. The shape is also a differing factor between Oriental and Occidental pears, where the Oriental pears, in general, are round, resembling an apple without the narrow neck of the Occidental pear. Another factor that sets Occidental pears apart from the Oriental is a higher content of fructose seen in *P. communis* (Silva *et al*. 2014). However, the most predominant difference between Occidental and Oriental pears is their respective ripening habits. Where Oriental pears mature *in situ* during the growing season and

Occidental pears generally require chilling hours to initiate maturation on the tree (Itai & Fujita 2008). The general harvest time for Oriental pears is August through September whereas harvest time for Occidental pears varies from July to November with slight variations in locality and cultivar. However, harvesting of Occidental pears usually peaks in August and September (Ghazouani *et al.* 2020).

3.2.1 How does *P. sinkiangensis* Yü differ from other groups of Oriental pears?

Oriental pears are divided into three classifications according to their respective ethylene production post-harvest, where most cultivars belong to the medium to low-level producing classes. Occidental pears is classified as climacteric and the Oriental pears are classified as non-climacteric and climacteric according to respiration rate and ethylene production (Itai & Fujita 2008).
According to Liu *et al.* (2019) ethylene has no impact on quality in *P. sinkiangensis* Yü, which is why the fruit is possible to consume immediately upon harvest. With Occidental pears, sensory qualities enhance when ethylene triggers ripening processes. Studies of the volatile content in 'Korla' fragrant pears (*P. sinkiangensis* Yü) showed no significant changes during storage, in comparison to that of 'Abbé Fetel' (*P. communis*) which aromatic components increased during ripening. Where Occidental pears soften when they mature, *P. sinkiangensis* Yü only shows a slight change in firmness after five months of storage, according to Chen *et al.* (2006).

3.2.2 Content and chemical constitution

Belonging to the Rosaceae family all pears assimilate sorbitol as their main sugar during photosynthesis to be translocated from source to sink (Folta & Gardiner 2009). The sorbitol is then converted into glucose, fructose, and sucrose in various concentrations. An analysis made by Pan (2002) of several Xinjiang cultivars (*P. sinkiangensis*) determined a small fresh fruit weight of less than 100 g on average yet a high content of sugars, mainly fructose. Of the tested cultivars 'Kuikejuju' turned out to hold the highest content of sugar, at 180.5 mg/ml juice. The fruit was smaller than the average weight at 57 g. All tested cultivars had low levels of sorbitol. In a comparative study of cultivars of each group of Oriental pears, Gao *et al.* (2004) determined that of the Oriental pears, Xinjiang cultivar 'Kuerle' fragrant pear showcased the highest sugar: acid ratio. A well-balanced ratio of sugar and acid is identified with higher-quality fruit. The primary organic acid present in all studied cultivars was malic acid.

In a study of the compounds involved in the aroma of Xinjiang cultivar 'Kuerle' (*P. sinkiangensis*), Chen *et al.* (2006) used gas chromatography-olfactometry to acquire information on what substances are at play. In the study 43 compounds were noted, involving aroma. The most prominent volatiles in 'Kuerle' cultivar comprised of:

> "hexanal (17.80%), ethyl hexanoate (12,96%), ethyl butanoate (11.29%), α-farnesene (12.31%), ethyl acetate (9.69%) and hexyl acetate (2.94%)." (Li et al. 2015: 580).

The fact that α-farnesene is found to be a major component in the aroma is speculated to play a role in the general popularity of pears in the Xinjiang group, as it is the compound responsible for the fresh, green note in the aroma of *P. sinkiangensis* Yü (Li *et al.* 2012). Moreover, six-carbon (C6) aldehydes such as hexanal, present in a meaningful quantity among the volatiles of 'Kuerle' pears, are together with alcohols and their esters responsible for green leaf volatiles (GLV:s). GLV:s are present in many plants and generator of a scent of freshly cut grass which has an impact on the organoleptic qualities of fruit (Ruther 2000, Poltronieri *et al.* 2019).

Cuticular wax in fruit is a hydrophobic layer that protects the fruit from water loss and biotic and abiotic stresses. Cuticular wax and the polymer cutin make up the cuticle and depending on fruit type or variety within a species, the composition of wax differs. Environmental circumstances also affect the makeup of the cuticular wax. In the biosynthesis of the cuticle, ethylene and abscisic acid (ABA) signalling appear to have roles (Wang *et al.* 2021). In a study of ethylene in apples, the presence of ethylene induces a higher cumulation of waxes (Ju & Bramlage 2001). Thus, cuticular wax does not only serve as protection for the fruit, it also plays a role in fruit development in different stages. In a study executed by Wang *et al.* (2020), cuticular wax was extracted from 'Korla' pears with the help of chloroform and analysed with chromatography. The wax composition was found to be made up of alkanes, olefin, fatty acid, alcohol, aldehyde, ester, and terpenoid. The composition and morphology of the wax changed with environmental factors and storage. To sustain wax content at optimal capacity, a high relative humidity was necessary. Positive results in post-harvest quality were observed with high humidity treatments of fruit in the study and could be one factor playing into the long storability of 'Korla' pears.

3.2.3 Cultural differences in preference

The Occidental pear has numerous cultivars with different characteristics but the collected term Oriental pear regarding cultivated pears of Asia consists of several different species grouped. This group comprises the five species Ussurian pear (P. ussurensis) Chinese sand pear or Japanese pear respectively (P. pyrifolia), Chinese white pears (P. x bretschneideri Rehd.), and Xinjiang pears (P. sinkiangensis Yü). There are differences between the five groups, where P. sinkiangensis shares the most qualities of P. communis (Zhang et al. 2016). Although nashi pears, P. pyrifolia, has gained some interest in the European fruit market, P. communis is given little attention in Asia except for northern Japan where a harsh winter climate renders the cultivation of most Oriental pears challenging (Dondini & Sansavini 2011). Oriental pears in general have a low aroma with a high sugar to acid content ratio. Customers in Asia generally expect a juicy, crunchy texture and sweet taste with subtle aroma. Then there are the exceptions, for example, P. ussurensis have a higher content of volatile compounds and thus a more intense flavour much like P. communis and P. sinkiangensis Yü (Zhang et al. 2016). In Europe there has been limited cultivation of snow pear (P. nivalis) over the past 400 years in Britain and France for use in the making of alcoholic pear cider, perry, but P. communis is by far the domineering species of cultivation in Europe with customer expectations on a soft and buttery texture (Korban 2019, Hancock et al. 2008).

3.3 Market in Scandinavia

Sweden has a low degree of self-sufficiency in pears of 6% (Stiftelsen Lantbruksforskning 2016) and an import volume of 25665 tonnes (FAO 2022). 90% of the Swedish production area for pears is located in the Scania region of southern Sweden (Jordbruksverket 2007). The total production area for pears in Sweden was 128 hectares in 2017, according to Jordbruksverket (2018).

Sales of organic produce have increased in Europe during the past decades retailing at 45 billion euros, however, the yearly increase in organic farmland of 6% does not match the sales growth of 8% (FiBL 2021). Organic production and demand in Sweden reflect that of the European situation. Pear cultivation in Sweden has been in decline for decades and given the challenges in growing organic pears commercially, only a small amount of the Swedish production is organic. The Scania region has the lowest percentage of organic production area for all products in comparison with all other regions in Sweden, at 8% (Jordbruksverket 2020). According to Jordbruksverket (2018), the typical pear producer uses two hectares for organic pears, mainly as a supplementary business aside from conventional production areas.

3.4 Cultivation conditions

The adaptability within the genus Pyrus offers resilience towards many biotic and abiotic stresses such as different soil types, climates, drought, and salinity (Kishor et al. 2017). The largest share of production area for ‘Korla’ fragrant pears is located in central Xinjiang, spread in oases northwest of the edge of the desert that dominates the area in central Xinjiang, the Tarim Basin. The basin is the result of an amalgamation between the ancient microcontinent and the growing Eurasian continent during the Carboniferous and Permian periods. Melting water from K2 flows into rivers that never reach the sea. Parts of the meltwater supply the oases with irrigation resources, the rest accumulates in salt lakes. Thus the ‘Korla’ pears are grown in an arid environment with saline soils. The arable land in parts of Xinjiang is highly calcareous and alkaline with a pH above 8.2. This complicates the iron uptake of the culture, which can lead to deficits that show up in, among other symptoms, chlorotic leaves. One way to address this problem is to use an iron-rich foliar fertiliser in cultivation. Another problem is that the arable land has a low content of organic material and is of a rough structure. Severe sandstorms in the area lead to the soil being easily depleted (Zhao et al. 2016). In a study conducted by Xu et al. (2016), 100 cultivations with ‘Korla’ pears of different ages between 8-25 years were examined. Soil samples from all crops were taken after harvest in September and the results suggest the complex ecological cooperation between the organism and the soil's status. The samples show a variety of character traits that reveal the influence of the region and special cultivation conditions on the nutrient content of the soil in cultivation. The proportion of organic material in the soil samples ranges between 26.48-44.68%. In addition to iron (Fe), manganese (Mn) is the micronutrient that is lacking in the arable land around the city of Korla.

According to FAO (1997) the environment in northwest China where Xinjiang is located is beneficial for deciduous fruit production due to the climatic conditions prevailing with plenty of sunshine, high light intensity, and a large daily temperature range between night and day. Fruits grown in Xinjiang and nearby provinces show greater weight, better colour, and higher sugar content in comparison with deciduous fruit grown in other regions of China. It also shows better storage capacity. In a study performed by Cho et al. (2021), measurements made in 2018-2019 indicate that a greater daily temperature variation leads to a higher sugar accumulation in the fruit. Deciduous fruit trees have certain chilling requirements to break bud dormancy. Each cultivar has specific requirements but for P. communis in general, 60-90 days with an optimal temperature of 4°C is needed (Westwood 1988). There is little information at hand regarding the specific chilling requirements of P. sinkiangensis Yü.

3.4.1 Climate of Xinjiang

Xinjiang is located in northwestern China, bordering Mongolia, Russia, Kazakhstan, Tajikistan, Afghanistan, Pakistan, and India. Surrounded by mountain ranges, the area has an inland climate, without the influence of surrounding bodies of water. The area generally has a continental, dry climate and consists mainly of uninhabitable desert or steppe. The region's dry, hot summers make large parts of Xinjiang endorheic as there is no surface water inflow from outside bodies of water. The area surrounding the city of Korla has a high concentration of pear orchards and a long tradition of cultivation of P. sinkiangensis Yü. The area can show an extreme temperature variation through the seasons. The location of Korla is in the central Xinjiang Uygur Autonomous Region which has a cold desert climate (Xiao, X. et al. 2021). The characteristics of a cold desert climate are brief, slightly warm, and humid summers with longer winters that exhibit cold temperatures of an average of -2 to 4°C and a fair amount of snow precipitation with a mean annual precipitation of 15-26 cm (UC Berkley, 2019). Typically, in cold desert areas evaporation exceeds the precipitation. In the Korla region, the annual average temperature is 14-15°C and there is far less precipitation than the average in cold desert climates. Maximum evaporation is 2788.2 mm annually. There are 180-200 frost-free days and 2889 hours of sunshine (Xiao, X. et al. 2021). The Korla region average temperature in July is 26.4 °C. July is also the month of the year with the most rainfall with an average of 12.4 mm spread over 5.8 days. The annual rainfall in the Korla area is 57.4 mm divided over 31 average rainfall days per year (Britannica no date).

3.4.2 Climate of Sweden

According to SMHI (2021) and the Köppen system classification, the climate in Sweden is divided into the two classes C and D, warm temperate climate with deciduous forestation and respectively continental climate with boreal forestation. Class C is the dominating climate around the southern coastal line in Sweden. The mean temperature in January 1961-1990 of the Scania coastline, in the southernmost part of Sweden, was 0° C while the mean January temperature of Lapland in the farthest north was -16 to -17°C at times reaching -50°C. In the same period, the mean temperature in July was 17 °C in the south and 7 °C in the northernmost parts. There has since been a rise in mean temperature of roughly one degree Celsius (SMHI 2021). This thesis will focus on climate and growing conditions in the south of Sweden. The frost-free days in Alnarp, Scania are 220. Average temperature range from +7.9 to 12.1 °C. Annual precipitation range from 658 to 400 mm and 1592 to 1263 hours of sunshine annually (Fogelfors *et al.* 2015).

3.4.3 Rootstock

Wild genotypes within *Pyrus* are adapted to tolerate a wide range of biotic and abiotic stresses such as drought, floods, different soil types, saline soils, and fungal and bacterial diseases (Kishor *et al.* 2017). Therefore, they are useful as rootstocks and in breeding programs. Vegetative propagation through grafting scions onto an interstock and rootstock is necessary on account of self-incompatibility within the *Pyrus* genus. Intergrafting between Occidental and Oriental pear species is possible. The principal rootstocks used when grafting *P. communis* are cultivars within *P.*

communis, P. betulaefolia, or *Cydonia oblonga*. In Oriental pears, the main rootstocks are *P. pyrifolia, P. pashia, P. calleryana, P. ussuriensis, and P. betulaefolia* (Korban 2019). Emphasis is laid on *P. betualefolia* in northern China (Teng 2011). According to Jannick & Paull (2008) most species are used in the commercial propagation of pears, such as the seedlings o*f P. pyraster*, and *P. calleryana.* The latter is less useful for planting in soils with high pH due to poor iron uptake. For soils with these characteristics in China, where this type of soil is common, rootstocks of the local species *P. ussuriensis* are used. For cultivation in poorly drained clay soils where a strong-growing tree is desired, *P. betulaefolia* is advantageous to use. *P. betulaefolia* is used in China and the rest of East Asia for cultivation in the northern regions, for higher cold resistance. For Asian pears grown on light sandy soils, 'Winter Nelis' (*P. communis*) seedlings can be an alternative. In milder climates in Western and Eastern Europe, rootstocks of quince, *Cydonia oblonga*, are used. The use of quince as a rootstock can result in a tree 40-60% smaller in size than when using seedlings of *P. communis*. Examples of some of the most commonly used quince varieties in European production are 'Provence Lapage C', 'Sydo', and 'East Malling C' where the latest is the most dwarfed. This can lead to a high production density, efficient harvest, and a high yield. However, there is an incompatibility with some pear cultivars due to the substance prunasin, a cyanogenic glycoside, within *C. oblonga,* which makes the production of pear trees with quince rootstock expensive to produce. There is also a risk of underdeveloped root systems with poor soil anchoring, which advocates support devices in cultivation (Janick & Paull 2008). Furthermore, quince rootstocks are not suitable for cultivation in cooler climates. A promising cultivar to use for rootstocks used for grafting Oriental cultivars is 'Zhongai 1', *Pyrus ussurensis* x *communis*, which can render a reduction in tree size by up to 70% (Ou *et al.* 2015). In North American trials with grafted *P. communis,* the first rootstock resistant to fire blight (*E. amylovora*) was found in 'Old Home' x 'Farmingdale' (OH x F). Trials with 'OH x F69' selection in the 'Old Home'- series have shown positive results when tried in European cultivation (Bell 2019). According to Beutel (1990), all Oriental pears are compatible in propagation with rootstocks of 'OH x F'.

3.4.4 Fertilisation

Aiming to establish fertilisation recommendations for Korla fragrant pears in orchards located in Korla, Xinjiang, Chai et al. (2014) conducted a study with positive results on biomass and an increased nutritional profile in fruits. Results as quoted below:

> "Compared with no fertilizer treatment (CK), the accumulation of biomass dry matter, nitrogen, phosphorus, potassium, and yield of the fertilization treatment with N, P and K (NPK) increased by 7 383.21 g, 167.30 g, 39.66 g, 182.74 g and 12 326.78 g in a year growth period, respectively. The contribution rate of nutrient N, P2O5, and K2O to the production of 'Korla Fragrant Pear' was 17.69 kg.kg-1, 9.62 kg.kg-1, and 20.52 kg.kg-1, respectively. Utilization rate of fertilizer N, P2O5, and K2O was 52.22%, 20.78%, and 216.50%, respectively. The correction coefficient of soil available nutrients N, P2O5, and K2O was 0.18, 0.28 and 0.13, respectively. Conclusion: Fertilization had significant promoting effect on biomass dry matter formation, nutrient accumulation and yield formation, while nitrogen fertilizer played a special decisive role." (Chai et al. 2014: 423).

3.4.5 Irrigation

Trials in Xinjiang performed by Zhang *et al.* (2021) aimed to find ways of conserving water in an arid environment where freshwater is very sparse, successful results were made in using activated brackish water for irrigation in Korla orchards of fragrant pear. The brackish water was obtained from an underground well and had a salinity of 1.83-2.74 $g{\cdot}L^{-1}$ and was then processed to become either magnetised or ionised before being utilised in the experiment. As previously indicated by Zhao *et al*. (2021) and also Wang *et al.* (2021) in experiments with activated brackish water irrigation on wheat, results suggested that such treatment could improve root activity and structure, supplement chlorophyll accumulation and increase yield. The experiment lasted for two years and found evidence of improved yield while also amending efficient water usage. Tested fruits in the experiment also met the qualifications for super-grade fragrant pears, indicating that the treatments had little or improved effects on fruit quality (Zhang *et al*. 2021).

Partial Root-Zone Drying (PRD) has desirable effects on harvest results and quality. PRD involves watering only one side of the root system and alternating sides regularly. The treatment results in less vegetative growth and better solar radiation and induces assimilation (dos Santos *et al.* 2007; Chaves *et al.* 2010; Yang & Zhang 2010; Zhang *et al*. 2010; Price *et al.* 2013). PRD has been shown to stimulate the biomass of the root zone as well as higher activity of microorganisms in the soil, which increases water and nutrient uptake (Li *et al.* 2010). The method has been shown to save water, increase the fruit's nutritional content and at the same time maintain or increase the harvest outcome (Jovanovic & Stikic 2018).

3.4.6 Pollination

There are some cultivars of pear that produce fruit without fertilisation of the ovule. Fruit formed through parthenocarpy have no seed and have inferior quality and storability (Lysiak & Antkowiak 2015). Oriental pears will cross-pollinate with *P. communis* with positive results, given that flowering appears simultaneously for both cultivars (WSU Tree Fruit no date; Bieniasz *et al.* 2017, Stern *et al.* 2018). In Xinjiang, *P. sinkiangensis* Yü bloom in April (Mansur-Nasir *et al.* 2019).

3.4.7 Pruning and training

According to Janick *et al.* 2008, Oriental pears form strong-growing trees, but within the group the branch angles vary. Pruning and supporting trees should be adapted to the rootstock of the tree. To get a good size of fruit, Oriental pears require a slightly harder pruning than *P. communis.* Oriental pears tend to bear large amounts of fruit due to larger flower clusters than Occidental pears. The optimal amount of harvest has been determined to a general recommendation of one fruit per 12 cm bearing shoots. Thinning is necessary in the years when the harvest is large, to stimulate flower induction and to reduce weight-related damage. Chemical thinning with auxin-like substances is possible but can result in a large loss of harvest if a late frost damages the remaining fruit. Bioregulator naphtalene acetic acid, NAA, may also be used pre-harvest to prevent the trees from releasing the crop prematurely. To ensure that no over-thinning occurs, it is a good idea to use hand thinning. In established orchards, older fruit spurs should be removed to rejuvenate the plant material and maintain the fruit size of the crop.

3.4.8 Pests and diseases during cultivation

Scab disease is a pathogen that occurs in pear cultivation both in Asia and Europe, as well as any part of the world where pears are cultivated. Scab is caused by infections from species of the fungal genus *Venturia* Sacc. (anamorphic *Fusicladium* Bonordl.), responsible for considerable economic losses in fruit cultivation across the world (González-Domínguez *et al.* 2017). There are two species of *Venturia* spp. that cause scab in pears and they affect Oriental and Occidental pears respectively. Host specificity is very high within the genus, with little or no outreach beyond the affected host species (Chevalier *et al*. 2004). Attempts were made by Ishii and Yanase (2000) to inoculate *V. nashicola* and *V. pirina* in Occidental and Oriental pears respectively, with unsuccessful results. Equal for both *V. nashicola* and *V. pirina* is a need for 10-12 hours of consecutive wetness to infect its host at temperatures ranging between 10-35°C (Gottwald 1985). For the time being *V. nashicola* is under a quarantine regime in the EU, USA, Israel, and Turkey (EPPO 2016).

The main fungal disease in pear orchards in Xinjiang is blackhead disease, *Alternaria alternata*. The disease is primarily a problem during transport and long-term storage, where the incidence can be up to 10% (Ouyang *et al.* 2021). The fungus thrives best in a warmer climate but occurs in Sweden, where it attacks potatoes (Edin 2011). Furthermore, gray mold, *Botrytis cinerea*, has been discovered in pear orchards in China, which indicates susceptibility to *P. sinkiangensis* Yü (Zhang *et al.* 2014). The same situation is present with the different species of pear rust, *Gymnosporangium* spp., where Oriental pears only are susceptible to *G. asiaticum* and vice versa regarding European pear rust infecting only *P. communis* (Kaijura 2002).

In an American experiment performed by Walsh *et al*. (2016) long-term field trials of growing Oriental pears in Maryland by the Atlantic coast, some cultivars showed good results however there were losses in other cultivars due to bacterial disease fire blight, *E. amylovora*. The results of the study deemed Oriental pears as a commercially feasible new crop of the region however still concluded the potential as a crop in direct-market production due to their tree-ripe qualities. Fire blight has been detected in many parts of Europe, including southern Sweden during the past decades with a few notable outbreaks in peak pear-producing regions such as northern Italy and Spain (Jock *et al.* 2002).

Fungal disease brown spot, *Stemphylium vesicarium*, has an important impact on pear production with outbreaks in prime production areas in Europe, such as the Emilia-Romagna region in Italy and Catalonia in Spain. Worldwide losses due to brown spot range from 1-10% of total production. Up to 90% infection rate in fruit can be observed some years. Like other fungal diseases, temperature and humidity are factors that affect infection rates. Optimum conditions for germination are 15-32°C and a minimum of 6 hours of wetness (Itai 2007).

Powdery mildew, *Podosphaera leucotricha* (Ell. & Ev.)—anamorph *Oidium farinosum* Cooke is another fungal disease infection pears in various severity. In a study comparing infection rates between *P. communis* and Oriental species and hybrids of *Pyrus,* field and greenhouse inoculations were made. Results showed a higher incidence in greenhouse specimens of all cultivars however consistently lower infection rates in Oriental cultivars and hybrid cultivars (Serdani *et al.* 2005).

Pear psylla, *Cacopsylla pyri* is an established pest insect in European pear cultivation causing substantial economic damage during infestations. Systems with high-density planting enhance susceptibility. Infested trees are affected in two ways, either through a weakening of the organism when the sap is extracted or from secondary injuries due to sooty mould that has developed in the heavy amounts of honeydew produced by *C. pyri.* Fruit production in affected trees is also reduced (Civolani, 2012). There are three species of *Cacopsylla* spp. in Sweden (Tornérus 2001). In Italy outbreaks of vector-transmitted disease, pear decline has been connected with *C. pyri* (Poggi Pollini *et al.* 2001).

3.5 Harvest maturity and fruit quality

In China, the ripening period for pears ranges from late July to late October. Fruit of *P. sinkiangensis* Yü grown in Xinjiang intended to export or store are harvested at a minimum level of the soluble solid content of 12 ° Brix (Chen *et al.* 2006). The quality of the fruit is assessed by combining all measurable factors. During the maturation process, firmness and chlorophyll decrease while SCC and vitamin C content increase (Liu *et al.* 2021). Other physical and chemical ripeness indications for 'Korla' pear in Xinjiang is when the fruit measures 4.23-7.99 kg / cm2 in firmness, 3.17-6.54 mg / 100 g chlorophyll, 11.54-11.41% SSC and 0.36-0.6 mg / 100 g vitamin c (Lan et al. 2014). Another study performed in 2014 of the maturation pattern in fruits of 'Korla' pears concluded that:

"The fruit hardness and the content of chlorophyll decrease gradually, while SSC and vitamin C content increase with the deepening of the pear mature." (Haipeng et al. 2014: 19-23).

The results of the study were intended as a basis for predicting maturity and classification of 'Korla' pears. Nečas *et al.* (2020) stated after having conducted a field study evaluating the performance of 23 Oriental pear cultivars in middle European climate conditions that firmness of the flesh is not a valid method for measuring maturity, contrary to Occidental pears. The study suggests skin colour and taste as indicators for fruit maturing on trees. The best quality was observed when firmness reached 1.60 to 1.88 kg/cm2.

By comparing five cultivars from the most cultivated groups of pears across the world different characteristics could be detected. Occidental pears and some of the Oriental groups, in varying severity, are climacteric. Climacteric pears do not fully mature on the tree and if left past the optimal harvesting time, there is unfavourable lignification leading to a gritty texture and the buttery and juicy consistency is lost. If harvested too late the fruit also loses storability. If harvested too early, fruit tends to attain a rubber-like texture, lesser aroma, and larger susceptibility to pathogens post-harvest (Murayama *et al.* 1998). Overall quality also declines the longer past optimum harvest time the fruit passes, along with a greater susceptibility to pathogens and senescence disorders (Wang 2020). The optimum quality of the Oriental pear is reached when the fruit is allowed to mature on the tree (Quinet & Wesel 2019), unlike the climacteric characteristics of the Occidental pear. The Occidental pear differs from other climacteric fruits in that almost all cultivars inherit the complicating quality of ripening resistance in varying degrees. For the fruit to fully develop in terms of marketable sensory qualities, timing is of the essence as well as a need for specific post-harvest handling and treatments. These factors not only make the commercial handling of *P. communis* difficult, but it also makes pears vulnerable as a commodity (Stiftelsen Lantbruksforskning 2015). With *P. communis*, ethylene triggers the onset of higher metabolic activity, respiration, and mellowing of the flesh (Nashima *et al*. 2013). Ethylene is present also in the non-softening cultivated groups of *Pyrus* but in varying concentrations. In low ethylene level producing Japanese cultivar 'Housui' there is little softening however genes coded for ethylene synthesis are present and activated during ripening (Nishitani, *et al.* 2010).

In a study performed by Nashima *et al.* (2013), microarray analysis was executed to map out patterns in gene expression during maturation in the fruit of *P. communis*. Within the maturing responsible genes, it was found that specifically one of the superfamily *cupin* protein-coding genes (Dunwell *et al.* 2004) was induced in *P. communis* but not in the Japanese pear, *P. pyrifolia* (Nashima et al. 2013). According to Zhang *et al.* (2016), the different maturation patterns of climacteric and non-climacteric pears can be analysed through their disparate transcriptome profiles. In fruit maturation, the genes ACO (1-aminicyclopropane-1-carboxylate oxidase) and XTH (Xyloglucan endotransglucosylase/hydrolase) are responsible for the consequent cell wall disintegration, softening.

Ethylene is responsible for triggering maturation processes in climacteric fruit. For example, 'Bartlett' pears are a climacteric cultivar that is harvested in a mature preclimacteric stage (Paul *et al.* 2012). In a study performed by Murayama *et al.* (2006), 'Bartlett' pears were treated while maturing on the tree. Phloem transportation was cut above the abscission zone of the fruit, by girdling. Studied pears reacted similarly as harvested pears after this treatment, due to an enhanced ethylene release. Ethylene is present in fruit maturing on the tree however in a much smaller proportion. Pears harvested were significantly softer than pears left on the tree after 12 days. The full mechanism of ethylene function in climacteric pears is not fully understood but results in the study suggest that ethylene is involved in the inhibition of maturation on the tree however it cannot be ruled out that assimilates and other sap substances are involved.

During the development of the pear on the tree, the composition of sugar forms of the fruit changes. These changes are notable from June and continue until harvest. Initially, the main sugar forms in pears are glucose and sorbitol, and gradually during the season, there is a decrease while there is an opposite development for fructose and sucrose. Changes in the composition of organic acids, sugars, and alcohols may also instigate processes that alter texture, aroma, and other sensory qualities. There are many factors at play regarding fruit quality, for example, genotype, abiotic factors, or measures executed during cultivation (Hudina & Stampar 2000). During the maturation process of fruits, certain ripening pathways rely on ethylene biosynthesis while others are independent of ethylene such as the process of saccharification. For development such as softening, decrease in acidity and astringency, and volatile biosynthesis to occur, ethylene is needed. (Fluhr *et al.*

2008). Some studies suggest that in non-climacteric fruit, instead of ethylene, ABA regulates gene expression during ripening (Jia *et al*. 2013) and that ABA treatment could be used in post-harvest ripening processes of non-climacteric fruit (Daminato *et al*. 2013).

Another key factor that affects product quality is the content of lignin in the fruit. The presence of lignin in pears causes stains of hardened skin and accumulations of stone cells, sclerenchymas, in the flesh. The reason behind why some cultivars of *P. sinkiangensis* Yü tend to develop these traits is investigated and research methods have been developed. One method of determining fruit quality relative to lignin content is the use of near-red spectroscopy in combination with a chemometric method to establish a predictive non-destructive model for ripening fruit (Sheng *et al*. 2020).

3.6 Post-harvest

In a study performed by Niu et al. (2020) different methods for determining storage quality were compared. The quality indicators measured were fruit firmness, SSC, chlorophyll, and vitamin C content. The study aimed to investigate how harvest ripeness affects quality during storage, to determine an optimal harvest time for fruit not to be sold for direct consumption. The study established a link between low harvest maturity and a faster loss of quality in storage. Of all the participating quality indicators, the study showed that the strongest correlation was found between firmness, harvest maturity, and storage time. Therefore, it can be assumed that the firmness of the fruit according to the index and the use of a penetrometer can be the most effective method of calculating the shelf life and quality of P. sinkiangensis Yü in cold storage (Niu et al. 2020). Another study conducted by Liu et al. (2021) determined that 'Korla' fragrant pears harvested at 80-90% ripeness show the most delayed quality losses. The firmness of the fruit depends on its cell structure. Before ripening, the cell wall consists mainly of insoluble protopectin, this creates a solid structure in the fruit. During the maturation process, the protopectin breaks down to consist of soluble pectin, which at the same time breaks down the cell structure. Due to the permeability of the cell membrane and its electrolyte leakage, this eventually leads to the dissolution of the cell. This is the reason why the firmness of the fruit decreases according to the degree of ripeness (Panaiagua et al. 2014). Pears harvested after the optimal harvest time also showed a faster decomposition during storage, which indicates the importance of harvesting at the right time according to the ripeness of the fruit.

The loss of flesh firmness in P. sinkiangensis Yü during storage is very slow in comparison to other fruits. Chen et al. (2006) reported only a slight change in sugar content during storage. A slow increase from 12 ° Brix to 13 ° Brix during the first month and a slow decline back to 12.5 ° Brix after five months of storage. During the first three months of storage, there was a rise in fructose and glucose content, while adverse development was observed regarding the content of sucrose during the same period. This loss of sucrose is possibly attributed to enzyme sucrase hydrolysing sucrose, which could explain the initial increase of glucose and fructose during storage. Loss of sucrose, glucose, and fructose is ascribed to respiration and starch hydrolysis during later stages of storage. Fructose was the most abundant throughout the test period. There were observable changes in volatile compounds during storage however not to the extent that it resulted in a meaningful loss in quality. According to Mao *et al.* (2022), *P. sinkiangensis* Yü has the potential to be stored until September the following year in storage with a controlled atmosphere. Oriental pear cultivars of the climacteric and the non-climacteric group do not respond to CA conditions in the same fashion as Occidental pears however an oxygen level of 3%-5% for 'Yali' pears, *P.* x *bretschneideri* Rehd. preserved flesh firmness and skin colour during prolonged storage time. Oxygen levels of less than 2% are harmful to most Oriental cultivars (Wang 2020).

3.7 Cultivation system

Fruit production in China entails 50 families, over 300 species, and 10,000 varieties grown in a wide range of environments and fruit zones, of which pear cultivation takes place in five different (Yuan et al. 2016). The total volume of Chinese fruit production in 2020 was measured to 287 million metric tonnes (Statista 2021). Protected cultivation of fruit emerged in the middle of the last century and has since the beginning of the 1990s has become a key feature in fruit production in China. Protected cultivation of several fruit crops has since been tried out and deemed successful and the protected production area has increased on behalf of the high profitability and government aid. There are several techniques at hand when cultivating in a protected environment and measures needs to be drawn to meet the criteria of each cultivated species. The structures employed in Chinese production might range from simple bamboo frames with plastic coverage to more sophisticated structures with the technique for environmental management. For growing pears, it is necessary to ensure the chilling requirements are met, thus no heating is required in the winter season. Watering of deciduous trees during dormancy is neither necessary (Gao et al. 2004). Another advantage of protected cultivation is the possibility of an earlier bud break with spring heating at the cultivation site. In doing so along with for example calcium cyanamide treatment, it is possible to have an earlier harvest in cases where forced cultivation is desired (Kisaki et al. 2002). However, the main reason for producing pears in a protected environment would be rain protection to ensure a lower degree of infectious pressure from pathogens. In a study performed by Lim et al. 2014, rain-sheltered pear cultivation showed an increase in biomass and a higher yield. Less frost damage and infection were observed in plant material and fruit. The overall quality of the fruit was also higher than in the open-field comparison group regarding SSC, titratable acidity, and appearance. The experiment was executed in two organic orchards. In some parts of the pear-producing areas of the world, including Sweden, the production of organic fruit presents challenges due to fungal diseases that spread in humid conditions or through rain splatter (Tahir 2014; Sardella et al. 2016).

3.8 Cultivars of *P. sinkiangensis* Yü

The local germplasm in Xinjiang is rich and there are many traditional and newly created cultivars in production. Cultivar 'Kuerle' is one of the most popular in China due to its texture, taste, and storage performance. The latter quality is ascribed to the relatively high cuticular wax content of the cultivar (He *et al.* 2019). By combining 'Kuerle' with a local traditional cultivar, 'Xuehua' (*P*. x *bretschneideri* Rehd.) the hybrid cultivar 'Yuluxiang' was created. 'Yuluxiang' inherited the sensory qualities of 'Kuerle' as well as the storability and a larger size from 'Xuehua'. In research of the wax composition of the three cultivars, only the cuticular wax of 'Yuluxiang' contained the triterpene squalene, (Wu *et al*. 2017) important in defense against certain pathogens. 'Yuluxiang' has exhibited resistance towards *Alternaria* rot, a pathogen causing problems in pear cultivation in ia (Reddy & Couvreur 2009).

4. Discussion

4.1 The Swedish market

Against a background of pear cultivation reaching back millennia both in Europe and Asia, with the latter offering a greater width of diversity it might seem like a lost opportunity not to explore the possibility of a new introduction of a variation of a fruit that is already accepted as one of the three most important deciduous fruit-tree crops around the world. Given the similar appearance of *P. sinkiangensis* Yü, and *P. communis,* it is fair to expect that little convincing is needed in order for customers looking for pears, to at least try the fruit once. Depending on local period for harvest, it might even be advantageous to introduce a pear that needs no cold-storage ripening before consumption thus being ready to sell before other varieties. However, local expectations of sensory qualities need to be taken into consideration. There is also the risk of customer habits in relation to *P. communis* would complicate the customer impression of the pear initially. The main concern would be in case fruit of *P. sinkiangensis* Yü is handled in the same manner as the common pear, with a delayed consumption after purchase rendering a lesser quality fruit. Further on, there is a need for a suitable trade name for *P. sinkiangensis* Yü in Sweden. In the case with Japanese pears, *P. pyrifolia*, sold in international markets, the Japanese word for pear, *nashi*, was chosen. However, the Chinese word for pear is *li*, which may be too short. The local term for *P. sinkiangensis* Yü in China is *Xiang li* and a more westernised version might be a rough translation into Sinkiang li or Sinkiang pear. However, the general term for pears in the Xinjiang group ‘Korla’ referring to the origin of the pear might be best suited.

During the research for this thesis, my perspective has widened from that of the Eurocentric mindset regarding sensory expectations of a pear. Realising that the soft texture of *P. communis* is a fairly new quality developed by breeders raises my curiosity towards these natural hybrids which parents once crossed paths only to develop differently during the centuries. On account of the wide span of different traits and qualities present within the Oriental group and the sheer size of the Asian continent, further investigation in regard to cultural differences in terms of sensory expectations would possibly clarify the picture. How do pears from other groups of Oriental pears affect the local impression of the cherished aroma of *P. sinkiangensis* Yü? How would the sensory qualities *P. sinkiangensis* Yü stand against perfectly ripe specimens of *P. communis* in different parts of the world? How is the export of *P. sinkiangensis* Yü from Xinjiang to foreign market related to immigrated populations in said country? These questions deserve further investigation in order to evaluate if *P. sinkiangensis* Yü has a place in the Swedish market. Taking into consideration the increase in production of *P. sinkiangensis* Yü in China and the limited selection in western commerce, there are reasons to believe that there is an unseen place in the market for *P. sinkiangensis* Yü.

4.2 Cultivation

All factors and possible methods for cultivation would have to be evaluated at depth in order to assume which would be best suited for a specific site when introducing a new variety of pear in Scania, Sweden. The adaptability and resilience within *Pyrus* may provide a basis for positive result and historically, introduction of *Pyrus* varieties has been done with successful outcome. However, it should not be denied that a change of cultivation environment might affect product quality. In order to evaluate a possible outcome in fruit quality a more in-depth investigation of cultivation conditions in Xinjiang and how that information could be translated to Swedish conditions would be necessary. If followed by a field study a more comprehensive answer to the research question would be attained. Another aspect worthy of investigation is if there are possible future benefits that come from taking advantage of the genetic resources of the Oriental pear germplasm and the fact that the two groups of pears seem to have developed somewhat convergently. Examples of that would be drought and salinity tolerance, factors that seemingly will be of importance in the foreseeable future.

4.2.1 Cultivation system

Tunnel cultivation already is and may become an even more important method of production in times to come, in terms of sustainability and food security. With a relatively minor investment there are many benefits to be reaped. Protected cultivation offers a more controlled environment regarding pathogenic pressure, pests, fertilisation, irrigation, weeds and climatic circumstances (SLU 2018). As is evident in UK cherry production, high tunnels are being utilised with satisfactory results. In a 2017 Norwegian study Haygrove multibay tunnel systems was used in an intensive production of sweet cherry in Ullensvang, western Norway. Results of the study showed less fruit cracking per consequence of rain that positively affected the yield (Meland *et al.* 2017). Another ten-year study performed in Michigan, USA (2016) proved less infection rates and a greater consistency in fruit quality of sweet cherries grown in a protected cultivation in a less-than optimal area for cherry production (Lang *et al.* 2016). Given the difference in humidity between the Scania marine climate and the arid climate of Xinjiang of which *P. sinkiangensis* Yü is adapted to, it is fair to believe that cultivation would have to take place in a protected environment. Given the positive results of rain-sheltered pear cultivation in Asia, it is easy to imagine a future for such a production system in Sweden. With the current situation regarding pathogens and pests in cultivation in Europe and Sweden, there is a possibility that there could be economical winnings made beyond the initial cost. Further investigation is needed to evaluate which local adjustments that are needed in order to maintain a beneficial microbial activity in the rhizospheric zone, as is studied extensively in areas with rain-sheltered cultivation (Zhang *et al.* 2020). It is hard to evaluate the performance of *P. sinkiangensis* cultivated in an open field, only speculations can be made. Besides from the major difference in humidity, the climatic factor of temperature might play into the fruit quality of open field cultivated pears. Would the day temperature of the Scania growing season be sufficient to ensure fruit quality? Yet again, cultivation in a rain-sheltered environment such as a tunnel perhaps would provide a better diurnal range in order to maintain or replicate the quality of fruit grown in Xinjiang.

4.2.2 Irrigation

The 'Korla' pear, *P. sinkiangensis*, is genetically adapted to the cold desert climate that prevails in the area around the town of Korla. The soil is poor in nutrients and the climate is dry with very little precipitation. The cultivations around Korla are contained from rivers where meltwater from the massifs collects in the spring. To sustain an adequate harvest despite minimal precipitation orchards are traditionally with watered using flood irrigation. With an increasing population and increased production areas in Xinjiang, the need for resource-saving irrigation methods has risen. In experiments with drip irrigation an optimal surface wet percentage has been established for production. Best results were gained at 32% surface wetness (average 3.02 kg / m3) and drip irrigation showed the greatest efficiency in relation to harvest after two years of experimentation. However, the growth of green mass decreases, something that can be interpreted as beneficial as the tree's energy is saved for next year's fruiting and that less pruning is necessary. The experiment used 50% less water than the traditional flood irrigation in dry climates (Zhao et al. 2012). The positive results of Zhao *et al*. (2021) in using brackish water and the several studies on using RDI with increased yield and fruit quality confirms the drought- and saline resistant qualities of *P. sinkiangensis.* These qualities and the findings of the studies performed speaks of the potential of *P. sinkiangensis* as being a sustainable fruit crop in the future.

4.2.3 Fertilisation

Since no known previous trials in cultivation of *P. sinkiangnensis* in the Scania region of Sweden has taken place general measurements of fertilisation of *Pyrus* species could be of use until individual adjustments could be made. Fertilisation measures depend on the soil status of the cultivation site, which should be analysed before any decision regarding fertilisation is made. In general, *Pyrus* genus can handle many types of soils and conditions, with the exception of waterlogged soil. In an analysis, soil type, pH and nutrient content should be taken into account before planting and then tissue samples should be taken on young leaves to determine uptake.

4.2.4 Cultivar and pollination

As previously stated, it is difficult to evaluate the performance of *P. sinkiangensis* under southern Swedish growing conditions, let alone certain cultivars, without physical trials. However, based on the results of the research of this study, some cultivars could be assumed to function well. According to Qi *et al.* 2011, cultivars 'Sha 01' and 'Kuerlexiangli' showed positive results in pollination of 'Kuerlexiangli' in field studies. Fruits of cultivars 'Sha 01' was also found to be of larger size, as well as 'Lanzhou Dadongguo' and 'Kuerle Xiangli' which could be advantageous in presenting a new fruit in a market setting. The latter also having an especially well-balanced ratio of sweetness and acidity. Going by storability 'Yulixiang' stand out as a possible candidate for trials in Sweden. To ensure pollination communities of bumble bee, *Bombus terrestris*, should be provided during inflorescence.

Table 1. Comparative table P. sinkiangensis *and* P. communis

	P. sinkiangensis	*P. communis*
Ripening resistance	No, ready to consume after harvest.	Yes, needs chilling to develop aroma and texture.
Storability	Yes, up to a year in CA environment.	Different for every cultivar. Three months is a common storage time.
Restistance to scab and rust	Yes, to the European species.	Yes, to the Asian species.
Resilience to drought and salinity	Yes, adapted to an arid climate and saline soil.	Moderately, but adapted to European climate and soils.

5. Conclusion

In conclusion, after researching the different cultivation methods at hand and its characteristics, *P. sinkiangensis* Yü seem like a promising future cultivar in southern Swedish production. Based solely on the argument of scab resistance, one could argue that *P. sinkiangensis* Yü deserves to be tried as a commercial cultivar in Europe and southern Scandinavia. The need for rain-shelter and the costs associated with that may be compensated by a higher yield and a higher quality fruit. Such a production system would also render the opportunity of organic cultivation of pears, which is scarce in Sweden today. The need for a program evaluating the field performance of *P. sinkiangensis* Yü under southern Swedish growing conditions could therefore be considered justified.

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