Evaluation of fruit leathers made from New Zealand grown blueberries

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Minakschhi Karki

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Evaluation of fruit leathers made from New Zealand grown blueberries

By Minakschhi Karki

Five different cultivars of blueberries (*Vaccinium* sp), Blue Magic, Burlington, Jersey, Puru, and Reka, commercially grown in Canterbury, New Zealand, were used to manufacture fruit leather. The fresh fruits were pureed with ingredients (honey, pectin and lemon juice) then dried in an oven at 60°C for 8 hours. The physio-chemical, textural, proximate and mineral contents of the dried leathers were then determined on all samples.

Proximate analysis of the fruit leathers showed that they contained low fat, protein and ash and consisted mainly of carbohydrates (mean 60.4%), fibre (mean 9.7%) and water (mean 22.2%). There were few differences between the compositions of the different cultivars. The total moisture and water activity (a_w) levels (mean 0.5) were low and the titratable acidity (mean 2.6% citric acid) and pH (mean 3.3) were high, suggesting that the products would have acceptable storage characteristics and would be microbiologically safe.

The 1 mm thick slices prepared from each cultivar showed acceptable physical characteristics. The texture of the five products was soft with low hardness and tensile force; the mean hardness of the five fruit leathers was 538.1 g and the mean tensile force was 18.9 N.

L*a*b* colour analysis showed that the colour of the fruit leather was lighter (mean L* value 28.5) than the corresponding fresh berry but, overall, the five different fruit leathers still retained an acceptable blue / purple colour even though the mean a* value (the redness) reduced from 7.2 to 1.7, a 76% reduction in red colour from the mean value for the fresh berries. Processing the blueberry cultivars led to a reduction in total phenolic contents (mean reduction 15%) and antioxidant activity (mean reduction 32%) for all cultivars. Among the cultivars, Blue Magic and Burlington had the highest antioxidant and phenolic contents in both the fresh and dried fruit leathers.

Sensory analysis using an untrained (consumer-type) panel of Lincoln University staff and students showed that the fruit leathers were well accepted. The two most liked fruit leathers with an overall acceptability of 5.3 (‘moderately liked’) were Puru and Reka. These cultivars were liked by panellists due to their colour, appearance, texture, stickiness, sweetness and chewiness. The lowest score was achieved by Blue Magic and Burlington, these cultivars were disliked by panellists due to their colour, overall appearance and flavour. Puru scored the highest for almost all attributes, was ‘liked’ by 38% of the panellists and had an overall acceptable of 5.0 out of 7.0. Overall, 93% of the panellists liked the fruit leathers which confirmed that it would form an acceptable new product.

Significant correlation was found between sensory attributes and instrumental parameters of the prepared fruit leathers. This research found that ORAC value was positively correlated to colour and overall appearance. Acidity was also positively correlated with hardness and tensile but negatively correlated with ORAC value.

Keywords: Fruit leather, blueberries, antioxidants, sensory evaluation.

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Chapter 1
Introduction

Blueberries are plants belonging to the genus *Vaccinium*. They are a member of the family, Ericaceae, and sub-family, Vaccinoidiae. Blueberries contain nutrients, phyto-nutrients, polyphenols, salicylic acid, carotenoids, fibre, folate, vitamin C, vitamin E, manganese, iron, riboflavin, niacin and phytoestrogens. Prior *et al*. (1998) found that blueberries were one of the richest sources of antioxidant phyto-nutrients, with higher levels of anthocyanins and phenolic contents than many other fruits or vegetables. Antioxidants can neutralise free radicals. Free radicals are unstable molecules that may cause the development of a number of diseases such as cancers and cardiovascular and neurodegenerative diseases (Prior *et al*., 1998). The primary sources of naturally occurring antioxidants are found in whole grains, fruits and vegetables. Prakash *et al.* (2010) studied these naturally occurring antioxidants and found that antioxidants like vitamin C, vitamin E, carotene, phenolic acids, phytate and phytoestrogens have been recognised as having the potential to reduce disease risk.

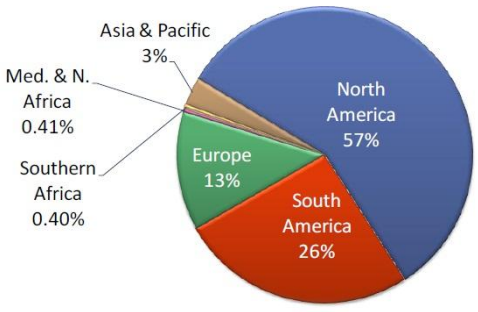
There are numerous epidemiological studies which suggest that the antioxidant contents of fruits and vegetables make a major contribution to the prevention of the degenerative process (Ames *et al*., 1993). Velioglu *et al.* (1998) mentioned that anthocyanins were probably the largest group of phenolic compounds in the human diet and their strong antioxidant activities suggested their importance in maintaining health. La Vecchia *et al.* (2001) analysed data from a series of case control studies conducted in northern Italy between 1983 - 1999 to find the relationship between frequency of consumption of vegetables and fruit and the risk of cancer. The authors reported that vegetable intake was associated with a substantial reduction in the risk for several common epithelial cancers. They also found that fruit intake had a favourable effect on reducing the risk of cancer of the upper digestive tract, stomach and urinary tracts.

Of the different berries in the *Vaccinium* family, blueberries and cranberries are ranked highly for both their antioxidant quality and quantity; especially Highbush blueberries which contain anthocyanins in the range of 120 to 208 mg/100 g for the fresh fruit (Neto, 2007) and antioxidant capacities, using the oxygen radical absorbance capacity (ORAC) assay, ranging between 14 - 45.9 µmol/g depending on variety (Prior *et al*., 1998). Prior *et al.* (1998) found that the antioxidant capacity of blueberries is higher than that for strawberries. A study conducted using rat models showed that the antioxidant rich phytochemicals in strawberries reduced, or retarded, the central nervous system deficits seen in aging and protected against

oxidative stress. Consumption of a more concentrated source of antioxidants (such as blueberries) would have a greater impact on the *in vivo* antioxidant capacity (Prior *et al*., 1998). The antioxidant capacity of cranberries were studied by Wang & Stretch, (2001) who found that the average antioxidant capacity was 10.4 µmol of Trolox equivalents per gram (TE/g) of fresh fruit. Cranberries contained high contents of total phenolics and have been shown to possess a high antioxidant capacity (Zheng & Wang, 2003).

Due to the claimed health benefits of blueberries, consumption of blueberry products has increased significantly globally. Blueberry production and consumption is expanding around the world. Global production of Highbush blueberries grew, between 2008 and 2010, by 66.33 million kg, from 275 to 341 million kg, an increase of 24% over two years (Brazelton, 2011); almost all the additional production was sold fresh. In North America, about 50% of all blueberries produced are sold on the fresh market, where they have only about 7 - 14 days shelf life (Shi *et al*., 2008). In order to extend the availability of blueberries out of season, fresh blueberries are dried directly or processed into different products or ingredients. The split between fresh and processed sales was 237.81 million to 101.40 million kg; this is a ratio of over 2 : 1 between fresh and process diversion (Brazelton, 2011). Figure 1.1 shows the world fresh and processed blueberry production in 2010, as shown by Brazelton, 2011. The processed blueberry market has the potential to grow. As blueberry production increases globally, it may be feasible to introduce new blueberry products to the food industry / consumer.

Fresh Blueberry Production



Processed Blueberry Production

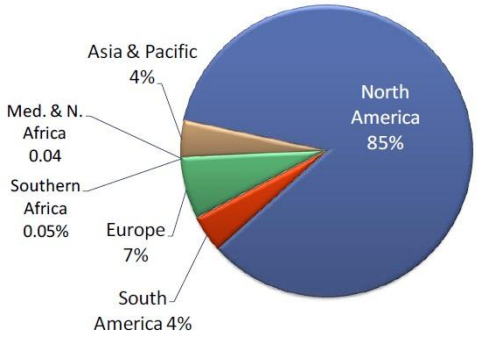


Figure 1.1 Fresh and processed blueberry production in 2010 (Brazelton, 2011)

The local blueberry production in New Zealand has increased significantly since the early 1990's. According to Ministry of Agriculture and Forestry (Ministry of Agriculture and Forestry, 2010), fresh fruit exports were worth $6.8 million in 2000 compared to $9.2 million

in 2005. Some of the blueberry cultivars bred in New Zealand are of exceptional quality and are sold overseas to premium markets; the main importers being Japan and the USA.

In addition to fresh sales, blueberries are used in a wide range of processed food product such as baking, beverages, cereals, confectionary, dairy snacks, sauces and 'real sealed' products (USHBC, 2010). Dried fruits such as sultanas, peaches, apricots and berries are also high in demand (Lohachoompol, 2007). For example, dried blueberries are mixed with breakfast cereals, energy bars and fruit snacks to produce healthy and flavoursome products. Other blueberry products include jellies, jams, pies, juice, flavoured drinks and muffins. Blueberries are also used in yogurt, ice-cream, cake and fruit desserts. Because of the high level of antioxidant activity found in blueberries, and the ability to slow the anti-aging process (Mason *et al*., 2006), nutraceutical and pharmaceutical industries have started using blueberries in their nutritional and skin care products. Zafra-Stone *et al*. (2007) reported that a mixed berry extract (known as OptiBerry) exhibited high antioxidant efficacy, as shown by its high oxygen radical absorbance capacity (ORAC) values, novel antiangiogenic and anti-atherosclerotic activities and potential cytotoxicity towards *Helicobacter pylori*. Both *in vivo* and *in vitro* studies suggest that antioxidants are an important part of a healthy diet (Neto, 2007; Prior *et al*., 1998; USHBC, 2010; Zafra-Stone *et al*., 2007). Consumption of ½ a cup of blueberries per day would increase ORAC intake by 1-3.2 mmol (Prior *et al*., 1998) and may reduce the risk of cardiovascular disorders, the advance of age-induced oxidative stress, inflammatory responses and diverse degenerative diseases. Although there are numerous blueberry products available in the market; and the perceived health benefits are a focus of the product's appeal, very little product development has occurred in the use of blueberries that are not suitable (or of lower quality) for export or being sold fresh in local markets.

Fresh blueberries have a limited shelf life (~ 7-14 days) and are a seasonal crop. As a result, the preservation of a fresh substitute and year round availability is important to meet the demands of consumers. Drying of agricultural products (such as blueberries) is the oldest and most widely used preservation method. It involves the reduction of as much water as possible from the fresh fruit to arrest enzyme and microbial activities, hence, stopping deterioration (Teshome, 2010). Drying processes include sun drying, oven drying, cabinet drying and dehydrator drying and freeze drying. Moisture left in dried foods varies between 2 -30% depending on the food type. The reduction of moisture content to a safe level extends the shelf life of the product and provides microbiological stability and reduces deteriorative chemical reactions. The process also allows a substantial reduction in terms of mass, volume, packaging requirement, storage and transportation costs (Okos, 1992).The drying process is,

therefore, an effective means to extend the shelf life of blueberries and offers an alternative way for consuming blueberries all year round.

Fruit leather is one product that can be made using a drying process. Fruit leathers are dried sheets of fruit pulp that have a soft, rubbery texture and a sweet taste. They are produced by dehydrating of fruit puree into a leathery sheet (Raab & Oehler, 1999). The edible portion of fruit (one or more types) is pureed, mixed with other ingredients to improve its physico-chemical and sensory characteristics, heated, formed (flattened and shaped) and then dried on a flat trays until a cohesive fruit leather is obtained (Moyls, 1981; Phimpharian *et al*., 2011). Fruit leathers can be eaten as snack foods or added to a variety of food preparations.

Fruit leathers can be dried using various drying processes including sun drying, oven drying, cabinet drying and dehydrator drying (Irwandi *et al*., 1998; Raab & Oehler, 1999). The composition of the final fruit product may vary depending on the processing conditions. Sun drying has traditionally been the process employed for preparing fruit leather from ripe fruit. However, sun-dried products can become discoloured and the process can be unhygienic and lengthy (Teshome, 2010). Hot air drying is an alternative method that needs less drying time and improves the quality of the dried fruit (Maskan *et al*., 2002; Garau *et al*., 2007); however it has been shown that hot air drying can promote a decrease in the antioxidant capacity of fruit (such as oranges). The author determined that the highest antioxidant capacity for the peel or pulp of oranges was when they were dehydrated at 60°C. Drying at higher temperatures (i.e. 80 to 90°C) or for longer drying time temperatures (i.e. around 30 to 40°C) decreased the antioxidant capacity of the final product. Heikal *et al*. (1972) and Mir & Nath (1995) used the cabinet drying method to make mango fruit leather and found that this technique resulted in a product with improved colour and flavour compared to old traditional sun drying method. This is the preferred drying method for manufacturing fruit leathers.

The preservation of fruit leathers depends on their low moisture content (15 - 25%), the natural acidity of the fruit and a high sugar content. Major quality parameters associated with dried fruit products, in no particular order, are change of colour / visual appeal, flavour, shape, texture, shelf life, microbial load, retention of nutrients, porosity or bulk density, rehydration properties, water activity, chemical stability and contaminants. These qualities of dried food products are dependent on the raw materials, composition of the food, processing method, environment, packaging and storage conditions (Perera, 2005). When fruit leathers are properly dried and packaged, they have a shelf life of up to nine months.

Most studies and research on fruit leathers incorporate not only fruit purees in the development of fruit leathers, but also other ingredients (especially sugars) and additives. For example, Che Man *et al*. (1992) prepared sapota leathers from sapota puree, sucrose, rice flour, sorbic acid and sodium metabisulphite. The fruit leathers were shelf-stable for three months. Jackfruit leathers with added sucrose and sorbic acid were produced by Che Man and Taufik (1995) and the product remained stable for two months. Irwandi *et al.* (1998) produced 12-week stable durian leathers from a formulation including sucrose and sorbic acid. Vijayanand, *et al*. (2000) produced three month shelf-stable guava leathers with the addition of sucrose and sodium metabisulphite. In addition to extending shelf life, it is also possible to improve the nutrient content of the fruit. Mangoes, for example, have very low protein content (1–2%). Several studies have increased this protein content by adding shrimp flour, rice flour, whey protein isolate and soy protein isolate to mango fruit leather (Chauhan *et al*., 1998). All the above-mentioned studies reported good consumer acceptance of the fruit leather product.

1.1 Hypothesis

This research work is focused on the development and evaluation of a blueberry fruit leather product using five different cultivars grown locally in Canterbury, NZ. Fruit leather will be prepared using a cabinet dryer. This process is expected to modify the colour, aroma and flavour of the product. It is also expected to reduce the antioxidant capacity and phenolic content of the fresh blueberries. The main aim of this project is to develop a blueberry fruit leather that retains its quality with respect to bioactive compounds such as antioxidants and phenolics. The addition of natural ingredients such as honey, pectin and lemon juice will be examined in the development of blueberry fruit leathers. To produce high quality blueberry fruit leathers, low temperature (at 60°C) drying is expected to be better in terms of physico-chemical qualities such as colour retention, nutrient content and lower water activity.

1.2 Objectives

The general objective of this thesis was to study the influence of processing on some quality attributes of blueberry fruit leathers. To achieve this overall objective the following objectives were identified:

- To produce blueberry fruit leathers from locally grown blueberries using natural ingredients such as pectin, honey and lemon juice and to identify the best cultivar to developing blueberry fruit leather.
- To develop blueberry fruit leathers using the cabinet drying method while preserving the antioxidants and phenolics contents.
- To conduct and compare physico-chemical analysis of both fresh and processed blueberries

Chapter 2

Literature Review

2.1 Blueberries in New Zealand

Blueberries were first introduced into New Zealand by the Department of Agriculture in 1950 (Poll & Wood, 1985). Blueberries are native to North America, primarily the United States and Canada, and have been produced commercially for many years. Due to popularity and demand, blueberry industries have also developed in South America, Australia, New Zealand and Europe. According to the United Nations Food & Agricultural Organisation (2009) more than 42,000 tonnes are harvested each year, of which 90% derives from North America (Ministry of Agriculture & Forestry, 2010).

Blueberries are a perennial crop that can produce for more than 30 years. Ideal conditions for cultivating blueberries require sandy soil, high in organic matter, a pH of 4.5 – 5.0 and a water table 30 - 60 cm deep, to provide moisture during the growing season (Hui *et al.*, 2008). Blueberry plants require 6 - 8 years to reach full production potential.

There are three main classes or varieties of blueberries grown for commercial purposes. They are:

- *Vaccinium corymbosum* (Northern Highbush) – this variety grows wild in the forests of North America and was used to cultivate the modern Highbush or cultivated blueberry industry along with *V. ashei*.

- *Vaccinium ashei* (Southern Rabbiteye) – this variety thrives in southern USA and is named after the calyx of the blueberry which resembles the eye of a rabbit.

- *Vaccinium angustifolium* (Lowbush or 'Wild Blueberry') – this variety of blueberry is known as a 'dwarf' bush as they only reach a height of 30 – 60 cm and are very cold hardy; surviving in the wild as far north as Arctic North America.

Highbush (*Vaccinium corymbosum* L.) and Rabbiteye (*Vaccinium ashei* Reade) blueberries were introduced to New Zealand as a potential crop for the wetland peat areas of Waikato (Poll & Wood, 1985). During the 1970s, the Ministry of Agriculture and Forestry (MAF) began an innovative blueberry development programme using micro-propagation technology that aimed to produce blueberry cultivars that could add value to the industry (Patel, 1997).

Initial plantings were based on information and literature available from overseas that focused primarily on only four cultivars: Atlantic, Jersey, Dixi and Burlington (Poll & Wood, 1985). However, other varieties such as Early Blue, Collins, Bluecrop, Rubel, Darrow, Garden Blue, Blueray, Coville, Herbert, Berkley, Tifblue and the Rabbiteye were also cultivated but limited information was available as they covered less than 5% of the total planting compared to the main varieties (Langford, 1982).

Although there were a few production problems in the early 90s, the development of the blueberry industry has been rapid since 1975 (Poll & Wood, 1985). According to Poll & Wood (1985), during the industry establishment phase, research concentrated on plant propagation and selection. The main emphasis was placed on the evaluation of berry characteristics, yield and fruit season of a range of cultivars. As a result, Highbush and Rabbiteye blueberries were subsequently chosen to be introduced and reproduced in New Zealand because of their adaptability to a warmer climate. Another reason for the rapid growth of the blueberry industry was for fruit production during the out-of-season period in the Northern Hemisphere. The popularity of growing blueberries has also significantly increased recently due to the demand for their bioactive compounds such as polyphenolics, pectic acids, ascorbic acid, carotenes, and antioxidant activity.

The low chill (temperate climate) blueberries planted in the Southern Hemisphere ripen from October to April depending on the area in which they are grown and this provided an opportunity for New Zealand to release New Zealand bred cultivars into the Northern Hemisphere to supply a year round demand for blueberries. According to the Agriculture Census (2002) there were 430 hectare of blueberries planted / grown in New Zealand with 80% of this crop being grown in the Waikato region (Patel, 1997). There are 75 growers of blueberries in New Zealand and the cropping area is now expanding into Hawke's Bay and other regions. Fresh blueberry exports were valued at $7.5 million in 2003.

There are over 50 varieties of Highbush, 15 varieties of Rabbiteye and several clones of Lowbush in cultivation. In addition, some varieties are based on intermediate forms of these groups including the `Half High' group (Highbush x Lowbush).

The three major commercial types of blueberries in New Zealand are the Highbush blueberry (of which the *Vaccinium corymbosum* is the most common), the Rabbiteye blueberry (*V. ashei*) and the Lowbush blueberry (*V. angustifolium* and *V. myrtilloides*). The main differences between these varieties are their stature, deciduous or evergreen habit, winter

chilling requirements and fruiting season. Based on these differences, growers in different areas can select species that are more suited to their particular micro-climate. Blueberries grow best in acidic soils, with an optimum pH requirement for growth of 4.8 (Gough, 1994). They require a chilling period to open their flower buds. A longer chilling period enhances the percentage of flower buds that open (Eccher *et al.*, 2006). However, most blueberry plants cannot survive temperatures below -29°C (Mazza & Miniati, 1993). Lowbush blueberries need more chilling to bud than the Highbush and Rabbiteye blueberries, therefore, this variety tends to grows well in colder parts of the Northern Hemisphere.

Figure 2.1 Highbush blueberries and Rabbiteye blueberries, Canterbury, NZ

2.1.1 Highbush blueberries (*Vaccinium corymbosum* L.)

Highbush blueberries are native to North America and are extensively grown in the temperate region of the United States and Canada. *V. corymbosum* (Northern Highbush) grows wild in the forests of North America and was used to develop the modern cultivated Highbush blueberry industry, along with *V. ashei*. Highbush blueberries are perennial, deciduous and long lived shrubs that can easily be cultivated to produce a desirable flavour, texture and colour for the fresh and / or 'processed' markets.

Fruit from Highbush blueberries has a single layered outer epidermis with no stomata, are covered with a cuticle about 5 µm thick and have a waxy bloom at maturity (Gough, 1994). Highbush blueberry is the most cultivated blueberry variety in New Zealand. There are two main species cultivated commercially *V. corymbosum* and *V. austral* (New Zealand Berryfruit Propagators, 1999). There are two sub groups that belong to the Highbush blueberry species – the 'Northern Highbush' and 'Southern Highbush' (see Table 2.1). These sub species are based on geographical lines. The Northern Highbush species grown in New Zealand requires a high degree of winter chilling (minimum of 800 chilling hours) compared to Southern Highbush (New Zealand Berryfruit Propagators, 1999). The ripening of fruit also depends on

the seasons. For example, high sunshine hours in December will induce earlier ripening of blueberry fruit (Ian Sheerin, pers. comm.).

Table 2.1 Northern and Southern Highbush blueberries cultivars grown in NZ

Northern Highbush Blueberries	Southern Highbush Blueberries
Aurora, Berkely, Bluecrop, Bluegold, Blueray, Burlington, Chandler, Collins, Darrow, Dixi Draper, Duke, Earlieblue, Elliot, Hardyblue, Harrison, Herbert, Ivanhoe, Jersey, Legacy, Liberty, Northland, Nui, Patriot, Puru, Reka, Rubel, Spartan, Toro, Stanley.	Emerald, Jewel, Jubilee, Misty, O'Neal, Sharpblue, Southmoon, Star, Sunshine blue and Marimba.

The following cultivars can be categorised by their harvesting period.

- Early season (early December to January): Puru, Nui, Reka and Duke
- Mid - season (January onwards): Jersey and Dixi
- Late season (February): Elliot and Burlington

In Canterbury, the harvesting periods are three weeks later than in the North Island. For example, Puru and Reka are fully ripe in mid-January, Jersey in February and Burlington in late February.

2.1.2 Rabbiteye blueberries (*Vaccinium ashei*. Reade)

Rabbiteye blueberry production, unlike Highbush or Lowbush, is based only on one species. *ashei*, and is common to south eastern USA (from Georgia to South Alabama). Compared to Highbush, *Vaccinium ashei* is more drought and heat tolerant, has lower chilling requirements and a wider pH tolerance (Eccher *et al.*, 2006). Rabbiteye grows better in light well drained soils with a pH from 4.2 to 5.5. The chilling requirement is generally around 400 – 500 hours (Eccher *et al.*, 2006).

Rabbiteye blueberry production in New Zealand has expanded in recent years in response to its ability to crop late in the season (February to early April). Rabbiteye varieties are not as popular as Highbush varieties; however, as previously mentioned, there are distinct advantages in growing Rabbiteye as they produce late in the season. There has been much criticism of the breeding programme in New Zealand regarding Rabbiteye varieties. In the past, Rabbiteye cultivars were bred in the South Island but MAF moved the programme to the Ruakura breeding station in Hamilton where Rabbiteyes suitable for North Island, were bred, but these blueberries are not suitable for the South Island (Ian Sheerin, pers. comm.).

Rabbiteye is susceptible to bacterial blast, particularly in the South Island. However, if a breeding programme were developed in Canterbury, suitable Rabbiteye varieties can be developed and could establish well in this region (Ian Sheerin, pers. comm.).

Rabbiteye blueberries can be grown in most localities in the North Island, but require temperatures of 20 - 25°C in late summer to ripen the fruit. In New Zealand, Climax, Premier, Tifblue, Powderblue, Maru, Rahi and Delite are the most popular Rabbiteye cultivars (Patel, 1997). In Canterbury, Ian Sheerin has found only Powderblue and Blue Magic were suited to the climate.

2.1.3 Titratable acidity and °Brix

The quality and flavour of blueberries depends on its soluble solids (mainly sugars), titratable acidity (organic acids), fruit firmness and antioxidant capacity. Blueberries are 'soft' fruit berries that do not require peeling or cutting before use; they are described as a mildly sweet and are not tart like cranberries, strawberries or raspberries. Titratable acidity is an important quality factor related to the flavour of blueberries. If the acidity is too low, the product may be bland and unappealing. Titratable acidity and sweetness varies between blueberry species due to their chemical composition.

The sugar content of fruit is measured using a °Brix refractometer. One degree 1g of sucrose in 100g of solution represents the strength of the solution as mass percentage (% w/w). If the solution contains dissolved solids other than pure sucrose (which is the case for most fruit juices), then the °Brix gives the approximate value for the dissolved solid content.

A °Brix range from 7 – 14° is generally found in most blueberry cultivars. The types of sugars that are found in blueberries are glucose, fructose and sucrose. Kalt and McDonald (1996) found that these three sugars were found in the larger Highbush blueberry cultivars that are grown in California. Lowbush blueberries, which are wild, smaller and grow mostly in Maine, were found to lack sucrose. Hui *et al*. (2008) measured the °Brix and titratable acidity of common cultivated blueberries. The °Brix and titratable acidity readings were 12° and 0.80%, respectively. Commercially available cultivated blueberries from the Pacific Northwest however were found to have higher °Brix (17.5°) and titratable acidity (1% as citric acid). Connor *et al*. (2002a) found °Brix and acidity of some cultivated blueberries in the range of 11 - 12.6° and 0.9 – 2.46%, respectively. The °Brix of blueberries also depends on the harvesting time and year of production (Kalt *et al*., 2001).

2.1.4 Nutritional qualities

The nutritional value of food products has become an important consideration in marketing. Raw blueberries are low in calories and can be a good source of fibre, natural sugars, vitamins and minerals. Generally the human body requires large amounts of carbohydrate, fat and protein and low amounts of vitamins and minerals on a daily basis. Carbohydrates and fats are two major sources of energy in the diet. A diet that provides abundant carbohydrate (45 to 65% of energy intake) and some fat (20 to 35%) within a reasonable energy allowance best supports good health (Whitney & Rolfes, 2011). Dried or dehydrated blueberries are high in dietary fibre and sugars and low in total fat (Hui *et al*., 2008). Major minerals found in blueberries are potassium, calcium and sodium (Table 2.2). These minerals are required by the body to maintain fluid and electrolyte balance and cell integrity (Whitney & Rolfes, 2011). According to Table 2.2, dehydrated blueberries contain higher amounts of potassium than calcium and sodium. Other minerals found in raw blueberries are iron, phosphorous, magnesium, zinc, copper and manganese (USDA National Nutrient Database, 2006).

Table 2.2 Nutrient content of blueberries (Hui *et al*., 2008; USDA National Nutrient Database, 2006)

Nutrients / 100 g FW	Raw Blueberries	Dehydrated Blueberries
Protein (g)	0.74	4.22
Total Fat (g)	0.33	2.39
Total Carbohydrate (mg)	14.49	89.00
Total Fibre	2.40	8.19
Total Sugar	9.96	80.80
Calcium (mg)	6.00	38.00
Potassium (mg)	77.00	561.00
Sodium (mg)	1.00	38.00
Vitamin C (mg)	9.70	81.90
Vitamin A (IU)	54.00	630.00
Water (g)	84.21	3.00

Fresh Lowbush blueberries contain 81 - 85% moisture and individually quick frozen (IQF) berries may have up to 87% moisture (Yang & Atallah, 1985). They also contain 9% sugar and a small amount of protein. A100 g of Lowbush blueberries would provide 6.8 mg of vitamin C and 46 µg of vitamin A. In addition to these nutrients, blueberries also contain other non-nutrient compounds including phytochemicals which are found in plants that have biological activity in the body. Phytochemicals in the body can have profound physiological effects – acting as antioxidants, mimicking hormones, stimulating enzymes, interfering with

DNA replication, destroying bacteria and binding physically to cell walls (Whitney & Rolfes., 2011).

2.1.5 Antioxidant capacity and phenolic compounds in blueberry cultivars

Fruit and vegetables contain many different phytonutrients, many of which have antioxidant properties. Blueberries are known to have a high antioxidant capacity and a high concentration of phenolics, particularly anthocyanins and chlorogenic acid (Skrede *et al*., 2000). Anthocyanins are the most abundant and important group of water-soluble pigments in plants, and are glycosides of anthocyanidins (You *et al.*, 2011). Chlorogenic acid is a well-known colourless co-pigment that can significantly increase the colour intensity of anthocyanins. The typical blue colour of blueberries is due to the presence of anthocyanin pigments. Anthocyanins are mainly distributed in the flowers, pulp and skin of fruit and are responsible for their bright colours, orange, red or blue, depending on pH values (You *et al*., 2011).

Zheng & Wang (2003) reported four major anthocyanin pigments: malvidin (purple), petunidin (blue - purple), delhphinidin (blue-violet) and cyanidin (red, in the Highbush blueberry Sierra). Kalt *et al*. (1999) described the anthocyanins of blueberries as a complex mixture of anthocyanins. They reported that blueberries contain cyanidin, delphinidin, petunidin, peonidin and malvidin glucosides, arabinosides and galactosides. Quantitatively, delphinidin and malvindin glycosides were present in large quantities whereas derivatives of peonidin were the least abundant in blueberries (Scibisz & Mitek, 2009). The majority of the antioxidants are concentrated in the skins and the fruit is one of the most desirable and nutritious among fresh fruits and vegetables (You *et al.*, 2011; Prior *et al*., 1998).

Phenolic compounds are closely associated with the sensory and nutritional quality of foods, contributing directly or indirectly to desirable or undesirable aromas and tastes. In low concentration, phenolics may protect food from oxidative deterioration; however, at high concentration, they, (or their oxidation products) may participate in the discolouration of foods, and interact with proteins, carbohydrates and minerals (Imeh & Khokhar, 2002).

Phenolic components in Highbush, Lowbush and Rabbiteye blueberries are found mainly in the skin (Su & Silva, 2006). Lee & Wrolstad (2004) found cinnamic derivatives and flavanol-glycosides in the skins and seeds, whereas only cinnamic acid was found in the flesh.

A multitude of environmental factors such as storage, temperature, seasonal harvesting time and fruit maturity can influence the phenolic content of the fruit and leaves. Many fruit-based

foods are processed into products such as beverages, baked goods or confectionary. It is proposed that the processing treatment the fruits undergo may have detrimental effects on their antioxidant capacity (Kalt *et al*., 2001). According to Kalt *et al*., (2001), processing parameters, including heat, aeration and pH were found to significantly decrease the antioxidant capacity of blueberries. The authors found that the total phenolic content increased when raspberries were stored at greater than 0°C. In addition, fruit stored at a higher temperature (60°C) initially showed that it was possible to extract more phenolics and ORAC but, subsequently, showed more damage after storage.

Antioxidant capacity of blueberries

Blueberry antioxidant capacity varies among cultivars (Howard *et al*., 2003; Mason *et al*., 2006; You *et al*., 2011; Scalzo *et al*., 2009). Researchers and growers are interested in cultivating varieties that have high antioxidant levels. However, the antioxidant capacity of blueberries is highly affected by environmental growing conditions such as season and location, genotype, maturity and postharvest storage conditions (Howard *et al*., 2003).

Mason *et al*. (2006) studied the antioxidant activity and total phenolic content of four blueberry cultivars grown in NZ. Of the four cultivars studied: Burlington, Alanta, Stanley and Jersey; Burlington blueberries had a slight advantage over Atlanta, Jersey and Stanely cultivars as they showed a higher level of antioxidant activity, with 1369 ± 141 mg GAE/100 g dry weight (DW) when measured by SASA (superoxide anions scavenging activity). The other cultivars ranged from 975 to 1011 mg GAE/100 g DW. Scalzo *et al*. (2009) undertook a similar study on three cultivated blueberry types: Northern Highbush, Southern Highbush and Rabbiteye, to analyse the total antioxidant activity and anthocyanin composition between the different genotypes and different fruit traits (size, firmness, colour and fruit and scar diameters). The author found that there was some variation among genotypes. The variations resulted from advanced selection of the Northern Highbush blueberry which provided improved fruit traits compared to the commercial cultivars, but with a reduced phytochemical composition (total antioxidant activity and anthocyanins). Phytochemical composition was also reduced for the Southern Highbush advanced selection but the weight of the berries increased by 10% whereas for Rabbiteye, advanced selection had improved phytochemical composition without loss of quality in the fruit traits.

There are numerous methods for the measurement of antioxidant capacity. The oxygen radical absorbance capacity (ORAC) assay has been used widely to measure the net antioxidant capacity (or peroxyl radical absorbance capacity) of blueberries. Other methods used to

measure free radical scavenging activities of food are photochemiluminescence (PCL) assays (Cho *et al.*, 2005), superoxide anion scavenging activity (SASA) and free radical scavenging activity (DPPH). Prior *et al.* (1998) used four varieties of *Vaccinium sp* to demonstrate that ORAC was linearly related to the anthocyanin and total phenolic contents. However, this relationship was not confirmed by Rossi *et al.* (2003) for *Vaccinium* varieties and other berries.

Determination of antioxidant capacity by using the oxygen radical absorbance capacity (ORAC) method

The ORAC method was developed by Cao *et al*. (1993) and measures antioxidant scavenging activity against a peroxyl radical induced by 2,2-azobis (2- amidinopropane) dihydrochloride (AAPH) at 37°C (Ou *et al.*, 2001). According to Ou *et al*. (2001), the loss of fluorescence in this assay indicates the extent of damage from the reaction of fluorocein with the peroxyl radical. The protective effect of an antioxidant is measured by assessing the area under the fluorescence decay curve (AUC) of the sample compared to a blank with no antioxidant present. The ORAC assay provides a unique and complete assessment in which the inhibition time and inhibition degree are measured as the reaction goes to completion.

Prior *et al*. (1998) compared total phenolics, total anthocyanins and antioxidant capacity in appropriate berry samples from selected cultivars of blueberries (Highbush, Rabbiteye, Lowbush and Bilberry). The comparison was based on the ORAC, total anthocyanin and total phenolics content of each species. According to Prior *et al*. (1998), total antioxidant capacity, measured as ORAC, for blueberries ranges from a low of 13.9 to a high of 45.9 µmol TE/g in fresh berries for the acetonitrile extraction of different cultivars of blueberries. The mean for the five Highbush and five Southern Highbush were 24.0 and 28.59 µmol TE/g FW, respectively, with values ranging from 17 to 42.59 µmol TE/g FW.

Kalt *et al*. (1999) found that the antioxidant capacity was stable or even increased during storage of fresh strawberries, raspberries and Highbush and Lowbush blueberries at 0, 10, 20, and 30ºC for up to eight days. The antioxidant capacity was strongly correlated to the content of total phenolics ($r = 0.83$) and anthocyanins ($r = 0.90$).

Kalt *et al*. (2000) examined the effect of various processing factors on the antioxidant capacity of blueberry juice, puree and commercially processed blueberry products. The research showed that the antioxidant capacities in fresh fruit and frozen fruit were very similar, 52.9 mmol Trolox eq/100 g DW and 31.2 mmol Trolox eq/100 g DW, respectively.

The fruit puree also showed similar values (42.0 mmol Trolox eq/100 g DW). The ORAC value of dried blueberry was found to be lower in fruit that had been more thorougly dried. The ORAC level for intermediate moisture fruit was 25.5 mmol Trolox eq/100 g DW, low moisture dried blueberry was 15.1 mmol Trolox eq/100 g DW, blueberries in cereal fruit was 2.97 mmol Trolox eq/100 g DW, sugar infused fruit was 11.3 mmol Trolox eq/100 g DW and blended powder 7.44 mmol Trolox eq/100 g DW. The results indicated that the less processed products have higher antioxidant capacity than the more processed fruit.

Determination of total phenolics

The main method of determining total soluble phenolic content uses an ethanol / acetone / water / acetic acid extract. The Folin-Ciocalteu reagent is used according to the method of Slinkard & Singleton (1977), using gallic acid as a standard.

Kalt *et al*. (2001) measured total dissolved phenolics using the Folin Ciocalteu assay with a 96-well microplate reader for Highbush blueberries (*Vaccinium corymbosum* L) and Lowbush blueberries (*Vaccinium angustifolium* Aiton). The absorbance was read at 700 nm, using gallic acid as a phenolic standard, with results expressed as mg gallic acid equivalents/g of fresh weight (mg GAE/g FW). The authors found that the Highbush and Southern Highbush cultivars both had 1.91 mg GAE/g FW. Similarly, Mason *et al*. (2006) also compared total phenolic content of four New Zealand grown blueberry cultivars. These cultivars were Atlanta, Burlington, Stanley and Jersey. Blueberries were analysed for total phenolic using the Folin-Ciocalteu reagent. The total phenolics of the New Zealand blueberries ranged from 230.10 ± 18.0 to 497.10 ± 63.20 mg GAE/100 g DW. Among the four cultivars, Burlington blueberries had a significantly ($P < 0.001$) higher total phenolic content than the other cultivars sampled.

2.2 Introduction to fruit leathers

Fruit leather is prepared by dehydrating fruit puree into leathery sheets. It is made by removing the moisture of the fruit puree, using a large flat tray, until the desired cohesive ‘leather’ is obtained (Moyls, 1981). Most fruits are suitable for this type of processing. Common fruit used in the production of fruit leather include kiwifruit (Vatthanakul *et al*., 2010), mangoes (Azeredo *et al*., 2006), grapes (Maskan *et al*., 2002), guava (Vijayanand *et al*., 2000) and durian (Irwandi *et al*., 1998).

Fruit leather is eaten without further preparation and can be consumed directly as a snack or chopped into small peices combined with nuts and breakfast cereals (Irwandi *et al*., 1998). As

fruit leather is made of fruit, it is generally nutritious and is often targeted at health food markets, using marketing images such as ‘pure’, ‘sun-dried’ and ‘rich in vitamins’ (Vatthanakul *et al*., 2010). Fruit leather that is made without sugar is a healthy choice of snacks for diabetic adults or children (Bharambhe *et al*., 2009).

The main advantange of making fruit leathers is to preserve food by drying and, hence, controlling postharvest spoilage. Making fruit leather from ripe or slightly over-ripe fruit that is not suitable for fresh consumption will enable producers to satisfy market demand during off season periods. For example, strawberries have a high post-harvest physiological activity with short ripening and senescence periods which makes marketing of this high-quality product a challenge. As discussed by Lee & Hsieh (2008), one of the most promising methods for preservation of strawberries is through drying. Fruit with minor blemishes and bruises that is not suitable for canning and freezing can be used to make fruit leather (Raab & Oehler, 1999).

Blueberries are similar to strawberries in that they have a short harvest season, are only available in the summer months and can only be stored under refrigerated conditions for up to six weeks after harvesting (Kim & Toledo, 1987; cited in Stojanovic & Silva, 2007). To extend the shelf-life, blueberries are often preserved by methods such as canning, dehydrating and freezing. Blueberries are also a soft fruit so can easily be bruised and crushed during picking and processing. Developing fruit leather from this ‘damaged’ product could be an economic and convenient value-added substitute for natural fruit.

2.2.1 Fruit leather processing and quality

Although fruit leather is a relatively well established product overseas, few academic studies have been published on the topic. Of the few papers available, most studies utilise not only fruit purees in the production of fruit leather, but also other ingredients and additives. Different ingredients and additives are added to enhance the flavour, increase shelf-life, extend stability and protect the fruit leather from the microbial contaminants. Fruit leathers, however, can be prepared without the addition of any preservatives or sweeteners (Azeredo, 2006). Studies on fruit leathers have shown that fruit puree can be mixed with other ingredients (especially sugars) and additives to enhance the texture, flavour and colour of the final product. Popular ingredients are ascorbic acid or fruit juice for colour preservation (to avoid darkening during drying), honey and sugar (to sweeten the product), nutmeg, cinnamon, chopped nuts and coconut (as a flavours) (Raab & Oehler, 1999).

Different types of fruit can also be mixed together to prepare a fruit leather. Kumar *et al.* (2010) prepared papaya fruit leather by blending it with guava pulp to enhance the papaya's flavour. This was necessary as the poor odour of the fruit was its main hindrance in the commercial exploitation of this fruit in processing. Similarly, a mixed fruit leather was processed by mixing sapota pulp, mango pulp, papaya pulp, banana pulp and soya milk powder (Bharambhe *et al*., 2009). The product was found to be acceptable during sensory evaluation.

Different types of preservatives such as sulphur dioxide (SO_2), potassium metabisulphite and sodium metabisulphite are often mixed in fruit puree for preservation and to reduce enzymatic browning. Chan & Cavaletto (1978) prepared papaya fruit leather with sucrose and SO_2. They observed that SO_2 inhibited browning and reduced changes in the colour of papaya fruit leathers during processing and storage. Che Man *et al*. (1992) prepared sapota leathers from sapota puree, sucrose, rice flour, sorbic acid and sodium metabisulphite; the fruit leathers were shelf-stable for three months. Jackfruit leathers with added sucrose and sorbic acid were produced by Che Man & Taufik (1995); the product remained stable for two months. The addition of glucose syrup, sucrose, hydrogenated palm oil and soy lecithin into durian resulted in a flavoursome durian fruit leather (Irwandi *et al*., 1998). The durian fruit leather, which contained sucrose and sorbic acid, was stable for 12 weeks. Similarly, a guava puree was prepared by mixing maltodextrin, pectin, soluble starch and wheat flour to the guava juice to improve the texture of fruit bars; the product was shelf-stable for three months at room temperature with the addition of sucrose and metabisulphite (Vijayanand *et al*., 2000). However, the use of SO_2 has been increasingly controlled and it has been banned in many foods in the USA and Europe. As a result, citric acid has been substituted to prevent browning, however, this is less efficient than sulphur dioxide (Anonymous, 2001). The use of preservatives is not always necessary to create a quality fruit leather product. Mango fruit leather, for example, was well accepted (especially in terms of flavour) when no preservatives or sugars were included in the final product. The reductions in sugar additives and preservatives are driven by consumer demand for a healthy natural product (Azeredo *et al*., 2006)

Fruit such as cranberries, raspberries and strawberries have a tart taste and, therefore, the addition of sugar is recommended to sweeten the final product. During the development of fruit leather, corn syrup, golden syrup, honey, glucose syrup and artificial sweeteners, such as aspartame are added to the fruit puree to sweeten the fruit leather. Huang & Hsieh (2005)

reported that the addition of corn syrup to pear fruit leather softened the fruit leather texture when compared to the addition of other ingredients. Corn syrup and golden syrup are considered to be the best additives for longer storage / shelf life as they prevent crystal formation, whereas, sugar is only acceptable for immediate use or short storage (Bharambhe *et al*., 2009). The glucose and fructose present in corn syrup or golden syrup crystallises less readily than sucrose but provides good preservation quality. Koukel (2009) mentioned that granulated sugar is not a good option as it may crystallise during storage, making the leather brittle. Aspartame sweeteners may also cause loss of sweetness during drying (Bharambhe *et al*., 2009). Honey is a recommended sweetener for fruit leather (Koukel, 2009) as it also has antioxidant, antibacterial and anaerobic quality that acts as a food preservative and is a good heathly choice. Honey is also a good ingredient as it allows for longer storage and extends shelf life; it also prevents crystallisation. Not only may the added sugar crystalise but some dried fruits (such as figs, dates, mangoes, papaya, guava and persimmons) are subject to sugaring on the surface or within their flesh, which is not a positive feature (Perera, 2005). Another common ingredient used in the development of fruit leather is pectin. Pectin is produced from vegetables with a high natural pectin contents, such as apple pomace, citrus peels and beet chips (Herbstreith & Fox, 2010). In fruit leather, pectin acts as a thickening agent and stabilises the mass of the product. The amount of pectin used in the fruit leather will affect its textural qualities, such as toughness, chewiness, hardness and stickiness. Pectin has been found to be the most important factor that influenced all of the five texture profile analysis properties of pear fruit leather (Huang & Hsieh, 2005). According to Huang & Hsieh (2005), the higher the pectin content, the higher the hardness, cohesiveness, springiness and chewiness of the fruit leather. High degree of esterification (DE > 50%) pectin forms gels at acidic pH and in the presence of high concentration of sucrose (Pomeranz, 1991). At higher DE pectin molecules hydrogen-bonded with each other and formed cross-links that enhanced the pear fruit leather's ability to resist the deformation caused by the texture analyser's probe and increased the fruit leather's hardness, springiness, cohesiveness, and chewiness. Similarly, Phimpharian *et al*. (2011), studied the effects of glucose syrup (2, 4 and 6%) and pectin (0.5, 1.0 and 1.5%) concentrations on machine formed pineapple fruit leather. The authors found that increasing the pectin concentration from 1.0 to 1.5% negatively affected the toughness acceptability, which was attritbuted to reduced moisture and water activity, and increased tensile force. The optimum formulation range consisted of 3.5 - 6.0% glucose syrup and 0.5 - 1.0% pectin for pineapple fruit leather.

2.2.2 Preparation of fruit leather

The basic technique for preparing fruit puree is to wash, peel, and then remove the stones from the fruit, if required. The fruit is then cooked if required before drying. Raab & Oehler (1999) decribed two different methods, 'cold break method' and a 'hot break method'. In the 'cold break' method the fruit is first pureed and then cooked in a boiler for 10 minutes. In the 'hot break' method pieces of chopped fruit are steamed for 15 minutes, cooled and then pureed. The fruit leather developed by Kendall & Sofos (2010) was prepared by cutting fruits into chunks and placing them in the top of a double boiler. Water was placed in the bottom of the double boiler and brought to boil. The fruit puree was covered and steamed for 15 to 20 minutes until the fruit was soft. In the past, recommendations for preparing fruit leather from both fresh and cooked fruit have been given. However, because of increasing concerns with bacteria contamination, such as *Escherichia coli* O157:H7 being able to survive the drying process, it is considered best practice to heat the fruit to ~70°C before drying (Kendall & Sofos, 2010). Azeredo *et al*. (2006) produced mango fruit leathers by cleaning and sanitising fruit in a 50 mg/L free active chlorine solution. The mangoes were pureed and passed through a 1mm sieve. The puree was spread on petri dishes and oven-dried. However, to make berry purees, berries were rinsed, drained and blended until the consistency of a thick puree was achieved. Most berries do not need to be cooked (Koukel, 2009) as the soft fruit goes mushy quickly and loses flavour and colour during cooking due to oxidation processes. Berry fruits such as blueberries and cranberries have been shown to be effective in combating bacterial infection. The anthocyanosides present in blueberries and cranberry have been well studied for their ability to prevent *Escherichia coli* from adhering to the epithelial wall of the urinary tract, limiting the development of a urinary tract infection (Patras *et al*., 2010). Unfortunately, cooking fruit destroys anthocyanosides and reduces the ability to combat microorganisms.

Furthermore, cooking berries at high temperature can destroy nutrients. Khanal *et al*. (2010) studied anthocyanin contents of grape and blueberry pomace by cooking the pomaces at 40, 60, 105 and 125ºC. The authors found that the total anthocyanin contents of both grape and blueberry pomace decreased considerably when the heating temperature was increased from 60 to 125°C, but was not affected when heated to 40°C.

2.2.3 Drying methods

Drying is one of the oldest methods of food preservation techniques and is the most commonly employed commercial technique in the food processing industry. Two processes take place simultaneously during drying, these processes are heat transfer to the product from

the heating source and mass transfer of moisture from the interior of the product to the surface and from the surface to the surrounding air (Perumal, 2007). The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time, normally regarded as the 'safe storage period' (Ekechukwu, 1998).

To achieve a high quality product, close monitoring of the drying process is important. Moyls (1981) studied the two main factors that influenced drying time: air temperature and velocity. It is vital to get fresh dry air in contact with the surface of the product and the hotter the air the more effective it was in removing moisture. When drying, care must be taken to maintain a consistent thickness of product, otherwise moisture patches will cause the leather to rip when it is removed from the drying trays.

Common drying methods used for drying fruit leathers are oven-drying (including convection / fan forced), sun-drying, electric cabinet drying and off-the-shelf food dehydrators (Raab & Oehler, 1999). Both cabinet and oven drying are reported to produce higher quality leathers with cabinet dried leather being more acceptable (Raab & Oehler, 1999; Che Man & Sin, 1997). Moyls (1981) conducted leather drying trials using two types of tray dryers – metal trays and wooden trays. The author found that the metal trays were from 20 - 30% more efficient than wood trays in terms of reducing drying times. An oscillating vane system was found to be best for drying thin leathers than a fixed vane system. The insertion of a perforated plate upstream of the air flow through the tray produced more uniform leather. The plate and vane, together, disrupted the airflow and spread the hot air evenly around the dryer cabinet, resulting in evenly dried leather.

Sun dried fruits and fruit products are the most widely known of all dried foods. Sun drying permits the drying of a product with a rich colour, a translucent appearance and a desirable gummy texture, but this method also has many disadvantages (Maskan *et al*., 2002). Open air sun drying is not well suited to large scale production. The disadvantages of sun drying include the lack of ability to control the drying operation properly, the slowness of the process, weather dependancy, high labour costs due to the need for hand labour, insect infections, the exposure to environmental contamintation due to mixing with dust and other foreign material (Maskan *et al*., 2002).

Popular drying methods currently used for making fruit leathers include dehydrator drying, electrical ovens and convective hot air drying. Dehydrator drying takes approximately four to tweleve hours (Sunbeam Manual, 2010), but the time ultimately depends on the type of fruit

leather, humidity in the room and thickness of the fruit puree. Trays are placed in the dehydrator and rotated every three to four hours to promote even drying. As a general rule, fruit leather should be dried at around 60°C.

The technology of electrical oven drying has long been employed to extend the shelf-life of food. However, oven drying may take up to 18 hours for fruit leathers to dry to a moisture level of 15 - 25%. According to Henneman & Malone (1993), one disadvantage of oven drying is that older style ovens do not have built-in fans for air movement. It takes two to three times longer to dry fruit leather in an oven without a fan than in a dehydrator. However, newer style convection ovens do have fans.

Hot air drying needs less drying time and improves the quality of the dried product (Maskan *et al*., 2002). Hot air drying is one of the common unit operations in the food processing industry. The drying characteristics of strawberry fruit leathers by hot air drying was investigated by Lee & Hsieh. (2008). Strawberry fruit leathers were prepared by blending strawberry puree, corn syrup, pectin and citric acid in a ratio of 200:40:2:1.The puree was spread into thin layers (1.8, 2.7 and 3.6 mm) and dried in a convection oven at 50, 60, 70 and 80°C. The authors recorded the moisture loss at constant time intervals during drying and observed that both drying air temperature and sample thickness influenced the values of the apparent moisture diffusion coefficient (Deff), which varied from 2.40×10^{-9} to 12.1×10^{-9} m^2/s. However, the drawback of the hot air drying method is controlling the drying conditions (including increasing drying temperature and decreasing initial moisture content of the puree) that increase the quality of the fruit leather (Teshome, 2010).

During drying, desirable or undesirable chemical or biochemical reactions may lead to changes in colour, texture, odour and nutritional properties of the final product. It was reported that solar and oven dried leathers resulted in a greater loss of colour than cabinet dried fruit leather. This is likely because solar and oven dryers have longer drying times (72 and 18 hours, respectively) compared to cabinet drying (6 hours) (Okilya *et al*., 2010). Improper drying may also lead to physical changes, such as shrinkage, puffing and crystallisation of the product (Maskan *et al*., 2002). Dehydration of food materials containing antioxidants is a difficult food processing operation, mainly because of undesirable changes that occur in the quality of the dehydrated products. To achieve a safe and quality product, a good understanding of the fundamental and nutritional properties of fruit leather is required.

Fruit leathers dried at higher temperatures and for shorter drying times have been found to be darker. Che Man & Sin (1997) found that drying at temperatures greater than 60°C caused a rapid increase in non-enzymatic browning. The author produced jackfruit leather with acceptable aroma using a cabinet dryer at 50°C for 24 hours. The aroma in the fresh fruit is due to volatile substances such as esters, ketones and aldehydes. According to Okilya *et al*. (2010), drying time can influence the volatile substances and lead to a decrease in aroma detection. They found that the aroma of solar dried leather was generally disliked and had significantly lower acceptability scores compared to cabinet and oven dried leather ($P < 0.05$). The aroma for both cabinet and oven dried leather was acceptable. The authors suggested that high aroma acceptability scores for cabinet and oven dried leathers could be attributed to the short drying times (6 - 18 hours) used, as opposed to 72 hours for solar drying.

Non-enzymatic browning is considered one of the major causes of quality deterioration in fruit products. Kumar *et al.* (2010) studied the effect of pulp blends on the physical and microbial quality of papaya fruit leather. Non-enzymatic browning increased with increased of papaya pulp in the finished product. This can be treated enzymatically by adding suitable additives such as sodium metabisulphite or sulphur dioxide (Che Man *et al*., 1992; Perera, 2005; Vijayanand *et al*., 2000). Che Man & Sin. (1997) proposed that extended boiling times can destroy the enzyme that causes enzymatic browning. Chan and Calvetto (1978) stated that reducing the sugars involved in the browning process can also be effective in improving the end product.

2.2.4 Biochemical quality

Food quality is the sum of all desirable attributes which make a food acceptable for consumption. Quality attributes of a product may be divided into three major categories such as sensory, hidden and quantitative (Salunkhe *et al*., 1991). The sensory attributes are colour, flavour, texture, taste, etc. The hidden attributes are nutritive values, presence of dangerous contaminants and poisonous materials. The quantitative parameters are those that contribute to the overall food quality such as the yield of a dried product. In order to determine the quality of the dried product, several parameters need to be examined through quality evaluation. For blueberry fruit leather, parameters such as colour, water activity, moisture content, texture (hardness and tensile strength) and nutrient content in terms of antioxidants, phenolic contents, proteins and carbohydrates, are considered to be appropriate for evaluation.

2.2.5 Colour

Colour is a major quality attribute in dried fruit products. Colour has been considered to have a key role in food choice, food preference / acceptability and may even influence taste thresholds, sweetness perception and pleasantness, as reported by Clydesdale (1993). Major food processing activities such as ambient temperature processing, processing by the application of heat and processing by the removal of heat will affect the flavour, aroma and pigment of a food product. Many naturally occurring pigments are destroyed by heat processing, chemically altered by changes in pH or oxidised during storage. As a result the processed food may lose its characteristic colour and, hence, its value. Therefore, these attributes are very important quality factors in processed blueberries and influenced in consumer acceptability.

Fruit and vegetable products often contain phenolics, which are degraded by substrates to a naturally occurring enzyme in most plant tissues, called polyphenoloxidase (Perera, 2005). During drying, this enzymatic reaction may proceed to form oxidised forms of phenolic compounds, which further polymerise to form brown pigments during drying, storage and distribution.

Other chemical reactions that occur during drying and storage are the Maillard reaction (browning reaction formed by the reaction of reducing sugars with amino acids), caramelisation and ascorbic acid browning. Okilya *et al*. (2010) assessed the effect of solar drying on the quality and acceptability of jackfruit leather. In this study it was found that all the drying methods significantly reduced the Tintometer colour reading of the leathers compared to the colour of the fresh fruit. Both solar (0.61) and oven (0.80) dried fruit leathers had significantly lower colour readings compared to cabinet (1.85) dried leather ($p<0.05$). This browning upon drying occurs in most fruit and is especially prevalent in light coloured fruit (Che Man & Sin, 1997).

Colour is the human perception of light waves reflected from the surface of a material. It is one of the first noticed characteristics of food and in early periods it was evaluated only subjectively or with the use of colour comparison charts. The most common technique used today to assess food colour is by using a colorimeter. There are several colour scales in which the surface colour can be represented. It is usually defined by three coordinates. The L*, a* and b* scale is recognized to show a better discrimination between small colour differences in the darker region of the colour space, providing good discrimination for saturated colours, as in the case of tomato products (Barreiro *et al*., 1997).

The three dimensional L*, a* and b* values can be measured using a Minolta chromameter. The L* is the lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The a* is the purple red (positive a* value) and blue-green (negative a* value) is on the horizontal axis. The second horizontal axis is b*, which represents yellow (positive b* value) and blue (negative b* value) (McGuire 1992). For further manipulation, hue angle and chroma aspects of colour are used. From the hue and chroma calculations, an index somewhat analogous to colour saturation and intensity is achieved. According to McGuire (1992), hue angle is defined as the angle between the hypotenuse and the a* (bluish-green / red-purple) axis and chroma represents the hypotenuse of a right triangle created by joining points (0, 0), (a *, b*) and (a*, 0).

Blueberries are a dark red colour due to high concentrations of anthocyanins. The Wild Blueberry Association of North America (WBANA) reported 125 mg of anthocyanins per 100 g of fresh blueberries. This would be reflected in Hunter colour evaluations by a low L* and high positive a* values (Yang & Atallah, 1985). The author noticed that a significant increase in L* values occurred after drying blueberries in both forced air and micro convection oven indicating a high loss of anthocyanins due to the thermal degradation. The positive a* values for dried berries were also significantly decreased in both forced air and microconvection ovens, which is suggested to be due to oxidation as well as heat degradation during dehydration. Also, b* values were significantly decreased, which indicated a shifting of the colour from yellow towards blue.

2.2.6 Moisture content

The preservation of fruit leathers depends on the moisture content (typically 15 to 25%) (Perera, 2005). Moisture content is influenced by the type of fruit, drying process, temperature and humidity. The natural acidity and sugar content of the fruit can also influence the moisture content of fruit leathers. Jackfruit leather developed by Che Man & Taufik (1995) had 16.48% moisture content, while papaya leather had 12 to 13% moisture (Chan & Cavaletto, 1978). For mango fruit leathers, a combination of low water activity (0.62), low pH (3.8) and a moisture content of 17.2% was required for the product to be shelf-stable for at least six months without the need for chemical preservation (Azeredo *et al*., 2006). A low moisture content can inhibit microbial growth and prolong the shelf-life of a product. However, at very low levels of moisture content in fruit leathers, the texture quality becomes too crisp and is affected negatively (Huang & Hsieh, 2005; Irwandi *et al*., 1998).

Salunkhe *et al*. (1991) proposed the following water activity values for food according to moisture contents (Table 2.3).

Table 2.3 Food classification according to moisture contents (Salunkhe *et al*., 1991)

a_w	Moisture content	Food	Characteristics
>0.7	> 30%	High moisture	Soft, must be heated to prevent microbial growth
0.85	20-30%	Intermediate	Semi-moist, firm, prone to Maillard reactions, less susceptible to fat oxidation than low moisture foods
<0.7	< 20%	Low moisture	Hard, firm, resistant to microbial growth and less prone to Maillard reactions, prone to fat oxidation.

2.2.7 Water activity (a_w)

Water activity is an important factor in food processing as high moisture leads to microbial growth, toxin formation, enzymatic and non-enzymatic reactions (Leung, 1984). The availability of water for microbial growth, enzyme activity or chemical reactions is an important factor and determines the shelf-life of dried products or intermediate moisture foods. The water activity (a_w) of dried products is relatively low. Generally, bacteria will not grow below $a_w = 0.85$, yeasts will not grow below $a_w = 0.70$ and moulds will not grow below $a_w = 0.65$ (Perera, 2005).

Because of the low water activity (<0.65) in fruit leather, microbiological growth is prevented. At low water activity, spoilage and deterioration of fruit leather can be caused by the growth of osmophilic yeasts and moulds (Chan & Cavaletto, 1978). Intermediate water activity (0.40) can also lead to a browning reaction during storage (Perera, 2005). In order to prevent this nonenzymatic browning it is important to have an appropriate preservative such as SO_2, citric acid or lemon juice.added to the leather If this is not present, the fruit leather has to be dried to an a_w of around 0.2-0.4 to prevent nonenzymatic browning (Perera, 2005).

Water content can also affect the water activity of the dried product. The higher the moisture content, the higher the a_w in kiwifruit (Lodge, 1981), jackfruit leather (Che Man & Taufik, 1995; Irwandi *et al*., 1998) and pear fruit leather (Huang & Hsieh, 2005). These research findings suggested that there was a clear relationship between moisture content and a_w. In the development of pear fruit leather, increasing the intial water additions to the fruit puree raised the fruit leather's moisture content but did not significantly affect water activity. This is a result of the initial differences in the water content diminising during the dehydration process

(Huang & Hsieh, 2005). The author also stated that pectin was the only factor that has a significant effect on water activity. When 4 – 8% of water was added to pear fruit leather it was tightly bound with pectin (16 to 24%) and did not affect the water activity noticeably after drying. The water activity of pear fruit leather ranged between 0.36 – 0.48.

2.2.8 Texture

The texture of fruit leathers is generally affected by the moisture content and drying temperature (Che Man & Sin, 1997). Most air dried products undergo a collapse of structure, leading to a firmer texture and increased chewiness. As a result, they rehydrate slowly and, therefore, certain air dried products can be undesirable to the consumer because of their firmer texture (Perera, 2005). High temperatures and long drying times are associated with a lower moisture content and harder texture. Differences in the texture of leathers could also be due to variations in the genetic make-up of the fruit, the rate of water absorption from the surroundings and the protein content of the fruit (Babalola *et al*., 2002; Okilya *et al*., 2010).

The addition of other ingredients can also affect the texture of fruit leather (Phimparian *et al*., 2011). For example, the addition of sugar (Raab & Oehler, 1999) and pectin to the fruit puree can improve the texture of fruit leather. The addition of sucrose at levels of 4.5 and 9% w/w lowered the extensibility of the final product to 5.53 and 0.68 mm indicating a very brittle sample and decreased the energy to break to 0.0618 and 0.0101J (Gujral & Khanna, 2002). Similarly, pectin concentrations above 1.5% increased the tensile force (13.9 to 17.1 N) and energy to break (0.026 to 0.028 J) of pineapple fruit leather. This negatively affected the acceptability of toughness (Phimparian *et al*., 2011). Huang and Hseish (2005) compared their pear fruit leather's hardness with the Stretch Island (SI) fruit company's fruit leathers. The authors found that hardness of SI fruit leathers had a mean value of 6130 g.

2.2.9 Sensory attributes

Food companies regularly use sensory tests, such as descriptive analysis and consumer affective tests, to study ingredient effects, processing variables and storage changes on the perceived sensory properties of their products. Sensory analysis provides marketers with an understanding of product quality, directions for product quality, profiles of competing products and evaluations of product reformulations from a consumer perspective (Stone & Sidel, 2010).

There are three types of testing commonly used in sensory analysis, each with a different goal. These are:

- Discriminative sensory analysis
- Descriptive sensory analysis
- Consumer affective tests.

Discriminative sensory analysis tests are used to detect differences between two or more types of products (Lawless and Heymann, 2010). Among the discriminating sensory tests, paired-comparisons, duo-trio tests and triangle tests are the most commonly used.

Descriptive sensory analysis tests are used to quantify the perceived intensities of the sensory characteristcis of a product (Lawless & Heymann, 2010). This type of sensory analysis has been widely used to characterise aroma, flavour and oral texture attributes of food products. All descriptive analysis methods involve the objective detection, description and quantification of sensory attributes of a product by trained panelists (Meilgaard *et al.*, 1999).

Consumer affective tests are used to quantify the degree of liking or disliking of a product, This type of testing is also called hedonic or effective testing (Lawless & Heymann, 2010). Consumer affective tests are the most straightforward approach and offer consumers / panellists a choice between alternative products to see if there is a clear preference from the majority of respondents. Data obtained from consumer affective tests are very important in product development, quality control, food product acceptance, and food service evaluation. There are two types of affective tests: quantitative and qualitative. Qualitative tests (i.e. focus group interviews, focus panels, one-on-one interviews) measure the subjective responses of a small group of representative consumers to the sensory properties of products by having them talk about their feelings in an interview or group setting (Meilgaard *et al.*, 1999). Quantitative tests determine the responses of a large group of consumers to a set of questions regarding preference, liking, sensory attributes, etc. (Meilgaard *et al.*, 1999).

The most important quality attributes of a food product to the consumer are its sensory characteristics (e.g. texture, flavour, aroma, shape and colour). In this research, fruit leathers composed mainly of blueberries are being developed; this is a natural product and has yet to be commercialised in quantity. Therefore, conducting a sensory trial of the product is necessary as it will characterise the sensory properties of blueberry fruit leather and determine the consumer sensory profile that will drive product acceptance and purchasing intent.

A hedonic scale is often used in product development and redevelopment to establish the degree of acceptability for a product. Given that blueberry fruit leather is a new product, a hedonic approach is an appropriate choice to find the degree of consumer acceptability.

Several other studies on fruit leather have used a hedonic scale to assess the degree of acceptability for a product. Che Man & Sin (1997) used a hedonic scale for their research on jackfruit leather and Irwandi (1998) conducted sensory analyses for taste, texture, appearance, aroma and overall acceptability for durian leather using a 7-point hedonic scale (1=dislike extremely, 7= like extremely). Gujral & Khanna (2002) used a 9-point hedonic scale to evaluate mango fruit leather samples for flavour, colour and texture, whereas Azeredo *et al*. (2006) used a 7-point hedonic scale for colour, flavour and toughness attributes of mango fruit leather with no preservatives or added sugar. The sensory panel for both mango leathers studies comprised 20 trained and 30 non-trained pannelists, respectively. For the evaluation of papaya leather (Kumar *et al*. 2010), a 9-point hedonic scales and 10 semi-trained panellist were used to measure appearance, flavour, fruitiness, toughness and chewiness of the product.

It was necessary to measure all of the above quality attributes for the production of blueberry fruit leather. Therefore, the objectives of this project were to produce blueberry fruit leathers using locally grown blueberry cultivars and natural ingredients. Sensory evaluation was conducted to find the acceptability of the blueberry fruit leather. For both fresh and processed blueberries, physico-chemical analyses were conducted to find the effect of drying on the nutritional properties.

Chapter 3
Material and Methods

3.1 Objectives

Five blueberry cultivars (Blue Magic, Burlington, Jersey, Puru and Reka) were selected for the blueberry fruit leather trial. These cultivars were evaluated before and after the production of blueberry fruit leather. The quality of fresh fruit and fruit leathers were evaluated by the determination of total phenolic compounds and antioxidant capacity, nutritional analysis, texture and physico-chemical analysis. Finally, sensory evaluation was conducted to compare five different cultivars of blueberries.

3.2 Raw materials

Five cultivars of two species of blueberries namely V. *corymbosum* (Highbush) and V. *ashei* (Rabbiteye) were harvested from well-established blueberry bushes 12-15 years old from a farm in Canterbury, NZ. These cultivars have been found to be suitable for commercial production. Four cultivars were Highbush blueberries; Puru, Reka, Burlington and Jersey. The other cultivar was the Rabbiteye blueberry: Blue Magic, Burlington and Jersey were from original cultivars imported from North America. Puru, Reka and Blue Magic were New Zealand selections that were bred at Ruakura Agricultural Research Centre. All cultivars were harvested at the ripe stage from January to March, 2011. Puru and Reka cultivars were picked during the first week of January. Burlington and Jersey were picked in the last week of January, Blue Magic was picked during the first week of March. Ripe berries were determined by measuring their °Brix level, which ranged 12 - 15°. After harvesting, fresh fruit was washed in clean cold water, strained, surface dried and kept at -20°C until analysis and further processing could commence. Preliminary formulations were used to optimise a formula and method for the production of blueberry fruit leather. These trials are found in Appendix A.

The other three major ingredients used in the trials were honey (Creamed honey, Airborne Honey Ltd. Leeston, NZ), pectin (Classic AF401, Herbsteith & Fox, Germany) and lemon juice (Country Gold, Auckland, NZ).

3.3 Equipment

A laboratory scale cabinet dryer which consisted of a drying chamber, electrical heater, a fan and temperature controller (up to 100°C) was used to dry fruit leathers. The temperature (55 to 60°C) was chosen for the trials (Henneman & Malone, 1993). The drying air velocity was set to 1 - 1.5 m/s and the cabinet dryer was monitored regularly using a data logger (Tinytag Data Loggers, West Sussex, UK). Before drying, the thickness of a sample was measured using a Toledo stainless ruler (Toledo Steel, Japan). The ruler was placed vertically onto the tray and the thickness measurement was taken at all four corners and the middle of the tray and the mean value was recorded. All samples were placed on the middle shelves and samples were rotated every hour. The samples were dried until fully dried (i.e. dry to touch). The thicknesses of dried samples were measured using callipers (Mitutoyo, USA). Fruit leathers were dried on stainless trays (190 mm x 290 mm).

3.4 Procedure for making blueberry fruit leather

The following procedure was developed based on the preliminary trials (Appendix A) to optimise the ingredients and methods.

For each cultivar, frozen blueberries were thawed at 4°C overnight in the fridge. Six hundred grams of thawed blueberries were weighed. Honey (112.5 g), lemon juice (30 ml) and pectin (7.5 g) were weighed and mixed with blueberries. The mixture was blended using a blender (Cascade, model CE071BR, China) into puree (2 minutes). A small amount of puree was taken for pH and °Brix measurement. Stainless steel trays were lightly sprayed with cooking oil and 200 g of puree was spread evenly over the trays using a metal spreader. Thickness and colour were measured for each sample which was then left at room temperature for 10 minutes. The dryer was preheated to 60 ± 2°C and leathers were dried in the middle compartment of the cabinet dryer. The dryness of the leather was regularly inspected during the drying period.

For each cultivar two batches were made and each batch had three trays. The trays were turned and rotated every hour during the drying time. The trays were dried for 8 hours for each cultivar. A process flow chart of blueberry leather production is shown in Figure 3.1.

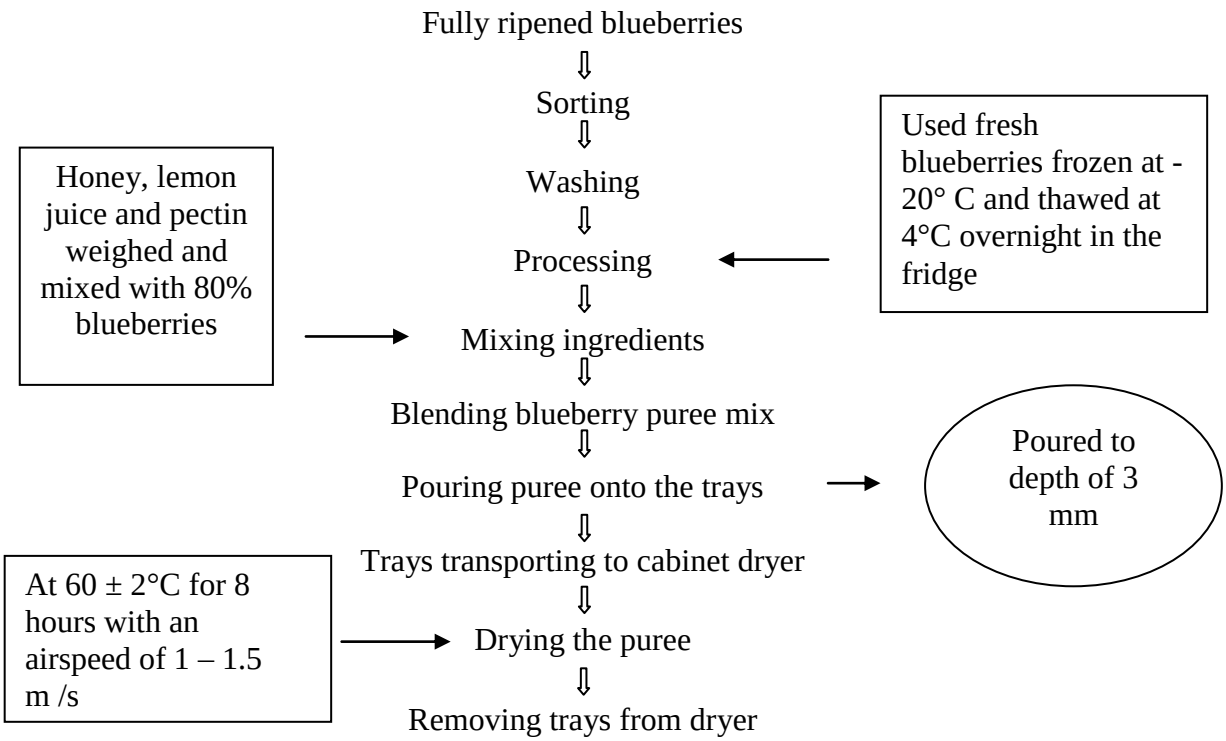


Figure 3.1 Process flow diagram of the blueberry fruit leather making process

3.5 Biochemical analyses

3.5.1 Analysis of proximate and mineral compositions of the fruit and leather

The following proximate analyses were performed on fresh blueberry puree and dried blueberry fruit leathers. The analyses were conducted at Lincoln University in the Agriculture & Life Sciences Analytical Laboratory. Ash, nitrogen, protein, neutral detergent fibre (NDF), fat, carbohydrates and moisture content were determined.

Ash content was determined gravimetrically by incinerating dried blueberry samples in a crucible. The organic material was burnt in a furnace at 550°C. The minerals left in the crucibles were then weighed. Crude protein was determined by combustion of the dried sample under oxygen supply and high temperatures (900°C) in a Variomax CN Analyser (Elementar). NDF was determined gravimetrically using the method of Van Soest *et al*. (1991). Dried sample was treated under standard conditions. First it was boiled with dilute sulphuric acid, and then sodium hydroxide was diluted. The fibrous residue was then washed with alcohol and ether to remove any fat and wax. The residue was then dried and weighed. Total fat content was determined using an automated soxhlet extraction (Tecator Soxtec 1043, FOSS Hillerod, Denmark). Dried samples were weighed in to cellulose thimbles and were extracted with petroleum ether (Shell X4) for three hours at 80˚C. Carbohydrates were

determined by Anthrone reaction based on Pollock & Jones (1979) & Jermyn *et al.* (1956). All measurements were carried out in triplicate.

The mineral contents of blueberry fruit and leathers were analysed. All equipment used was soaked in 10% HCL for 48 hours and left to dry before the procedure began. The Teflon microwave digestion vessels used were also soaked in Decon solution (Decon laboratories Ltd., Hove, Sussex, UK) and then rinsed with acid to eliminate any contamination. Dried samples (0.5 g) were weighed into 100 ml Teflon microwave digestion vessels. Five ml of 69% nitric acid (Aristar, BDH Chemicals, Ltd., Poole, Dorset, UK) and 2 ml of 30% hydrogen peroxide (AnalaR, BDH Chemicals, Ltd., Poole, Dorset, UK) were added and the digestion vessels were allowed to stand for 12 hours at room temperature. The samples were then digested for 40 minutes in a microwave digester (Milestone Ethos Sel microwave oven, Sorisole, Italy) with the temperature rising to 200°C at the end of the digestion cycle. The digests were then cooled and the digested solution was made up to 25 ml with nanopure water. The mineral content was determined by aspirating the diluted sample into an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP – OES, Varian Inc., Mulgrave, Victoria, Australia) through an ultrasonic nebuliser (Cetac 50000, Varian Inc., Mulgrave, Victoria, Australia). The Varian ICP was calibrated using a multi – element standard solution (Merck & Co. Inc., Whitehouse Station, NJ, USA). Recovery ranged from 92.2 – 123.4%. Due to time restraints and funding limitation, mineral testing was not replicated, therefore results will be presented as a single analysis.

3.5.2 Determination of antioxidant capacity

To measure the antioxidant capacity, blueberries were freeze dried, finely ground in a coffee grinder and stored in -20°C until analysis.

Sample extraction for fresh fruit and fruit leathers

Approximately 1 g of dried blueberry sample was weighed in a screw-cap tube with 10 ml of acetone/water/acetic acid (70:29.5:0.5, v/v/v) according to the method described by Velioglu *et al*. (1998), with minor modifications. The mixture was vortexed for 30 seconds and sonicated at 37°C for 5 minutes. After sonication, the samples were shaken occasionally for 10 minutes at room temperature. Samples were then centrifuged at 3500 rpm (4000KUBOTA, 520 W, Japan) for 15 minutes. The supernatant was diluted to 25 ml with extraction solvent (acetone/water/acetic acid).

Oxygen radical absorbance capacity assay

The ORAC – fluorescein assay was performed, as described by Wu *et al*. (2004), with minor modifications. Briefly, 25 µL of sample (blueberry fruit leather) extracts or trolox [(±) – 6 – hydroxyl-2,5,7,8 – tetramethylchroman-2-carboxylic acid, Aldrich] standards (0 – 200 µM) and 25 µL of 10 nM fluorescein (Fluorescein sodium salt, Sigma –Aldrich) in 150 mM phosphate buffer (pH 7.4) were pipetted into a Greiner 96-well flat bottom micro plate and pre-incubated for 30 min at 37°C. Twenty five µL of AAPH (2-2'-azobis - 2-methyl-propanimidamide dihydrochloride, Sigma –Aldrich) was added to each well. Fluorescence (excitation 485 nm, emission 525 nm) was recorded every minute for 90 minutes using HITACHI AS-4000 Spectra-Physics Intelligent Auto Sample (Molecular Devices). Data were analysed using MARS software and Trolox standards were used to construct curves of area under curve (AUC) versus concentration. The AUC was calculated by subtracting the AUC in the absence of antioxidant from the AUC in the presence of antioxidant. ORAC values were expressed as µmol Trolox equivalents (TE) per gram dry weight.

Determination of phenolic compounds

A modified method from Imeh & Khokhar (2002) was used to extract the total (conjugated) phenolics fraction of the blueberries. Blueberries, frozen at -20°C, were thawed at room temperature and crushed using a pestle and then freeze dried. After freeze drying they were ground to a fine powder in a coffee grinder (Sunbeam, Australia) and 0.5 g was accurately weighed into a 50 ml screw cap test tube. To this, 25 ml of 50% v/v methanol (AR) and deionised water with 1.2 M HCL was added, vortexed for 10 seconds and then extracted with gentle agitation, in the dark at 90°C, for 120 minutes. Extracts were then centrifuged at 3500 rpm for 15 minutes and analysed immediately.

The phenolic content was measured using a 0.2 N Folin - Ciocalteu reagent (Sigma, St Louis, USA) according to a method adapted from Singleton *et al*. (1966). After centrifugation, a 0.25 ml of sample was diluted with 0.25 ml of distilled water. Then 2.5 ml of 0.2 N Folin-Ciocalteu reagent and 2.0 ml of 7.5% w/v sodium carbonate solution (aqueous) were added to a 20 ml screw cap test tube, which was then vortexed for 5 seconds and incubated for 5 minutes at 50°C. The test-tubes were then immediately cooled to room temperature before reading the absorbance at 760 nm on a Unicam Helios-beta UV-VIS spectrophotometer (Unicam, Cambridge, UK).

A standard curve was prepared in duplicate by making a standard solution of 1 mg/ml gallic acid (Sigma, St Louis, USA) in 50% v/v methanol: deionised water with 1.2 M HCL and

diluting to final concentrations of 0, 25, 50, 100, 150, 200 and 250 μg gallic acid/ml. The final results are expressed as mg gallic acid equivalents per 100 g fresh weight (mg GAE/100 g FW).

3.6 Quality parameters measured

To determine the overall quality of blueberry fruit leather from five cultivars, the following parameters were measured.

3.6.1 Moisture content

The moisture content was determined by drying samples of approximately 1 g at 105°C in an forced air oven (Watson Victor Ltd, NZ) for 16 hours (Method 950.46a, AOAC, 1991).

Determination of the moisture content was carried out in triplicate.

3.6.2 Water activity (a_w)

The method of Huang and Hseih (2005) was used to measure the water activity (a_w) of the dried leather using a Decagon CX2 Water Activity Meter. The sample was cut into round pieces of approximately 19.00 mm (diameter) before being placed in the testing chamber. The tray was fully covered by the samples and readings taken. All measurements were carried out in triplicate.

3.6.3 Physico-chemical analysis

The physico-chemical analysis including pH (Metler Toledo) and °Brix (Atago Co. Ltd, Japan), was measured for both the fresh blueberries and the fruit leathers.

Titratable acidity was determined using a Metrohm Titrino -730 Sample Changer (Herisau, Switzerland and the method given by Ranganna (1977) and AOAC (1984). The sample was ground and 10 g was transferred to a 25 ml conical flask. The sample was dissolved in 20 ml of distilled water and left on the bench for 20 minutes to allow it to dissolve completely while being stirred frequently. After 20 minutes the sample was diluted to 50 ml with distilled water. The sample was mixed thoroughly and 10 ml was titrated with 0.1 N NaOH using phenolphthalein indicator.

For the fresh fruit titratable acidity measurements, the acidity was measured in 10 ml of juice (squeezed from puree) using a Metrohm Titrino Titrator. All measurements were carried out in triplicate.

3.6.4 Colour

Colour, chroma and hue angle were measured using the Minolta Reflectance Chroma Meter CR 210 (Minolta, Japan) before and after the puree was dried. All blueberry samples were blended before the measurements were taken. All readings were taken as L*, a *, b * colour space values. Chroma C* is calculated as $\sqrt{a^{*2} + b^{*2}}$ and hue is calculated from, the arctangent of b*/a*. Calibration of the instrument was performed using a white ceramic tile (L* = 98.06, a* = - 0.23 and b* = 1.87) before measuring each new set of triplicate samples.

3.6.5 Texture analysis

The texture analysis method was adapted from Azeredo *et al*. (2006). Texture analysis was performed by puncture tests with a 2 mm diameter cylindrical stainless steel probe (p / 2) monitored on a TA.XT plus Texture Analyser (Stable Micro Systems, Godalming, UK) equipped with XTRAD Dimensions software (Stable Micro Systems). The compression and tensile strength of the blueberry fruit leathers were assessed in this study. The compression test was designed to imitate incisor teeth cutting through a food sample. The pre-test speed of the probe was 1.0 mm/s, the test speed was 2.0 mm/s and the post-test speed was 10.0 mm/s. The samples were supported using a hole twice the diameter of the punch. To stop the leather being dragged down through the hole a 20 mm diameter ring was held on the r surface of the leather around the area of penetration. For hardness, 10 samples were tested for each cultivar.

The tensile strength was measured using the same texture analyser (Gujral & Khanna, 2002). Sample sizes were approximately 30 mm x 30 mm. The leather was clamped on two sides. The pre-test speed of the probe was 1.0 mm/s, the test speed was 0.5 mm/s and the post-test speed was 1.0 mm/s. The samples were supported using a hole twice the diameter of the punch. The probe moved upward and pulled the sample. Five samples from each cultivar were tested for tensile strength. Mean values of the peak force and standard errors were reported.

3.6.6 Sensory evaluation

A consumer acceptability sensory trial was conducted at Lincoln University in the Food Safe Laboratory. Panellists comprised 60 volunteers who were staff or students at the University. A sample of the forms, research instruction sheet and consent form used can be found in Appendix B (B.1.1, B.1.2 and B 1.3, respectively). Each panellist was asked to taste five samples, one from each cultivar (3 x 3 cm square). Each panellist was asked eight quality attributes questions and three preference questions about each sample and one question about their overall preference for the sample. Attributes selected for the blueberry fruit leather were

colour, overall appearance, texture (perception, stickiness and chewiness) sweetness, chewiness, blueberry flavour and overall acceptability of the sample. A 7-point hedonic scale was used, therefore, the respondents answers were coded 1-7 with 7 being ‘like extremely’ and 1 being ‘dislike extremely’. Three further questions were asked to assess whether the respondents liked the fruit leathers they had tasted, if they would buy the product and which cultivar they liked the best. Respondents were also asked if they liked eating blueberries. Responses were subjected to one-way ANOVA to determine any statistical differences (raw data not shown) between cultivar means and the level of confidence was 95% (based on pooled standard deviation).

The sensory analysis assessments were carried out in sensory testing booths (Figure 3.2 and 3.3). Samples were labelled using 3-digit random numbers and presented on a tray to each panellist in a random order. A sample of instructions for panellist and the questionnaires used can be found in Appendix.

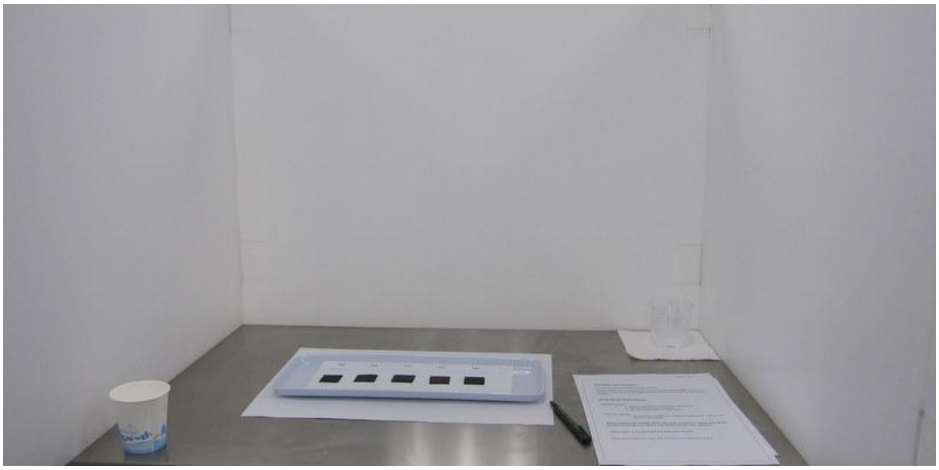


Figure 3.2 Booth presentation for consumer sensory trial

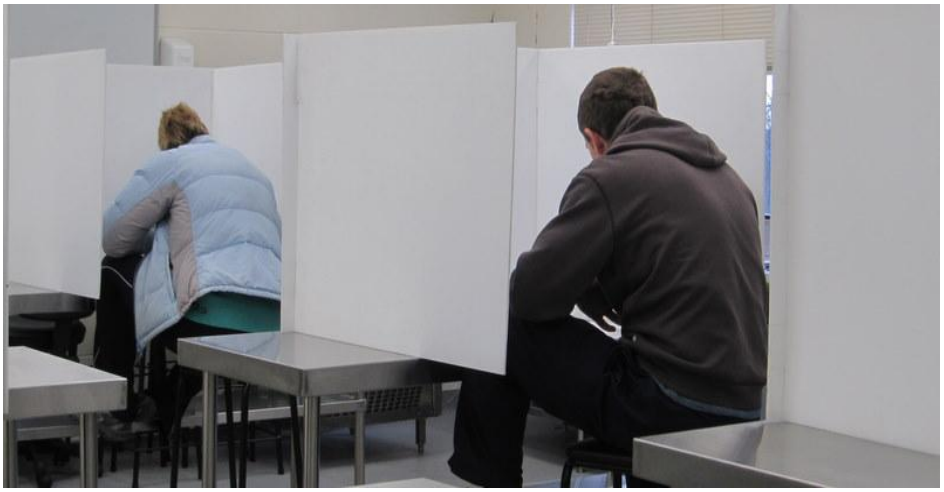


Figure 3. 3 Panellists evaluating five blueberry fruit leathers

3.7 Statistics analysis

Statistical analysis and calculations were performed using Statistical Analysis System version 9.21 and sensory evaluation data were analysed using Minitab version 16.1 and Microsoft® Office Excel 2007. Means ± SD were calculated and a one-way ANOVA was used to determine any statistical differences between the mean values. The raw data was calculated using R Statistical software version 2.13.2, 2011, which were then used to model the relationships. Pearson product-moment correlation coefficient and Spearman's rank correlation coefficient were used to compare the subjective and objective data.

Chapter 4

Results

Blueberry fruit leathers were prepared from the blueberry five cultivars and tested for water activity, moisture content, texture parameters, colour, physico-chemical properties, antioxidants and total phenolics content.

4.1 Temperature and humidity during drying process

Blueberry leather was successfully made from each of the five cultivars using a formulation and optimised method obtained from preliminary trials, as described in Appendix A. For all cultivars, when the samples were placed in the cabinet dryer, the temperature dropped from the 60°C set to approximately 53°C and humidity was high (around 60%). When the puree started drying the cabinet dryer temperature increased and stabilised at 60°C while the humidity decreased to 22.0%. The average temperature reached was between 58.3 to 58.8°C and relative humidity was 19.8 to 23.2%.

4.2 Nutritional analysis of five blueberry cultivars and their fruit leathers

The proximate analysis of fruit from the different blueberry cultivars can be seen in Table 4.1 and for leathers prepared from them, in Table 4.2 (raw data can be found in Appendix C.1). The results are based on dry weight basis. There was no significant difference ($P > 0.05$) between mean dry weight of fruit from the five cultivars. However, for other analyses, there were significant differences between the cultivars ($P < 0.05$). The mean dry matter for fresh fruit was 16.7 ± 0.7% and for fruit leather it was 77.8 ± 0.6%. The overall mean ash for fresh fruit was 1.5 ± 0.1%, crude protein (3.2 ± 0.1%), fat (1.7 ± 0.3%) and NDF (neutral dietary fibre) was 19.1 ± 0.1%. Carbohydrate was found to be higher in fresh fruit than in fruit leathers. Puru (78.4 ± 0.7), Reka (75.5 ± 0.2) and Blue magic (74.9 ± 1.4) had the highest carbohydrate contents. After drying the leather, the moisture reduced to 22% and, therefore, the mean dry matter was 77.8 ± 0.6%. The mean ash of fruit leather was 1.02 ± 0.1% and crude protein it was 2.0 ± 0.1%. After drying, the amount of fat was reduced to 0.8 ± 0.2% and NDF was 9.7 ± 0.1%, (almost a 50% reduction). Carbohydrates were also reduced (by 18.05%) to a mean value of 60.4 ± 0.7%.

Table 4.1 Proximate analysis (%) and dry matter (%) of fresh fruit from five cultivars of blueberries

Variety	Dry Matter	Ash	Crude Protein	Fat	NDF	Carbohydrate
Blue Magic	18.1 ± 0.7^{a}	1.4 ± 0.1^{c}	2.0 ± 0.1^{e}	1.0 ± 0.3^{e}	21.5 ± 0.1^{a}	74.9 ± 1.4^{a}
Burlington	18.3 ± 1.3^{a}	1.6 ± 0.1^{a}	2.9 ± 0.1^{d}	2.2 ± 0.1^{b}	21.0 ± 0.1^{b}	70.1 ± 0.9^{b}
Jersey	16.9 ± 0.9^{ab}	1.5 ± 0.1^{b}	3.5 ± 0.1^{c}	2.7 ± 0.1^{a}	21.7 ± 0.1^{a}	71.2 ± 1.1^{b}
Puru	15.9 ± 0.3^{ab}	1.4 ± 0.1^{b}	3.9 ± 0.1^{a}	1.5 ± 0.1^{c}	15.8 ± 0.1^{c}	76.8 ± 0.9^{a}
Reka	14.2 ± 0.2^{b}	1.6 ± 0.1^{a}	3.7 ± 0.1^{b}	1.4 ± 0.1^{d}	15.7 ± 0.1^{c}	75.5 ± 0.2^{a}
Mean	16.7 ± 0.7	1.5 ± 0.1	3.2 ± 0.1	1.7 ± 0.3	19.1 ± 0.1	73.7 ± 0.9

Mean values with the same superscript within a column are not significantly different ($p < 0.05$).

Table 4.2 Proximate analysis (%) and dry matter (%) of fruit leathers made from five cultivars of blueberries

Variety	Dry Matter	Ash	Crude Protein	Fat	NDF	Carbohydrate
Blue Magic	78.5 ± 0.3^{a}	0.9 ± 0.1^{c}	1.6 ± 0.1^{b}	0.4 ± 0.2^{c}	11.2 ± 0.9^{b}	58.1 ± 0.8^{bc}
Burlington	76.5 ± 0.7^{b}	1.1 ± 0.1^{a}	1.8 ± 0.1^{b}	0.8 ± 0.1^{b}	9.9 ± 0.1^{c}	56.7 ± 0.1^{bc}
Jersey	78.6 ± 0.6^{a}	1.0 ± 0.1^{b}	2.1 ± 0.1^{a}	1.6 ± 0.1^{a}	12.2 ± 0.1^{a}	59.3 ± 0.6^{c}
Puru	78.4 ± 0.7^{a}	1.0 ± 0.1^{b}	2.2 ± 0.1^{a}	0.6 ± 0.1^{c}	7.7 ± 0.1^{d}	67.4 ± 0.3^{a}
Reka	76.8 ± 0.5^{ab}	1.1 ± 0.1^{a}	2.3 ± 0.1^{a}	0.5 ± 0.1^{d}	7.4 ± 0.2^{d}	60.6 ± 1.7^{b}
Mean	77.8 ± 0.6	1.0 ± 0.1	2.0 ± 0.1	0.8 ± 0.2	9.7 ± 0.1	60.4 ± 0.7

Mean values with the same subscript within a column are not significantly different ($p < 0.05$)

4.3 Minerals

The mineral contents of the fresh fruit and leathers are shown in Table 4.3. Fresh fruit had marginally lower levels of minerals compared to fruit leathers. On a dry weight basis, the raw blueberry contained high levels of calcium, 41.3to 85.7 mg/100 g DM, potassium, 283.1 to 324.4 mg/100 g DM, sodium, 29.2 to 33.8 mg/100 g DM, and magnesium, 19.0 to 34.3 mg/100 g DM. Phosphorous and sulphur were also high in raw blueberries (ranging from 43.2 to 57.6 and 49.5 to 119.6 mg/100 g DM, respectively). After drying, all mineral contents of the fruit leathers increased significantly. The mineral contents for calcium were 52.5 to 123.8 mg/100 g DM, potassium was 389.8 to 498.0 mg/100 g DM, iron was 2.4 to 3.0 and magnesium was 31.3 to 56.5 mg/100 g DM.

Table 4.3 The mineral contents (mg/100 g DM) of the five cultivars of blueberry fruit and their leathers

	Al		B		Ca		Cu		Fe		K	
	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather
Blue Magic	13.4	2.9	0.5	0.3	41.3	52.5	0.3	0.4	2.0	2.4	283.1	389.8
Burlington	17.2	7.0	0.8	0.6	81.6	123.8	0.3	0.5	2.3	2.9	305.3	419.2
Jersey	13.8	5.4	0.8	0.5	85.7	118.3	0.4	0.5	2.5	3.0	288.5	403.6
Puru	7.7	7.2	0.7	0.5	47.6	61.7	0.2	0.3	2.4	2.6	311.0	461.2
Reka	10.8	7.8	0.7	0.5	56.3	77.4	0.2	0.3	2.5	2.5	324.4	498.0
Mean	12.6	6.1	0.7	0.5	62.5	86.7	0.3	0.4	2.3	2.7	302.5	434.4

	Mg		Mn		Na		P		S		Zn	
	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather	Fresh	Fruit Leather
Blue Magic	19.0	31.3	0.7	1.1	32.6	11.4	43.2	72.6	49.7	51.0	0.3	0.5
Burlington	30.5	52.8	1.3	2.3	30.1	3.5	54.6	92.2	49.5	48.3	0.3	0.5
Jersey	34.3	56.5	2.6	4.2	29.2	4.8	57.6	83.4	50.8	45.0	0.5	0.6
Puru	23.3	40.2	1.0	2.1	31.2	4.1	46.7	81.2	52.1	55.8	0.4	0.7
Reka	24.6	41.4	2.3	4.2	33.8	5.3	46.7	79.5	119.6	50.5	0.4	0.6
Mean	26.3	44.4	1.6	2.8	31.4	5.8	49.8	81.8	64.3	50.1	0.4	0.6

4.4 pH, titratable acidity and °Brix of the fresh fruit and fruit leathers

Table 4.4 shows the blueberry weights (per berry), pH, °Brix and titratable acidity (± SE) for the five cultivars (the raw data are given in Appendix C.2). The results showed that Blue Magic berries were heavier (mean value of 2.4 ± 0.1 g) than the berry weights of the other cultivars. The lightest berry fruit was Jersey with a mean value of 0.9 ± 0.1 g. The mean pH of the fresh berries was 3.4 ± 0.1. No significant differences were found among the cultivars after the drying processes. The pH range after drying was 3.2 to 3.4. However, compared to the pH of the fresh berries of all cultivars, the pH was slightly lower after the drying process.

The °Brix results showed that there was a significant difference ($p < 0.05$) between the five cultivars. The mean °Brix of the fresh fruit was 13.4 ± 0.4. Overall, Blue Magic and Jersey had higher °Brix, at 14.3°. The °Brix of Reka was 12.0 ± 0.5 and this was lower than the other cultivars. After drying, the °Brix of all fruit leathers increased significantly (mean °Brix was 87.5) but there were no significant differences observed between the cultivars.

The pH and °Brix were also monitored for the blueberry purees, which were taken just before drying; the raw data are found in Appendix C.

In this study, significant differences were found between the cultivars regarding the titratable acidity of berries both in fresh fruit and dried fruit leathers. In fresh fruit, Burlington had the highest mean total acid content (0.7% of citric acid) followed by Jersey, Puru and Reka (all had 0.5% of citric acid), and Blue Magic (0.3% of citric acid). After drying, the titratable acidity of all fruit leathers increased significantly. The average acidity of fruit leather was 2.6 ± 0.1% of citric acid. Fruit leathers, Jersey, Puru and Reka exhibited the highest acidity and Blue Magic the lowest (Table 4.5).

Table 4.4 Mean berry weight (per berry), pH, °Brix and titratable acidity values (± SE) for blueberry fruit and fruit leathers for five cultivars

	Berry weight (g)	pH		°Brix		Titratable acidity (% citric acid)	
Variety		Fresh	Fruit leather	Fresh	Fruit leather	Fresh	Fruit leather
Blue Magic	2.4 ± 0.1[a]	3.4 ± 0.1	3.3 ± 0.1	14.3 ± 0.3[a]	88.0 ± 1.1	0.3 ± 0.1[c]	2.1 ± 0.1[c]
Burlington	1.0 ± 0.1[d]	3.4 ± 0.1	3.3 ± 0.1	12.8 ± 0.6[bc]	85.3 ± 1.3	0.7 ± 0.1[a]	2.4 ± 0.1[b]
Jersey	0.9 ± 0.1[d]	3.4 ± 0.1	3.4 ± 0.1	14.3 ± 0.1[a]	86.0 ± 1.1	0.5 ± 0.1[b]	2.9 ± 0.1[a]
Puru	1.8 ± 0.1[b]	3.4 ± 0.1	3.2 ± 0.1	13.5.±.0.2[ab]	89.0 ± 2.5	0.5 ± 0.1[b]	2.8 ± 0.1[a]
Reka	1.7 ± 0.1[c]	3.5 ± 0.1	3.3 ± 0.1	12.0 ± 0.5[c]	89.3 ± 0.3	0.5 ± 0.1[b]	2.8 ± 0.1[a]
Mean	1.6 ± 0.1	3.4 ± 0.1	3.3 ± 0.1	13.4 ± 0.4	87.5 ± 1.3	0.5 ± 0.1	2.6 ± 0.1

Mean values within a column with the same superscript are not significantly different ($p < 0.05$).

4.5 Moisture content, water activity, texture and thickness of blueberry fruit leathers

The moisture content and water activity results are in Table 4.5 and the raw data are in Appendix C.3. The average moisture content for the fruit leathers was 22.3%. The results show that there were no significant differences ($p > 0.05$) between the moisture content of the fruit leathers from different cultivars. Similarly, the water activity of the leathers ranged from 0.4 to 0.5 (Table 4.6) with an average of 0.5 ± 0.1.The average water activity for Burlington was lower (0.4) compared to the other four cultivars.

The overall means for both tensile force and hardness were 18.9 ± 0.4 N and 538.1 ± 19.6 g, respectively. The results (Table 4.6) showed there were significant differences ($p<0.05$) in texture parameters between the blueberry cultivars. For tensile strength of fruit leather, Jersey and Puru required the highest tear of force than the other three cultivars. The tensile strength for Blue Magic, Burlington and Reka were in the range of 15.8, 15.5 and 19.6 N, respectively, which means less force was required to tear the leather. However, for hardness, Puru was found to be harder than Reka, Jersey, Burlington and Blue Magic.

There were no significant differences in thickness between leathers of the five cultivars. Before drying, the thickness of the samples was approximately 3 mm and after drying the average thickness of the samples was 1.2 ± 0.1 (range 1.2 to 1.5 mm).

Table 4.5 Physico-chemical measurments (mean ± SE) of blueberry fruit leathers

Blueberry Variety	Moisture Content (%)	Water Activity (a_w)	Tensile Force (N)	Hardness (g)	Thickness (mm)
Blue Magic	21.7 ± 1.2	0.5 ± 0.1	15.8 ± 0.1^{b}	345.5 ± 7.7^{c}	1.2 ± 0.0
Burlington	23.9 ± 0.7	0.4 ± 0.1	15.5 ± 0.2^{b}	378.3 ± 23.4^{b}	1.5 ± 0.3
Jersey	21.5 ± 0.7	0.5 ± 0.1	22.1 ± 0.8^{a}	580.3 ±10.3^{c}	1.2 ± 0.1
Puru	21.7 ± 0.8	0.5 ± 0.1	21.3 ± 0.7^{a}	759.2 ± 34.6^{a}	1.2 ± 0.1
Reka	22.6 ± 1.2	0.5 ± 0.1	19.6 ± 0.2^{a}	627.4 ± 21.8^{b}	1.1 ± 0.1
Mean	22.3 ± 0.9	0.5 ± 0.1	18.9 ± 0.4	538.1 ± 19.6	1.2 ± 0.1

Mean values within a column with the same superscript are not significantly different ($p < 0.05$).

4.6 Colour measurements

Figure 4.1 shows the colour differences between different blueberry cultivars and the results in Table 4.6 show the CIE values for colour for the fresh fruit and fruit leathers. The raw data can be found in Appendix C.6. The CIE L* values correspond to the lightness of the sample.

As L* increased the sample became lighter. The mean L* value of fresh fruit was 25.2 ± 0.2. The L* value showed that Burlington and Blue Magic were darker compared to Puru, Reka and Jersey but there were no significant differences between the cultivars. The lightness (L*) increased for all cultivars after drying. The mean L* value of fruit leathers was 28.5 ± 0.2. The lightest fruit leathers were Puru and Burlington (29.3 ± 0.1). Reka and Jersey had a similar lightness value of (28.1 to. (28.6).

The intensity of red colour decreased after the drying process. In the fresh fruit, the CIE value for a* (redness) was found to be higher in Puru and Jersey compared to Reka, Blue Magic and Burlington. When the extra ingredients were added and the blueberry mix was pureed, the a* value (Appendix C.4) for Puru and Reka increased (the red colour fruit turned to dark red) whereas the redness of Burlington, Jersey and Blue Magic decreased. Burlington, Jersey and Blue Magic were less red / or more purplish – red than Puru and Reka. After the blending processes, the samples were darker than the fresh fruit. After drying, the mean redness value of the fruit leather was in the range of 0.2 to 4.3. The redness was greater in Puru (4.3), followed by Reka (3.1) > Jersey (1.3) > Blue Magic (1.0) and Burlington (0.2). Burlington was less redder than the other cultivars (Figure 4.1 and Table 4.6).

The mean chroma value for the fresh fruit was 7.1 ± 0.3. The chroma value was affected after the addition of the extra ingredients and drying. The mean chroma value of fruit leather was 2.1± 0.1. The hue angle (h) ranged from 361.1 to 358.3 for fresh fruit corresponding to purplish-red. The hue angle for all fruit leathers ranged from 94.2 to 358.5, indicating that the fruit leathers were still purplish-red and, except for Burlington, the hue angle was somewhat yellowish.

Figure 4.1 Fruit leathers made from different blueberry cultivars

Table 4.6 CIE colour readings for fresh fruit and blueberries fruit leathers

Variety	Fresh fruit					Fruit Leather				
	L*	a*	b*	Chroma	°Hue	L*	a*	b*	Chroma	°Hue
Blue Magic	23.8 ± 0.5^{b}	6.1 ± 0.2^{c}	0.2 ± 0^{c}	6.1 ± 0.2^{a}	358.3 ± 0.5^{a}	27.4 ± 0.1^{d}	1.0 ± 0.1^{c}	-0.2 ± 0.1^{b}	1.0 ± 0.1^{dc}	353.2 ± 2.2^{a}
Burlington	23.0 ± 0.2^{b}	4.9 ± 0.1^{d}	0.5 ± 0^{a}	5.0 ± 0.3^{bc}	355.4 ± 0.6^{c}	29.3 ± 0.1^{a}	0.2 ± 0.1^{d}	0.8 ± 0.1^{a}	0.8 ± 0.1^{d}	94.2 ± 7.6^{b}
Jersey	26.1 ± 0.3^{a}	9.1 ± 0.2^{a}	0.3 ± 0^{b}	9.1 ± 0.3^{ba}	361.1 ± 0.3^{d}	28.1 ± 0.2^{c}	1.3 ± 0.1^{c}	-0.1 ± 0.0^{b}	1.3 ± 0.1^{c}	358.5 ± 0.6^{b}
Puru	26.7 ± 0.1^{a}	9.4 ± 0.1^{a}	0.3 ± 0^{b}	9.4 ± 0.5^{d}	357.5 ± 0.4^{ab}	29.3 ± 0.1^{a}	4.3 ± 0.1^{a}	-0.4 ± 0.0^{c}	4.3 ± 0.1^{a}	311.8 ± 0.8^{a}
Reka	26.5 ± 0.1^{a}	6.6 ± 0.1^{b}	0.3 ± 0^{b}	7.3 ± 0.4^{dc}	357.2 ± 0.2^{b}	28.6 ± 0.3^{b}	3.1 ± 0.3^{b}	-0.1 ± 0.1^{b}	3.1 ± 0.3^{b}	299.7 ± 1.0^{a}
Mean	25.2 ± 0.2	7.2 ± 0.1	0.3 ± 0	7.1 ± 0.3	358.1 ± 0.2	28.5 ± 0.2	1.7 ± 0.1	-0.1 ± 0.1	2.1 ± 0.1	283.5 ± 2.4

Mean values within a column with the same superscript are not significantly different ($P<0.05$).

4.7 Antioxidant capacity and total phenolic content in berries and blueberry fruit leather

Table 4.7 (raw data are in Appendix C.5) compared the antioxidant capacity and the total phenolic contents in fresh fruit and fruit leathers. For fresh fruit, the average antioxidant activity was 37 ± 1.1 µ mole TE/g FW and the total phenolic content was 524 ± 12.9 mg GAE/100 g. The results showed that Blue Magic and Burlington had the highest average antioxidant capacity at 48 ± 0.8 and 43 ± 2.1µ mole TE/g FW, respectively. The total phenolic content was also higher in Blue Magic (676 ± 14.8 GAE/100 g FW) and Burlington (590 ± 21.5). Reka had the lowest antioxidant activity of 29 ± 0.7 and total phenolic content of 398 ± 19.9 GAE/100 g FW.

Similar trends were also exhibited by the dried fruit leathers (mean was 25 ± 0.9 µ mole TE/g FW) however, the ORAC values for fruit leather were lower than for the fresh fruit. After drying, the amount of antioxidant capacity reduced in all cultivars by 24 to 42% (based on fresh weight). The antioxidant capacity reduction was higher in Puru (42%) whereas Reka had the lowest reduction (24%). Similar results were also found in the total phenolic contents of the fruit leathers. Blue Magic showed the highest level of total phenolics (561 ± 9.4 GAE/100 g FW) but Jersey had the lowest (377 ± 1.9 GAE/100 g FW). After drying, the amount of total phenolics reduced in all cultivars by 2 to 29% (based on fresh weight). Total phenolic reduction was highest in Jersey (29%) and was lowest in Reka (2%).

Table 4.7 Antioxidant activity (µmole TE/g FW ± SE) and total phenolic contents (mg GAE/g FW ± SE) in blueberry fruit and fruit leathers

Variety	Antioxidant activity (µmole TE/g FW)		Total phenolics contents (mg GAE/g FW)	
	Fresh	Fruit leather	Fresh	Fruit leather
Blue Magic	48 ± 0.8[a]	33 ± 0.7[a]	676 ± 14.8[a]	561 ± 9.4[a]
Burlington	43 ± 2.1[b]	28 ± 0.9[b]	590 ± 21.5[b]	494 ± 17.0[b]
Jersey	36 ± 0.6[c]	25 ± 1.0[c]	534 ± 3.8[c]	377 ± 1.9[c]
Puru	31 ± 1.3[d]	18 ± 0.6[e]	426 ± 4.6[d]	395 ± 5.7[c]
Reka	29 ± 0.7[d]	22 ± 1.5[d]	398 ± 19.9[d]	406 ± 19.3[c]
Mean	37 ± 1.1	25 ± 0.9	524 ± 12.9	446 ± 10.6

Mean values within a column with the same superscript are not significantly different (P<0.05).

4.8 Sensory evaluation

A total of 60 responses were used for statistical analysis of the organoleptic assessments. Two response forms were incomplete (i.e. panellist missed the questions) and were excluded. Of the valid responses 2% were smokers. Twenty eight percent of the panellists were male and 66% female. Six percent of the panellists did not specify gender. The age groups were divided into: <19, 19-25, 26-30, 31-50 and >50 years, with 0%, 42%, 15%, 30% and 7% of the panellists in each category, respectively.

Table 4.8, Figure 4.2 and 4.3 shows the mean scores for 8 eight attributes from all fruit leathers. For each attribute, the scores were 1, 'dislike extremely' to 7 'like extremely'. For example, score 7 was given if the panellist ticked 'like extremely', 6 - 'like very much', 5 – 'like moderately, 4 – 'neither like nor dislike', 3- 'dislike moderately', 2 - 'dislike very much' and 1 – 'dislike extremely'.

For the overall preference for the colour, the mean score for fruit leather was 4.8 ± 0.1. The highest score for the colour attribute was 5.9 for Puru and 5.2 for Reka. The overall appearance score was also higher for Puru than other cultivars. The mean overall appearance for all samples was 4.8 ± 0.1. The two cultivars (Puru and Reka) with a lighter red colour had higher overall acceptability compared to the darker (Burlington, Blue Magic and Jersey) cultivars. Although the highest means for overall appearance of the different cultivars only fell between "like moderately" and "like very much", the mean overall appearance was just above "neither like nor dislike".

The texture and stickiness of the products showed a significant difference among the cultivars. For texture, all samples received mean scores between 4.7 to 5.2. The texture of Puru was moderately liked by many panellists whereas the texture of the Blue Magic cultivar neither liked nor disliked. In terms of the stickiness and texture attributes, Puru was most preferred by panellists compared to other cultivars.

Panellists scored Blue Magic's sweetness significantly lower ($P < 0.05$) than the other four cultivars. The overall mean for sweetness was 5.2 ± 0.1. Overall, Jersey fruit leather had the highest score of 5.5 ± 0.2 for sweetness. The sensory results also showed blueberry fruit leather made using the Jersey cultivar had the most preferred blueberry flavour (mean was 5.6 ± 0.2) compared to the other cultivars. The blueberry flavours of Reka, Puru and Burlington were moderately liked by panellist whereas the Blue Magic cultivar was just above 'neither like nor dislike'.

Overall, the fruit leathers made from all cultivars were moderately liked by the panellist as the mean overall acceptability of the product was 5 out of 7. Puru and Reka fruit leathers were most preferred, followed by Jersey. However, Blue Magic and Burlington were neither liked nor disliked by the panellists. Blue Magic and Burlington were given the lowest score in all attributes compared to Puru, Reka and Jersey.

Ninety three percent of the panellists liked the taste of fruit leathers and 96% liked eating fresh blueberries. About 4% of the panellists did not like eating blueberries and only 7% did not like the taste of the fruit leathers. Sixty nine percent of the panellists said that they would buy this product if it was available in the market. Among the cultivars, 38% of the panellists found Puru fruit leather was the best fruit leather, followed by Jersey (23%), Reka (18%). Burlington and Blue Magic were the least favoured fruit leathers.

Panellists were asked to comment on the fruit leathers they were given to taste. The majority of comments were about the number of seeds in the fruit leather – 15% of the panellist suggested that some of the fruit leathers were gritty due to the presence of seeds. Twelve percent of panellists would like the fruit leathers to be more tangi or sour or wanted more blueberry flavour in the fruit leathers. Ten percent of the panellists found the fruit leathers were slightly thin and 6.7% of the panellists suggested improving the colour of the fruit (reducing the darkness of fruit) leathers.

Sensory data was plotted to show trends and patterns for all eight attributes. Figure 4.2 shows the boxplots for colour, overall appearance, texture, stickiness, sweetness, chewiness, blueberry flavour and overall acceptability, respectively. A boxplot shows four different statistical attributes in one diagram. These statistical attributes are the median, upper and lower quartiles and outliers. In the boxplot, the median was the middle of the data where half of the observations were less than or equal to this value. The upper whisker extends to the highest data value within the upper limit whereas the lower extends to the lowest data with the lower limit. Outliers are values beyond the whiskers, denoted by asterisks in the boxplot.

From Figure 4.2, it can be seen Puru and Reka fruit leathers scores exhibit a trend of higher scores than the other cultivars. All the other cultivars were more evenly distributed, apart from Jersey which trended towards a lower value for texture score. Jersey and Reka were the only cultivars showing a higher blueberry flavour score. For chewiness, sweetness and flavour, all cultivars were evenly distributed, apart from Blue Magic, trended (4 -5 score) towards lower overall acceptability score.

Table 4.8 Mean preference scores (± SE) for colour, overall appearance, texture, stickiness, sweetness, chewiness, blueberry flavour and overall acceptability for different blueberry cultivars of fruit leathers (score 1 = dislike extremely to 7 = like extremely)

Fruit leather	Colour	Overall appearance	Texture	Stickiness	Sweetness	Chewiness	Blueberry flavour	Overall acceptability
Blue Magic	4.1 ± 0.2^{d}	4.2 ± 0.2^{d}	4.7 ± 0.2^{b}	4.8 ± 0.2^{c}	4.6 ± 0.2^{b}	4.8 ± 0.2^{b}	4.6 ± 0.2^{c}	4.5 ± 0.1^{c}
Burlington	4.3 ± 0.2^{cd}	4.4 ± 0.2^{cd}	4.8 ± 0.1^{ab}	5.0 ± 0.2^{bc}	5.3 ± 0.2^{a}	5.0 ± 0.2^{ab}	5.2 ± 0.2^{ab}	4.8 ± 0.1^{ab}
Jersey	4.6 ± 0.1^{bc}	4.6 ± 0.2^{c}	4.8 ± 0.1^{ab}	4.7 ± 0.2^{c}	5.5 ± 0.2^{a}	5.2 ± 0.1^{ab}	5.6 ± 0.2^{bc}	5.1 ± 0.1^{bc}
Puru	5.9 ± 0.1^{a}	5.7 ± 0.1^{a}	5.3 ± 0.1^{a}	5.4 ± 0.1^{a}	5.4 ± 0.2^{a}	5.1 ± 0.1^{a}	5.0 ± 0.2^{a}	5.3 ± 0.1^{a}
Reka	5.2 ± 0.1^{b}	5.0 ± 0.1^{b}	5.2 ± 0.1^{ab}	5.3 ± 0.1^{ab}	5.4 ± 0.1^{a}	5.3 ± 0.1^{a}	5.4 ± 0.1^{ab}	5.3 ± 0.1^{a}
Overall Mean	4.8 ± 0.1	4.8 ± 0.1	5.0 ± 0.1	5.0 ± 0.1	5.2 ± 0.2	5.1 ± 0.2	5.2 ± 0.2	5.0 ± 0.1

Mean values within a column with the same superscript are not significantly different ($P<0.05$).

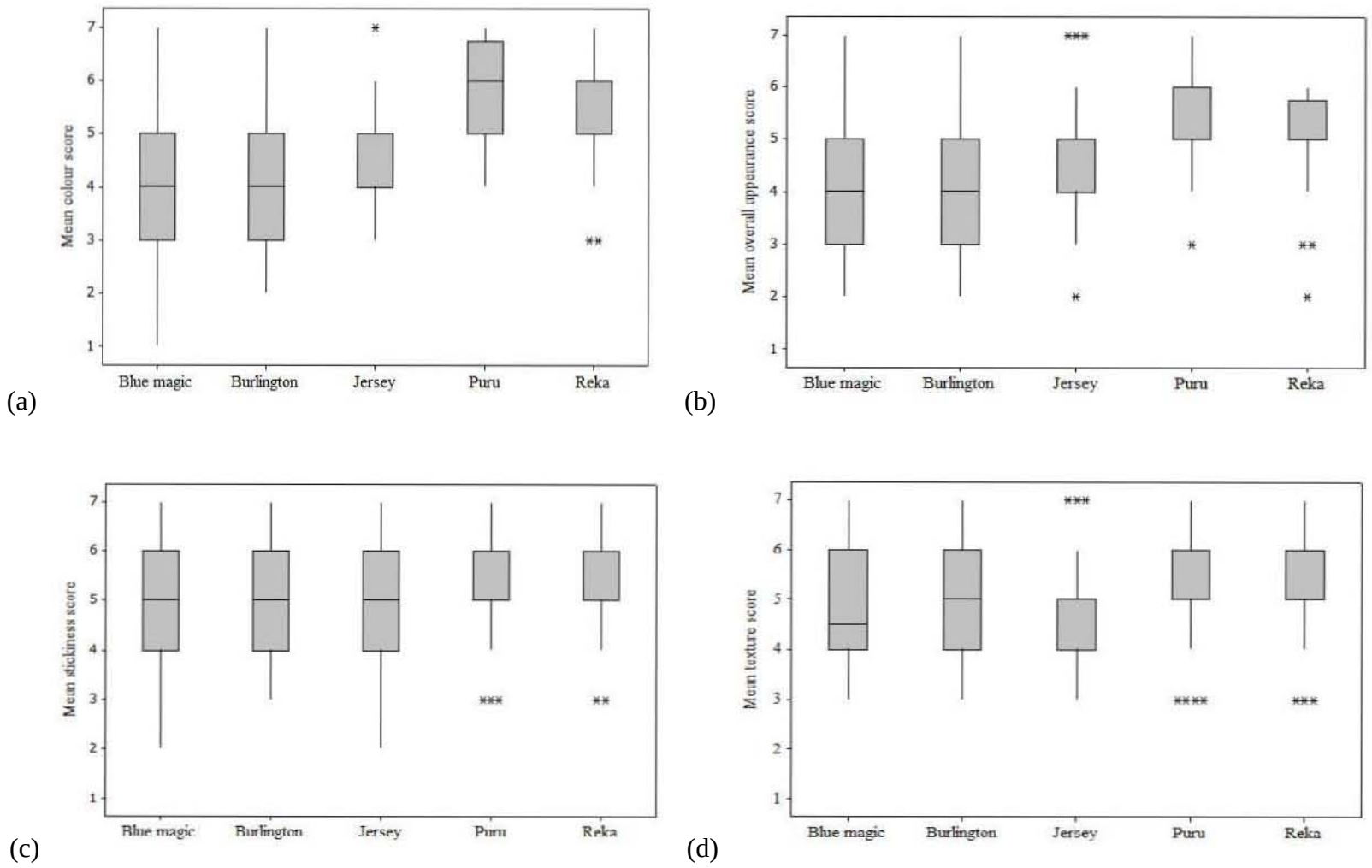


Figure 4.2 Boxplot of mean (a) colour, (b) overall appearance, (c) stickiness, (d) texture scores scores for fruit leather samples produced from 5 cultivars of blueberry

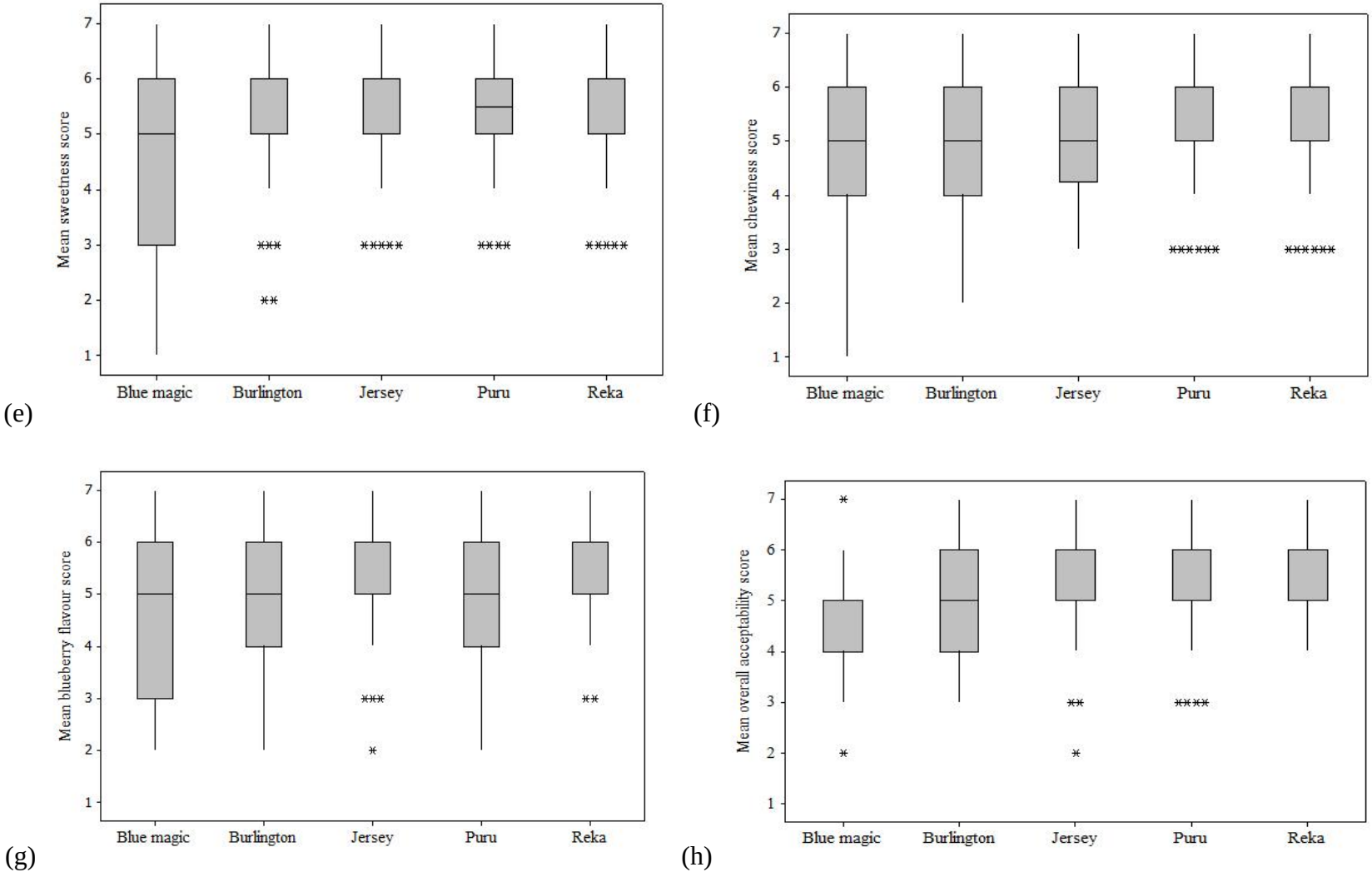


Figure 4.3 Boxplot of mean for (e) sweetness, (f) chewiness, (g) blueberry flavour and (h) overall acceptability scores fruit leather samples produced from 5 cultivars of blueberry

4.9 Correlation between sensory attributes, instrumental parameters and proximate analysis data

Two different correlations methods (Spearman and Pearson) were used depending on whether ranking of preferences or actual measurements were calculated. Spearman's rank correlation coefficient measures correlation using ranking dependence between two variables while Pearson's correlation coefficient measures correlation using a linear dependence between two variables.

Spearman's rank correlation was used to assess the relationship between sensory perception and instrumental parameters in order to predict consumer responses towards blueberry fruit leather. Correlation between sensory attributes and instrumental parameters using Spearman's rank correlation coefficient is shown in Table 4.9. This table also shows correlation between the various sensory attributes. Some parameters in Table 4.9 were found to be significantly correlated using 95% confidence interval. Significant correlation ($P < 0.05$) was seen between colour and overall appearance. Positive correlation was also seen between same sensory attributes and instrumental parameters, for example, ORAC values were significantly correlated to colour and overall appearance. Negative correlation was noted between leather hardness and colour and overall appearance, and to a lesser extent water activity was negatively correlated with sweetness and chewiness.

Correlation between instrumental parameters and chemical data using Pearson's correlation coefficients is shown in Table 4.10. This table also shows correlation between the various instrumental parameters. Significant correlation ($P < 0.05$) was only seen between the instrumental parameters. For example, acidity was significantly correlated with hardness and tensile strength. Interestingly enough, there was no significant correlation found between instrumental parameters and chemical data measured (being protein, NDF, fat, dry matter and carbohydrates).

Table 4.9 Spearman's rank correlation coefficients between sensory attributes and instrumental parameters

	Colour	Overall appearance	Texture	Stickiness	Sweetness	Chewiness	Overall acceptability	Water activity	ORAC	Hardness	Tensile	Thickness
Colour	1.0	1.0*	0.9	0.6	0.6	0.7	0.3	-0.5	1.0*	-1.0*	-0.6	1.0
Overall appearance	1.0*	1.0	0.9	0.6	0.6	0.7	0.3	-0.5	1.0*	-1.0*	-0.6	1.0
Texture	0.9	0.9	1.0	0.7	0.3	0.5	0.1	-0.2	0.9	-0.9	-0.2	0.7
Stickiness	0.6	0.6	0.6	1.0	-0.2	0.1	-0.5	0.0	0.6	-0.6	0.0	0.7
Sweetness	0.6	0.6	0.6	-0.2	1.0	0.9	0.9	-0.8*	0.6	-0.6	-0.8	0.7
Chewiness	0.7	0.7	0.7	0.1	0.9	1.0	0.8	-0.8*	0.7	-0.7	-0.6	0.5
Overall acceptability	0.3	0.3	0.3	-0.5	0.9	0.8	1.0	-0.6	0.3	-0.3	-0.5	0.9

* denotes significant correlation coefficients (P<0.05) between sensory attributes and instrumental parameters.

Table 4.10 Pearson's correlation coefficents between instrumental parameters and proximate analysis data

	Thickness	Water activity	Moisture content	Acidity	pH	Brix	Hardness	Tensile	Total phenolics	ORAC	Protein	NDF	Fat	Dry Matter	Carbohydrate
Thickness	1.0	-1.0	-1.0	-0.3	0.0	-0.7	-0.5	-0.5	0.3	0.2	-0.5	0.1	0.1	-0.4	-0.3
Water activity	-1.0	1.0	0.9	0.4	0.1	0.6	0.5	0.7	-0.5	-0.3	0.5	-0.1	0.1	0.6	0.4
Moisture content	-1.0	0.9	1.0	0.3	-0.1	0.8	0.5	0.5	-0.3	-0.3	0.5	-0.4	-0.3	0.2	0.4
Acidity	-0.3	0.4	0.3	1.0	0.0	0.2	0.9*	0.9*	-1.0*	-0.9*	1.0	-0.4	0.4	0.0	0.6
pH	0.0	0.1	-0.1	0.0	1.0	-0.6	-0.4	0.0	-0.1	0.4	-0.1	0.7	0.7	0.0	-0.7
Brix	-0.7	0.6	0.8	0.2	-0.6	1.0	0.5	0.3	-0.2	-0.4	0.5	-0.7	-0.7	0.1	0.7
Hardness	-0.5	0.5	0.5	0.9*	-0.4	0.5	1.0	0.9	-0.9	-1.0*	0.9	-0.6	0.1	0.2	0.9
Tensile	-0.5	0.7	0.5	0.9*	0.0	0.3	0.9	1.0	-0.9*	-0.8	0.8	-0.1	0.5	0.4	0.6
Total phenolics	0.3	-0.5	-0.3	-1.0	-0.1	-0.2	-0.9	-0.9*	1.0	0.9	-0.9	0.3	-0.5	-0.1	-0.6
ORAC	0.2	-0.3	-0.3	-0.9*	0.4	-0.4	-1.0*	-0.8	0.9	1.0	-0.9	0.7	-0.1	0.0	-0.8

* denotes significant correlation coefficients (P< 0.05) between instrumental parameters and proximate analysis data

Chapter 5
Discussion

5.1 Blueberry fruit leather

The nutritional value of food products has become an important consideration for consumers in today's marketplace. In order to choose the most suitable method of drying it will be necessary to know the rate of loss of nutrients caused by the drying process. Water removal through the drying process may lead to serious loss of the nutritive and sensory properties of food. Because of the possible beneficial roles of phytonutrients present in blueberries, it is critical to monitor their changes during processing to better assess the direction for product development. The nutritional value and quality parameters of the five different cultivars used in the development of blueberry fruit leather are discussed below.

5.2 Nutritional analysis

Significant differences were found between the five cultivars during nutritional analysis. The mean moisture content of the fresh blueberry cultivars in this research was 83.3 ± 0.8%; which was similar to the moisture content, as measured by Mazza (1982), who undertook the proximate analysis of the 'Bluecrop' Highbush cultivar. Protein and fat were also comparable to values quoted by Mazza (1982), however, ash, total dietary fibre and carbohydrates in this research were found to be high compared to previous studies. According to the USDA Nutrient Database (2006), the proximate compositions of blueberries were: moisture 84.2%, crude protein 0.7%, crude fat 0.3%, ash 0.2% and NDF 2.4%. However the database does not specify which blueberry cultivar this applies to.

Compared to fresh fruit, the results from proximate analyses of the dried fruit leathers were lower for all cultivars. However, the values are similar to dried fruit proximate analyses conducted by Vega-Gálvez (2009). The author observed the chemical composition of dried blueberry using the O'Neil variety. After drying, the proximate analysis of O'Neil blueberries gave an initial moisture content of 78.1%, crude protein 0.6%, total lipids of 0.4%, crude fibre of 6.5%, ash of 1.2 and non-nitrogen extract (by difference) of 12.9%. However, it should be noted that the crude protein of fresh blueberries in this study were higher (mean value of 3.2 ± 0.1) than the O'Neil cultivar so, therefore, it was expected to have a higher crude protein (mean value of 2.0 ± 0.1) after drying.

When comparing fresh fruit with the corresponding dried fruit leather, it was shown that the drying operation led to reductions in protein, fat and fibre by 38%, 56% and 49% respectively. The loss of protein can be explained by the denaturation or changes in solubility during drying and the release of amino acids from the proteins after denaturation, which could then react with other compounds via the Maillard reaction (Perera, 2005; Scala *et al.,* 2011; Miranda *et al.,* 2010). The decrease in lipid (fat) content was likely due to either enzymatic hydrolysis during the first drying period or lipid oxidation because of the thermal treatment (Perera, 2005). The loss of fibre was likely due to thermal degradation resulting in disruption of the polysaccharide network of the cell wall (Miranda *et al.,* 2010; Scala *et al.,* 2011).

Processing steps such as washing, freezing, drying and storage may also contribute to changes in the nutritional properties of blueberries. Any dehydration process can impact the nutritional value of fruit but some processes are harsher than others. During the drying process fruit loses water and its nutrients and sugars become more concentrated. It is noted that the sum of proximate analyses of blueberry fruit leather did not add up to 100%. This could be due to various problems with the carbohydrate analysis. Carbohydrates present in the blueberry fruit leather are mostly sucrose, glucose and fructose. For nutritional purposes, it is inadequate to consider the carbohydrates as single components of food as each of these carbohydrates have a distinctive metabolic and physiological properties. It is possible that the carbohydrates measured during proximate analysis did not correspond precisely with physiological properties or with analytical fractions. Most foods contain a mixture of three or more components and separation of these components is required to produce accurate results.

The mineral compositions of raw blueberries were similar to the chemical composition of blueberries, as presented by Hui *et al*. (2008) and the USDA Nutrient Database (2006). Raw blueberry provides 0.5% of calcium, 3.5% iron, 1.5% magnesium, 14% manganese and 1.5% zinc of the Recommended Daily Allowance (USDA Nutrient Database, 2006). From the mineral results, it was shown the blueberry fruit leather contained higher levels of minerals than raw blueberries. The cooking process required to make fruit leather resulted in a significant increase in several of the major minerals when compared to fresh fruit. For example, magnesium increased 69%, calcium increased 39% and potassium increased 44%. However, there was an 81% reduction in sodium. This is a positive by-product of the cooking process as food products with high potassium and low sodium may help in the prevalence of high blood pressure and decrease the risk of heart disease and stroke (Whitney and Rolfes., 2011). During fruit leather preparation, the addition of ingredients such as honey and lemon juice may have led to an increase in mineral composition found in the fruit leather. Major

minerals of honey are calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium and zinc. The minerals in the honey, lemon juice and pectin used in this study are shown in the Appendix C.7. The honey used in this research had high levels of potassium (72.8 mg/100 g FW), calcium (5.4 mg/100 g FW) and phosphorous (11.3 mg/100 g FW). The levels were, subsequently, higher in the blueberry fruit leather than the fresh fruit. Similarly, lemon also contained high levels of potassium (131.6 mg/100 g FW) which increased in the blueberry fruit leather. Pectin was also found to contain calcium (283.4 mg), potassium (290.6 mg), magnesium (22.4 mg), sodium (385.0 mg) and iron (10.6 mg), which increased the levels of these minerals in the blueberry fruit leather.

5.3 Titratable acidity, pH and °Brix

This research found that fresh blueberries had a titratable acidity (TA) between 0.3 ± 0.1 to 0.7 ± 0.1% (of citric acid equivalent). The range is in agreement with the range between 0.3 – 1.3% published by Beaudry *et al*. (1992) and the pH value within the range given by Gough (1994). TA values in fresh blueberries were also consistent with those reported by Prior *et al.* (1998). Connor *et al*. (2002a) also reported acidity of cultivated blueberries in the range of 0.9 – 2.5%. The increase in TA levels of blueberry fruit leather for all cultivars is due to the addition of lemon juice (4%) to the fruit leather puree. The drying process also concentrated the natural acidity of the fruit. As a result, the acidity of the fruit leather increased significantly after drying. In this research, the pH of lemon juice was 2.7 and the titratable acidity was 5.3% of citric acid. Lemon juice is approximately 5 to 6% (0.3 M) citric acid, therefore, an increase in acidity is expected. The mean value of acidity was 2.6 ± 0.1 (% of citric acid). The titratable acid found in the Burlington berries (0.7%) was higher than in all other cultivars. However, after drying the titratable acidity of Burlington leather was the lowest compared to the other cultivars. Leathers made from Puru, Reka and Jersey had the highest titratable acidity after drying. High acidity in fruit leather prevents the growth of microorganisms and helps maintain the colour and flavour of the fruit; therefore, it is important from a processing or manufacturing point of view to use blueberry cultivars with high acidity. In this study, cultivars Puru, Reka and Jersey are more suitable for the production of fruit leathers. Vaidya *et al*. (2007) reported the acidity of fruit leather made from kiwifruit which was found to be 3.8% but the reason for the high acidity was not discussed.

Vega Galvez *et al*. (2009) reported an acidity of 2.2 ± 0.12% (monohydrated citric acid), pH of 2.7 ± 0.09, and soluble solids of 15.0 ± 0.07 °Brix in dried O'Neil blueberries. In this study, pH value did not change significantly and was within the range given by Stojanovic &

Silva (2007). Their pH value was between 2.9 to 3.2 for osmotically concentrated and dehydrated blueberries.

The °Brix for all the processed blueberry fruit leathers were higher than for the raw fruit. In previous studies, °Brix of fruit leathers was also found to be higher than those of raw fruit, this was especially prevalent in sweet fruits. For example, °Brix was not affected by additions of glucose syrup or pectin (Phimparian *et al*., 2010). Raw pineapple puree had a °Brix that increased to 66.4 – 75.3 °Brix with the addition of other ingredients (such as pectin, glucose syrup, sugar and maltodextrin). After drying the final °Brix of pineapple fruit leather ranged from 82.4 to 86.9. Similarly, kiwifruit °Brix was increased by adding 15% sugar and was found to be higher (68 °Brix) after drying in a cabinet drier at 45 ± 2 °C for 15 hours (Vaidya *et al*., 2007). In this research, creamed honey (83 °Brix) was added as a sweetener. The °Brix found in creamed honey was similar to that found by Anupama *et al*. (2003). The additional honey (15%) led to an increase of °Brix in the blueberry fruit leathers. Kumar *et al*. (2010) proposed that the high °Brix of blended papaya fruit leather could be attributed to the high carbohydrate content and, therefore, could be considered as good source of energy.

5.4 Moisture content and water activity

Fruit leathers from all cultivars in this research can be considered as concentrated or intermediate moisture foods (IMF) owing to the relative low water content, ranging from 22 to 24%, and water activity values of < 0.5 a_w. Compared with other fruit leathers, the moisture content of the blueberry fruit leather developed in this research was higher (even though it is within the IMF range) and a_w values were much lower. The high moisture and lower water activity in this product could be due to the thickness of the product. Final thickness of the product was reduced to 1 mm from 4 mm. Maskan *et al*. (2002) studied the hot air drying of grape leather in which they explained that at higher temperatures the surface of the product dries out quickly (this was especially prevalent in the thinner samples) and a partial barrier is generated to resist free moisture movement. C and, considering the thickness of the sample, the fruit leather dried quickly and could have trapped the moisture, which is likely to have been the reason why the product had low water activity and high moisture content. In addition, the lower a_w in the product could also be due to the spacing of the trays. Even though the trays were rotated during the drying process, the oscillating fan was placed 10 cm below the shelf. The space between the trays was approximately 2 cm, which may have impacted the even distribution of air flow over the

trays. This may also be the reason why some of the fruit leather samples dried unevenly with over-dried ends and damp mid regions.

The moisture content of jackfruit leather was measured at 11-17% (Che Man & Taufik., 1995), papaya leather 12 to 13% (Chan & Cavaletto, 1978) and blended papaya leather 20.80% (Kumar *et al*., 2010). Although a reduced moisture content can inhibit microbial growth and prolong shelf-life, in the case of fruit leather it may negatively influence the texture quality (Irwandi *et al*., 1998).

In a recent study conducted by Phimpharian *et al*. (2011), the pineapple fruit leather in their research had an a_w value of < 0.55. They found that the concentration of pectin affected the moisture content and water activity. The amount of pectin in Phimpharian *et al*. (2011) pineapple fruit leather (1.5%) was higher than the 1% used in the development of blueberry fruit leather in this research. The lower moisture content and a_w was likely due to the available water being tightly bound with pectin. Similarly, in pear fruit leather, the pectin concentration was found to have a significant effect on a_w on pear fruit leather. Huang & Hseih,(2005), found that increasing the pectin concentration (from 1 to 1.5%) affected the hardness of the sample and decreased moisture content and a_w of pineapple fruit leathers. Water can still act as a solvent at low water content and water activity (Labuza *et al*., 1970). In this research, there was no addition of water as blueberries in their natural fresh state contained, on average 83% water (see Table 4.8). As a result, the pectin did not have enough water to bind, therefore, raising the water content did not affect the water activity. Huang & Hseih (2005) included additional water in a puree of pear fruit leather, which raised the initial moisture content but did not significantly affect water activity. This was probably because the initial differences in the water content diminished as a result of after dehydration when making the fruit leather.

5.5 Colour

The final fruit leather product was lighter in colour (L* mean value of 28.5 ± 0.2) than the fresh fruit (L* mean value of 25.2 ± 0.2). All cultivars increased in brightness (L*) indicating that fresh blueberry had a darker colour compared to the fruit leathers. This was expected as the drying and addition of pectin, honey and lemon juice to blueberry puree can have significant effects on the colour of the blueberry fruit. For example, lemon juice is a strong acid and the addition of lemon juice in the blueberry puree may have impacted the stability of the anthocyanins. Anthocyanins are highly unstable and very susceptible to degradation. Anthocyanins are oxidised in the absence of oxidase enzymes and subsequent condensation

reactions can lead to brown pigment formation (Singleton, 1987). This reaction may have led to colour changes in the blueberry fruit leather but the addition of lemon juice was necessary in the production of blueberry fruit leather as it protected the natural colour and helped destroy bacteria during drying. Pectin concentration has also been found to affect the colour of the product as the absorbance intensity was decreased in the production of jam, which suggested a relationship between pectin and anthocyanin degradation (Dervisi *et al.*, 2001).

Significant increases in L* values after drying were also observed by Yang & Atallah (1985). The authors suggested that in both forced air and micro-convection dried berries, increased L* values indicated a higher loss of anthocyanin from thermal degradation. However, for a* values a significant decrease was found in both forced air and micro convection dried berries, which may be due to anthocyanin oxidation as well as heat degradation during dehydration. In this research, blueberry fruit leather also showed lower a* (mean 1.7 ± 0.1)) than fresh fruit (mean 7.2 ± 0.1), which may be due to the reddish anthocyanin being converted to a colourless carbinol base during the drying process and the remaining bluish brown co-pigments dominating the colour. Similar results were also observed in previous studies with jackfruit leather (Che Man & Sin, 1997; Okilya *et al*., 2010) and blended papaya leather (Kumar *et al*., 2010). After drying, these fruit leathers became darker. This was especially prevalent in light coloured fruit leather (Raab and Oehler, 1999).

Other factors that can also affect blueberry anthocyanins are: pH, storage, temperature, light, light, oxygen, concentration and structure of anthocyanins, other flavonoids, protein and minerals. These factors were associated with colour changes in blueberry fruit. In this study, during the development of fruit leather the interactions between heat and the food ingredients may have significantly affected the anthocyanins' stability and this could have resulted in the colour change of the fruit. Ingredients such as honey contain antioxidants as well as hydrogen peroxide, which may caused degradation of anthocyanins by oxidation mechanism or by indirect oxidation (Lohachoompol, 2007). Also, it is noted that under high concentrations of oxygen and ascorbic acid increased pigmentation loss occurred which resulted in change to the colour of blueberries. Other major factors mentioned by Irwandi *et al*. (1998) that influenced the colour of fruit leathers were: processing condition, storage time and temperature.

5.6 Texture analysis

The mean tensile force of blueberry fruit leather was 18.9 ± 0.4 N. The tensile force range was similar to the tensile force of pineapple leathers (range of 2.1 ± 0.5 to 17.1 ± 1.0 N) given

by Phimpharian *et al.* (2011). Their fruit leather contained 1.5% pectin and either 2, 4 or 6% of glucose syrup and the resulting fruit leathers had a tensile force of 17.1 ± 1.0, 12.8 ± 1.3 and 13.9 ± 1.3 N, respectively (to glucose syrup). The high tensile forces were likely due to pectin producing a firm gel structure leading to a tough texture. The pectin concentration of 1% in this research resulted in a high tensile force and was compounded by the low water activity (<0.5) and moisture content of the blueberry fruit leather. As explained by Okilya *et al.* (2010) and Che Man & Sin. (1997), higher temperatures and long drying times were associated with lower moisture content and harder texture. However, it was difficult to compare as the genetic make-up of this fruit was materially different (Babalola *et al*., 2002) and additional ingredients also played an important role in defining texture quality. In Gujral & Khanna's (2002) study, increasing sucrose levels (from 4.5 to 9%) decreased tensile force in the mango fruit leather. Furthermore, the addition of skim milk powder led to a larger decrease in tensile force compared to soy protein concentrate. In the current study, the addition of pectin, honey and lemon was likely to have influenced the tensile force or extensibility of blueberry fruit leathers.

Hardness of the blueberry fruit leathers in this study were found to be lower (firmer) than the bench mark product - Stretch Island fruit leathers, as used by Huang & Hseih (2005). The mean hardness value for Stretch Island fruit leathers was 6130 g compared to the blueberry fruit leathers in this study, which had a mean hardness value of 538.1 ± 19.6 g. In pear fruit leathers, as described by Huang & Hseih (2005), the hardness value was in the range of 4420 to 13200 g (18 formulations with different ratios of water, pectin and corn syrup). Their pectin concentrations were higher (20 – 24% w/w) than the pectin concentration used in this research (1% w/w). In addition, the ingredients were also different and the water absorption from the surroundings and the protein content of fruit may have affected the hardness of the leathers (Babalola *et al*., 2002). The values presented here are significantly lower than that found by Huang & Hseih (2005). This is likely to be the result of the blueberry fruit leathers in this study being only 1mm (approximately) in thickness, which reduced the amount of energy / force required to pierce the fruit leather.

5.7 Antioxidant activity and total phenolic content of fresh blueberry cultivars and fruit leathers

In the present study, the antioxidant activities were found to be higher than in previous studies conducted by Prior *et al*. (1998), Ehlenfeldt & Prior, (2001), Connor *et al*. (2002b). Only the Jersey cultivar had similar antioxidant value to that measured by Connor *et al*. (2002b). Among Highbush cultivars, Burlington exhibited higher antioxidant activity than Jersey, Puru

or Reka. Blue Magic, Rabbiteye cultivar, also had the highest antioxidant activity than Highbush cultivars studied in this research. The overall antioxidant activity ranged between 29 to 48 µmole TE/g FW, which was within the range specified by Prior *et al*. (1998). The authors had total antioxidant capacity, measured by ORAC, ranging from 14 to 46 µmole TE/g FW.

For the Highbush cultivars, a similar ranking was also observed by Ehlenfeldt & Prior (2001) but their ORAC values were lower than values achieved in this study. Interestingly, their antioxidant activity for the Puru cultivar was higher than Jersey, which was opposite to the results found in this research. It was noted that different antioxidant capacity and concentration of phenolics were found in different cultivars of blueberries. This difference may be attributed to the different cultivars, regions, climates and the solvents used for extraction. Other factors such as the lipid composition, antioxidant concentration, temperature, oxygen, anthocyanins, protein and water can also influence antioxidant activity. In this study, it was noted that Blue Magic and Burlington had the most sunshine hours during the season compare to the other three cultivars. It was possible that this increased the antioxidant capacity but further research will need to be conducted to confirm this.

After the drying process, it was noted that there was a reduction in antioxidant activity for all cultivars. The antioxidant activity loss after drying was between 24 to 42%. This significant loss could be due to the compounds present in the different cultivars. According to Okilya *et al*. (2010), drying processes for fruit leather could result in the oxidation of vitamin C and polyphenols. The amount of vitamins and polyphenols which both act as scavengers of the free radicals produced during oxidation reaction. Concerning the effect of the chemical degradation of polyphenols by the Maillard reaction on their antioxidant activity, the chemical oxidation of these compounds is generally responsible for a loss in antioxidant capacity (Scala *et al.*, 2011). However, further investigation is underway as recent observations suggest that partially oxidised polyphenols can exhibit higher antioxidant activity than non-oxidised phenols. Other factors, such as longer drying times, may promote a decrease in antioxidant activity (Garau *et al.*, 2007). Furthermore, in a mixture of food ingredients, redox reactions are likely to occur between different natural antioxidants and oxidation products. A significant loss of antioxidants may also occur due to leaching during washing, heat degradation and then during storage.

As previously mentioned, the Blue Magic cultivar exhibited the highest antioxidant activity (48 µ mole TE/g FW) among the five cultivars. This finding is in general agreement with the

work of Prior *et al*. (1998) and Sellappan *et al.* (2002) regarding antioxidant capacity of Rabbiteye blueberries. In both studies, the average content of antioxidant capacity in Rabbiteye blueberries was higher than for Highbush blueberries. The antioxidant capacity of Rabbiteye blueberries had ORAC values ranging from 13.9 to 37.8 µ mole TE/g FW (Prior *et al*., 1998). According to Sellappan *et al*. (2002), the premium cultivar from Rabbiteye blueberries gave a high Trolox equivalent antioxidant capacity (TEAC) value of 38.3 µM TEAC/g FW. The ORAC value for the Rabbiteye variety in the current study is slightly higher than the value given by previous studies. Again, comparison of results from previous research with the current study is difficult. Different assays, different extraction methods and different standards (TE, GAE) used for reporting the results make it difficult to compare antioxidant activities between studies, even with the same cultivar. For instance, results for Bluecrop Highbush blueberries achieved by Connor *et al.* (2002b) were similar to Scibisz & Mitek (2009).The result achieved by Moyer *et al.* (2002) also had a higher antioxidant capacity for the Bluecrop cultivar (50 µmol Trolox/g fruit) than the results reported in Scibisz & Mitek (2002) (28.9 µmol Trolox/g fruits). This supported the need for the development of a standardised assay, currently the ORAC assay (used in this study). However, the antioxidant activity depends not only on the quality of the original fruit but also on geographical and environmental factors, climatic conditions, harvesting date and storage conditions. In this study, the samples were harvested when ripe, frozen immediately (-20°C) and analysed within four weeks. Freezing and storing samples may have influenced the ORAC values. Blue Magic had the most sunshine hours as it ripened last compared to the other cultivars examined and, as such, this may have influenced the antioxidant capacity of the blueberry fruit and processed fruit leather.

When analysing the drying effect on total phenolic contents, a decrease in total phenolic contents was observed compared to fresh fruit for four of the cultivars. The phenolic content of the Reka fruit leather was higher than that found in the fresh fruit but the increase was only by 2%. This is discounted as a margin of error given the small variance. The loss of total phenolic contents for the other cultivars is likely to be due to thermal degradation. In addition, reductions in total phenolic contents during dehydration maybe ascribed to the binding of polyphenols with other compounds (proteins) or alterations in the chemical structure of polyphenols, which cannot be extracted and determined by available methods (Martín-Cabrejas *et al.,* 2009; Qu *et al.,* 2010; cited in Scala *et al.,* 2011). With the increase in consumer popularity for dried blueberries, there is demand for obtaining the most efficient and effective method for drying them, while retaining as much bioactive potential as possible. The antioxidant activity and total phenolic content measured in the blueberry fruit leathers in

this research were generally lower than that for fresh fruit (although the reduction is not considered significant).

5.8 Evaluation of the properties of blueberry fruit leather

The mean colour score of the blueberry fruit leather, as found in sensory trials, was 4.8 out of 7. This rating is just above the 'neither like nor dislike' category; the overall appearance of the fruit leather in the sensory trials was 4.8 out of 7. Blue Magic had the lowest acceptability scores for colour and overall appearance of the five cultivars. This result indicated that the visual appearance of the product was very important. The dark coloured blueberry fruit leathers, Blue Magic and Burlington, were less preferred than the reddish colour of Jersey, Reka and Puru. Interestingly, this was not the case when the blueberry fruit was eaten raw. In Saftner *et al,* (2008), Highbush cultivars Coville and Hannah's Choice scored highest among the cultivars in sensory scores for intensity of blue colour and for acceptability of appearance, colour, fruit size, sweet / tart balance, flavour and overall eating quality. Gujral & Khanna (2002) improved the colour, flavour and texture of mango fruit leather by increasing the level of sucrose, which increased both lightness and yellowness of the mango fruit leathers. Similar investigations are required for the development of blueberry fruit leathers to disguise the darker colour of some blueberry varieties. It was possible that the addition of other colourless fruit would improve the colour of the resulting blueberry fruit leather.

The texture score of the fruit leather was 4.9 out of 7 and is just below the 'moderate liking' category. The texture was influenced by the presence of blueberry seeds in the fruit leather, which gave the product a 'gritty' taste. It has also been suggested that the 'gritty' taste and presence of seeds in the fruit leather was due to harvesting of unripe fruit (Ian Shreen, pers. comm.). Furthermore, to try and improve the texture of the blueberry fruit leather, the puree was passed through a sieve. This method removed the seeds but the sieve became clogged and a large amount of pressure was required to force the puree through the sieve. In larger scale this method would not be practical and so the 'grit' was subsequently, left in the puree.

The mean sweetness score of the fruit leathers was 5.6. This indicated the product sweetness was 'liked' by panellists and therefore, the addition of sugar was not required. Increasing the amount of sugar beyond the optimum amount may reduce the overall taste rating (Kumar *et al*., 2007).

The panellists also 'moderately liked' the chewiness of the blueberry fruit leather; the mean score was 5.1. The texture of fruit leather is generally affected by the moisture content and drying time. Higher temperature and longer drying times are associated with lower moisture

content and harder texture (Okilya *et al*., 2010). In this study, the texture of the fruit leather was due to variations in the genetic makeup of the fruit, rate of water absorption from the surroundings and protein content of the fruit. This was also seen in research by Babalola *et al*. (2002). Ingredients such as pectin, honey, sugars, nuts, salt and other fruit added to improve the flavour and colour can also influence the texture quality of the final product (Raab & Oehler, 1999).

The mean score for blueberry fruit leather flavour was 5.1. The flavour score was higher in Jersey and Reka cultivars compared to Burlington, Blue Magic and Puru. The taste of the fruit leather is influenced by the amount of sugar contained in the fresh pulp (Okilya *et al*., 2010). In this research, the addition of honey and lemon juice improved the taste of blueberry fruit leather. Preliminary studies (Trial two), showed that the addition of honey and lemon reduced the tartness and improved the flavour of the blueberry fruit leather. Addition of ingredients is also known to have a significant impact on papaya and guava fruit leather as studied by Kumar *et al*. (2010). Adding 60% papaya and 40% guava resulted in a significantly better overall rating for sensory properties (than if scored individually) and without impairing the nutritional and textural quality of the fruit leather. This addition was required to improve the poor odour of papaya fruit, which was the main hindrance to the commercial exploitation of this fruit. Other ingredients such as leaf oregano and garlic-salt (among others) could also be used to improve the taste of fruit leather (Raab & Oehler, 1999)

The mean overall score for the blueberry fruit leather was 5.0. This means that, on average, the fruit leathers were ‘moderately liked’ by panellists. The overall acceptability of the blueberry fruit leather was theoretically an overall impression of all sensory attributes. The two most liked fruit leathers with an overall acceptability of 5.3 (‘moderately liked’) were Puru and Reka. These cultivars were liked by panellists due to their colour, appearance, texture, stickiness, sweetness and chewiness. The lowest score was achieved by Blue Magic and Burlington, these cultivars were disliked by panellists due to their colour, overall appearance and flavour. Puru scored the highest for almost all attributes, was ‘liked’ by 38% of the panellists and had an overall acceptable of 5 out of 7.

5.9 Correlation between sensory attributes, instrumental parameters and chemical data

This study used correlations to assess the relationship between the instrumental parameters and sensory perception in order to predict consumer responses towards blueberry fruit leather. Correlation between colour and colour appearance (both sensory attributes) implied that if the panellist liked the colour of the fruit leather then there is a 95% confidence interval that they will like the overall appearance of the fruit leather. ORAC was also significantly correlated with colour and overall appearance of the blueberry fruit leather. Sensory evaluation showed that the darker fruit leathers were less preferable than the lighter fruit leathers but strong positive correlation was seen between ORAC and colour and ORAC and overall appearance. This is expected as ORAC is a measurement of antioxidants, and antioxidants influence the colour of the blueberries and hence blueberry fruit leather.

No significant correlation was found between instrumental parameters and proximate analysis data despite having an r value of greater than 0.80 (for example, protein and hardness).

The lack of correlation between variables could be due to many pitfalls in applying linear correlation coefficient, or the manner by which objective measurements were performed which may have influenced the results. It is also possible that during sensory evaluation, the psychological and methodical factors may have influenced the panellist results which might have impacted the correlation results.

According to Szczesniak, (1968), the heterogeneity of the test samples may also influence the nature and degree of correlation between sensory and instrumental measurements of food texture. Therefore, if the relationship between sensory and instrumental data is nonlinear, the calculation of a linear correlation coefficient between the two untransformed sets of data may not be appropriate.

Chapter 6
Conclusions

Fruit leather was successfully developed from five different blueberry cultivars using three additional ingredients - honey, pectin and lemon juice. The main purpose of this processed food product was to keep or improve the nutritional value and sensory quality of blueberry and develop a convenient consumer product with an extended shelf life and that was easy to consume. The final product needed to have an extended shelf life so that it will be a commercially viable product.

The fruit leathers made from the five cultivars had low a_w (< 0.5) and moisture content (22%). These levels indicated that it should be microbially safe and can be considered as an intermediate moisture food. The addition of lemon juice as a preservative increased the acidity level of the fruit leather from 0.5 to 2.6% (citric acid). This was expected for a dried product, especially if it contained an acidic juice with a pH of 2.7 and acidity of 5.3%. The texture analysis showed that blueberry fruit leather had a soft texture. This was expected as the thickness of the product was approximately 1mm.

The proximate analysis for all the cultivars indicated that processing affected the nutritional composition of the blueberry fruit leather. Because of the high sugar content it contained a high energy content. The leather had low fat, protein and ash contents and mainly consisted of neutral detergent fibre, carbohydrates and water.

The drying process used in the development of fruit leather caused reductions in total phenolics (2 -17%) and, hence, reduced the antioxidant activity by 24 to 42%. The mean antioxidant capacity loss was higher for fruit leather dried at 60 ± 2°C. Blue Magic and Burlington, however, exhibited high levels of antioxidant capacity and total phenolic content. Therefore, drying fruit leathers at 60 ± 2°C may be suitable for some cultivars; however, others required lower drying temperatures to reduce the loss of antioxidant capacity.

Consumer sensory evaluation has shown that significant differences in colour, appearance, flavour and overall acceptability. The mean of the overall acceptability score was 'like moderately'. The study concluded that the selection of cultivar for blueberry fruit leather was important. Among the five cultivars, Blue Magic and Burlington cultivars exhibited higher level of antioxidant activity and phenolics content than the

other three cultivars. But the sensory evaluation results indicated that Blue Magic and Burlington fruit leathers were least preferred and were more often scored as ‘neither like nor dislike’.

The findings of this research are very important for manufacturers of blueberry fruit leathers. Blueberry colour, sweetness and flavour were noted to be important factors influencing the acceptance of fruit leathers. Fresh fruit blueberries with darker blue colours were considered to be healthy and of nutritional importance but when processed, the darker coloured products were considered to be less appealing and least preferred by consumers.

The blueberry fruit leathers developed were generally judged to be acceptable by the sensory panellists. Fruit leather development was a relatively new concept for preserving fruit that can be easily implemented and its advantage is that it may utilise fruit not suitable for canning, freezing or other storage methods. Blueberries can be preserved by the production of blueberry fruit leather without addition of any artificial / chemical preservatives. The additions of honey, lemon and pectin added in this research was very small and so this can be considered as natural product. This met consumer demands for healthy food products. This product has strong appeal and sales potential. Manufacturing of fruit leather required simple processing technology and was cost effective. However, the product needed further improvement for better market acceptability. Due to the different characteristics of cultivars, fruit leather’s quality was a complex issue and involved growers balancing trade-offs between characteristics such as colour, flavour and texture. This study will benefit growers, blueberry marketers and product developers who were interested in diversifying into blueberry products. These parties will need to ensure that the blueberries products they produced met the quality parameters favoured by their consumers.

Recommendations for future work

Investigation of the shelf life of blueberry fruit leathers is still required. Studying shelf-life will help to understand the stability of the product and identify optimal suitable packaging and storage conditions. The fruit leather could then be packaged in a manner, as suggested by Irwandi *et al*. (1998) who looked at various different packaging materials.

Given blueberries contained seeds, passing the puree through a 1 mm sieve was not possible in this study. Better sieve technology needs to be designed to eliminate the blueberry seeds, which some people found unpleasant during sensory evaluation. If processors are interested in the potential of second grade fruit, it is likely that unripe berries and stalks would be included. A method would then become necessary for removing stalks, leaves and unripe fruit, as well as any seeds. This issue could potentially be solved by either employing more skilled pickers to ensure that no unripe berries are picked, or alternatively if machine picked, by delaying the time of picking until the majority of berries are ripe.

Only one variety of Rabbiteye was studied in this research. Further research on Rabbiteye cultivars (cultivars available in New Zealand include Tifblue, Maru, and Powderblue) are required to gain a better understanding of the different types of blueberry cultivars. Preparation of fruit leather by mixing different types of cultivars could help to balance the nutritional properties and physical characteristics of blueberry fruit leather. However, Rabbiteye blueberries were susceptible to bacterial blast disease and only a few Rabbiteye cultivars are suitable for the Canterbury climate.

To improve the colour of the fruit leather, different proportions of various types of fruit could be mixed to develop nutritionally enriched fruit leather and to increase customer demand. Adding a variety of ingredients, preservatives or protein rich nuts could create an interesting fruit leather product and deserved further evaluation.

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Appendix A

A.1 Preliminary Experiments

Preliminary formulation trials were conducted to determine the process, and selecting ingredients, for making blueberry fruit leathers. Preliminary formulation trials were conducted using frozen blueberries (Sujon Blueberries, Nelson, NZ) bought from the local supermarket. The frozen blueberry was a mixed blueberry available in New Zealand and imported from Canada.

Four trials were conducted to ascertain the best possible way of making blueberry fruit leather. The objectives of these trials were:

- Trial One - To optimise the preparation of the blueberry fruit puree. Three different methods, uncooked, hot break and concentrated of puree were used.
- Trial Two - To study the combination of honey and pectin in blueberry fruit leather
- Trial Three - To determine the amount of ingredients required to produce blueberry fruit leather.
- Trial four - To determine the optimum temperature required to dry blueberry fruit leather

A.2 Investigation of three different methods of producing blueberry fruit puree

Three different cooking methods were explored (uncooked, hot break and concentrated puree) to produce blueberry fruit leather. The methods used were adapted from Raab and Oehler (1999).

Frozen blueberries were thawed at a room temperature.

a) Uncooked method

One hundred grams of thawed blueberries, 0.5 g of pectin, 6 g of honey and 2 ml of lemon juice were poured into a mixing bowl. The blueberry mixture was pureed using a blender (Braun, Kronberg, Germany) for 2 minutes. The puree was poured into a baking

tray (32 x 22 x 1.5 cm) smeared with cooking oil (Sunfield canola oil, Tasti Pty Ltd. Auckland).

b) Hot break method

One hundred grams of thawed blueberries were placed in the top of a double boiler. The fruit was covered and steamed for two minutes. The fruit was removed and cooled for another 2 minutes. The cooled blueberries were put in a mixer bowl and 0.5 g of pectin, 6 g of honey and 2 ml of lemon juice and then blended.

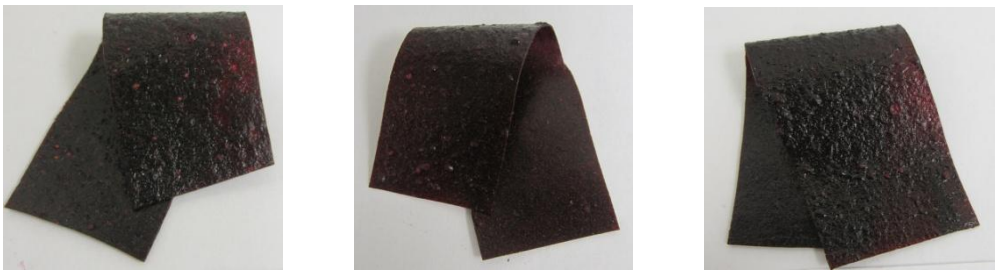
c) Concentrated the puree method

One hundred grams of thawed blueberries, 0.5 g of pectin, 6 g of honey and 2 ml of lemon juice were placed into the mixing bowl. The blueberry mix was pureed with a blender for 2 minutes. The puree was then heated over a low heat until the temperature reached 60ºC.The puree was stirred constantly and heated until the mixture was thickened (~ 5 to 10 minutes).

All purees were left to cool for 10 minutes at room temperature. The drying temperature was set to 60°C (optimum temperature to produce fruit leather) (Henneman & Malone, 1993); thickness of the was 2 mm.

A.2.1 Results and Discussion

After six hours drying all samples were dry to touch and the trays were removed from the cabinet. Samples were slightly sticky due to the honey content in the product but it was able to be peeled off off the trays. The formulations were darker than their puree colour. Samples produced by the hot break method were a lighter reddish colour than samples produced using ‘concentrated puree’ and the ‘uncooked method’. Figure 1 shows the blueberry fruit leathers produced by using three different cooking methods.



Uncooked Method Hot Break Method Concentrated puree

Figure A.1 Blueberry fruit leather trial using three different methods

The water activity readings for all the samples ranged from 0.39 to 0.41, final thickness were (about the same) 0.64 to 0.55 mm and moisture contents for the ‘hot break method’

and ‘uncooked method’ were 18 to 19% respectively. The moisture content for fruit leather made by the ‘concentrated the puree method was much higher (25%) than for the ‘hot break method’ (18%) and ‘uncooked method’ (19%). Samples made by the ‘concentrated puree’ method was a harder to cut and had a lot darker colour than the ‘hot break’ and ‘uncooked’ methods. It was also stickier than the other two methods.

The ’uncooked method’ tasted better than other two products and the texture was softer. However, the colour was still darker than the ‘hot break method’ but lighter than ‘concentrating the puree’. The ‘hot break method’ flavour was sour and blueberry taste very light. It was observed during the blanching that the skin pigment colour faded and leached into the boiling water. The heating process thawed the blueberries and began to reduce the fruit volume. It also appeared to slow the enzymatic browning process because when the dried leathers were removed from the dryer this batch seemed to be slightly lighter in colour.

A.3 To study the impact of honey and pectin in blueberry fruit leather

This trial was conducted to find the impact of honey and pectin on blueberry puree. Four formulations were prepared, as shown in Table 1. Formulation 1 was without the addition of honey and pectin. Formulation 2 was prepared by adding pectin (2.5 g) and no honey, Formulation 3 was prepared using honey (6 g) only and formulation 4 used both honey (2.5 g) and pectin (6 g).

Leathers were prepared using the basic protocol guide, as stated in Appendix A.1. Except the additional ingredients were modified and the heating temperature was increased to 65ºC for 10 minutes. Lemon juice was not added in this study. The puree was left to cool for 10 minutes at room temperature.

Table A.1 The ratio of honey and pectin in the formulation trial

Formulation	Blueberry	Honey	Pectin
1	100	0	0
2	100	0	2.5
3	100	6	0
4	100	6	2.5

The dryer was set to 60°, air velocity was 1.5 m/s and the thickness of the purees were 1mm. The puree was dried until it was dry to touch (~ 3 hours).

A.3.1 Results and Discussion

This trial was designed to find out the effect of honey and pectin in blueberry puree. Four formulations were prepared with and without honey and pectin.

After the puree dried the fruit leather was tasted informally by Food Science Group students. Formulation 1 (without pectin and honey) produced a dry fruit leather, the taste was very bland and the product was too crunchy. The product was sticky at the bottom and difficult to peel from the tray. Blueberry with 2.5 g pectin (Formulation 2) produced dry fruit leather and it was easier to peel from the tray. The product was not tasty and it was crunchier than the other three formulations. The blueberry taste was masked by pectin, hence, the product tasted bland. Also, the amount of pectin (2.4%) was higher, therefore, the sample was harder. However, the product had a slight tangy of blueberry after taste. Blueberry with 6 g of pectin (Formulation 3) was slightly stickier than the other formulations. Due to the stickiness the fruit leather it was harder to peel from the tray. Although this sample was stickier, all the members found the product tastier, sweeter and flavoursome than three formulations. The final formulation made mixing blueberry with honey and pectin (Formulation 4) was drier than the other fruit leathers. The fruit leather was easier to peel and less sticky than the other fruit leathers. However, Formulation 4 was tastier than other three formulations but the product was also a little too dry.

A.4 To determine the amount of ingredients required to produce blueberry fruit leather

A total of 12 treatments were investigated. The amount of honey used in the formulations was 10 g, 15 g and 20 g and pectin was 0.5, 1 and 2 g. The amount of lemon was increased and fixed to 5 ml. Table 2 shows the formulations made in this trial. A 75 to 85 g blueberry was used to make a final formulation weight of 100 g. Muslin was used as a strainer instead of a sieve to reduce amount of seed in the product.
The puree was prepared as in Appendix A.2.

Table A.2 Ingredients used for initial trial (g)

Formulations	Blueberries	Pectin	Honey	Lemon
1a	84.5	0.5	10	5
1b	84.0	1.0	10	5
1c	83.5	1.5	10	5
1d	83.0	2.0	10	5
2a	89.5	0.5	15	5
2b	89.0	1.0	15	5
2c	88.5	1.5	15	5
2d	88.0	2.0	15	5
3a	74.5	0.5	20	5
3b	74.0	1.0	20	5
3c	73.5	1.5	20	5
3d	73.0	2.0	20	5

Based on the results from the second trial it was decided to decrease the drying temperature to 55°C and to increase the thickness of the puree by 1 mm, to 3 mm. The puree was dried until it was dry to touch (approximately six hours).

A.4.1 Result and discussion

In this trial, Formulation D (Trial 2) was re-formulated. From Trial 2 it was decided to add more sweetness and improve the texture of honey by making it firm, therefore, different amounts of pectin and honey were used to find the exact ratio of these two ingredients that were required.

During the cooking process, samples that had 2% pectin gave a thicker puree. It was also harder to sieve through muslin and a lower yeild of fruit leather was produced. At pectin concentrations (1.5 – 2.5g), Formulaions 2c and 2d became thicker within seven minutes of cooking at the low heat (65°C).

A group discussion was conducted regarding the product's chewiness, flavour, tanginess, sweetness, stickiness and overall preferences.

Formulations 1a – 1d containing 83 – 84.5% blueberries produced soft and sour fruit leather. The formulations had a good blueberry flavour, however, the taste was too sour. The higher amount of lemon juice did not make a large visual difference. The leathers were a dark plum red colour.

Formulations 2a- 2d containing 88 – 89.5% blueberries produced fruit leathers that were acceptable. The sweetness, stickiness, tanginess was just about right. Formulations 2c and 2d had 2% pectin and were slightly drier than 2a and 2b. Formulations 2a and 2b were tastier and less sticky than the other formulations. The texture softness was about right

and it had the characteristics texture of fruit leather. Honey added at about 15% as was just right to give sweetness to the blueberry fruit leather.

Formulations 3a - 3d, which had higher levels of honey and pectin, had a stickier texture when dried. There was no cracking around the edges in these batches and the texture was very firm. The leather was very dark in colour and was rigid (rubbery feeling) and difficult to tear apart. Fruit leathers containing 20% of honey were all very sweet; the taste was mostly dominated by the taste of honey. Increasing the amount of pectin from 1.5 to 2% did not produce a good fruit leather as it produced undesirable toughness, colour and appearance.

A.5 To determine the optimum drying temperature to produce blueberry fruit leather

Based on the observation and results from Trials 1 and 3, the uncooked method was used to investigate the optimum drying temperature required to produce blueberry fruit leather. The Formulation 2b (from Trial 3) was selected for this trial. The leathers were prepared, as described in Appendix A.1 (uncooked method). For each sample, three different drying temperatures were tested (55, 60 and 65°C). Triplicate samples were used for each drying temperature.

A.5.1 Results and discussion

Table 3 shows the thickness, water activity and moisture content of blueberry fruit leathers dried at three different temperatures (55, 60 and 65ºC).

Table A.3 Physico-chemical (mean ± SE) for blueberry fruit leathers at different temperatures

Temperature (°C)	Moisture Content (%)	Water Activity (a_w)	Thickness (mm)
55	23.3 ± 0.5	0.4 ± 0.1	0.5 ± 0.03
60	18.6 ± 0.6	0.4 ± 0.1	0.6 ± 0.03
65	17.3 ± 0.9	0.4 ± 0.1	0.5 ± 0.03

When the product was dried at 65°C, the sample started cracking from the edges within four hours. When the leather was fully dried, it was harder to peel from the tray and did not produce a good leather. From Table 7.3, all three temperatures produced fruit leathers with moisture content within the range 15 – 25%. However, the moisture content of product dried at 55°C was higher (23.31% ± 1.36) than the other two temperatures. At 60°C and 65°C, the moisture contents were between 18.62 ± 1.10 and 17.25% ± 2.71, respectively, for all samples. The water activity readings of the product, using three

different temperatures, ranged from 0.35 to 0.39 a_w. As these were all below the level that any microorganisms would grow at, the products were considered to be microbially safe for storage at room temperature (20°C). The thickness of the products ranged from 0.46 to 0.63 mm. It was decided that the initial thickness of puree would be increased to 3 mm.

A.6 General discussion for the preliminary trials

Based on the results of the informal sensory trial, the 'uncooked' method was used to prepare fruit leathers from five blueberry cultivars. Despite the result of the sensory trial, there were some other issues associated with the 'concentrated puree' and 'hot break' methods that supported the 'uncooked' method. Previous studies have found thermal treatment causes significant changes in phytochemical contents of blueberries (Sablani *et al.*, 2010).The magnitude and duration of heating were also found to have a strong influence on anthocyanin stability (Patras *et al*., 2010). The study conducted by Brownmiller *et al*.(2008) found high temperature C for 3 minutes) resulted in 43% loss in total monomeric anthocyanins, compared to the original levels found in fresh fruit (this study was conducted in combination with pasteurisation). This suggested that heat liable factors can accelerate anthocyanin pigment destruction and endogenous enzymes in fruit caused pigment destruction during juice processing (Patras *et al.*, 2010). In the current research, concentrating the puree method was trialled (at 65°C) and the hot break method used boiling water (i.e. 10 C). Based on existing research, it can be predicted that heating blueberries using these two alternative methods would significantly reduce the anthocyanin contained in foods such as blueberry fruit leather. However, only limited information was available on the temperature stability on an anthocyanin derived from food. According to Patras *et al*. (2010), thermal degradation of anthocyanin resulted in the formation of polyphenolic degradation products (shown in the loss of the blue colour) but it was not clear if the formation of these components resulted in an overall reduction in antioxidant activity.

Drying using a cabinet dryer was successful. The puree was dried on solid stainless steel trays at a fixed airspeed and temperature. From the results gathered in the preliminary trials, drying was conducted at a temperature of 60°C, using an air velocity of 1- 1.5 m/s, and a drying time of eight hours. At higher temperatures (e.g. 65°C), fruit leather was brittle, thin and the blueberry seeds gave the product

C produced a fruit leather that was more appealing and did not look over cooked.

Appendix B

B.1 Sensory evaluation

B.1.1 Approval letter from Human Ethics Committee for sensory evaluation

Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH•NEW ZEALAND
New Zealand's specialist land-based university

Research and Commercialisation Office

T 64 3 325 3838
F 64 3 325 3630
PO Box 84, Lincoln University
Lincoln 7647, Christchurch
New Zealand

www.lincoln.ac.nz

Application No: 2011-20 22 August 2011

Title: Development and Evaluation of Blueberry Fruit Leather

Applicant: Minakschhi Karki

The Lincoln University Human Ethics Committee has reviewed the above noted application.

Thank you for your detailed response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed.

I am pleased to give final approval to your project. Please advise Julie Ward when you have completed your research and confirming that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

Yours sincerely

Grant Cushman

Professor Grant Cushman
Chair, Human Ethics Committee

cc G Savage, S Mason

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

B.1.2 Research Information Sheet for panellist

Lincoln University

Faculty, Department or Research Centre: Wine, Food and Molecular Biosciences, AGLS

Research Information Sheet

You are invited to participate as a subject in a project entitled

Name of project: ***Evaluation of Blueberry Fruit Leathers***

I am developing a fruit leather (fruit rolls or snack bar) from five different types of Blueberry cultivars. Fruit leathers are dried sheets of fruit pulp which have a soft, rubbery texture and a sweet taste. It is produced by dehydration of fruit puree into a leathery sheet. This survey is to give me a better understanding of whether people would like blueberry fruit leather and what their expectations of it would be.

Participation in this research project is voluntary and participants may withdraw from the study, and ask the researchers to remove their data from the study at any time, up until the end of sensory evaluation session. It is expected that participation requires a total time commitment 20-15 minutes.

Your participation in this project will involve tasting and observing blueberry fruit leathers. Participants are expected to hold the samples and observe the colour, overall acceptance, texture and stickiness of the sample. The sample is then tasted for your sensory attributes such as sweetness, flavour and overall acceptability of the product. Full instructions for task will be explained orally by the experimenter before you begin. Participation may also require that you provide information to the researchers about your gender and age.

After tasting each sample presented, you will be asked to report your judgments on a paper. Panellist instruction will be given by the experimenter before you begin.

Please see the information below about the allergic reaction that can be caused by eating blueberries. If you have any berry fruit allergies, you will be excluded from participating in this study.

In the performance of the tasks and application of the procedures, there are risks of:

Allergic reaction *- Blueberries contain salicylate, which is a natural-occurring chemical in plants. If participants are allergic to blueberries, it is often because they have sensitivity to this compound. Salicylate are also found in many fruits and vegetables, as well as many common health and beauty products. Some examples of vegetables and fruits that contains salicylate are apples, avocados, blueberries, dates, kiwi fruit, peaches, raspberries, figs, grapes, plums, strawberries, cherries, grapefruit, and prunes. A vegetable such as alfalfa, cauliflower, cucumbers, mushrooms, radishes, broad beans contains salicylate.*

To ensure anonymity the following steps will be taken:

All the forms, panelist questionnaires and documents will be locked in an office in a securely way. The questionnaires and forms will be all locked and coded. Participant's personal details will not be asked.

The project is being carried out by:

Minakshhi Karki
Wine, Food and Molecular Biosciences Department
PO Box 84, Lincoln
Email: Minakshi.karki@lincolnuni.ac.nz

She will be pleased to discuss any concerns you have about participation in the project.

Name of Supervisor: Prof. Geoffrey Savage
Wine, Food and Molecular Biosciences Department
PO Box 84, Lincoln
Email: Geoffrey.Savage@lincoln.ac.nz

Dr. Sue Mason
Wine, Food and Molecular Biosciences Department
PO Box 84, Lincoln
Email: Sue.Mason@lincoln.ac.nz

The project has been reviewed and approved by the Lincoln University Human Ethics Committee.

B.1.3 Consent form for panellist

Lincoln University Policies and Procedures

Consent Form

Name of Project: Development and Evaluation of Blueberry Fruit Leathers

I have read and understand the information sheet for volunteers taking part in the study designed to evaluate the blueberry fruit leathers. I have had the opportunity to discuss this study. I am satisfied with the answers I have been given.

On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I do not have any allergies to berry fruit and I know whom to contact if I have any side effects about the study. I will contact a medical centre on campus (phone number +64 3 325 3835) or 1st Aid officers.

I know whom to contact if I have any questions about the study. I can withdraw from the study and ask the researchers to remove their data from the study at any time, up until end of the sensory evaluation.

Name: _____

Signed: _____ Date: _____

B.1.4 Instruction for panellists

Panellist Instructions

You will be evaluating 5 fruit leather samples.

Please evaluate the samples in the order presented (**left to right**). Be sure to answer the questions on the questionnaire that accompanies the fruit leather samples.

Evaluation Techniques:

Hold the sample:

- Observe the colour and overall appearance
- Feel the texture and stickiness
- Record your answers on the sheet.

Taste the sample:

- Record your answers for sweetness, chewiness, flavour and overall acceptability.

Before tasting each sample please take a sip of water to cleanse your palate. Retaste the product as needed and tick the box for your response.

Please take a 1 minute break between each sample.

Raise your hand if you have any questions or need more water.

B.1.5 Sensory Evaluation Questionnaires

Panellist Code:___

Sensory Evaluation Questionnaire

Sex ☐ Male ☐ Female

Age Range ☐ <19 ☐ 19-25 ☐ 26-30 ☐ 31-50 ☐ >50

Smoker? ☐ Yes ☐ No

Sample Code: **541**

Rating Scale	Like extremely	Like very much	Like moderately	Neither like nor dislike	Dislike moderately	Dislike very much	Dislike extremely
Colour							
Overall Appearance							
Touch / Texture							
Touch / Stickiness							
Sweetness							
Chewiness							
Blueberry Flavour							
Overall Acceptability							

Sample Code: **840**

Rating Scale	Like extremely	Like very much	Like moderately	Neither like nor dislike	Dislike moderately	Dislike very much	Dislike extremely
Colour							
Overall Appearance							
Touch / Texture							
Touch / Stickiness							
Sweetness							
Chewiness							
Blueberry Flavour							
Overall Acceptability							

Sample Code: **692**

Rating Scale	Like extremely	Like very much	Like moderately	Neither like nor dislike	Dislike moderately	Dislike very much	Dislike extremely
Colour							
Overall Appearance							
Touch / Texture							
Touch / Stickiness							
Sweetness							
Chewiness							
Blueberry Flavour							
Overall Acceptability							

PTO...

Sample Code: 776

Rating Scale	Like extremely	Like very much	Like moderately	Neither like nor dislike	Dislike moderately	Dislike very much	Dislike extremely
Colour							
Overall Appearance							
Touch / Texture							
Touch / Stickiness							
Sweetness							
Chewiness							
Blueberry Flavour							
Overall Acceptability							

Sample Code: 825

Rating Scale	Like extremely	Like very much	Like moderately	Neither like nor dislike	Dislike moderately	Dislike very much	Dislike extremely
Colour							
Overall Appearance							
Touch / Texture							
Touch / Stickiness							
Sweetness							
Chewiness							
Blueberry Flavour							
Overall Acceptability							

Please answer the following questions. (Please circle one)

- Did you like any of the fruit leathers you have just tasted? Yes / No
- Would you buy these fruit leathers? Yes / No
- Which sample did you like the best? _____
- Do you like eating blueberries? Yes / No
- Any comments on flavour, or anything else

_____

_____

Thank you for taking the time to complete this survey!

Appendix C

C.1 Raw data

Table C.1 The raw data dry matter (%) and proximate composition (g/100 DW) of the fresh and dried for five cultivars

Variety	Sample Type	Replicates	Dry Matter	Ash	Crude Protein	Fat	NDF	Carbohydrate
Blue Magic	Fresh	1	17.21	1.22	2.00	1.04	21.51	77.44
Blue Magic	Fresh	2	18.94	1.21	2.00	0.99	21.49	74.33
Blue Magic	Fresh	3	-	1.29	1.94	0.96	21.43	72.83
Blue Magic	Dried	1	78.32	0.91	1.59	0.42	11.29	57.04
Blue Magic	Dried	2	79.12	0.88	1.6	0.39	11.04	59.55
Blue Magic	Dried	3	78.02	0.91	1.47	0.38	11.12	57.65
Burlington	Fresh	1	16.94	1.54	2.95	2.23	20.73	68.89
Burlington	Fresh	2	19.57	1.59	2.91	2.2	20.75	71.80
Burlington	Fresh	3	-	1.56	2.92	2.23	21.47	69.55
Burlington	Dried	1	75.64	1.09	1.58	0.79	9.74	56.64
Burlington	Dried	2	76.32	1.10	1.85	0.85	9.94	56.52
Burlington	Dried	3	77.54	1.06	1.82	0.8	10.08	56.96
Jersey	Fresh	1	17.78	1.48	3.51	2.74	21.86	69.02
Jersey	Fresh	2	15.97	1.43	3.52	2.63	21.83	71.92
Jersey	Fresh	3	-	1.44	3.42	2.65	21.4	72.58
Jersey	Dried	1	79.24	1.03	2.19	1.67	12.08	60.29
Jersey	Dried	2	79.29	1.01	1.89	1.64	12.2	59.55
Jersey	Dried	3	77.38	0.98	2.17	1.63	12.3	58.12
Puru	Fresh	1	15.56	1.43	3.85	1.51	16.00	75.71
Puru	Fresh	2	16.17	1.40	3.89	1.49	15.55	76.00
Puru	Fresh	3	-	1.42	4.01	1.49	15.86	78.78
Puru	Dried	1	78.76	1.05	2.09	0.52	7.47	66.97
Puru	Dried	2	78.96	1.02	2.19	0.55	7.69	67.26
Puru	Dried	3	77.40	0.98	2.30	0.58	7.85	67.85
Reka	Fresh	1	14.03	1.57	3.69	1.40	15.5	75.18
Reka	Fresh	2	14.33	1.61	3.72	1.39	15.65	75.46
Reka	Fresh	3	-	1.60	3.75	1.31	15.81	75.91
Reka	Dried	1	75.98	1.10	2.24	0.45	7.42	59.69
Reka	Dried	2	76.24	1.09	2.32	0.47	7.13	58.21
Reka	Dried	3	78.13	1.05	2.29	0.47	7.69	64.02

(-) No data, replication was done instead of triplicates.

Table C.2 The raw pH, °Brix (°B) and titratable acidity data for blueberry fresh fruit, puree and fruit leather during processes

Variety	Replicates	Fruit pH	Puree pH	Fruit Leather pH	Fruit (°B)	Puree (°B)	Fruit Leather (°B)	Fruit Titratable Acidity (%)	Fruit Leather Titratable Acidity (%)
Blue Magic	1	3.4	3.2	3.2	14.0	26	86	0.3	2.1
Blue Magic	2	3.5	3.2	3.4	15.0	26	90	0.4	2.1
Blue Magic	3	3.4	3.2	3.3	14.0	26	88	0.3	2.1
Burlington	3	3.4	3.3	3.3	14.0	26	84	0.7	2.4
Burlington	3	3.5	3.2	3.4	12.0	26	84	0.6	2.4
Burlington	3	3.4	3.2	3.3	12.5	25	88	0.7	2.5
Jersey	1	3.4	3.1	3.6	14.5	26	86	0.5	2.9
Jersey	2	3.4	3.1	3.4	14.5	26	84	0.5	2.8
Jersey	3	3.4	3.3	3.2	14.0	26	88	0.5	2.9
Puru	1	3.4	3.2	3.1	13.5	26	91	0.5	2.8
Puru	2	3.5	3.1	3.2	13.0	26	92	0.5	2.8
Puru	3	3.4	3.3	3.3	14.0	27	84	0.6	2.9
Reka	1	3.6	3.2	3.5	12.5	25	89	0.6	2.8
Reka	2	3.4	3.2	3.3	11.0	25	89	0.5	2.9
Reka	3	3.4	3.2	3.1	12.5	23	90	0.5	2.7

Table C.3 The raw data for moisture content, water activity, texture and thickness for fruit leathers using five cultivars

Variety	Replicates	Moisture Content (%)	Water Activity (a_w)	Tensile force (N	Hardness (g)	Thickness (mm)
Blue Magic	1	20.88	0.44	15.92	385.34	1.2
Blue Magic	2	19.51	0.45	15.36	368.95	1.2
Blue Magic	3	19.01	0.44	15.99	352.08	1.2
Blue Magic	4	21.97	0.44	15.89	332.21	1.2
Blue Magic	5	27.29	0.46	-	309.11	1.2
Blue Magic	6	21.68	0.45	-	345.12	1.0
					336.09	
					334.77	
Burlington	1	24.36	0.45	15.04	348.16	1.3
Burlington	2	23.68	0.47	16.67	338.07	1.1
Burlington	3	22.46	0.08	14.85	403.89	1.1
Burlington	4	25.06	0.41	15.23	401.89	1.2
Burlington	5	21.66	0.43	-	403.74	0.9
Burlington	6	26.02	0.46	-	408.27	2.8
					409.37	
					338.21	
					352.29	
Jersey	1	20.76	0.48	20.59	577.23	1.1
Jersey	2	20.71	0.52	26.01	541.63	1.3
Jersey	3	18.98	0.46	21.71	463.31	1.2
Jersey	4	22.41	0.44	20.18	589.77	1.1
Jersey	5	22.62	0.44	-	598.77	1.2
Jersey	6	23.53	0.45	-	528.54	1.1
					672.55	
					670.63	
Puru	1	21.24	0.45	20.73	852.33	1.0
Puru	2	21.04	0.43	19.63	581.51	0.9
Puru	3	19.69	0.45	19.52	705.88	1.1
Puru	4	20.60	0.44	24.57	850.93	1.4
Puru	5	22.60	0.47	-	720.81	1.5
Puru	6	24.92	0.45	-	768.61	1.3
					834.22	
Reka	1	21.65	0.52	18.99	651.26	1.1
Reka	2	17.78	0.41	20.07	720.77	-
Reka	3	24.01	0.46	19.18	567.85	0.9
Reka	4	23.76	0.43	20.24	704.62	1.2
Reka	5	21.86	0.41	-	645.48	1.2
Reka	6	26.76	0.56	-	555.15	1.1
					549.47	
					624.77	

(-) Data was not collected. Sample was too sticky and was harder to peel off and therefore thickness could not be measured.

Table C.4 Mean CIE colour readings, pH and °Brix (mean ± SE) for puree for five cultivars

Variety	L*	a*	b*	pH	°Brix
Blue Magic	23.7 ± 0.2^{c}	4.6 ± 0.1^{c}	-0.2 ± 0.1^{b}	3.16 ± 0.00^{c}	26.00 ± 0.00^{a}
Burlington	23.8 ± 0.4^{c}	2.9 ± 0.1^{d}	-0.5 ± 0.1^{c}	3.25 ± 0.03^{a}	25.67 ± 0.33^{a}
Jersey	24.0 ± 0.1^{bc}	4.7 ± 0.0^{c}	-0.2 ± 0.1^{b}	3.18 ± 0.04^{bc}	26.00 ± 0.00^{a}
Puru	25.4 ± 0.3^{a}	10.1 ± 0.3^{a}	0.4 ± 0.5^{a}	3.21 ± 0.05^{bc}	26.33 ± 0.33^{a}
Reka	24.5 ± 0.1^{b}	7.3 ± 0.3^{b}	0.3 ± 0.1^{a}	3.24 ± 0.00^{ab}	24.33 ± 0.66^{b}
Mean	24.28 ± 0.2	5.9 ± 0.1	0.3 ± 0.1	3.20 ± 0.0	7.66 ± 0.0

Table C.5 The raw data of the antioxidant (ORAC) acitivities (µM TE/g FW) and total phenolic contents (mg GAE/g DW) of the fresh and dried for five cultivars

Variety	Replicates	ORAC (Fruit)	ORAC (Fruit leather)	Total Phenolics (Fruit)	Total Phenolics (Fruit leather)
Blue Magic	1	49.03	32.65	662	567
Blue Magic	2	46.14	34.74	661	574
Blue Magic	3	47.43	32.82	706	543
Burlington	1	40.52	29.02	614	503
Burlington	2	46.74	28.15	582	474
Burlington	3	40.47	27.29	573	504
Jersey	1	37.07	23.02	534	373
Jersey	2	35.13	26.04	540	379
Jersey	3	35.34	25.76	527	378
Puru	1	28.33	17.10	418	401
Puru	2	32.32	18.61	425	384
Puru	3	32.33	19.13	434	401
Reka	1	27.45	24.18	425	405
Reka	2	28.63	21.34	359	440
Reka	3	29.78	21.86	409	373

Table C.6 Raw data for colour measurements of five varieties blueberries during the production of fruit leathers

		Fruit					Puree					Fruit Leather				
Variety	Rep	L*	a*	b*	°Hue	C	L*	a*	b*	°Hue	C	L*	a*	b*	°Hue	C
Blue Magic	1	23.97	6.03	0.18	359.1	6.03	24.13	4.51	-0.28	357.90	4.52	27.40	0.79	-0.04	354.90	0.79
Blue Magic	2	24.73	5.78	0.23	357.8	5.78	23.43	4.67	-0.10	357.70	4.67	27.51	0.95	-0.12	350.30	0.95
Blue Magic	3	22.84	6.42	0.10	359.3	6.42	24.56	4.56	-0.21	358.10	4.57	27.58	0.98	-0.22	347.50	1.01
Blue Magic	4	-	-	-	-	-	23.73	4.45	-0.23	356.40	4.45	27.63	0.69	-0.06	357.80	0.69
Blue Magic	5	-	-	-	-	-	23.34	4.62	-0.20	359.30	4.62	27.27	1.23	-0.33	357.40	1.27
Blue Magic	6	-	-	-	-	-	23.27	4.72	-0.21	357.80	4.72	27.03	1.33	-0.35	351.40	1.38
Burlington	1	22.81	4.97	0.49	354.9	4.99	24.05	2.82	-0.47	350.10	2.86	29.30	0.13	0.61	97.80	0.62
Burlington	2	22.76	4.91	0.44	354.7	4.93	25.47	2.96	-0.48	351.20	3.00	29.13	0.09	0.58	70.20	0.59
Burlington	3	23.48	4.93	0.46	356.5	4.95	23.32	3.08	-0.50	352.40	3.12	29.31	0.08	0.70	105.70	0.71
Burlington	4	-	-	-	-	-	23.29	2.84	-0.43	350.60	2.88	29.68	0.43	1.07	104.20	1.15
Burlington	5	-	-	-	-	-	23.24	2.98	-0.45	350.80	3.01	29.14	0.19	0.87	103.90	0.89
Burlington	6	-	-	-	-	-	23.24	2.88	-0.40	352.90	2.91	29.50	0.33	1.00	83.60	1.05
Jersey	1	26.25	8.65	0.37	361.3	8.66	23.88	4.68	-0.23	356.80	4.69	28.35	1.19	-0.09	359.50	1.19
Jersey	2	25.61	9.36	0.31	360.6	9.37	24.20	4.65	-0.32	356.20	4.66	28.06	1.34	-0.17	357.30	1.35
Jersey	3	26.55	9.19	0.21	361.5	9.19	23.78	4.67	-0.31	357.90	4.68	27.35	1.50	-0.23	359.50	1.52
Jersey	4	-	-	-	-	-	24.46	4.73	-0.32	355.70	4.74	28.43	1.17	-0.03	357.70	1.17
Jersey	5	-	-	-	-	-	24.12	4.80	0.22	358.20	4.80	28.17	1.19	0.00	357.30	1.19
Jersey	6	-	-	-	-	-	23.59	4.90	-0.17	357.60	4.90	28.08	1.26	-0.10	359.50	1.26
Puru	1	26.88	9.51	0.32	358.1	9.52	25.81	9.36	0.25	361.50	9.36	28.89	4.55	-0.31	97.00	4.56
Puru	2	26.44	9.35	0.39	357.7	9.36	25.13	9.50	0.25	361.20	9.50	29.41	4.28	-0.24	357.00	4.29
Puru	3	26.63	9.31	0.32	356.7	9.32	25.05	9.39	0.26	362.60	9.39	29.78	4.14	-0.34	353.70	4.15
Puru	4	-	-	-	-	-	25.81	10.90	0.54	362.50	10.91	29.20	4.50	-0.46	354.20	4.52
Puru	5	-	-	-	-	-	25.53	10.69	0.49	361.00	10.70	29.23	4.18	-0.44	354.10	4.20
Puru	6	-	-	-	-	-	25.30	10.90	0.54	360.90	10.91	29.06	4.07	-0.42	355.00	4.09
Reka	1	26.32	6.78	0.36	357.0	6.79	24.82	7.83	0.30	362.50	7.84	28.69	3.79	-0.26	354.80	3.80
Reka	2	26.69	6.73	0.3	357.5	6.74	24.73	7.72	0.28	361.60	7.73	28.70	3.42	-0.18	359.50	3.43

Reka	3	26.49	6.33	0.32	357.1	6.34	24.44	7.77	0.14	361.10	7.77	28.86	3.49	-0.11	358.70	3.49
Reka	4	-	-	-	-	-	24.00	6.92	0.27	361.50	6.92	27.4	2.74	0.03	359.50	2.74
Reka	5	-	-	-	-	-	24.32	6.55	0.36	361.50	6.56	29.17	2.10	0.28	6.70	2.12
Reka	6	-	-	-	-	-	24.49	7.00	0.21	360.60	7.00	28.90	2.93	-0.11	359.00	2.93

(-) No data, for fresh fruit, colour measurements were taken three times only

Colour measurements were recorded as L = lightness (100 = white, 0 =black); a* (+ a* = redness, -a* = greenness) and b* (+ b* = yellowness, - b* = blue). These values were taken for fruit, puree (before drying) and fruit leather (after drying).

Table C.7 The mineral element contents (mg/100 g FW) of lemon juice, honey and pectin used to make blueberry fruit leather

	Al	B	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Zn
Lemon	0.02	0.00	8.45	0.00	0.00	0.52	131.64	8.40	0.01	5.65	0.00	13.73	6.42	0.04
Honey	0.11	0.64	5.41	0.01	0.02	0.67	72.78	1.89	0.07	5.97	0.00	11.31	5.43	0.10
Pectin	1.21	0.00	283.42	0.06	0.33	10.59	290.56	22.41	0.40	384.96	0.08	35.09	548.15	0.52

Figure C.1 Blueberry farm, Canterbury, NZ

Figure C.2 Blueberry fruit (Jersey cultivar) grown in Canterbury, NZ

Figure C.3 Blueberry fruit used in the production of blueberry fruit leather

Figure C.4 Five blueberry cultivars. From top left – Jersey, Blue Magic, Puru, Reka and Burlington

Figure C.5 Fruit leather puree after blending processes

Figure C.6 Oven dried Reka cultivar blueberry fruit leather

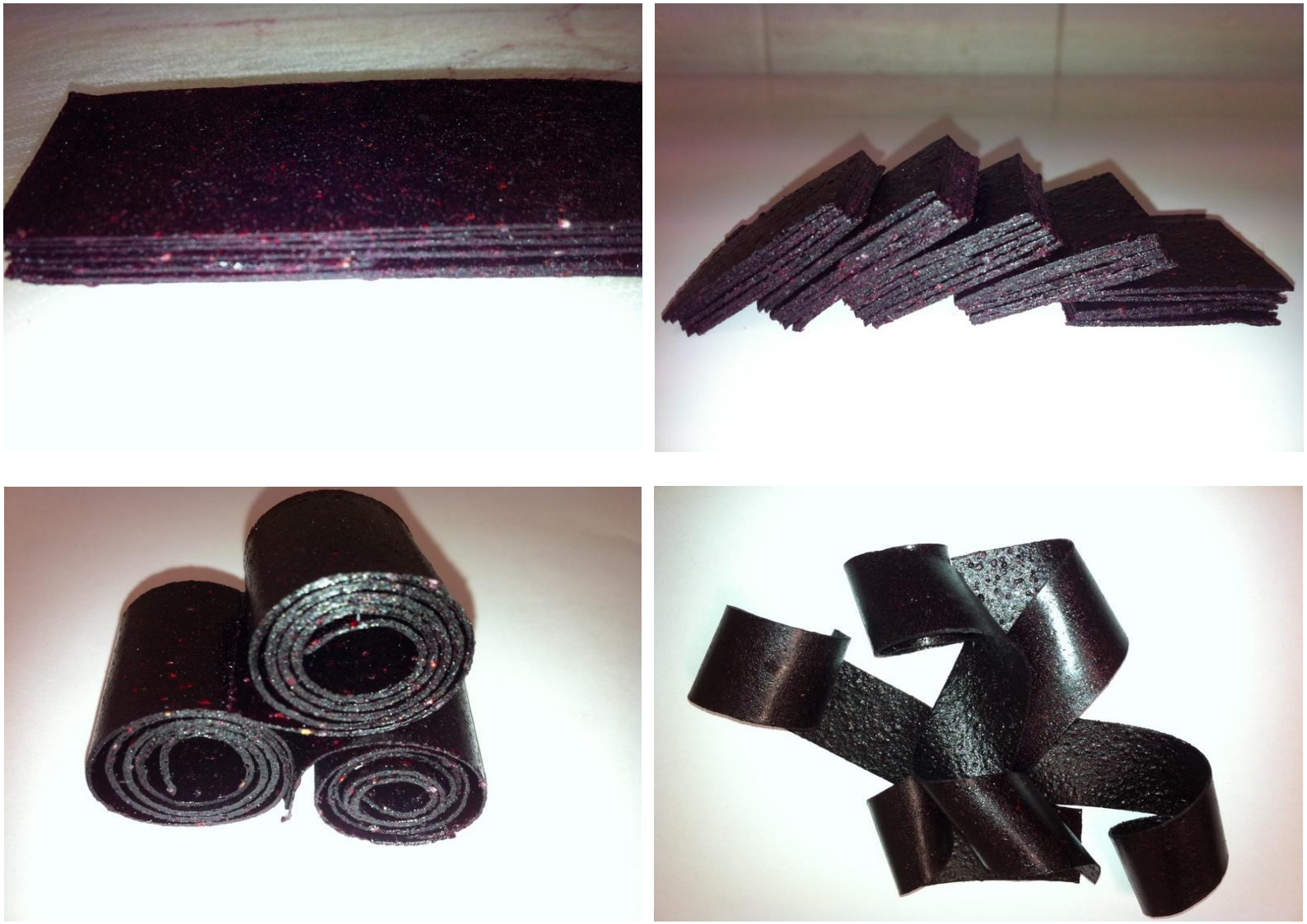


Figure C.7 Blueberry fruit leathers can be eaten as a snack bar or a fruit roll.