FACULTY OF BIOSCIENCE ENGINEERING

OPPORTUNITIES AND PROBLEMS CONCERNING POTATO PRODUCTION AND QUALITY IN LAM DONG, VIETNAM

Pieter-Jan Loveniers
Student number: 01170155

Supervisor: Prof. dr. ir. Geert Haesaert

Master's Dissertation submitted to Ghent University in partial fulfilment of the requirements for the degree of Master of Science in Bioscience Engineering Technology: Food Industry

Year: 2018 - 2019

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Auteur
Pieter-Jan Loveniers

Promotor
Prof. dr. ir. Geert Haesaert

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Abstract

Although potato is a small crop for Vietnam, it can be a significant added value for local farmers. Lam Dong, a province in the Central Highlands of Vietnam, is known for its high fertility soils and mild climate where potatoes could grow all year round. However, potato cultivation is under pressure because of problems regarding quality. For this study, conducting a targeted farmers' questionnaire in Lam Dong, provides insight into problems and opportunities concerning potato production. Also, the expectations of local consumers regarding quality requirements is assessed. Moreover, several samples are bought on local markets in Lam Dong to establish the current available quality. These samples were assessed for typical quality parameters. The results of the farmers' questionnaire showed that less than 40% is aware of training and research institutes to improve their farming practices. Major yield losses were mostly attributed to late blight (*Phytophthora infestans)*, leafminer flies (*Liriomyza* spp.) and bacterial wilt (*Ralstonia solanacearum*). Fertilizers are consitently over-used. Crop rotation practices and male farmers showed significant higher yields. Farmers manage to produce relative high yields despite the fact that there is plenty of scope for quality improvements. Received pirices by farmers is relatively high, on average 396 $ tonne^{-1} but fluctuating between seasons. Consumers experience bad quality on local markets and 57% would buy more if the quality was better. Poor quality on local markets is perceived but not statistically confirmed. Between district Dalat, Duc Truong, Don Duong and Lam Ha, there is no difference in tuber quality except for depth of eyes, mealiness of cooked potatoes and flavour of French fries.

Keywords: *Potato, production, tuber quality, Lam Dong*

Content

List of abbreviations

Afkorting	*Anderstalige betekenis*
CIP	International Potato Centre
PVFC	Potatoes, Vegetables and Flowers research institute
DM	DM
N	Nitrogen
P	Phosphate
K	Potassium
FAO	Food and Agriculture Organization
RRD	Red River Delta
MARD	Ministry of Agriculture and Rural Development

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Introduction

1.1 Background

Solanum tuberosum L., generally known as potato, is the third most important staple food crop in the world, after wheat and rice. It has a production of 388 million tonnes per year according to the Food and Agriculture Organization of the United Nations (FAOSTAT, 2017). Potatoes contribute to world food security and they are currently the most important crop in developing countries. The ability of potato plants to grow in a wide range of climates has contributed to an increased consumption of it. Consistently, the production is expanding faster than other food crops (Scott et al., 2000).

However, in Vietnam which is one of the most rapidly growing economies in Southeast Asia, potatoes are still a small crop and the cultivation decreased significantly from a production area of 100 000 ha in 1980 to only 20 400 ha today (FAOSTAT, 2017). Two major potato producing regions in Vietnam are distinguished: The Red River Delta (RDD) and the Central Highlands. First, the RRD which accounts for 95% of all potato production in Vietnam (Fresh Studio, 2015). Second, the remaining 5% comes from small-scale farmers in the Central Highlands of Vietnam including Lam Dong province (Figure 1). This study will focus on potato production in the latter region. In view of altitude, is Lam Dong suitable for potato production throughout the year. With at least 200 000 ha available land area for potato production current situation offers opportunities. Also in terms of yield per hectare there is room for improvement. Productivity is rising with about 9.2 tonnes ha^{-1} in 1980 to 14.8 tonnes ha^{-1} in 2019. However, when comparing these numbers with other countries such as Belgium (47.5 tonnes ha^{-1}) and New Zealand (49.3 tonnes ha^{-1}), there is a remarkable difference (FAOSTAT, 2017).

Figure 1: Geographical location Lam Dong province

Although the low consumption (5 kg per capita per year), the Vietnamese trade statistics demonstrate that the potato sector is not able to produce enough potatoes to meet the growing

demand. Fresh potato import increased from $ 1.1 million in 2003 to $ 23.7 in 2017 (UN COMTRADE statistics, 2017). Even though domestic demand exceeds local supply, potato remained a low interest crop to consumers as well as to producers. The lack of interest for the potato has led to a low-quality level. Multiple causes can be at the root of the problem. For instance: the quality of the tuber seeds, carrying pests and diseases. Also, farming practices are poor (e.g. inadequate fertilization, poor control of *Phytophthora infestans, ...)* and storage techniques are bad (Tung, 2000). This results in an inconsistent volume and poor-quality supply of both processed and table potato.

1.2 Objectives

This study attempts to describe the current situation of potato production in Lam Dong. A diagnostic survey will provide valuable information to understand major potato production constraints and pave the way for its improvement. The questionnaire aims to identify the causes of poor-quality tubers in Lam Dong province and will discuss measures to improve tuber quality. In the end, better quality production will enhance consumer appreciation, resulting in higher potato consumption. Furthermore, an improved quality will benefit the technological value of potato destined for industrial use.

A consumer survey, conducted in Dalat City, will provide more insight into what consumers understand by qualitative potatoes. The questionnaire sheds light on consumers attitudes toward potato and its preparation. The findings will be evaluated to comprehend consumers' needs.

Assessment of several samples, bought on local markets, spread in Lam Dong, make it possible to determine tuber quality of available potatoes. Quality is assessed by evaluating external tuber quality (e.g. size, skin, greening, etc.), internal tuber quality (e.g. dry matter content, growth cracks, hollow hearts, etc.), cooking behaviour and sensory analysis of French fries.

This master dissertation starts with a literature review consisting of three parts. First, botanical characteristics of a potato plant are described. Second part defines tuber quality and reviews the factors that affect the quality. Third and last part focuses on potato production and consumption in Vietnam, especially in the Lam Dong province.

1 Chapter 1: Literature review

1.1 Botanical characteristics of *Solanum tuberosum L.*

Potato, botanically known as *Solanum tuberosum L.*, belongs to the *Solanaceae* or nightshade family together with nearly 2.800 other crops like tomato, tobacco and petunia. Spooner et al. (2014) updated the latest taxonomic classification of potato and recognizes eight cultivated species, classified according to ploidy levels, varying from diploid (24=24) to hexaploid (6n=72). Only the tetraploid (4n=48) *S. tuberosum ssp. tuberosum* subspecies is commonly cultivated all over the world (Patil et al., 2016).

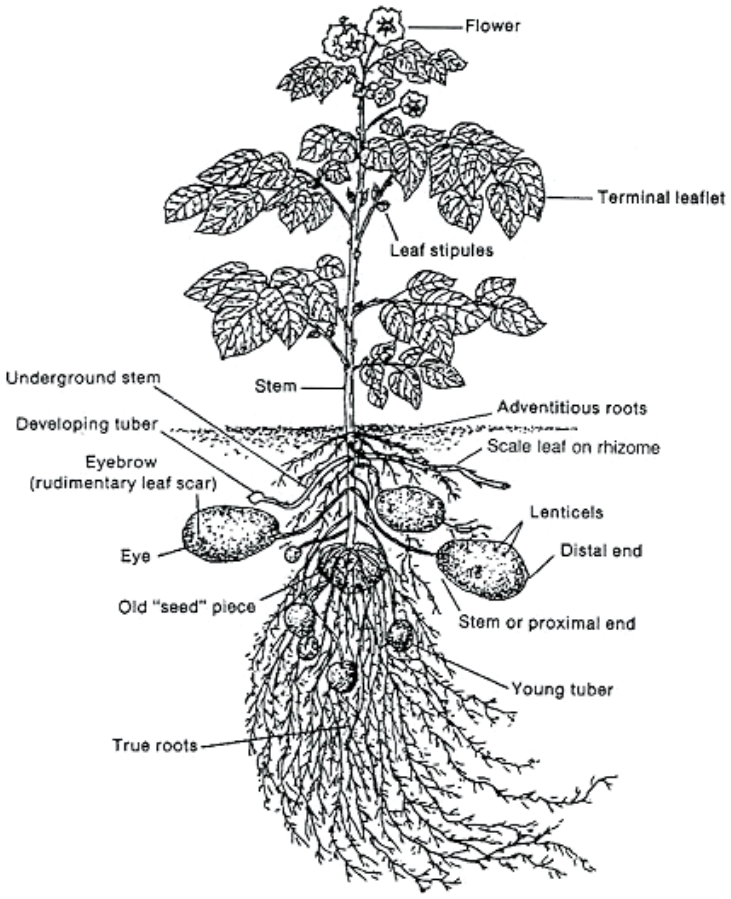

Figure 2: Morphology of potato plant (Pajerowska – Mukhtar, 2005)

The potato plant is an herbaceous plant which can grow up to 140 centimetres tall. Potato varieties can be vegatively reproduced by planting (pieces of) tubers included with at least one or two eyes. The produced edible tubers will be genetic identical to the mother seed plant. Potato plants also produce berries, containing poisonous alkaloids (*Solanine*) which contain 100 – 400 seeds. The seeds can be planted and will be genetically different from the mother plant. The inflorescences are branched and may contain up to 25 flowers. The peduncle or the stalk that holds flower clusters, is 0 – 22 cm. Potato flowers are bisexual and possess calyx, corolla, androecium and gynoecium (Hawkes, 1990). The calyx is green or coloured, hairy

and has five sepals. Each flower has five petals which give a star shape; the corolla may be a range of colours, including white, lilac and red-purple. The androecium has five stamens with short filaments that are 1 – 2 mm and anthers that are 3 – 8 mm. The colour of anthers varies from deep orange to light yellow (Huaman, 1986).

The stem, hairless to densely hairy, is erect in the early stage but becomes prostate later on. Lateral stems are branches of main stems. Morphologically, stolons are lateral stems which grow horizontally underground. The length of the stolons is an important cultivar character. When a stolon is not covered in the soil, it may develop in a vertical stem with normal foliage. Stolons may form tubers by enlargement of their terminal end. The tuber has buds from which next season's growth will emerge. These buds or called eyes and are concentrated near the apical end of the tuber. The number and distribution depend on the variety. A mature tuber consists of skin, cortex, vascular ring, permedullar, medulla and pith (figure 3). The tuber skin is composed of an epidermis, an outer layer of single cells and a periderm, or several layers of corky cells. Below the periderm is the cortex followed by the vascular ring which contains the cells responsible for the transport of nutrients from the above ground stems to the tuber. The medulla represents the primary storage area for the tuber. Cells in the medulla increase in size and number when they are supplied with nutrients, which causes the tuber to grow in size (FAO, 1998).

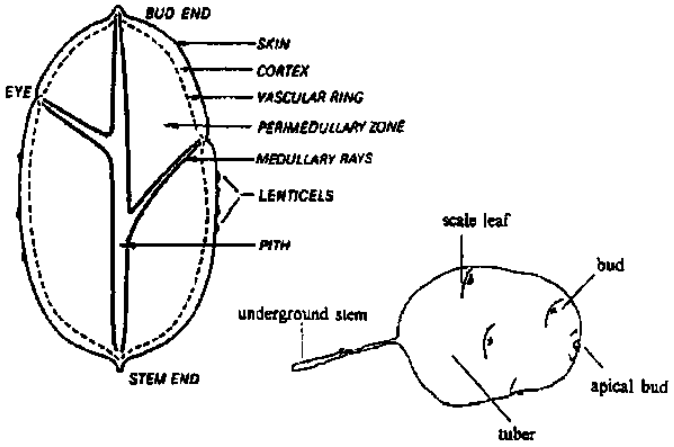

Figure 3: Morphology of potato tuber (FAO, 1998)

The tubers are the edible part of the potato plant. The relatively low-fat content and high carbohydrate level of the tuber makes it a perfect energy source for humans. Potato tubers also contain numerous essential nutrients which are recommended for a healthy diet. Compared with rice, one medium-sized potato (eaten with skin) contains half of the daily intake of Vitamin C while rice doesn't have any Vitamin C. Potatoes also contain at least 11 other essential vitamins and minerals and are a rich source of thiamine, folic acid and iron (Kolasa, 1993).

The growth and development of potato plants, if grown from seed tubers, can be roughly divided into five stages: sprout development, vegetative growth, tuber initiation, tuber bulking and maturation. These five growth stages are summarized in table 1.

Table 1: Five growth stages of the potato plant (Obidiegwu, 2015)

1. Sprout Development:	**2. Vegetative Growth:**	**3. Tuber Initiation:**	**4. Tuber Bulking:**	**5. Maturation:**
				
Sprout developing from eyes on seed tubers and grows upward to emerge from the soil.	Leaves, branches, roots and stolons develop from emerged sprouts. Begins at emergence and ends when tubers start to develop.	Tubers are formed at the end of stolons, but are not yet enlarging.	Tubers expand with accumulation of water, nutrients and carbohydrates.	Tubers reach full size. The top of the plant dries out and dies. Tuber skin toughens which extends shelf life.

1.2 Tuber quality

In developing countries there is an increase market for fresh potatoes. Consumers' requirements for fresh market potatoes are often associated with visual characteristics such as appearance of the tuber and freedom from disorders including damage and diseases. For the processing industry, quality conditions that potatoes must meet, have to be determined to obtain efficient production and avoid wastage (Storey and Davies, 1992). In this context it is crucial to define tuber quality.

'Tuber quality' is a diverse term covering features such as external and internal tuber morphology. Cooking quality is also considered to be important in this respect (Eskin, 1987). Quality of potato tubers associated with external appearance include: tuber size, shape, skin and flesh colour, depth of eyes, greening and mechanical damage. Internal quality factors contain: DM content, growth cracks, hollow heart, internal bruising. Factors related to cooking quality are enzymic and non-enzymic browning, texture and flavour (Storey and Davies, 1992).

Following paragraph describes these various quality features.

1.2.1 External quality

1.2.1.1 Size and shape

The required tuber size and shape depends on the end of use of the potatoes. Consumers prefer tubers within the size range of 4,0 to 7,5 cm (Gray & Hughes, 1977). Large-sized uniform tubers are usually required for processing. Small-sized tubers entail greater peeling losses during processing. However, these small-sized tubers can be used as seed tubers. Whitehead et al. (1953) recognized several different shapes of potato tubers (e.g. round, oval, longitudinal, etc.).

1.2.1.2 Flesh and skin colour

Consumers appear to be less discriminating about flesh colour of potatoes since they are attaching more importance for its intended use (BPC, 2004). In the processing industry, chips require light-yellow flesh. Skin colour preferences vary in many countries. Most common skin colours are light-yellow and red (Vreugdenhil, 2007).

1.2.1.3 Depth of eyes

Tuber eye depth is an important parameter for determining potato quality. Deep eyes are detracting from visual appearance and adding an extra cost of peeling during processing. Souza et al. (2005) described a method to measure the depth of eyes, attributing grades according to the scale (1= shallow to 3=deep).

1.2.1.4 Scabies

One of the most prevalent disease that lowers tuber quality is common scab caused by *Streptomyces* spp.. It is a soil born disease that infects the immature tubers and as the tuber grow, the lesion expands. The lesions of common scab impair the tuber visual with a corky looking appearance, which is highly important for the consumer (Beukema and Vander Zaag, 1990).

1.2.1.5 Greening

Green coloration of potatoes occurs after prolonged exposure to light in the field, in storage, or at home. Formation of green pigmentation, chlorophyll, near the surface of the potato is considered safe and occurs in every plant. However, in potato tubers, greening is a sign of an increase in glycoalkaloids (mainly solanine). Solanine biosynthesis occurs parallel but independent of chlorophyll biosynthesis. While chlorophyll is harmless, the toxic solanine is responsible for the bitter taste of potatoes after being cooked. A study in 2001 claims that a green potato of 450 gram is enough to make an adult ill (Pavlista, 2001).

1.2.1.6 Mechanical damage

Mechanical damage effects the final quality as well as the storability of the crop. The causes of potato bruising vary but mostly results from physical contact with other objects during harvesting. A damage that breaks the skin of the tuber is a potential entry point for diseases and pathogens that cause storage rot. When the skin of a potato is broken and bruised water loss from the tuber increases.

1.2.2 Internal quality

1.2.2.1 Dry matter content

The dry matter (DM) content is the mass fraction (%) that remains after the water fraction (%) has been removed by drying. It is an important factor to determine the starch content of the tuber since 60 to 80% of the DM consists of starch. DM is disposed unevenly; highest levels are found in the vascular system, intermediate in the cortex and lowest in the pith. Specific gravity (SG) is correlated with the DM content and ranges from 1.0485 to 1.151 g cm^{-3}. For most processing products, a high percentage of DM is preferred. The higher DM content, the less water has to be evaporated which saves costs. DM is often used as an indicator of mealiness and susceptibility to internal bruising (Storey and Davies, 1992).

1.2.2.2 Growth Cracks

Growth cracking is an external disorder where the potato tuber splits while growing. This gap normally heals but leaves a crack in the tuber. Longitudinal cracks occur when the tissue inside the tuber grows faster than the outside tissues due to fluctuating water stress. Jefferies & MacKerron (1987) considered two forms of growth cracking: one form of cracking is associated with rapid tuber growth and high turgor due to over-watering or excessive rainfall. Another form occurs after re-wetting the soil after prolonged dry periods after tuber growth has stopped (Hiller et al, 1985).

1.2.2.3 Hollow heart

Hollow heart is an internal disorder and may be described as an internal growth related wound with no cells exposed to the external environment. It is characterized by the formation of an ‘star’ – shaped cavity in the tuber, typically surrounded by brown, discoloured tissue. It is caused by an abrupt change in tuber growth rate after a period of stress (Vreugdenhil, 2007).

1.2.3 Cooking quality

1.2.3.1 Enzymic and non-enzymic browning

A processing quality factor associated with internal structure, composition and culinary properties include enzymic and non-enzymic browning. Enzymic browning occurs when fresh potatoes are peeled or cut due to oxidation of phenolic compounds, mainly amino acid tyrosine. Non-enzymatic browning reaction (e.g. caramelization and Maillard reaction) causing pigmentation in processed potatoes. The extend of pigmentation is mainly determined by the amount of reducing sugars.

1.2.3.2 Sensory analysis of French fries

Sensory evaluation is an essential criterion for quality judgement to fulfil the wishes of consumers. Colour of potato French fries depends on reducing sugar levels. Determining the colour of fried chips is important for determining suitable potatoes for processing. Dark coloured crisps are unacceptable for the consumers (Sandhu et al, 2010).

1.2.4 Factors affecting tuber quality

In this section the factors determining tuber quality such as variety, environment during crop growth (e.g. temperature, light, water supply, soil type, etc.) and farming practices (e.g. nutrient management, crop rotation, irrigation, etc.) are described.

1.2.4.1 Variety

Potatoes may contain more genetic diversity than any other crop which may explain the ability of potatoes to grow in divergent environments. This genetic diversity is the most important factor that influences quality attributes and is a valuable resource toward further improvement of tuber quality. According to Carputo et al. (2002) traits that are genetically controlled can be grouped as biological traits (e.g. proteins, carbohydrates, vitamins, minerals, etc.), sensorial traits (e.g. flavour, texture, colour) and industrial traits (e.g. tuber shape, size, DM content, browning properties, greening, etc.).

1.2.4.2 Environment

Temperature: *S. Tuberosum* is a ‘cool weather crop’ with temperature being a major limiting factor on cultivation. High temperatures and drought reduce starch content, DM content and yield (Krauss and Marschner, 1984; Jefferies, 1995). The optimum temperature for photosynthesis is about 24°C. Even when only the tuber temperature increased, tuber growth can decrease because of reduction in the activity of starch synthesizing enzymes. Practical, temperatures higher than 25 °C are unsuitable for potato production (Vreugdenhil, 2007).

Tuber shape is partly controlled by climate conditions during growth. Temperatures of 12 to 20°C produce tubers of more even shape than temperatures below or above this range. Cool years and short growing seasons reduce DM production while warm sunny years and longer growing seasons results in higher DM content (Lisinska, 1989). High soil temperatures can induce a rough or scaled skin (Harris, 1991).

Light: DM production of disease and drought free crops has been shown to be linearly related to the amount of solar radiation (Manrique et al., 1991). Light intensities as low as 3 – 11 W m^{-2} for as short periods as 24h induce greening depending on variety, maturity of the tuber and by temperature (Larsen, 1949).

Water supply: The water requirement of crops is the amount of water required to meet evapotranspiration rate. This is the amount of water that is lost to the atmosphere through the soil surface as well through leaves of the plant. For potato plants, the amount of water requirement is very location specific and varies from 350 to 700 mm. Depending on: soil type, crop variety, atmospheric demand and length of growing season (Navarre et al., 2014).

In terms of quality, water supply and scheduling are very important. Moisture stress prevails at tuber initiation stage results in a higher yield loss than at tuber development stage. This is due to a greater reduction in photosynthesis and leaf area at tuber initiation stage than development stage (Kumar and Minhas, 1994). Water supply needs to be evenly distributed because the crop is very intolerant of even short periods of droughts. Inadequate water supply lead to poor yields and malformed tubers (Kay, 1973). Water deficit in the early part of yield formation followed by irrigation may result in tuber cracking or black hearts. DM content may increase when water supply is limited during the ripening period. An excess of rainfall during growth of potato plants may decrease tuber yield and DM content (van Oort et al., 2012) and can affect enzymic browning (Mapson et al., 1963). Drought does not affect greening but will promote erosion and ground cracking. This may result in tubers which are exposed to light penetrating through the cracks.

Soil: Potatoes planted in soil with pH level between 4.5 and 7.5 grow well. When pH value is higher there will be problems with common scab. When pH value is lower than 4.5, poor quality tubers will be produced, and abnormal growth occurs.

1.2.4.3 Farming practices

Farming practices, including for instance plant density, irrigation management and nutrient management, is another factor which influences tuber quality (Olanya et al., 2014).

Plant density influences the size of potatoes. An increase in stem density resulted in a significant reduction in number of tubers set per stem. High stem density is desired to produce

tubers with higher DM content (Scott and Younger, 1972). In contrast, many studies have shown an increased DM content with decreasing plant population (Beukema and Vander Zaag et al., 1990; Tamiru, 2004). Low DM content at wide plant spacing is due to the high photosynthetic rate and thus a high vegetative growth. On the other hand, with a high plant population there is a high competition for light and other important resources which leads to a low DM content (Mangani et al., 2015). Hollow hearts are caused by irregular growth due to a low plant density (Vansteenkiste, 2000).

For potatoes, the leading irrigation method is sprinkler irrigation. Furrow irrigation is still widely used worldwide. Drip irrigation occurs as well. Potato plants are more productive and produce higher quality tubers when proper irrigation management is applied. Under-irrigation results in losses in tuber quality and total yield. Over-irrigation leads to erosion, disease susceptibility and nitrogen leaching (Ati et al., 2012). However, potato plants can tolerate deficit irrigation before tuberset (Cappaert et al, 1994).

Since there are no strategies available to control the disease, it is important to use crop management practices that reduce the occurrence of common scab (Tein, 2015).

Hilling up is a common and important practice for potato cultivation. It helps to prevent greening, and blight infections. It also helps to loosen the subsoil for good aeration (Getachew, 2013). In terms of tuber skin, deep planting produces thin periderms.

The potato is a very adaptable plant which doesn't need ideal soil and growing conditions. However, the plant is susceptible for a lot of pests and diseases. Therefore, farmers grow potatoes in rotation with other dissimilar crops that are not susceptible for the same pathogens and pests as potato (Pavlista and Ojala, 1997). The duration and frequency of crops in potato rotation can influence soil-borne diseases incidence and development (Honeycutt et al., 1996). Legumes in potato rotation help to interrupt potato soil-borne diseases (Sanderson et al., 1999). Roinila et al. (2003) has shown that cropping systems effects starch and DM content as well as tuber nutrients (Järvan and Edesi, 2009). Leguminous crops in rotation are known to increase nitrogen availability in the soil (Stark and Porter, 2005).

Potato plants require more than 13 mineral elements which include macronutrients (N, P, K, Ca, Mg, S) and trace elements (Cl, Fe, Mn, Zn, Mo, Cu, B). Nitrogen, Phosphorus and Potassium are the top elements that determine yield (Dreyer, 2014). Insufficient nutrients concentration limits potato growth and can affect tuber quality. Also, an excess of nutrients can result in inhibition of growth and quality loss. The potato plant has the ability to protect itself against pests and diseases when the right amount of nutrients are available. Nitrogen is the most often limiting essential element for potato growth. Application of fertilizers

containing N is usually necessary because N is often not available for uptake. Timing and rate of the application can have a major impact on yield and quality.

The estimated removal of the macronutrients N-P-K from potato plants in a subtropical or tropical region (kg ha^{-1}) is shown in table 2. Recommendations for particular regions depend on climate, growing season, soil type, cropping system and variety, potential yield and production purpose (fresh or processed). The ratio of the main potato nutrients amounts is recommended to be 1:0.3:1.8 (N: P: K) (Mengel et al., 2001).

Table 2: Nutrient intake (Roy et al., 2006; White et al., 2007; Tein, 2015)

N (kg ha^{-1})	**P_2O_5 (kg ha^{-1})**	**K_2O (kg ha^{-1})**
70 - 300	25 - 132	50 – 249

Potatoes use ammonium and nitrate N but prefer ammonium. However, in high rainfall conditions a split application may reduce leaching losses. N application after the start of tuber development may delay crop maturity.

Table 3 presents the effects of fertilization on tuber quality. A distinction is made between the main macronutrients: N, P, K, Mg and Ca.

Table 3: Effects of nutrient fertilization

	Tuber quality effects	References
Potassium (K)	- Higher dose of K leads to a lower amount of reducing sugars content (K increases starch content) while a lower dose of K leads to a conversion of starch into sugar which makes the potato sweeter in taste (= not desirable quality). Lower starch content and higher K content results in less sensitivity for blue. - Lower dose of K (50 kg K ha^{-1}) increases vitamin C content, medium dose of K (100 kg K ha^{-1}) has no effect and higher dose (150 kg K ha^{-1}) reduced it. - Specific gravity, associated with starch content, DM or ash content, is positive correlated with K application. In excess, K fertilization reduces DM content. - K fertilization resulted in low internal blackening, mechanical damage, hollow hearts and increases shelf life of tubers. - Potassium increases the size of tubers but not the number of tubers per plant. - Higher tuber K levels reduce effect of disease caused by *Fusarium* - The levels of tyrosine, thus enzymatic browning, decrease with higher potassium fertilization rates.	Bansali, S., & Trehan, S. (2011), Smith, D., & Smith, R. (1977), Adhikary, B. H., & Karki, K. B. (2006), Roberts, S., & Mc Dole, R. E. (1985), Martin-Prevel, P. J. (1989), Trehan, S., Roy, S., & Sharma, R. (2001), Marschner, (1995), Panique et al., (1997)
Phosphorous (P)	- P application increases tuber DM content if P levels in soil are (very) low. However, where P levels in soil are (very) high, added P has little impact on DM content. - Higher P dose results in thicker tuber skin	Mulder and Turkensteen, 2005
Nitrogen (N)	- N-fertilization results in a lower DM content because high N-levels promote top growth which can prolong the growing season with the result that the tubers are not mature and therefore lower DM content. The tubers are also more prone to bruising, damage and diseases. - High level of N has an inhibiting effect on dry-rot - Taste of cooked potato tubers is found to be better when the tubers are grown without N-fertilization. Also, texture and baking colour is better without N applications. - Yield increases with use of N-fertilization - Late application of nitrogen can result in higher solanine content - Nitrogen increases enzymatic browning except under conditions of very low potassium.	Sowokinos and Preston, 1988), Lisinska, (1989), Dean and Thornton, (1992), Woltz and Engelhar, (1973), Eskin, (1987)
Magnesium (Mg)	- Higher Mg dose have a reducing effect on soft rot - Some studies show a slightly negative effect on DM content	McGuire and Kelman, 1986
Calcium (Ca)	- Higher Ca dose makes the potato plant resistant to soft rot (*Erwina spp.)* and dry rot (*Fusarium*) pathogens	Huber, 1994

1.3 *Solanum tuberosum L.* in Vietnam

1.3.1 History

Potato (*Solanum tuberosum L.*) was first cultivated between 8.000 and 5.000 BC in the Andes region near the present borders of Peru and Bolivia (Salaman, 1949). Andean Indians grow up to 200 different kinds of potatoes in one single field. Most of these variants do not taste or look the same as the potatoes we are used today. For example, they can have skin and flesh coloured bright yellow or deep purple. The shape can be also eye-catching, often being long or thin. Anyhow, most of them have a very high nutritional value rich in starch and minerals. In the 16th century, warrior sailors introduced the potato to Europe. After the import into Europe, the potato remained without any interest for a long time because the toxicity of the Solanaceae was feared. It was not until the 18th century that the potato was generally recognized as a nutritional food crop. The potato was now found more productive than alternative crops like wheat because of years of extreme bad grain harvests. Later on, the potato reached most other parts of the world because of European colonialization (Smith, 2011).

The potato, called "*khoai tây*" in Vietnam, which means "Western root" or "French tuber" was first introduced in the late 19th century by French colonialists (Tung, 2000; Van Ho, 1983). Until the late 1960's potato cultivation was not common and considered as a minor vegetable crop (Van Ho, 1983). During the 1970's population growth and an acute food shortage because of typhoon damage combined with the successful introduction of short growth circle rice varieties, motivated the farmers to use dry season (from November till February) for potato production. Potatoes at that time were considered as a staple food in the Vietnamese food system (Chung, 2001). The peak of potato production was in 1980 with a total production of 872 200 tonnes on an area of 93 900 ha. However, due to poor quality tuber seed and the introduction of more profitable crops, the area has declined to about 20 400 ha with an average yield of 14 tonnes per ha (Faostat, 2017). Figure 4 shows the fluctuation of potato production (red line) in tonnes and the total cultivation area (blue line) in hectare from 1994 to 2017 in Vietnam.

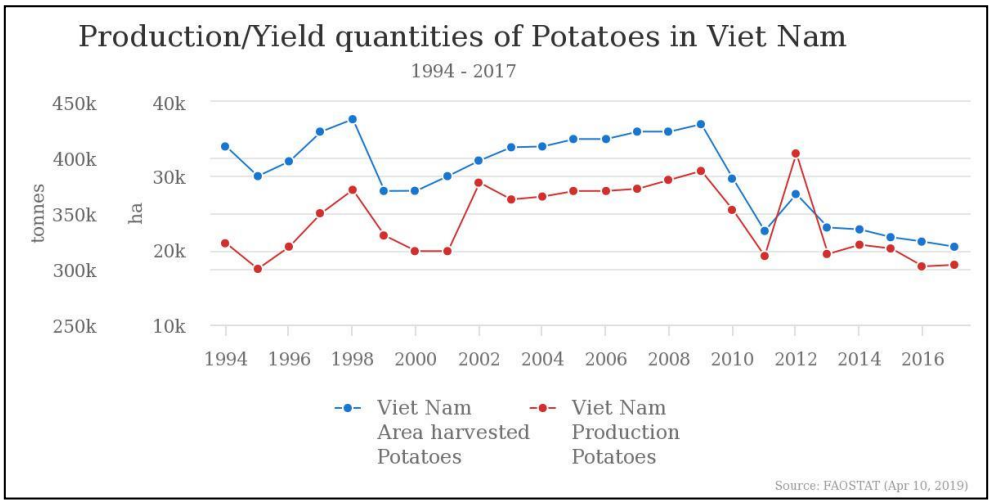

Figure 4: Production / yield quantities of Potatoes in Vietnam (FAOSTAT, 2017)

In Vietnam potatoes are mainly cultivated in the RRD, the northern part of the country. A fair amount of potatoes are grown in the Central Highlands of Vietnam, meanly in the Lam Dong province. Table 4 compared advantages and disadvantages of potato production in these two regions.

Table 4: Advantages and disadvantages of potato cultivation in RRD and Lam Dong (PVFC, 2016)

	Red River Delta	**Lam Dong province**
Advantages	✓ Cropping season from November – January ✓ Large production area ✓ Lower costs of labour, land and irrigation	✓ Favourable climate conditions ✓ Year-round production ✓ High yield potential and quality ✓ High potential of Land expansion ✓ Green houses
Disadvantages	- One season production - Low yield potential - Lower quality (DM)	- High costs of labour and land rental - High costs for irrigation during the dry season - High costs for pest and diseases control during the rainy season

1.3.2 Potato production

This section provides a short summary of the main factors affecting potato production and quality in Vietnam, more specific in Lam Dong.

1.3.2.1 Variety

In Lam Dong, improving drought tolerance and late blight resistance varieties with high and stable yield potential under irregular rainfall conditions is necessary.

Atlantic is well adapted to the growing conditions in Lam Dong province. Atlantic potatoes have a potential yield of 25 – 35 tonnes ha^{-1} and morphological (e.g. round or oval shape, shallow eyes) and quality properties (e.g. high DM content, low reducing sugar) for industrial processing. However, due to its susceptibility to late blight, Atlantic varieties should only be cultivated in dry season (Tung, 2011). TK 96.1 has a good resistance against late blight, especially in rainy season. In rainy season the variety has a potential yield from 18 to 33 tonnes ha^{-1} under conditions of the Highlands of Dalat (Tung & Tuyet, 2013).

1.3.2.2 Environment

In the tropical highlands of Vietnam, especially Lam Dong, mild temperatures and high solar radiation allow farmers to grow potatoes throughout the year and harvest within 90 days.

Light: Highland tropics are characterized by short-day lengths (11 – 13h). This short photoperiod in the tropics can have effect of restriction the size of foliage in varieties adapted to long days and thus restriction in yield. However, when varieties, adapted to short days are used, day length offer no explanation of low yield in the tropics. High light intensity in the (sub) tropics should generate sufficient potential photosynthetic energy which lead to higher carbohydrate production and hence tuber yield. High radiation levels lead to earlier tuberization and shorter growth cycles. In Lam Dong, where there are many cloudy days, radiation levels are lower than at lower latitudes. DM production is most efficient at low light intensities (Goudriaan & van Laar, 1978).

Temperature: The temperature is rather low in comparison with other regions in Vietnam, ranging from 20°C to 25°C. However, in the past decades its extrema, in Dalat, ranged from -0,6°C to 31°C. Burton (1973) estimated that DM production in the tropics is 20 to 45% lower at 25°C and 30°C than at 20°C.

Water supply: Annual rainfall in Lam Dong ranges from 1500 - 2400 mm. The rainy season, from May till October, accounts 80 – 90 % of the annual amount (ISLA, 2015). The average monthly rainfall during this season exceeds 200 mm with peaks in August and September. Excess (> 200 mm per month) in combination with optimal conditions for late blight limits potato production in tropical highlands (Devaux & Haverkort, 1987). Heavy rainfalls result in nitrogen leaching, potential for increasing late blight and soft rot, tuber malformations, growth cracks and hollow-heart developing due to the excessive precipitation. On the other hand, dry season is long with little rain causing serious water stress (ISLA, 2015).

Climate change: Climate change is reported all over the world. Especially (sub) tropical areas suffer the most negative effects. The Ministry of Agriculture and Rural Development (MARD) revealed evidence of changing rainfall conditions. Increasing rainfall amounts are recorded during rainy season. Also, the rainfall intensity in the wet season increases, whereas the number of rainy days decreases which results in a higher flooding risk and soil erosion rates. Floods wash away nutrient soil on the surface which results in negative situation of soil degradation in Lam Dong (Huyen, 2014). In dry season rainfall amounts decreases which results in more droughts. This causes a significant drop in productivity of annual crops (Duong Anh, 2011). Also, a significant increase in temperature was recognized. Maximum and minimum temperatures increase from 0.2 – 0.7°C per decade. A 1°C increase in temperature would correspond to a shortening of the growth cycle by 3 to 5 days for potatoes

(FAO, 2011). The seasons will be more pronounced. Dry season will be dryer and hotter and rainy season will be wetter and hotter (Tan et al., 2013).

Soil: Soil degradation in agricultural areas is a major problem in Lam Dong. Estimated 71% of basalt soil in Lam Dong is degraded which means a decline in land quality or reduction on its productivity (Beinroth et al., 1997; Khoa & Tu, 2014). Results of 250 soil samples in Dalat in 2000 reveals that the soil has a low humus level, low pH (acidic) and requires large amount of fertilizers to produce vegetables. In comparison with Lam Dong, Dalat land is still relative fertile. Fairly tick soil layer and steep slopes along with intense rainfall causes run off and erosion. Water holding capacity and nutritional soil is low, so special attention on farming management and improving organic soil is needed.

As humus level increases plant growth and health is favourably impacted. In general, increasing levels of soil humus following potential benefits for plants occur: increased water and nutrient holding capacity, increased resistance to soil pH changes, increased soil warmth, decreased erosion (Hopkins et al., 2003).

1.3.2.3 Farming practices

Nutrient management: Farmers in Lam Dong suffer low-quality chemical fertilizers. Fake and low-quality products are still available on the market. This does not help recover soil quality and even stimulates land degradation. Vietnamese agriculture has featured very heavy and sometimes inefficient use of fertilizers and pesticides. The application rate is about 30 – 200 percent higher than observed in other Southeast Asian countries (World Bank, 2016). Soil testing in Vietnam is rare and farmers often do not apply fertilizers with the optimal composition or at the optimal time (World Bank, 2016). Excess fertilizer use together with poor water management practices leads to a large proportion of fertilizers to run off into groundwater or be emitted as nitrous oxide (World Bank, 2016).

Manure, a mixture of animal faeces, urine, litter used as bedding material (straw, grass, etc.), is widely used in Vietnam as fertilizer because it contains all necessary nutrients (Table 5).

Table 5: Average amount of N, P, K in one tonne of manure (Tran Thi Thu Ha, 2009)

Animal	Amount of nutrient in one tonne of manure		
	N (kg tonne^{-1})	P_2O_5 (kg tonne^{-1})	K_2O (kg tonne^{-1})
Cattle	3 – 5	1.8 – 2	1.4 – 1.8
Goat	7 – 12	3 – 5	2.5
Pig	4 – 6	3 – 5	4.0
Poultry	12 – 30	11 – 26	7 – 20
Fish	8.5	7.4	0

Most of those nutrients are in organic form and degrade gradually so they don't leach away easily. However, the amount of nutrients in manure is often low and unstable. Moreover, the

continuous application of manure caused acidity of the soil due to the fact that during decomposition, lots of acids are released. Some authors have observed common scab suppression through animal manure amendment (Conn and Lazarovits, 1999). On the other hand, other studies claim controversial an increase in common scab following soil amendment with animal manure, such as poultry manure, which increases soil pH (Powelson et al., 2008).

Gurung (1997) and Jeptoo (2012) calculated an ideal amount of manure for cultivating potatoes in Vietnam. 10 – 25 tonnes per hectare manure is normally applied before planting. Tung (2000) revealed that among the chemical fertilizers, Urea, Super phosphate and potassium chloride/sulphate are the most commonly used fertilizers. The use of complex fertilizers is not a common practice among the farmers in Vietnam. In most cases the rate of applications is 100 – 120 kg N, 80 – 100 kg P_2O_5 and 120 – 150 kg K_2O per hectare.

Irrigation: In Lam Dong farmers have a limited knowledge about optimal water use. They use too much water to prevent low yields. Limited communication on water issues is one of the major causes of the limited awareness (ISLA, 2015).

Crop rotation practices: Potato production in most tropical highlands, like Lam Dong, is characterized by continuous planting of the crop on the same piece of land. Many temperate vegetables such as cabbage, Chinese cabbage, cauliflower, carrots and potatoes are intensively cultivated throughout the year. When these crops are grown continuously, soil-borne diseases such as bacterial wilt will break out.

1.3.2.4 Potato pests and diseases

The potato is affected by many pest and diseases including fungi, bacteria, viruses, nematodes and insects. The spread of the disease is influenced by climatic conditions, susceptibility of the variety and the common cultivation practices (Dang, 2008). In this paragraph most important pests and diseases in Vietnam are described.

1. Late Blight (*Phythophthora infestans*)

Late Blight is caused by the oomycete *Phytophthora infestans* which is especially adapted for growth under high humidity and low temperatures. The disease is identified by small black/brown lesions on leaves, surrounded by chlorotic borders (figure 5), usually at the tips or edges of lower leaves. During rainy weather, spores will be produced on the lower surface of the infected leaves or tubers. These spores can spread by wind and rain. The spread and sporulation will not occur in hot or dry conditions.

The disease can relatively easily be controlled using fungicides. However, in developing countries chemical control is hardly feasible because of high cost of fungicides. In addition, in the most developing countries, fungicides are imported. This makes the potato an expensive

vegetable (Henfling, 1987). Vietnam still has the "old" population of *P. infestans*, which was distributed worldwide outside central Mexico before 1970's (Hong et al., 2019).

2. Leaf-miner fly (*Liriomyza huidobrensis*)

Leaf-miner fly belongs to the order Diptera. The larva is a yellowish white to bright yellow. It lives in leaves before reaching the pupal stage. In the latter stage, the insect can fly away and invade new environments. The larvae dig characteristic small tunnels in the leaves of the potato plant *Liriomyza* spp. was only known in Lam Dong province at altitudes of 1000 – 1800 m. According to a study by Andersen et al. (2008) *Liriomyza huidobrensis* was found in potato plants in Lam Dong. These species were accidentally introduced to Vietnam with infested plants imported from the Netherlands.

3. Bacterial Wilt (*Ralstonia solanacearum*)

Bacterial Wilt (BW) or brown rot is caused by the soil-borne bacterium *Ralstonia solanacearum*, formerly called *Pseudomonas solanacearum*. This disease is the second important constraint for potato production and is present in almost every tropical or semitropical area of the world. Especially in rainy seasons and where excess of nitrogen fertilizers has been used the disease is prevalent. The first symptoms are wilting of leaves at the top of a single stem. The disease is carried over in seed tubers and has a wide range of hosts makes the control very difficult. Built-up of the disease increases when soil fertility decreases due to intensive cultivation with a high population density (Lemaga, 2001).

4. Virus diseases

In a study by Salazar (1996), more than 35 different viruses which can affect the potato are reviewed. Infected seed potato tubers are the fundamental source of viruses to other potato plants (Franc et al, 1996). Virus diseases are seldom lethal but reduce the potential yield to a degree depending on the virus. In Vietnam most common viruses are: Potato virus Y (PVY), potato leafroll virus (PLRV), potato virus X (PVX), potato virus A (PVA).

1.3.2.5 Pesticide usage

Pesticides have helped the world by increasing agricultural productivity through controlling pests and diseases. In Vietnam pesticides are widely used to control pests and diseases. Since 1990s pesticide use has nearly doubled to 76.000 tonnes in 2005 (Meisner, 2008). A study in 2017 revealed that the frequency of pesticide applications was high, and many types belong to highly toxic pesticides according to the World Health Organization (WHO). 80% of pesticides used in agriculture in Vietnam are used incorrectly resulting in high toxic loads to the environment (Nguyen, 2014). More than 7.000 incidents of food poising from pesticides residues were reported in 2002 (Nguyen, 2003). A consumer survey conducted in 2019

reveals that food safety was a primary concern. Consumers still worry about various food hazards, particularly about pesticides residues (92,6%) that are perceived to be invisible (Ha et al., 2019).

1.3.2.6 Potato tuber seeds

Poor seed tuber quality has been acknowledged as the major limitation of a productive potato cultivation system in Vietnam (Tung, 2000). The use of degenerated seed tuber, unavailability of good seed, pressure of high virus infection, late blight and bacterial wilt are the most important constraints for potato development. Vietnams' farmers store between 20 and 30% of small tubers (20 – 50 g) from harvest as seed for the next season (Hoa, et al., 1995). Potato seeds must be stored from February/March until October (8 – 9 months) under hot, humid conditions in diffused light or in a dark room of the farmers home. Small animals like rats, mice and cockroaches damages the tuber. Poor seed selection and long storage duration may result in considerable seed losses (45 – 60%). Tung (2000) believes seed losses may even exceed 80% depending on the conditions. Cold storage is preferred for storing seed tubers to minimize losses and better physiological state for next planting. However, cold storage requires too high cost for most Vietnamese farmers (Dang, 2008). There is no such thing as certified seed schedules, farmers have no clue whether the seeds they are buying is good or bad quality (Hue, 2006). To solve the seed problems, farmers in Dalat started with True Potato Seeds (TPS) in the late 1970's. In 2000 ten percent of potato area was regenerated with TPS (Tung, 2000).

1.3.3 Potato consuming

A study from '*Growing out of poverty with potato*' stated that although the domestic demand for potatoes already exceeding domestic supply, it remains a low interest crop for Vietnamese small-scale farmers. Vietnamese people will only replace rice by the potato as staple food if food is scarce (Tung, 2000). This results in an inconsistent supply and poor quality of both processed and table potatoes. Projects like '*Growing out of poverty with potato'* aims to make Vietnam more self-sufficient in potato production by creating a sustainable potato sector that is able to compete with the imported (Chinese) tubers.

A consumer survey shows that potato-consumption per capita in Vietnam is still relatively small compared with international standards. Households purchase potatoes 3 times per month and market are the main purchase channel for table potatoes. A trend towards a more globalized diet predict also an increase of consumption of potatoes.

2 Chapter 2: Methodology

2.1 Farmers' questionnaire

The study was conducted in Lam Dong province in August and September 2018. The survey sample size includes twenty-eight potato farmers from two districts (Duc Truong, Don Duong) and one city Dalat. The farmers were selected based on accessibility and availability. Twenty-three surveys were conducted together with ex-students of Dalat University. Four surveys were conducted together with a quality crop manager who worked for PepsiCo Vietnam. One additional interview was conducted by a researcher specialised in potato production at the Research Centre for Potatoes, Vegetables & Flowers (PVFC). PVFC is an agricultural science and technology research unit of the Ministry of Agriculture and Rural Development (MARD).

Quantitative data were collected from farmers during face-to-face, doorstep interviews. The questionnaire was based on published literature of previous crop cultivation research in Vietnam (Teirlinck & Haesaert, 2017; Ledent & Haesaert, 2017; Batt, 2003; Chung, 2003; Dang, 2008). To avoid misunderstandings the survey was translated in Vietnamese. Overall the questionnaire was set up in a multiple-choice format while some questions were put in full sentences to give more clarification. In the beginning of the interview, the farmers were told that their responses would only be used for research purposes.

The structured interview had six sections (Figure 5). In the first sections, the farmers were asked about their domestic background to gain basic insight of the farmer. In the second section, information about the general farming practices and their practices were asked, for example: farm size, origin of seeds, fertilizer usage, irrigation. Following the third section, the goal was to gain understanding in the occurrence of pests and diseases the farmer suffers. The goal of the fifth section is to acquire economic knowledge about the selling price and total yield levels. In the final section quality aspects and post – harvesting techniques are questioned. The complete survey can be found in appendix 1.

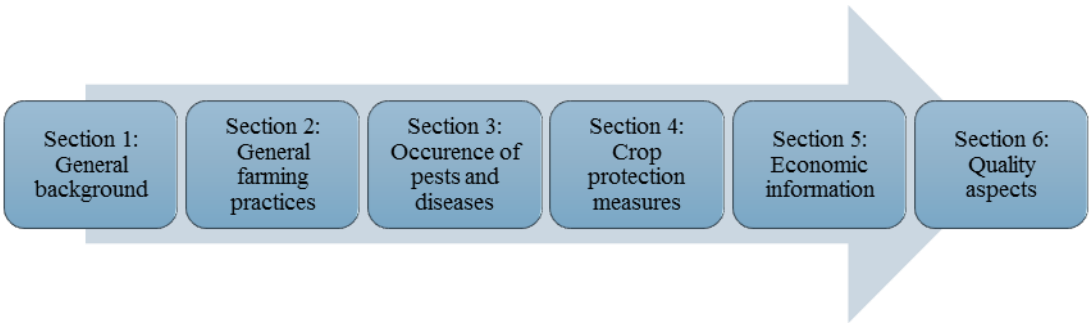

Figure 5: Sections of conducted farm questionnaire

2.2 Consumers' questionnaire

The approach of carrying out the consumers questionnaire was quantitative in nature. An online survey was created with Qualtrics (Qualtrics Labs, Inc., Provo, UT) and distributed via Facebook. Through this way, the intention was to reach as many people possible who live in Lam Dong province. The questionnaire consists of 19 questions, almost all are multiple choice questions apart from three where a 1 – 3 Likert scale is used (Important, neutral, not important). The participants were first asked about their general background (e.g. gender, age, education level, family size, etc.). Followed by questions about their preferences and behaviour towards potatoes. To verify if participants can notice the difference between local grown and imported potatoes, question 14 was asked. Here two pictures of potatoes where shown. The participant had to select the picture that represented the local grown potato. Lastly, the consumer is surveyed about his/her interpretation of tuber quality. The questions of the consumer survey can be consulted in appendix 4.

2.3 Assessment of tuber quality

Twenty-six samples, one kilogram each, were taken in four districts in Lam Dong (Dalat, Don Duong, Duc Truong and Lam Ha) on local markets. The samples were labelled and kept refrigerated immediately after the purchase. Quality assessment of every sample was determined within 5 days after purchase. The potato samples were labelled, washed with tap water until any soil was removed and dried on a cardboard before quality assessment was determined (Figure 6). First, an external and afterwards an internal quality assessment was carried out. The indicators used to assess the external quality of the potatoes were: size, skin colour, depth of eyes, scabies and greening. The internal quality is examined by testing the DM content, visually examination of growth cracks, hollow hearts and bruising damage. Furthermore, because the texture of potato tissue after heating is an important quality parameter, cooking behaviour and sensory analysis of French fries where researched. These quality assessments will be further discussed in the following paragraphs.

Figure 6: Labelled samples after being washed with tap water.
Photograph by Author, taken on 2018-08-26.

2.3.1 External quality

To measure external tuber quality, grading and standards are required. In literature different grading systems are being used. In this study, the grading system of the Potatoes, Vegetables & Flowers Research Centre (PVFC) in Da Lat is applied for quantifying size, scab content and greening.

2.3.1.1 Size

The diameter of each tuber was measured. For each sample the average diameter was taken to allocate a scale according to table 6.

Table 6: Tuber size scaling (PVFC, 2014)

State	Description	Scale
Very small	Most tubers are very small (<2cm)	**1**
Small	Small tubers, between 2 and 4 cm	**3**
Medium	Tubers are between 4 and 6 cm	**5**
Large	Large tubers, between 6 – 9 cm	**7**
Very large	Tubers are over 9 cm	**9**

2.3.1.2 Skin Colour

A distinction is made between a rather thick red/brown skin colour and a peelable yellow skin.

2.3.1.3 Depth of eyes

The tuber eye depth was visualized as described by Souza et al. (2005). Index number 1 is given when depth of eyes is shallow. Number 2 for mid-deep eyes and number 3 for deep eyes.

2.3.1.4 Scabies

The method for obtaining an index number for *scabies* is determined as follows: for each sample tubers are visually examined for *scabies*. The tuber with most external scab is used to estimate the index-number according to table 7. For example, for sample 22 the index-number is four because the surface of one tuber is estimated to be higher than 15%.

Table 7: Scab content rating criteria (PVFC, 2014)

State	Scab content (%)	Scale
Trace	1 %	1
Light	5 %	2
Moderate	10 %	3
Severe	> 15 %	4

2.3.1.5 Greening

Another external quality parameter was measured for each sample by estimating the green surface of the most obvious green tubers. An index number was given following the criterions in table 8.

Table 8: Criterions index number green tubers (PVFC, 2014)

State	% green	Scale
Trace	0 %	1
Light	20 %	2
Moderate	30 %	3
Severe	> 30 %	4

2.3.2 Internal quality

For measuring the internal quality of the potatoes, DM content and cooking quality is evaluated. Next these will be discussed more in depth.

2.3.2.1 Dry matter content

Specific gravity (SG) can be used to indirectly evaluate DM content. The weight in air/weight in water method is used to determine SG (Bonierbale, 1970). This method compares the weight of the tuber to the weight of the same volume of water. SG was determined by weighting one tuber in air on a precision scale (0,01 g).

The setup for the measurement was rather basic (Figure 7). First a plastic beaker was weighted on a balance, and re-calibrated to zero. One potato was placed in the beaker and weighted. The data is recorded as “weight in air”. Next the beaker was filled with water and with an iron tool a potato was held into the water without touching the walls. The weight represents “weight in water”. Specific gravity was calculated with following formula.

$$Specific\ gravity\ (SG) = \frac{weight\ in\ air}{(weight\ in\ air) - (weight\ in\ water)}$$

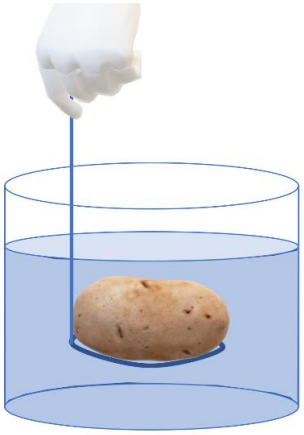

Figure 7: Setup measurement specific gravity

For each sample, SG was determined for three tubers and the average of these three was chosen to determine DM content with following regression equation (Schippers, 1976):

$$\%\, dry\, matter\; =\; -\,217.2\; +\; 221.2\,(specific\; gravity)$$

2.3.3 Cooking quality

Preparation of boiled potatoes for evaluating cooking quality involves peeling and cooking the samples for approximately 30 - 35 minutes or until cooked through as determined by a sharp knife.

Literature contains many variations on terminology for attributes measuring cooking quality (van Marle et al., 1997; Thybo and Martens, 1998). Vocabulary in this paper is based on a cultivation manual from Warnez nv (Vansteenkiste, 2000). Table 9 presents an English translation of the cooking behaviour attributes described in this manual with the terminology found in literature.

Van Marle et al. (1997) defines consistency/hardness/softness as "resistance of cooked potato tissue to mashing", sloughing as "the loosening of the outer layers of the cooked potato", mealiness as "easiness of cooked potato tissue to disintegrate (during consumption) into clusters of cells, without fracturing cells", moistness as "moistness/dryness of potato tissue (perceived during consumption)" and structure/graininess as "the presence of granules and vascular bundles in cooked potato tissue (perceived during consumption)". Cooking quality was assessed based on these definitions and table 9.

Table 9: Cooking behaviour attributes (Vansteenkiste, 2000, Marle et al., 1997; Thybo and Martens, 1998)

Attributes	**1**	**2**	**3**	**3**
Sloughing	Not crumbly	Little crumbly	crumbly	Very crumbly
Consistency	Firm	Rather firm	Rather soft	Soft
Mealiness	Not mealy	Little mealy	Mealy	Very mealy
Moistness	Humid	Fairly humid	Fairly dry	Dry
Graininess	Fine	Rather fine	Rather grainy	Grainy

2.3.4 Sensory evaluation of French fries

Two or three tubers were cut into 10 – 15 mm slices and washed for 1 minute. The slices were then fried in peanut oil for 3 – 5 minutes at 180 – 220 °C. To measure the sensory attributes texture and flavour, samples were randomly coded and served with bottled spring water between samples. One untrained panellist evaluated texture and flavour of each sample based on an 9–point hedonic rating scale (1: dislike extremely to 9: like extremely) described by Wichchukit and O'Mahony (2015). To evaluate the colour of French fries, the United States

Department of Agriculture (USDA) colour standard for quality was used and scored from 0 (=light) to 4 (=dark) (Gould and Plimpton, 1985).

2.4 Statistical analysis

First, the farmers' questionnaires were translated in English and encoded into Microsoft Excel spreadsheets (Office 2013, Microsoft, Seattle, WA, USA). Descriptive statistics (frequency, percentage) was performed with SPSS software version 25 (IBM, Inc., Chicago, IL, USA). To determine whether there are significant correlations between several questioned parameters, parametric and non-parametric analyses were performed. T-tests were done to look for significant differences when two groups needed to be compared (e.g. gender). An Analysis of Variance (ANOVA), or Kruskal-Wallis when conditions for ANOVA are not fulfilled, was conducted to look for differences between multiple groups (e.g. education level). Pearson correlation was used when the relationship between yield and another continuous variable (e.g. farm size) was assessed. When a significant influence was recognized, a boxplot was designed to highlight the differences between groups

Second, the consumers' questionnaire was analysed. Descriptive statistics (frequency, percentage) was performed by Qualtrics (Qualtrics Labs, Inc., Provo, UT) and graphs were made with Microsoft Excel (Office 2013, Microsoft, Seattle, WA, USA).

Third, to evaluate tuber quality assessments, descriptive statistics (frequency, percentage) was performed with SPSS software version 25 (IBM, Inc., Chicago, IL, USA). Moreover, correlations between SG and mealiness, moistness and mealiness, consistency and mealiness were evaluated by using Spearman's correlation.

Fourth, regarding the sensory analysis a one tailed t-test was performed to determine whether attributes texture and flavour were scored significant lower than 5.

Fifth, to recognize differences in tuber quality between districts an ANOVA analysis was performed for continuous variables (e.g. DM content). Kruskal-Wallis was appropriate when the dependent variable was measured on an ordinal scale (e.g. texture, colour, flavour) or if the assumptions for a parametric test were not met. When a significant difference between districts was found, a Tukey test (or a Dunn test in case Kruskal-Wallis test was done) was performed to determine which districts differ from each other.

All test were done at significance levels of $\alpha = 0.05$, thus a p-value lower than 0.05 points to significant differences between groups.

3 Chapter 3: Results and Discussion

3.1 Farmers' questionnaire

3.1.1 Section 1: General background of farmer

Table 10 reveals that most of the surveys were conducted in the city Da Lat. Difficult transportation options and the availability of the farmers ensure that most the surveys were conducted in Da Lat. The questionnaires conducted in Don Duong were possible with help of an employee who is responsible for the management of potato cultivation in Don Duong for the multinational PepsiCo. The institution that was interviewed in Da Lat is called PVFC. This research institute was established to survey the imported vegetables and flowers which could be cultivated in Dalat (PVFC, 2016).

Table 10: Distribution of respondents

Count	Da Lat	Don Duong	Duc Truong	Total
Male	10	5	4	19
Female	5	3	0	8
Institution	1	0	0	1
Total	16	8	4	28

General background information of the interviewed potato growers is recorded in table 11.

Gender and age: It was observed that most of the potato farmers were male (68%), while approximately 32% were female. The age of the interviewed farmers ranged from 27 to 67 years old. Most of them (71%) were in the range between 41 and 60 years old. Eleven percent was below 30 years old, followed by three farmers who were in the age range of 31 – 40 years. 39% of the interviewed farmers were between 41 and 50 years old. Seven percent was older than 60 years.

Education level: Only 11% of the growers had completed the college level or higher level of education, followed by the biggest group (54%) whom had reached a high-school level (=grade 10 – 12). Four out of twenty-eight farmers achieved intermediate or secondary high school (=grade 6 – 9). There was about 21% who stopped going to school after primary school (=grade 1 – 5).

Informal workers: 71% percent of the interviewed farmers runs the farm by them self or with their spouse. Contrary, eight out of twenty-eight interviewed farmers rely on other family members to help on their farm for potato cultivation.

Table 11: General background of farmer

Question	N	Responses	
		Frequency	Percentage
Gender	28		
Male		19	68%
Female		9	32%
Age	28		
< 21		0	0%
21 – 30		3	11%
31 – 40		3	11%
41 – 50		9	32%
51 – 60		11	39%
> 60		2	7%
What is your highest education level?	28		
College or University		3	11%
High school (grade 10 – 12)		15	54%
Secondary High school (grade 6 - 9)		4	14%
Primary school (grade 1 – 5)		6	21%
Home schooled		0	0%
Illiterate		0	0%
How many members of your family work at the farm?	28		
1 - 2		20	71%
2 - 3		2	7%
3 - 4		2	7%
> 4		4	14%

Labourers: In table 12 it is shown that 86% of the interviewed farmers has employees. Figure 8 shows the distribution of the number of labourers employed per period. Harvest is the most important stage where labourers are employed. In this stage 60% of the farmers employs more than five labourers. On average 14 labourers are employed during harvest. Growing period and hilling up are less important on labouring. For the growing period each farmer employs on average five labourers. For hilling up one, on average three labourers were hired. Most farmers claimed that they perform only one hilling up. Only two farmers perform a second hilling up.

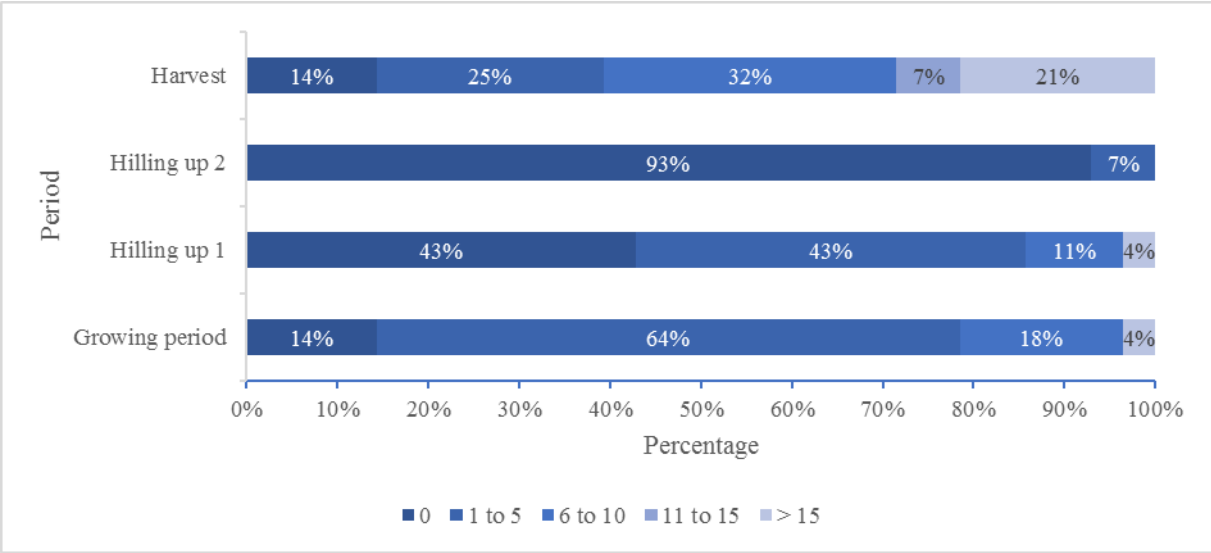

Figure 8: Distribution of the number labourers employed per period

Services: 61% thinks there is no service or doesn't know any service for contacting when they encounter agricultural problems. If they do know such services exist, 81% has contacted this service before. Six farmers contacted a potato retailer, two appeal to a neighbour, one farmer relies on the government as a service and another one uses the internet.

Table 12: Employed labourers and contacted services

Question	N	Responses	
		Frequency	Percentage
Do you employ labourers on your farm?	28		
Yes		24	86%
No		4	14%
If you encounter agricultural problems, is there a service you can contact for advice?	27		
Yes		11	39%
No		14	54%
I don't know		2	7%
If yes, have you contacted this service before?	11		
Yes		9	81%
No		2	19%
Which service did you contact?	15		
Government		1	4%
Potato retailer		6	21%
Potato company		3	11%
Neighbour		2	7%
Centre of Agriculture		0	0%
Internet		1	4%
Other		2	7%

3.1.2 Section 2: General farming system and practices

Size of farm: In Vietnam they use "sào" as a unit for area which is the same as 1.000 m^2 (one sào = 0.1 hectare). The size of farms in the surveyed areas was between one and 24 sào (=0.1 ha – 2.4 ha). Figure 4 shows that 79% of the interviewed farmers grow potatoes on an area smaller than one hectare. The farms bigger than 1.5 ha (14%) belong to farmers who worked for PepsiCo. Figure 9 prints these results graphically.

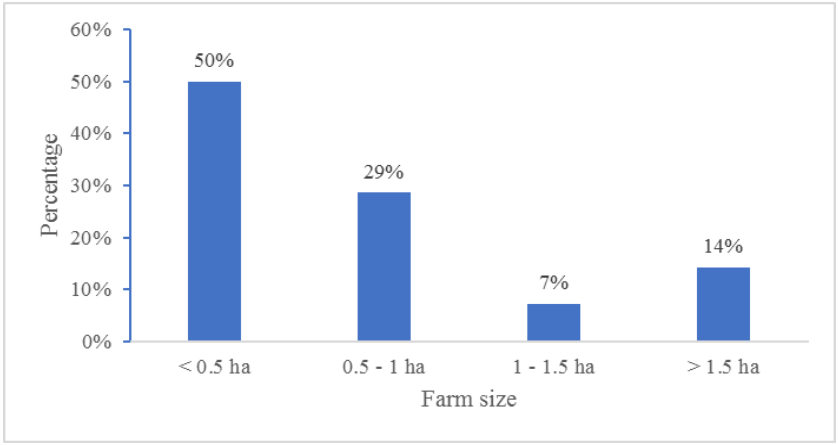

Figure 9: Distribution of farmers by their farm size

Growing season: Dry season is the main season for growing potatoes. Nevertheless, 11% additionally cultivates potatoes in rainy season. Only 14% of the farmers grow potatoes merely in rainy season. Many farmers mentioned during the interview that is not profitable for them to grow potatoes during rainy season.

Plant density: Figure 10 shows that most of the farmers (57 %) grow four plants per m^2. However, 36% prefer a higher density. Two out of twenty-eight farmers choose a plant density of 3 plants per m^2. On average conventional plant density is 4.3 plants per m^2.

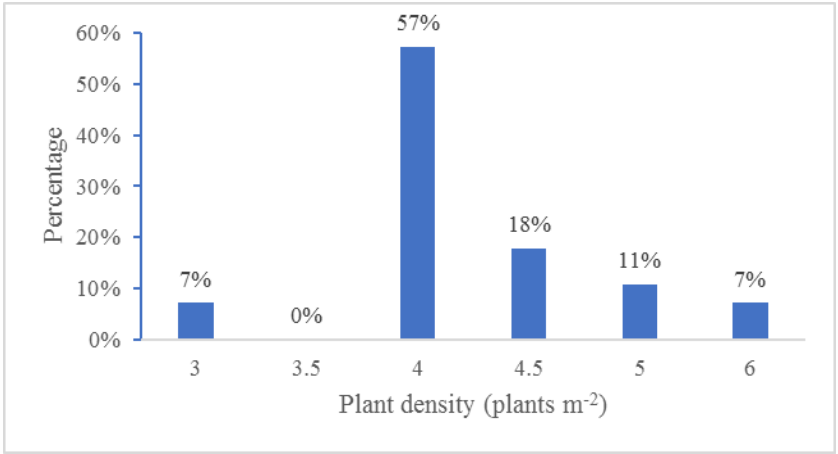

Figure 10: Distribution of farmers by their conventional plant density

Reproduction potato plants: Table 13 shows that 93% of the interviewed potato farmers got their seeds from a dedicated seller in district Don Duong. Only one farmer got her seeds from the government. The criteria to which the farmers refer to regarding the choice of cultivar, varies between recommendation by neighbour (8%), resistance (13%), shape of plant (17%), availability (17%) and productivity (21%). 54% percent choses 'other' on the question 'which were the criteria for choosing variety?'. Here they mentioned that they favour F1 cultivars (Figure 11).

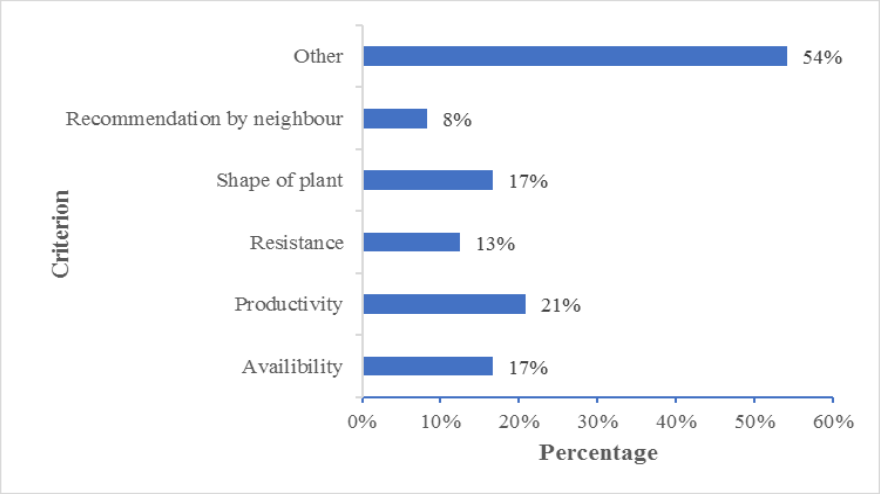

Figure 11: Distribution of criterion for choosing varieties

71% has knowledge of pest and disease resistant varieties but only 11% choose resistance as a criterion for selecting cultivars. When seed tubers are used as reproduction technique, 36% uses tubers with a size between 25 and 35 centimetres. 21% prefers seed tubers between 36 and 55 centimetres. The majority (43%) uses both.

Table 13: Reproduction potato plants

Question	N	Responses	
		Frequency	Percentage
Where did you get your seed tubers?	29		
Neighbour		0	0%
Market		0	0%
Own seed production		2	7%
Government		1	4%
Other		26	93%
Do you know anything about their disease and pest resistance levels of varieties?	24		
Yes		20	71%
No		4	14%
Which size of seed tubers are used?	28		
25 - 35 mm		10	36%
36 - 55 mm		6	21%
Both		12	43%

Usage of fertilizers: All the questioned farmers (100%) use fertilizers to maintain their soil fertility. Unfortunately, the farmers didn't know the composition of the fertilizers they use. Also, the name and amount they have used were hard to say. In table 14 the fertilizers are sorted by use. The amount N, P and K is calculated by what is stated on the packaging. The rate of application varies a lot between the farmers. A complex fertilizer containing Nitrogen-Phosphorus-Potassium (NPK) is the most used fertilizer (96%). Research in 2018 revealed that NPK will continue to be widely used in Vietnam. NPK is sold in different grades of nitrogen, phosphorus and potassium (e.g. NPK 16-16-8, NPK 20-5-5, NPK 7-7-14, NPK 12-5-10, NPK 15-15-15 and others). In terms of amount application rates vary between 500 and 2000 kg ha^{-1}. Some use a cheap equivalent of NPK. The second most used fertilizer is manure (79%). The origin of this manure varies between all the farmers. Manure of cattle is used the most, but some farmers also use manure from goats, fish and pigs. Supe Lan is used by eleven farmers with an amount varying from 300 kg to 2 500 kg ha^{-1}. Supe Lan consists of 10 – 16,5% P_20_5, > 5% S and additionally CaO, MgO and SiO_2. 68% uses Kalimag as a fertilizer in an amount from 100 – 2000 kg ha^{-1}. Kalimag consists of 30% K_2O, 10% MgO and 17% S. Less frequent used fertilizers are: Dynamic Lifter with an unknown NPK composition (21%), Phost A with 0-0-30 NPK composition (18%), Yara Mila with 16-16-16 NPK composition (11%), Urea K with 0-0-38 NPK composition (11%), Realstrong with 3-2-4 NPK composition (4%) and Novatec Premium with 15-5-15 NPK composition (7%). The farmers often combined three or more fertilizers and scatter multiple times per season.

Table 14: Fertilizers sorted by use

Fertilizer	Frequency	Percentage	Amount fertilizer (kg ha^{-1})	Amount N (kg ha^{-1})	Amount P_2O_5 (kg ha^{-1})	Amount K_2O (kg ha^{-1})
N-P-K	27	96%	500 – 2 000	35 – 400	25 – 320	25 – 300
Manure	22	79%	5.000 - 30.000	15 - 360	9 - 222	0 - 120
Kalimag	19	68%	100 – 2 000	-	-	30 – 600
Supe Lan	11	39%	300 – 2 500	-	30 – 412,5	-
Dynamic Lifter	6	21%	500 – 4000	?	?	?
Phost A	5	18%	200 - 2000	-	-	60 – 600
Yara Mila	3	11%	? – 1250	? - 200	? - 200	? - 200
Urea K	3	11%	100 - 300	38 – 114	-	-
Realstrong	3	11%	300 – 2 500	30 - 75	6 - 50	12 - 100
Novatec premium	2	7%	400 – 533	60 – 80	12 - 16	80 - 107

When the question was asked how the farmer decides when to use fertilizers, 96% answered that they rely on a calendar schedule. Some (15%) analyse the leaves and/or soil before they use fertilizers. 43% first visually exanimates the plants before they decide the amount of fertilizer to use. Only one farmer analyses the soil before using fertilizers and another one depends his fertilize usage on the rain.

Only 29% knows an advisory service exist in relation to soil fertility while 71% never heard of it. Eight out of twenty-eight farmers uses those services to know if they need more fertilizers. From those eight farmers, a fourth knows research institutes or agro-chemical retailers or other services who give those services. One farmer could receive information from a private company and another farmer could gain the service from the government. This last farmer works for the PVFC which explains why she had access to support of the government.

Table 15: Management of fertilize usage

Question	N	Responses	
		Frequency	Percentage
How do you decide when to use fertilizers?	28		
Calendar schedule		27	96%
Analysis of leaves		3	11%
Analysis of soil		1	4%
Visual examination of plants		12	43%
Random		0	0%
Depending on the rain		1	4%
Do you know if any advisory services exist in relation to soil fertility?	28		
Yes		8	29%
No		20	71%
Who organizes this service?	8		
Government		1	13%
Research Institute		2	25%
Agro-chemical retailer		2	25%
Private Company		1	13%
Other		2	25%
Have your soil or leaves been analysed to know if they need more fertilizers?	28		
Yes		5	18%
No		23	82%

Irrigation: Table 16 presents the recorded data from questions about the farmers irrigation management. All the interviewed farmers apply irrigation. They couldn't say the amount of water they used. 86% uses sprinklers from top. One farmer applies drip irrigation at the base of the plants. 11% uses other methods like simply watering the plants by hand.

When the irrigation is applied depends on the season. In dry season 82% irrigates on regular time points on an average of 2.6 times a week. About one tenth irrigates when the soil looks

dry or when it hasn't rained for a couple of days. In rainy season farmers only apply irrigation when the soil looks dry.

Table 16: Irrigation management

Question	N	Responses	
		Frequency	Percentage
Do you apply irrigation?	28		
Yes		28	100%
No		0	0%
If yes, how do you apply irrigation?	28		
Sprinkler from top		24	86%
Drip irrigation at the base of the plants		1	4%
Other		3	11%
When do you apply irrigation?	29		
Regular time points		23	82%
When the soil looks dry		3	11%
When it has not rained for ... Days		3	11%
Other		0	0%

Crop rotation: Alternating between two or more crops is important to avoid soil-borne pests and pathogens. 82% of the farmers cultivate other crops in rotation with potato to avoid diseases, while 18% doesn't think this is necessary to increase their yield and improve quality. It was not clear how many times they grow crops in rotation. However, in Figure 12 it is shows which crops the interviewed farmers rotate with potatoes. Cabbage is usually grown in rotation (43%) with potatoes. Gladiolus, a famous flower grown in Da Lat is the second important (18%) crop which is grown in rotation. Followed by Chinese cabbage (14%), carrots (11%), lettuce and cauliflower (7%). A few farmers also grow tomato, peas and celery in rotation (4%).

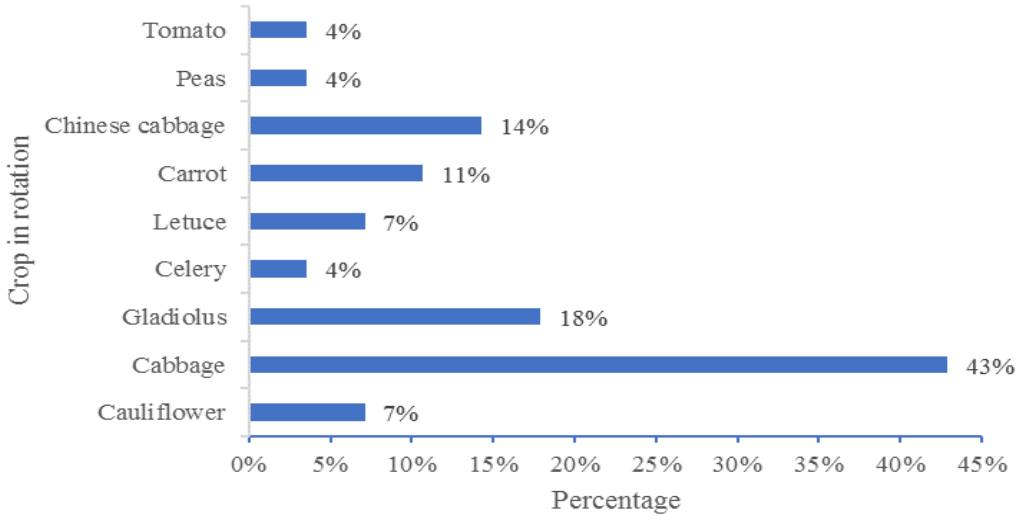

Figure 12: Distribution of farmers by their crops in rotation with potato

3.1.3 Section 3: Occurrence of pests and diseases

Table 17 presents the farmers' responses to questions concerning late blight (*Phytophthora infestans).* 86% recognizes the symptoms caused by *P. infestans* while 14% doesn't know the symptoms. The questionnaire also revealed that 79% knows that the disease is caused by a mould. About 21% had no idea what caused the disease. Despite the use of pesticides 68% of the farmers displayed symptoms from *P. infestans.* Most of the farmers (89%) noticed the symptoms since flowering season. All the interviewed farmers apply pesticides when they see symptoms of late blight. Additionally, 29% removed the diseased plants when they discover the symptoms.

Table 17: Handling *Phytophthora infestans*

Question	N	Responses	
		Frequency	Percentage
Do you recognize the following symptoms caused by *Phytophthora infestans?*	28		
Yes		24	86%
No		4	14%
Do you know that this is caused by a fungus/mould?	28		
Yes		22	79%
No		6	21%
How many plants displayed these symptoms in general?	28		
0%		9	32%
1 - 2%		3	11%
3 - 10%		7	25%
11 - 25%		3	11%
26 - 50%		5	18%
> 50%			0%
In which growing stage did you see the symptoms?	31		
Flowering Season		25	89%
Berry development		5	18%
Harvest season		1	4%
What do you do when you see these symptoms?	36		
Nothing		0	0%
Apply pesticides		28	100%
Remove affected plant parts		8	29%
Other		0	0%

Figure 14 shows the most common diseases farmers encounter during cultivation of potatoes. All the surveyed farmers (100%) suffer Late Blight disease (*Phytophthora infestans*). Leafminer flies (*Liriomyza spp.)* is the second most important pest (75%). 46% has to deal with Bacterial Wilt (*Ralstonia solanacearum*). Some farmers also mentioned following pests and diseases: Stem rot (*Scerotium rolfsii*), common scab (*Streptomyces scabiei*), brown planthopper (*Nilaparvata lugens*), dry rot (*Fusarium* spp.), grey mold (*Botrytis cinerea*), black dot (*Colletorichum coccodes*), early blight (*Alternaria solani*). Moreover, some diseases where described but farmers didn't know the name of the pest or disease. They described a

kind of worm, a stem borer and a nematode. In Figure 13 the latter pest and diseases are categorized as “unknown”.

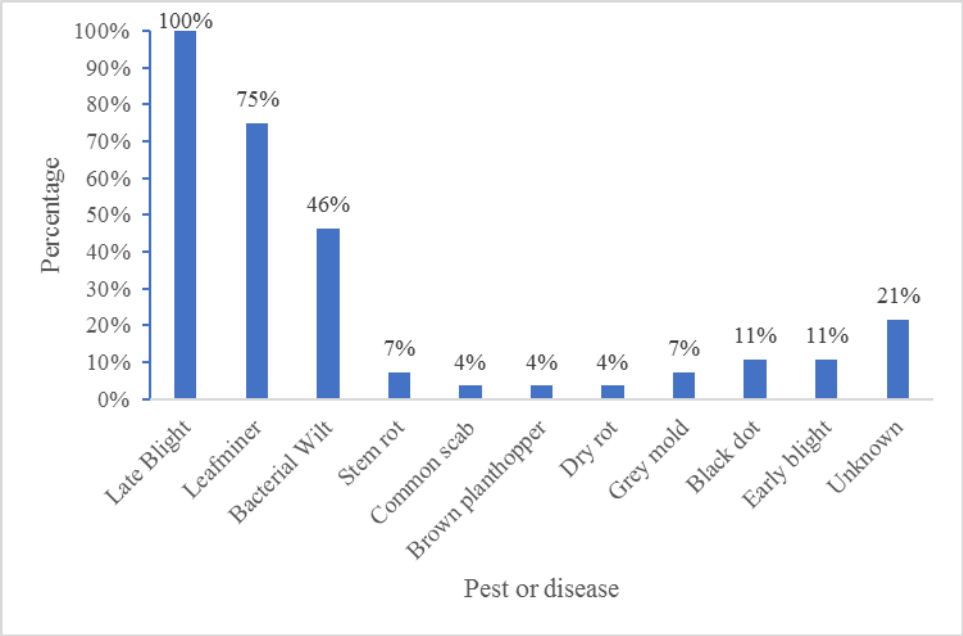

Figure 13: Distribution of pests and diseases suffered by potato farmers in Lam Dong

3.1.4 Section 4: Crop protection measures

Table 18 presents the list of pesticides used by farmers in surveyed locations. The farmers struggled to memorize the type of pesticide (fungicide, herbicide, insecticide), active ingredients, target pests or diseases and WHO Hazard Category. However, these data were completed through previous literature (Nguyen, 2017; Hoi et al., 2016). There were no pesticides classified as extremely hazardous (Ia) or highly hazardous (Ib). 4 out of 17 were unregistered for use on vegetables in EU (-). In Asia however these two are approved for usage. Some were slightly hazardous (III) and 7 were unlikely to present acute hazard in normal use. Most used fungicides fall within WHO Hazard Category U (unlikely to present acute hazard in normal use). 7 out of 17 pesticides were used for the main target disease, *P. infestans.*

Many farmers also indicated that they use more than one pesticide at the same time. They often mix 2 or 3 pesticides before application. When using pesticides, they follow instructions stated on the packaging.

Table 18: List of pesticides used by interviewed farmers

Pesticide	Use	Active ingredients	Target pests/disease	WHO class
Abatin 54 EC	i	Abamectin	*Heliothis armigera*	-
Binthox 1.8EC	i	Abamectin	*Heliothis armigera*	-
Alphacol 700WP	i	Propineb	*Xanthomonas campestris*	U
Trigard 100SL	i	Cyromazine	*Liriomyza huidobrensis, Ophimuia phaseoli*	III
Newsgard 75 WP	i	Cyromazine	*Liriomyza spp.*	III
Dupont Curzate M8 72WP	f	Cymoxanil + Mancozeb	*X. campestris*	II
Daconil 500SC	f	Chlorothalonil	*Peronospora parasitica*	U
Mancozeb 80WP	f	Mancozeb	*P. infestans, A. Solani*	U
Melody dou 66.75WP	f	Iprovalicarp + Propineb	*X. campestris*	U
Revus opti 440SC9	f	Chlorothalonil + Mandipropamid	*X. campestris*	III
Aliette	f	Fosetyl aluminium	*P. Infestans*	III
Ridomil Gold MZ 68	f	Mancozeb + Metalaxil	*P. Infestans*	III
Dithane Rainshield	f	Mancozeb	*A. Solani, P. Infestans*	U
Rampart 35D		Potassium phosphite	*P. Infestans*	U
Agri-Fos 600	f	Mono- and di-potassium salt of Phosphorous acid	*P. Infestans*	U
Avalon 8WP	f	Gentamicin sulfate + oxytetracycline	Bacterial diseases	-
Dupont Aproach	f	Picoxystrobin	*A. Solani, P. Infestans*	-

Ia: Extremely hazardous, Ib: Highly hazardous, II: Moderately hazardous, III: Slightly hazardous, U: Unlikely to present acute hazard, - : not listed

Table 19 shows the farmers' responses to the questions on pesticide use practices on potato plants. The majority choose their pesticides on effectiveness (89%). Some (29%) base their pesticide use on own decision based on pest. One farmer depends on recommendation by a neighbour and another one on recommendation by agro-chemical retailer. All of them experienced effectiveness of their pesticide application, used these pesticides before, and applies the pesticide themselves.

When applying pesticides 57% wear impermeable clothes, 89% gloves, 39% a hat and except for one they al wear boots. 36% of the questioned potato growers received pest management training.

Table 19: Pesticide management

Question	N	Responses	
		Frequency	Percentage
Why did you choose these particular pesticides?	35		
Own decision based on pest		8	29%
Price		0	0%
Effectiveness		25	89%
Recommendation by neighbour		1	4%
Recommendation by government		0	0%
Recommendation by agro-chemical retailer		1	4%
Other		0	0%
Was the pesticide application effective last season?	28		
Yes		28	100%
No		0	0%
Have you used these pesticides before?	28		
Yes		28	100%
No		0	0%
If yes, has the effectiveness changed compared with former applications?	28		
Yes		0	0%
No		11	39%
I don't know		17	61%

3.1.5 Section 5: Economic information

Table 20 shows general economic information about the questioned farmers.

Average price: The price which the farmer receives varies between 6.000 and 18.000 Vietnamese Dong per kilogram (= 258 - 774 dollar per tonne). On average 9.220 VND was received per kilogram (= 396 dollar per tonne). This huge price difference is mainly due to the period when the potatoes are sold. In rainy season potatoes are scarce which makes the price more expensive, up to 18.000 VND kg^{-1} [1]. However, most of the farmers grow potatoes in the dry season when the price can drop to 6.000 VND kg^{-1}. Also, some quality parameters which are discussed in the next section play a role in setting the price. The selling price for 36% of the farmers ranges between 6.000 and 8.000 VND kg^{-1}. The majority (54%) sells their potatoes for a price between 8.000 and 10.000 VND kg^{-1}. A small group (11%) managed to set the price higher than 10.000 VND kg^{-1}. This price is for 82% decides by the local wholesalers who sell the potatoes in their turn to retailers.

Total yield: Average total yield of the interviewed farmers is 28.742 kg ha^{-1}. Thirty-eight percent of the farmers' yield ranges between 12.000 and 24.000 kg ha^{-1}. 23% believed to have a total yield between 24.000 and 36.000 kg ha^{-1}. Approximately 31% considered their yield between 36.000 and 40.000 kg ha^{-1}. Even 8% regard their yield higher than 40.000 kg ha^{-1}.

[1] 1 EUR = 26.264 VND (Data extracted on 06 Mar 2019 14:32 UTC (GMT) from xe.com)

Table 20: Economic information

Question	N	Responses	
		Frequency	Percentage
What was the average price for potatoes last season?	28		
6.000 - 8.000 VND/kg		10	36%
8.000 - 10.000 VND/kg		15	54%
> 10.000 VND/kg		3	11%
How is the price decides?	28		
Local market		23	82%
Retailer		2	7%
Other		1	4%
What was your total yield last year?	26		
12.000 - 24.000 kg ha^{-1}		10	38%
24.000 - 36.000 kg ha^{-1}		6	23%
36.000 - 40.000 kg ha^{-1}		8	31%
> 40.000 kg ha^{-1}		2	8%

3.1.6 Section 6: Quality aspects

Mean usage of potato production: Figure 14 shows that the questioned farmers mainly sell there yield for consumption. 64% sell to traders for the fresh market and/or 32% sells them for the processing industry. Four questioned farmers who work for PepsiCo produce potatoes for processing chips. 7% grows potatoes for own seed tuber cultivation. 21% sells to traders and have no idea what the mean usage of their grown potatoes is.

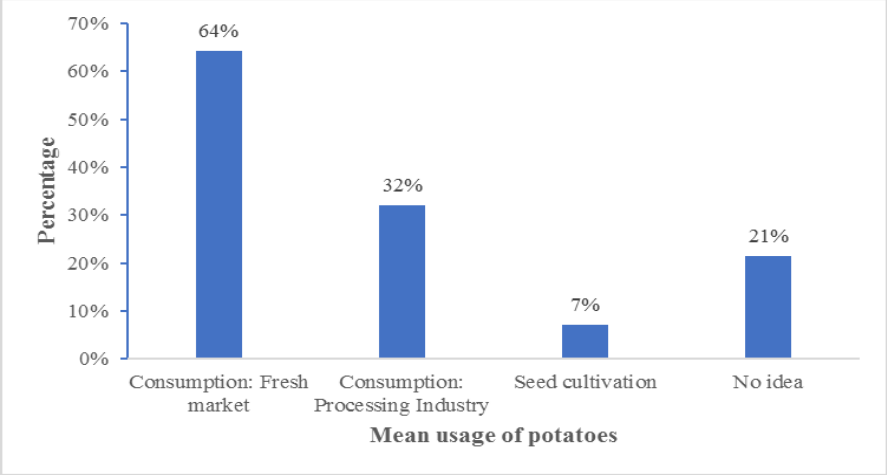

Figure 14: Mean usage of potato production

Quality parameters: The question "What are according to you the most important quality parameters?" was asked as an open-ended question. 82% replied that starch or DM content is the most important quality parameter. Some farmers add freshness, no pesticide residue, low sugar content, skin colour and strong, beautiful appearance.

Crop husbandry measures: Approximately 61% takes crop husbandry measures to improve quality, while 39% answered negative. As examples the farmers mentioned following measures: fertilizers, irrigation, distance between plants, usage of pesticides according to regulations. Four farmers also mentioned "VietGAP". This is an abbreviation of the Vietnamese Good Agriculture Practices. It is the application of production methods to produce clean and safe fruit and vegetables.

Table 21: Quality aspects

Question	N	Responses	
		Frequency	Percentage
Mean usage of potatoes?	28		
Consumption: Fresh market		18	64%
Consumption: Processing industry		9	32%
Seed cultivation		2	7%
No idea		6	21%
What are according to you the most important quality parameters?	28		
Starch		23	82%
Fresh		2	7%
No pesticide residue		1	4%
Low sugar content		1	4%
Skin color		1	4%
Strong, beautiful appearance		1	4%
Do you take crop husbandry measures to improve quality?	28		
Yes		17	61%
No		11	39%
Potatoes stocked?	28		
Yes		11	39%
No		17	61%
Do you use germination inhibitors or other chemicals?	28		
Yes		4	14%
No		24	86%
Are you seed potatoes stored?	28		
Yes		24	86%
No		4	14%
If the farmer search for seed potatoes, does he look to the plant or to the tuber?	17		
Tuber		6	35%
Plant		5	29%
Both		6	35%
Is the price calculated based on quality parameters?	28		
Yes		15	54%
No		13	46%

Seed tuber potatoes: Most of the farmers (86%), except the farmers who work for PepsiCo (14%), store their seeds. Tuber seeds were stored them on a 'wooden floor' inside or outside in a temperature ranging from 16 to 25°C (Figure 15). Depending on when the farmer starts growing potatoes, they store their seed tubers for 3 up to 9 months. Farmers who only grow in dry season store them from February/March till November/December. Farmers who also grow in rainy season store their seeds for 3 months. When they search for seed tubers after harvest 35% based their choice on the tuber, 29% on plants and 35% takes both into account.

Figure 15: Seed potato storage on wooden floor (e.g. farm 16)

Purchase price: The survey revealed that approximately 54% of the farmers claims that tuber quality plays a major role at what price they can sell their crop. These quality parameters include size, skin colour, external looks, shape. One farmer mentioned that the colour of the soil determines the price. Red soil is the desired colour.

Storage of harvested potatoes: 39% stocked their potatoes on the farm after harvest before selling them. An argument for this is that the farmer wants to wait for a better price. 61% immediately sells their yield. 14% uses germination inhibitors or other chemicals after harvest.

3.1.7 Statistical analysis farmers' questionnaire

In this section the correlation between of some questioned variables is analysed. No statistical evidence was found for most questioned variables regarding crop yield. The variables "age", "education level", "crop training", "farm size", "plant density", "amount of fertilizer", "selling price", "remove diseased plants from the field", "pest management training" didn't show any statistical differences between groups regarding total crop yield (table 22). There is also no statistical difference between usual plant density and tuber size. Which means that farmers will not depend their choice of plant density on seed tuber size.

Table 22: Significance levels of correlation between questioned variables

Independent variable	Dependent variable	p-value
Gender of farmer	Yield (kg ha^{-1})	**0,007***
Age of farmer		0,471
Farmers education		0,251
Training		0,956
Farm size		0,063
Plant Density		0,264
Amount of fertilizer		0,654
Price		0,433
Crop in rotation		**0,010***
Remove diseased plants from the field		0,443
Pest management training		0,129
Tuber size	Plant density (ha^{-1})	0,422

*Statistically significant difference between groups ("male" and "female" or "Yes" and "no")

By contrast, Student's t-test revealed that gender has a statistical effect on crop yield ($p<0,05$). Figure 17 highlights the differences in a boxplot. Female farmers harvest a statistically lower yield (Mean = 22.905 kg ha^{-1}) than male farmers (Mean = 30.893 kg ha^{-1}).

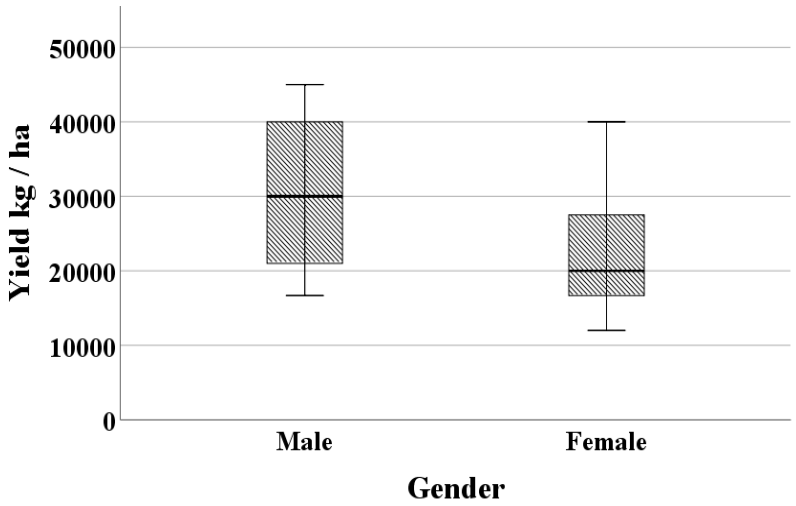

Figure 16: Comparison between yield for male and female farmers

Yield also has a significant difference between farmers who grow other crops in rotation (Mean = 30.900 kg ha^{-1}) and farmers who don't grow crops in rotation with potatoes (Mean = 16.875 kg ha^{-1}). Figure 14 highlights these difference in a boxplot.

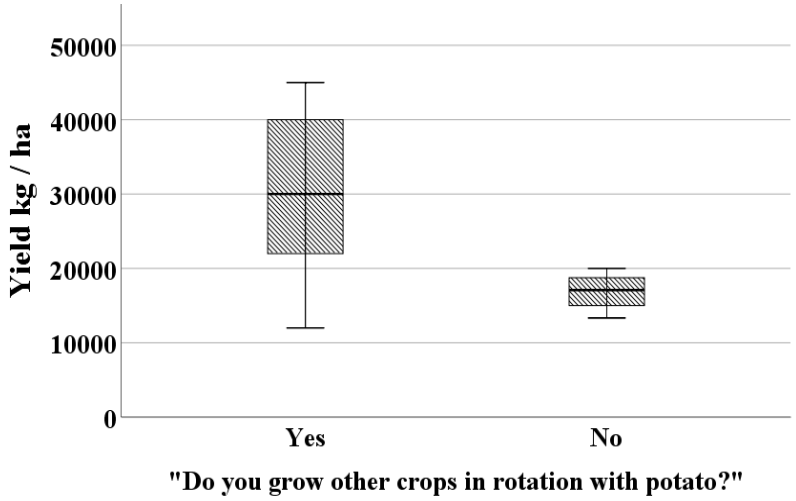

Figure 17: Comparison between yield for farmers who grow in rotation or who does not do so

3.2 Consumers' questionnaire

Table 23 summarizes the general background of the respondents who conducted the consumers questionnaire. Thirty-four percent of the participants were male, 65% female and 1% gender-neutral. Most of those surveyed were between 21 and 30 years old (60%). Most consumers had followed college or university education (85%). An average household of the participants consist of four to five members. Forty-two percent of the participants consumes potatoes at least once a week and 24% consumes potatoes at least 2 to 3 times a month. 13% of respondents let their choice of buying potatoes depend on the season. Most of those surveyed (83%) purchases potatoes at the fresh market. Quality (87%), followed by the origin (77%) are the most important parameter when the consumer buys potatoes. Also, the level of pesticide residues (69%) and a fair price for farmers (55%) is considered important. The shelf life (45%) and price (42%) are less important. Size (28%) seems to be the least important parameter (Figure 18).

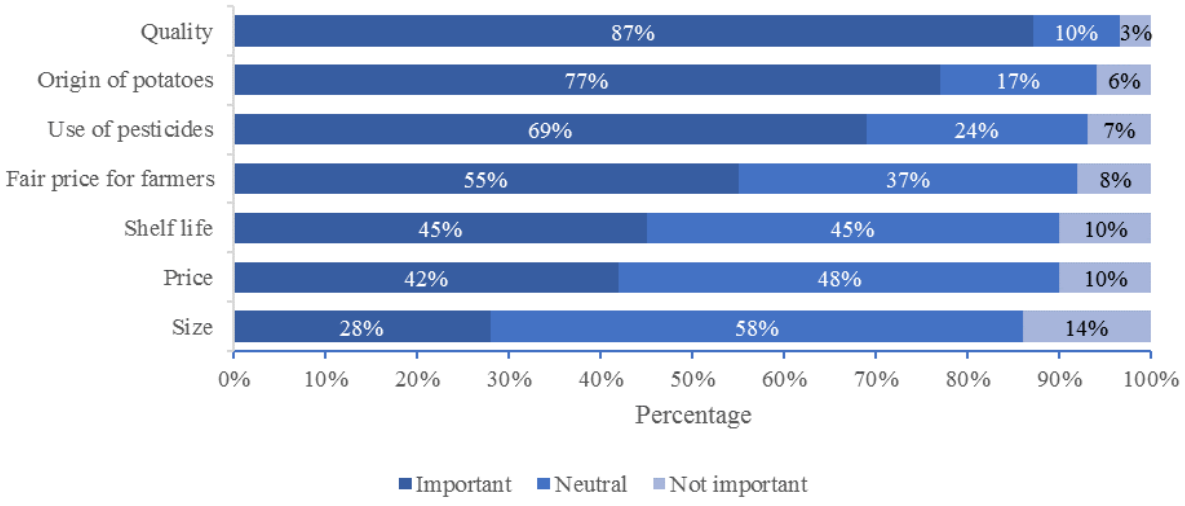

Figure 18: Distribution of consumers regarding importance of several parameters when buying potatoes.

Table 23: General background consumer

Question		N	Responses	
			Frequency	Percentage
Gender		177		
	Male		60	34%
	Female		113	65%
	Other		2	1%
Age		177		
	< 21		22	12%
	21 - 30		107	60%
	31 - 40		38	21%
	41 - 50		6	3%
	51 - 60		3	2%
	> 60		1	1%
What is your highest education level?		177		
	College or University		151	85%
	High school		21	12%
	Middle school		5	3%
	Primary school		0	0%
	Home schooled		0	0%
	Illiterate		0	0%
Family size		177		
	1		3	2%
	2		8	5%
	3		26	15%
	4		59	33%
	5		45	25%
	6		19	11%
	7		7	4%
	>7		10	6%
Do you live in the Lam Dong region?		177		
	Yes		148	84%
	No		29	16%

When asked what participants think about potatoes the majority agreed that potatoes are delicious (61,90%), healthy/nutritional (56,46%), versatile (54,42%), quick and easy to prepare or cook (46,94%) and a filling meal on there own (37,41%). This question also revealed that 64,10% agreed that potatoes are fattening and even 81,10% stated that potatoes are high in calories. Only 13,85% thinks potatoes are expensive. Figure 19 presents what consumer desire regarding tuber quality. Freshness is the major parameter (89%) closely followed by the skin colour (84%). Also feel (82%), taste (74%), appearance (70%) are considered important. Shape (53%), smell (45%), price (30%) and weight (27%) are the least important factors in terms of tuber quality for consumers in Lam Dong.

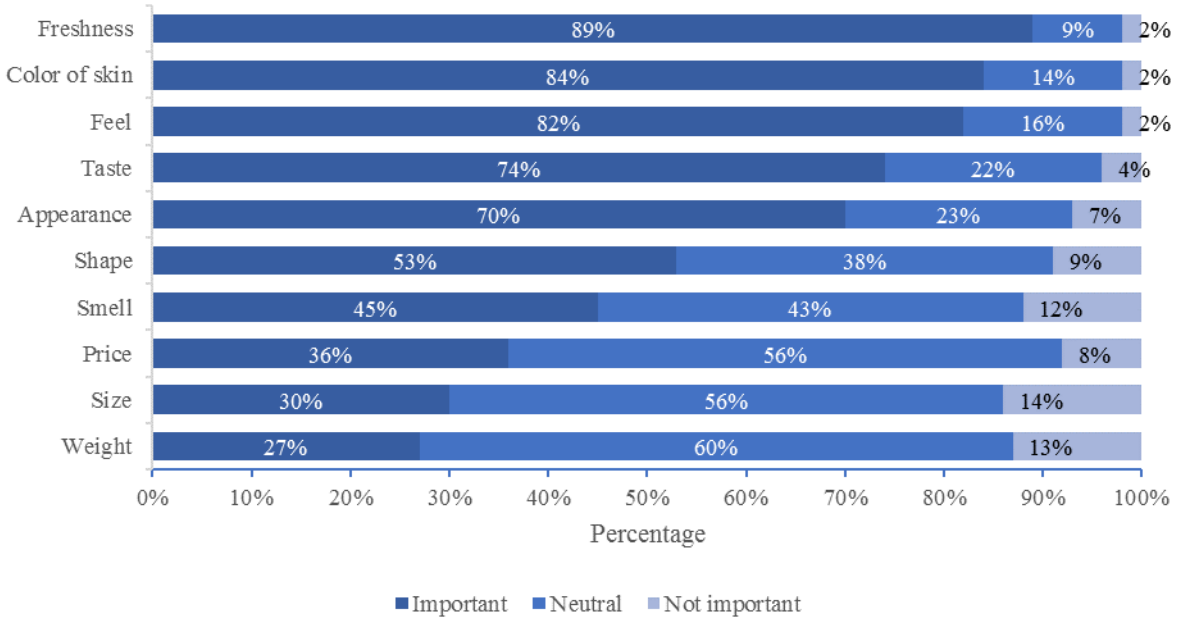

Figure 19: Quality preferences sorted by importance according to consumers in Lam Dong

The pie chart below (Figure 20) shows that among the surveyed participants potatoes are mainly used as a vegetable in a stew with other food (47%). Baked potatoes are also popular (31%) in contrast to mashed (9%), fried (8%) and roasted potatoes (5%).

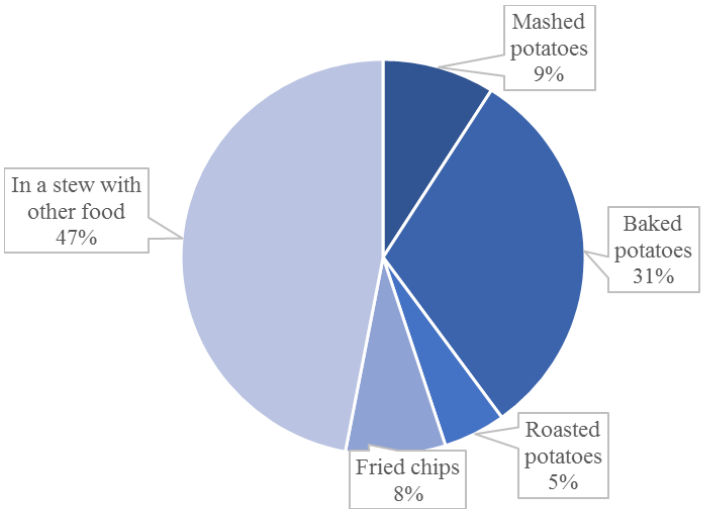

Figure 20: Main use of potatoes according to consumers in Lam Dong

Table 24 presented the results of consumers knowledge about the origin of the potato tubers they buy on local markets in Lam Dong. Sixty-five percent claims that potatoes, sold in Lam Dong, are sometimes imported from China. 33% thinks this might happen and only two participants didn't know this. 38% thinks one can see the difference between local grown and imported potatoes. Except for one respondent, they all prefer locally grown above imported potatoes.

Table 24: Origin of potatoes sold on markets in Lam Dong

Question	N	Responses	
		Frequency	Percentage
Do you know that potatoes, sold in Lam Dong, are sometimes imported from China?	147		
Yes		96	65%
Maybe		49	33%
No		2	1%
Can you notice the difference between local grown or imported potatoes?	147		
Yes		56	38%
Maybe		48	33%
No		43	29%
Do you prefer local grown or Chinese potatoes?	147		
Local grown		146	99%
Chinese		1	1%

When buying potatoes seventeen percent often experienced quality problems (Figure 21). For 74% of the respondents this might happen sometimes. Only nine percent has never experienced quality problems. Medium sized potatoes are the most preferred potato size (76%). Ten percent choose a small size as most preferred. Only 5% prefers large potatoes and for 8% of the interviewed consumers potato size doesn't matter. Fifty-seven percent of the questioned consumers would buy more potatoes if the quality was better.

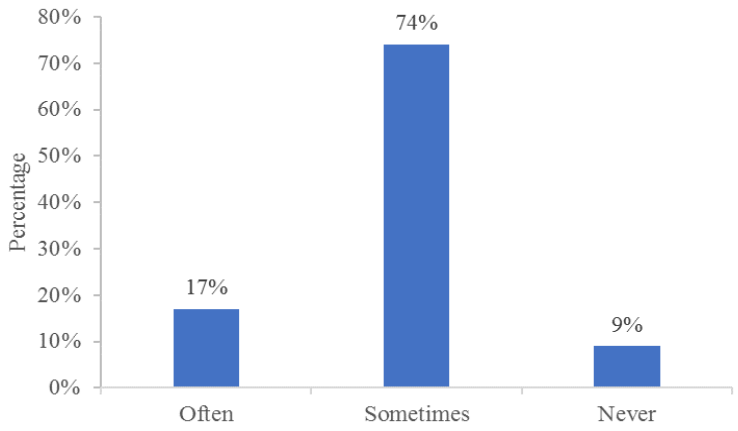

Figure 21: "How often do you experience quality problems when buying potatoes"

3.3 Assessment of tuber quality

3.3.1 External quality

Table 25 summarizes the results of the external quality assessments, carried out for twenty-six samples. The diameter of the examined tubers is mainly between 4 and 9 centimetres (96%). Fifty percent is categorized as medium (= between 4 and 6 centimetres), while even 46% belongs to the class “large” (= between 6 and 9 centimetres). The skin of sixty-five percent potato samples was yellow, the remaining part (35%) had a brown reddish skin. Fifteen percent of the examined samples had shallow eye depth. The depth of eyes of the majority (62%) was measured medium. 6 out of 26 samples had tubers with deep eye depth. Scabies was found to be severe for three sample taken in Lam Dong province. The majority (38%) suffers a moderate scab content. 27% of the samples was lightly affected by common scab, while four out of 26 samples only displayed traces of scabies. Greening was found to be severe for only one sample. No green discoloration was found for most samples (77%). Still 5 out of 26 samples showed some light green discoloration.

Table 25: Results external quality

Quality parameter	N	Frequency	Percentage
Size	26		
Very small (1)		0	0%
Small (3)		1	4%
Medium (5)		13	50%
Large (7)		12	46%
Very large (9)		0	0%
Skin colour	26		
Yellow (1)		17	65%
Brown/red (2)		9	35%
Depth of eyes	26		
Shallow (1)		4	15%
Medium (2)		16	62%
Deep (3)		6	23%
Scabies	26		
Trace (1)		6	23%
Light (2)		7	27%
Moderate (3)		10	38%
Severe (4)		3	12%
Greening	26		
Trace (1)		20	77%
Light (2)		5	19%
Moderate (3)		0	0%
Severe (4)		1	4%

3.3.2 Internal quality

Table 26 shows the results obtained in the tests to determine internal quality. The average DM content of the samples in all districts together is 17,95 % and ranges between 16,04 and 19,91 %. In 5 out of 26 samples growth crack occurred. Hollow hearts and bruising damage was negligible for al the samples.

Table 26: Results internal quality

		Internal Quality				
Sample	District	Specific Weight (-)	DM (%)	Growth cracks	Hollow hearts	Bruising
1	Dalat	1,062 ± 0,006	17,91 ± 1,14	0	0	0
2	Dalat	1,056 ± 0,002	16,31 ± 0,54	1	0	0
3	Dalat	1,070 ± 0,003	19,40 ± 0,61	0	0	0
4	Dalat	1,070 ± 0,002	19,41 ± 0,40	0	0	0
5	Dalat	1,062 ± 0,007	17,76 ± 1,61	0	0	0
6	Duc Truong	1,053 ± 0,006	15,64 ± 1,37	0	0	0
7	Duc Truong	1,067 ± 0,009	18,71 ± 2,07	0	0	0
8	Duc Truong	1,065 ± 0,001	18,38 ± 0,29	0	0	0
9	Dalat	1,067 ± 0,013	18,76 ± 2,81	1	0	0
10	Dalat	1,064 ± 0,014	18,07 ± 3,02	0	0	0
11	Lam Ha	1,064 ± 0,006	18,07 ± 1,24	0	0	0
12	Lam Ha	1,073 ± 0,001	19,94 ± 0,11	0	0	0
13	Lam Ha	1,055 ± 0,004	16,04 ± 0,98	0	0	0
14	Lam Ha	1,053 ± 0,005	15,69 ± 1,19	0	0	0
15	Lam Ha	1,057 ± 0,012	16,52 ± 2,80	1	0	0
16	Duc Truong	1,067 ± 0,008	18,61 ± 1,72	0	0	0
17	Duc Truong	1,067 ± 0,004	18,82 ± 0,83	0	0	0
18	Duc Truong	1,062 ± 0,001	17,64 ± 0,31	0	0	0
19	Don Duong	1,064 ± 0,005	18,15 ± 1,15	1	0	0
20	Don Duong	1,064 ± 0,011	18,12 ± 2,35	0	0	0
21	Don Duong	1,059 ± 0,004	16,99 ± 0,88	0	0	0
22	Don Duong	1,066 ± 0,008	18,48 ± 1,71	0	0	0
23	Don Duong	1,068 ± 0,006	18,93 ± 1,40	0	0	0
24	Dalat	1,064 ± 0,006	18,11 ± 1,25	1	0	0
25	Dalat	1,072 ± 0,010	19,12 ± 2,30	0	0	0
26	Dalat	1,058 ± 0,010	17,12 ± 2,35	0	0	0

3.3.3 Cooking quality

After internal and external quality was assessed, next cooking behaviour was evaluated. Table 27 presents the results. After cooking, 65% of the samples didn't loosen the outer layer. This is defined as a non crumbly outer layer. Thirty-one percent of the samples was a little crumbly, while one sample was found crumbly after cooking. Twenty-three percent was resistant to mashing after cooking, 54% was rather firm and 6 of of 26 samples where rather soft and not resistant to mashing. One sample was very mealy, 35% was mealy, the majority 46% was a little mealy and three samples were not mealy at all. Twelve percent was humid,

46% was fairly humid while 42% was perceived as fairly dry. 81% of the samples were rather grainy, tissue of 12 % was perceived during consumption as fine granules while 2 out of 26 samples was not grainy at all. No significant correlation between SG and mealiness and between moistness and mealiness was found ($p>0,05$). However, consistency was significant positive correlated with mealiness ($p<0,05$).

Table 27: Results cooking behaviour

Cooking behaviour	N	Frequency	Percentage
Sloughing	26		
Not crumbly (1)		17	65%
Little crumbly (2)		8	31%
Crumbly (3)		1	4%
Very crumbly (4)		0	0%
Consistency	26		
Firm (1)		6	23%
Rather firm (2)		14	54%
Rather soft (3)		6	23%
Soft (2)		0	0%
Mealiness	26		
Not mealy (1)		3	12%
Little mealy (2)		12	46%
Mealy (3)		9	35%
Very mealy (4)		1	4%
Moistness	26		
Humid (1)		3	12%
Fairly humid (2)		12	46%
Fairly dry (3)		11	42%
Dry (4)		0	0%
Graininess	26		
Fine (1)		2	8%
Rather fine (2)		3	12%
Rather grainy (3)		21	81%
Grainy (4)		0	0%

3.3.4 Sensory analysis of French fries

Finally, a sensory analysis of French fries was done. Results are presented in table 28. With a mean score of 3,54 texture of the French fries was rated bad. However, high standard deviations illustrate why this cannot be confirmed statistically. A one-tailed sample t-test shows that the texture of the French fries was not significantly disliked ($p>0,05$). Also, the rating of attribute ‘flavour’ was not significantly disliked ($p>0,05$). Nevertheless, the mean of the flavour score was 3,73 and thus between slightly and moderately disliked.

Table 28: Sensory analysis French fries

Sensory analysis French fries					
Sample	District	Texture[A]	Colour[B]	Favour[A]	Remarks
1	Dalat	5	3	5	/
2	Dalat	3	4	2	To dark
3	Dalat	4	2	5	Crispy outside
4	Dalat	6	1	8	Crispy
5	Dalat	4	2	6	/
6	Duc Truong	5	1	5	/
7	Duc Truong	3	2	2	/
8	Duc Truong	6	1	4	Good taste, better than they look
9	Dalat	3	2	4	Crispy, not too fat, mealy on the inside
10	Dalat	5	1	7	Crispy at the outside, soft inside. Delicious.
11	Lam Ha	4	2	4	/
12	Lam Ha	3	1	3	/
13	Lam Ha	2	1	3	/
14	Lam Ha	1	2	4	Very bad. Still hard inside, bad taste, fatty
15	Lam Ha	3	3	3	Not crispy, fat but good taste
16	Duc Truong	1	3	2	Burned, mealy inside, crispy outside
17	Duc Truong	2	2	1	Bad, not crispy, bad taste
18	Duc Truong	4	3	1	Bad, dry, crispy
19	Don Duong	3	3	2	Good taste, too fat, not crispy at the outside
20	Don Duong	2	2	3	To dark, fatty
21	Don Duong	2	3	1	Not crispy
22	Don Duong	2	3	2	Dry, not tasty
23	Don Duong	5	1	4	Crispy, bad taste
24	Dalat	5	4	2	Burned, not good
25	Dalat	4	1	6	/
26	Dalat	5	2	5	/
Mean		3,54	2,11	3,73	
SD		1,42	0,93	2,07	
t (1-tailed)		-1,656	-	-0,663	
p		0,055	-	0,255	

A: 9-point hedonic scale: 1 = Dislike Extremely; 2 = Dislike very much; 3 = Dislike Moderately; 4 = Dislike slightly; 5 = Neither like nor dislike; 6 = Like slightly; 7 = Like moderately; 8 = Like Very Much; 9 = Like extremely

B: USDA Colour scale for French fries' evaluation

3.3.5 Differences in tuber quality between districts of Lam Dong

Table 29 displays the mean scores and standard deviations for each quality attribute tested, divided into districts. Regarding external quality except for "depth of eyes", no significant mean difference among four districts was found ($p>0,05$). Potatoes on Dalat's markets differ significant from other districts. In Dalat, tubers are found with deeper depth of eyes in comparison with tubers from other districts. A boxplot in Figure 22 highlights these differences among the districts.

Potatoes sold on markets in Duc Truong seems to have the biggest size, followed by Dalat. Regarding tuber size Don Duong is third of the four districts and Lam Ha is last.

Table 29: Mean differences of quality attributes between district Dalat, Duc Truong, Don Duong and Lam Ha

	Attribute	**Dalat**		**Duc Truong**		**Don Duong**		**Lam Ha**		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	P
External quality	Size	6,00	1,05	6,66	0,81	5,00	1,41	5,40	0,89	0,074
	Skin colour	1,44	0,53	1,50	0,55	1,20	0,48	1,20	0,48	0,637
	Depth of eyes[A]	2,50[a]	0,53	1,67[ab]	0,52	2,00[b]	0,45	1,80[ab]	0,45	**0,031***
	Scabies	1,50	0,85	1,33	0,82	1,80	1,30	0,80	1,10	0,442
	Greening	0,30	0,48	0,00	0,00	1,00	1,41	0,40	0,54	0,167
Internal quality	DM	18,20	1,01	17,97	1,22	18,13	0,72	17,25	1,76	0,527
	Growth cracks	0,30	0,48	0,00	0,00	0,20	0,45	0,20	0,45	0,579
	Hollow hearts	-	-	-	-	-	-	-	-	-
	Bruising	-	-	-	-	-	-	-	-	-
Cooking behaviour	Sloughing	1,20	0,42	1,67	0,82	1,20	0,44	1,60	0,54	0,302
	Consistency	1,90	0,32	2,17	0,98	2,40	0,98	1,60	0,55	0,284
	Mealiness[A]	2,00[a]	0,67	2,50[b]	1,05	3,00[b]	0,00	2,20[b]	0,84	**0,028***
	Moistness	2,50	0,71	2,50	0,54	2,20	0,45	1,80	0,84	0,247
	Graininess	2,80	0,63	2,67	0,52	3,00	0,00	2,40	0,89	0,464
Sensory analysis French fries	Texture	4,40	0,97	3,50	1,87	2,80	1,30	2,60	0,89	0,065
	Colour	2,20	1,13	2,00	0,89	2,40	0,89	1,80	0,84	0,755
	Favour[A]	5,00[a]	1,90	2,50[b]	1,65	2,40[b]	0,71	3,40[ab]	0,55	**0,024***

*Statistically significant difference between districts

A: Means within the same row with the same subscript are not significant different

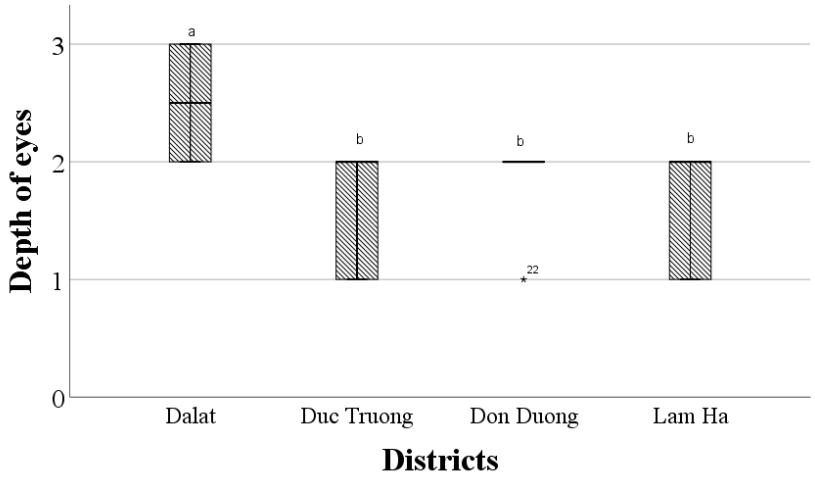

Figure 22: Comparison depth of eyes between districts

Since no growth cracks and bruising damage was found, no comparison between districts for these attributes can be made. For DM content and growth cracks however, the results are shown in table 29. The samples taken in Dalat seems to have the highest DM content (18,20%), followed by Don Duong with 18,13%. Duc Truong is third on the list with an average DM content of 17,97%. Lam Ha completes the list with a low average DM content of 17,25%. There is no significant difference (p>0,05) among the four districts.

Regarding cooking behaviour, mealiness is the only attribute which showed significant difference between districts (p<0,05). The boxplot in Figure 23 highlights the differences among the four districts. The potatoes sold in Don Duong differ significantly from tubers sold in Dalat. Tubers from Don Duong are more mealy (mean score=3) than potatoes from Dalat (mean score=2).

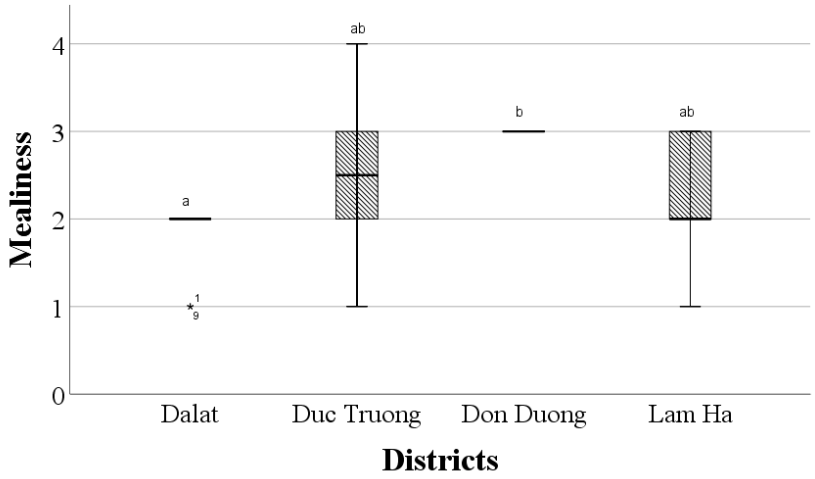

Figure 23: Comparison mealiness score between districts

Regarding the sensory analysis of French fries, it can be concluded that French fries have no difference in the specific sensory attributes texture and colour. However, the attribute 'flavour' shows significant changes between the four districts (p<0,05), especially district Dalat differs from district Don Duong and Duc Truong. Flavour of tubers sold in Dalat is scored higher than tubers sold in the other two districts (Figure 24).

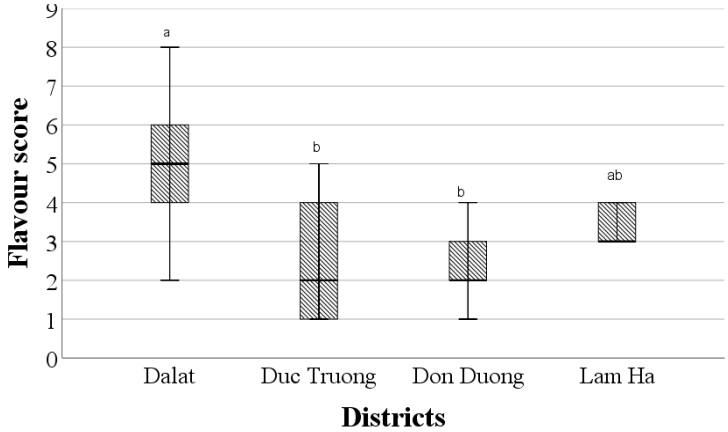

Figure 24: Comparison flavour scores between districts

4 Chapter 4: General discussion

4.1 Farmers' questionnaire

In this work, a questionnaire was used to assess local practices and knowledge of local production problems and opportunities to gain insight into potato production from the perspective of farmers.

The field survey data showed higher involvement of males compared with females in the production of potatoes. Even though female labour force in agriculture is almost 50% in South East Asia, a previous study confirms that vegetable production in Vietnam is headed by men (Thanh, 2017). In the latter study 28% interviewed farmers were females while 72% was male. A field study conducted in the RRD revealed a contractional distribution. 69% from 120 potato farmers appeared to be female, while 31% was male. This suggest that growing potatoes in the RRD is predominantly undertaken by women. In Africa, gender distribution of potato farmers is also inconsistent. For instance, in Malawi 62% of potato farmers are men while in Cameroon, 70% of potato farmers were women in 1992 (Maganga et al., 2012). Lam Dong's potato farmer's age ranges between 41 and 60 years old. The working age in Vietnam is between 15 and 60 years old for men and between 15 and 55 years old for women (FAO, 2010). Comparing with these general data potato farmers are rather old. The reason for this is perhaps the fact that the farm is passed from generation to generation. In this way, especially the older family members will run the farm. Dang (2008) suspect that young people in Vietnam prefer to work off-farm as they can earn more money compared to what they can earn from farming. In Lam Dong, sixty-five percent of the potato farmers have at least finished high school. The relatively high level of education of the household head compared to other Asian countries, according to the World Bank averaging 7 years, can be credited to the country's total government expenditure to education (World Bank, 2017). Rios et al. (2005) studies a model in Vietnam for coffee farmers which suggested that technical inefficiently is correlated with farmers having a higher education level which indicates better off-farm options and reduced farm management intensity.

Since Lam Dong province is favourable for agriculture practices, several research and trainings institutes exist (e.g. DARD, PVFC, VietGAP, etc.). However, only 39% of the potato farmers in Lam Dong has knowledge of these institutes. A study confirmed that training in improved vegetable production methods increases annual incomes (Weinberger and Genova II, 2005). Trainings convinces the farmer of the importance of using good varieties and high-quality seed (Schreinemachers et al., 2016). Nevetheless, for this study no positive correlation was found between receiving training and yield.

Low level of mechanization leads to very high labour requirement for potato cultivation (pest management, planting, soil preparation, harvest, etc. (Nath et al., 2011). The use of farm

machinery has decreased over the past decades resulting in only 11% of smallholders being motorized equipped (FAO, 2011). Increased mechanization was one of the most influential factors to expand potato production for potato producers in Saudi Arabia (Al-Hamed et al., 2017). Hilling up is done only once by potato farmers in Lam Dong. Ridging however is very important since it reduces incidence of green tubers. In Bulgaria potatoes are ridged twice to combat weeds. The ridging form is closely related to potato quality (Potrpin and Bernik, 2014).

The average area of agricultural land is 0.63 ha per farm in Vietnam (FAO, 2010). Potato is cultivated on small-holder farms in Lam Dong with an average area of 0.72 ha which is a little above average cultivation area. This result may be biased because also larger scale farmers from PepsiCo were interviewed. In the RRD, 97 percent of the farms were under 0.5 hectares in 2011 (World Bank, 2017). In Lam Dong, 50 percent of the farms are smaller than 0.5 hectares. In another study conducted the Central Highlands it was found that 23 percent of households have more than two hectares and only 21 percent under 0.5 hectares (FAO, 2010).

Even though potatoes could be grown all year around in the Central Highlands of Vietnam only 25% venture to cultivate potatoes in rainy season. Changes in temperature and rainfall distribution will affect water and disease management. For instance, late blight benefits from higher temperatures and weather conditions (Forbes, 2007). Also bacterial wilt is predicted to benefit from higher temperatures and be able to spread more easily through flooding (Haverkort, 2008). In the RRD potatoes are only grown in winter season, when it is cooler and the heavy rains stopped (Tung, 2000)

The average plant density of potato farmers in Lam Dong is 4,3 plants per m^2. These results correspond with a study in 2008 where Dang found that farmers use a plant density of 4 – 5 plants per m^2 due to the heavy soil type and to ensure they have enough soil for hilling up. Dang (2008) suggested a density of 3 plants per m^2 to make it possible to walk on the field to irrigate or control pests and diseases. Ngugi (1972) detect an optimal plant density of 4,6 plants per m^2 when 200 kg N ha^{-1} was applied. In north-western Europe, plant population vary among the countries. For instance, Van de Brink et al. (2008) found an average plant density of 4 m^{-2} in the Netherlands. In Denmark average plant density varies between 3,2 and 3,8 m^{-2} (Pederson, 2005). A field study in Zimbabwe researched the influence of plant density and seed tuber size on yield. From the results it can be concluded that optimum plant population density for good yield was 3,7 plants per m^2 (Masarirambi et al., 2012). Plant density may affect quality of the tubers. For instance, low density may produce overlarge, cracked potatoes (Brown, 1982). Getachew et al. (2013) found high plant density to be associated with low DM content.

De size of the seed tuber needs to be considered. When a high percentage of large tubers is preferred, plant population should be low. In this way smaller seeds may be an advantage since they develop fewer stems than bigger seeds. (Beukema and Vander Zaag, 1990). On the other hand, large seeds are advantageous if soil and weather conditions are unfavourable at planting. However, according to the field study in Zimbabwe, large seeds (diameter > 45 mm) gave the best marketable yield with an optimum low plant density (Masarirambi et al., 2012). In Lam Dong only 21% of the farmers uses nothing but large seeds and plant distances were not correlated with their tuber seed sizes. Total marketable yields can be improved if larger potato seed tubers are chosen and plant density is adjusted to the seed size.

In this study it was not totally clear how the farmers reproduce their potato plants. In section 2 results show that only two out of twenty-eight farmers got their seed tubers from own production. Everybody else told they buy their seed potatoes from a dedicated seller in district Don Duong. However, in section 6 all farmers, except the ones working for PepsiCo, claim that they store their seeds by themselves. In literature it was found that during the last years a large amount of seed potatoes has been imported from Southern China (Tung, 2000). This might mean that, when the output of the questionnaire is true, seed tubers are purchased at a dedicated seller and stored at the farm. Another possibility is that farmers store only a part of their potato seeds for next cropping season, but additional potato seeds may be bought. In Indonesia most farmers select and save small potato tubers from previous crops for seeds for planting in the next season. Due to build up bacterial diseases and viruses and therefore degenerated seed stock, farmers had to buy seed tubers from other farmers and traders (Gunadi et al., 2017). This also can be the case for the potato farmers in Lam Dong. Reducing degeneration rate can be done by practicing positive selection. In this method, best potato plants in the field are marked before crop maturation and are served as mother plant for seed potatoes for next season. A study conducted in Kenya noticed an increase of 34% in yield when positive selection was utilized (Gildemacher, et al. 2011). Since in Lam Dong one third of the farmers looks only at the tubers when searching for seed potatoes this might be one of the solutions for better yields and quality produce.

Seed potatoes are stored for 8 to 9 months from February/March until October/November in hot, humid conditions. This long storage time under poor conditions causes considerable seed degeneration (Tung, 2000). An opportunity can be seen in cold storage. Many studies show that cold storage of potato seeds significantly improves potato quality. For instance, Muthoni et al. (2013) published a paper where it was found that cold-stored tubers were acceptable after eight months of storage, while for diffused light storage seed potatoes the opposite was true. However, some studies proofed that storage of seed potatoes in diffused light meets the criteria for storing seed potatoes in the hill region at low or no cost (FAO 2011).

In Lam Dong, all potato farmers use fertilizers and only 18 % of potato farmers' soil have been analysed to know if they need more fertilizers. The rate of application varies a lot between the farmers. Although there are some farmers who fertilize a little, the majority fertilizes excessively compared to a Vietnamese potato production manual where 150 kg N ha^{-1}, 60 kg P_2O_5 $ha^{-}1$ and 350 kg K_2O ha^{-1} is recommended for a yield of 30 tonne ha^{-1} (Fresh studio, 2015). Also in Dak Lak province, farmers tended to use 180 – 250 kg N ha^{-1} more than required (Hong et al., 2013).

In the RRD, potato fields are irrigated 2 – 3 times during growing season by furrow irrigation (Tung, 2000). Surface irrigation is also used in some locations where farm size is too small and canals for furrow irrigation are not available (Dang, 2008). In Lam Dong irrigation is applied much frequently (2,6 times a week in dry season) through surface irrigation with sprinklers from top. A Vietnamese potato production manual calculated a recommended amount of water of about 25 mm per time. Considering that potato plants will evaporate about 6 mm per day with an air temperature of 25°C, the field needs to be watered every four days. Sprinkler irrigation was recommended in the manual because it reduces overflow and the water can penetrate deep into the soil. Long duration sprinkler irrigation however, favoured late blight (Shock et al. 2003b)

The typical crop rotation in the RRD is spring rice – early autumn rice – potato (Anonymous 1983). In the Central Highlands of Vietnam potato may be cultivated in cropping systems with other spring and summer crops such as sweet potato, soya bean and other vegetables. Inter-cropping is not a common practice in the RRD (Tung, 2000). In Lam Dong farmers potatoes are not rotated with rice but with other cool climate vegetables like Chinese cabbage, carrots, lettuce, cauliflower, etc.

In Lam Dong, the main diseases and pests suffered by potato farmers include late blight (100%), leaf miners (75%) and bacterial wilt (46%). Compared to the RRD late blight, bacterial wilt, potato virus Y and potato leafroll virus causes the most considerable crop losses and contribute to the rapid degeneration of seed potatoes (Dang, 2008). Another study added aphids and mites as most significant pest in RRD (Tung, 2000). No farmers mentioned a potato virus as pest or disease.

Late blight *(P. infestans)* causes considerable crop losses that are often in the range 5% - 50% (Tung, 2000). This study confirms the disastrous effect of the disease during the cropping season.

According to Ackerson and Awuah (2010), inappropriate utilization of pesticides could be associated with farmers who didn't receive training on pesticide usage. This survey confirmed a previously conducted study about pesticide use in the Central Highlands of Vietnam in 2017

in the sense that all farmers spray pesticides as the key measure to control pests and diseases (Nguyen, 2017). During the conducted survey many farmers additionally allege that they spray mixtures of two or three active ingredients. Ntow et al. (2006) reported that by spraying a combination of active ingredients, the efficacy of one may mask the efficacy of others in the mixture. Mancozeb, the active ingredient of the most popular fungicides to target late blight, could cause some harm to farmer's skin and eyes. It also posed a long-term risk for cancer development (Novikova et al. 2003). Avalon 8 WP consist of gentamicin sulphate mixed with oxytetracycline. This is an antibiotic which is used in for instance Mexico to control fire blight of apple and pear. In Latin America it is used to control various bacterial diseases of vegetable crops caused by species of *Ewinia*, *Pseudomonas*, *Ralstonia*, etc. Oxytetracycline is not approved in EU.

This study reveals that treatment of potato plants with pesticides is the main approach of disease management. For late blight farmers in Lam Dong apply fungicides up to daily if it rains, in the north of Vietnam longer intervals occur. Potato farmers are not aware of safer pest management strategies. Nguyen (2017) suggest promoting non-pesticide-based pest management by developing trainings programmes. A study in 2011 suggest a more effective pesticide market control is a first, effective and cheap strategy for Vietnamese government to start dealing with these problems. A more adequate list of pesticides, on which cheap but poor-quality pesticides are banned from the market would reduce the confusion among state officials and farmers.

In 2017 the average potato yield per hectare was only 14.827 kg ha^{-1} in Vietnam (FAOSTAT, 2017). The yield of the questioned farmers turned out to be almost twice as high. Those yields are almost comparable with yields achieved in north-western Europe where highest yields are produced (in excess of 30 tonnes ha^{-1}). Potato yields in developing countries average around 10 to 15 tonnes ha^{-1}. In the highlands of a tropical country potential yield of tubers could be up to 100 tonnes ha^{-1} (Zaag and Burton, 1978).

The FAO defines producer price as the price received by farmers for primary agricultural products. The average producer price for potatoes in Vietnam is rising from 160 \$ $tonne^{-1}$ to 537 \$ $tonne^{-1}$ in 2016 (Figure 25). In this study, the price received by the farmers was on average 396 \$ $tonne^{-1}$. These prices are high compared to other Asian countries. For instance, in China producer price is 260 \$ $tonne^{-1}$ in 2016. In Bangladesh farmers receive only 200 \$ $tonne^{-1}$ produced potatoes. Compared to developed countries, for instance like Belgium, producers' price in Vietnam is much higher (in Belgium: 210 \$ $tonne^{-1}$ in 2016). In Figure 25 fluctuations of potato prices in Belgium should be noted. This is due to the absence of stabilisation measures, inelasticity of demand and the high variable yield (CEC, 2007). FAOSTAT also indicate that the potato producer price in Vietnam varies due to a variable yield. From a minimum of 466 \$ $tonne^{-1}$ in dry season to 537 \$ $tonne^{-1}$ in rainy season in

2016. This study noted price fluctuations from 258 $ tonne^{-1} in dry season to 774 $ tonne^{-1} in low season.

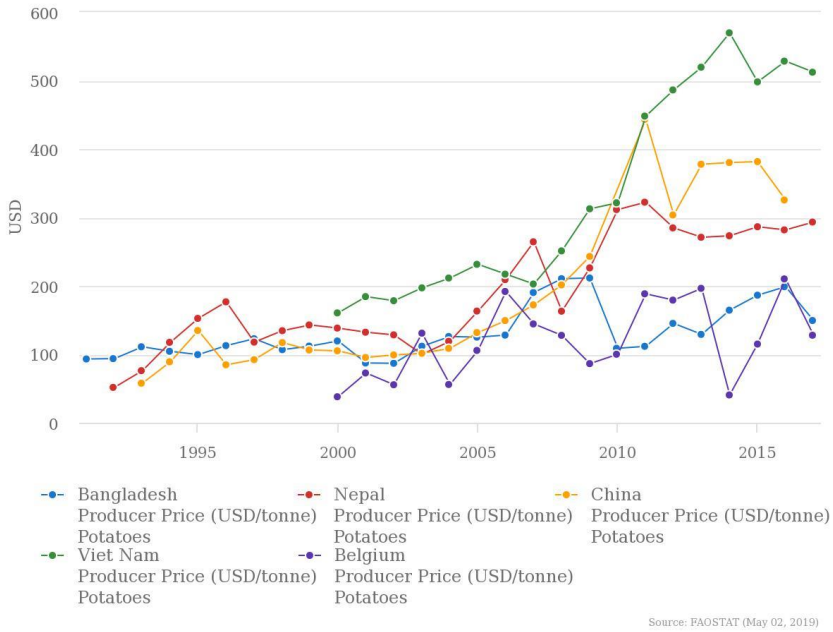

Figure 25: Average producer price for potatoes in Bangladesh, Nepal, China, Vietnam and Belgium (FAOSTAT, 2019)

4.2 Consumers' questionnaire

Traditionally, Vietnamese people do not eat potatoes. If they do, they consume it as a vegetable in soup with meat (mainly pork) or other Vietnams recipes with some herbs. Chips and French fries are considered as special dishes for reception dinners and parties (Dang, 2008). This consumers survey confirmed this since 46% uses potatoes mainly in a stew with other food and not even 8% uses them for French fries.

Freshness is cited as one of the most influential cues on consumer's decision to purchase fresh vegetables. Also, in Lam Dong consumers think freshness and appearance is most important in terms of quality. When purchasing fresh potatoes, consumers buy with their eyes. Consumers in Malaysia prefer clean skin, free from soil (Chamhuri, 2005). In Lam Dong, they favour soil on the tuber as a sign of locally grown potatoes.

The results of survey of Fresh Studio in 2015 for the project "*Growing out of poverty with potato*" shows that consumers prefer locally produced potatoes over imports. The same study showed that consumers prefer medium to large sized potatoes. Vietnamese consumers are mainly concerned about quality and safety. These results also follows from the conducted survey. Quality (87%), origin (77%) and use of pesticides (68%) is considered as the most important parameter when Vietnamese consumers buy potatoes. Size is less important and the majority (76%) prefers medium sized potatoes. In Argentina medium sized is also favoured

when buying fresh potatoes (Rodriguez, 2005). In the USA, skin quality and origin are the most important factors for consumers when buying potatoes (Jemison et al., 2008). Price is the second most important variable for Australian consumers. In Lam Dong price is not seen as an important factor.

Consumers confirm that potatoes, sold on the local market in Lam Dong, are often imported from China. Journalist reported the 22th August of 2018 that Chinese potatoes are repacked as Da Lat farm produce (Linh, 2018). Criminals do so by covering the Chinese potatoes with earth from the Central Highlands and then repack them into Da Lat labelled bags. Dat Viet newspaper reported that nearly 580 tonnes of Chinese potatoes where imported to Dalat since the middle of June 2018 until September 2018 (RFA, 2018).

4.3 Assessment of tuber quality

The required size of tubers depends on the acceptable level of peeling loss as this is greater for small than large tubers. Large potatoes are required for in processing industry. Here all samples, except one, were at least medium sized. Consumers prefer tubers within the size range of 4,0 to 7,5 cm (Gray & Hughes, 1977). In general potatoes on Lam Dong markets meets these requirements.

Skin colour is important in consumer acceptance of fresh market potatoes. In Canada for example, consumers favour red-skinned potatoes (Waterer, 2010). In Kenya red-skinned cultivars are favoured for home consumption while white-skinned cultivars are preferred for processing industry (Muthoni et al., 2013). In Lam Dong a distinction between yellow and red-brow skin, depending on variety was made.

While common scab has little impact on crop yields or eating quality, the visual appearance of tubers with common scab makes tubers unacceptable to consumers (Loria et al., 1997). In this study, scab is assessed light to moderate but is not considered as a major problem.

Another study conducted by the PVFC in Dalat reveals a potato variety with excellent quality potential such as shallow eyes, high DM and low reducing sugars (Tung, 2011). As 85% of the researched samples shows at least medium depth of eyes we can conclude that choosing the right variety may be important for growing quality tubers.

In general tubers with high specific gravity are prefer for processing (Adams, 2004). Since DM content must be higher than 20% for processing (Ezekiel et al., 1999). A high DM content is beneficial since less energy is required to evaporate sufficient water which lowers the processing costs. Lower DM concentration results in a higher fat content and too soft or too wat crisps which is undesirable by consumers (NIVA, 2002). In this study, DM content is consistently lower than 20%, therefore, they don’t meet the requirements for processing. A

study in 2007 revealed high ranging DM content from 21 – 23% in fields in Lam Dong province (Tung et al., 2011).

A positive correlation between mealiness and SG was found in literature (Maynard et al., 1965). However, this research didn't find any significant correlation between SG and mealiness. In previous literature no correlation between mealiness and consistency of cooked potatoes was found (Böhler et al.,1986; Leung et al., 1983). In this study however, a significant correlation between the two attributes was found. No significant correlation between moistness and mealiness was found. However, Böhler et al. (1986) found that these two attributes were highly correlated. Moistness was even used as a sensory descriptor for mealiness (Gray and Hughes, 1978)

Since colour of the French fries is rather high, we can conclude that potatoes are high in reducing sugars. The difference in colour of French fries between different district might be due to the genetic characters of the genotypes. Abong et al. (2009) reported that sensory traits including flavour and texture of French fries significantly varied among different genotypes.

4.4 Limitations

First, most of the farmers did not speak English, and therefore students from Dalat University helped by interpreting the Vietnamese answers to English. During most interviews, more than one family member was present. The interview was time-consuming and due to language barriers, it was difficult to get full attention of farmers. This may affect the survey negatively. Also, the hardworking and hospitality behaviours, especially the women who were busy with taking care of their children or preparing food while being interviewed may affect the results negatively. Second, in this study there were difficulties when asking the respondents to recall the name of pesticides, fertilizers they used and estimate on quantity of pesticides, fertilizers used per unit of land, etc. As a result, the information collected might not be totally correct. Third, most of the visited farmers were not growing potatoes at the time of visit. Therefore, no field research could be done. Moreover, they already sold their harvested crop, so no quality assessment of their fresh yield could be done.

When assessing the current situation concerning tuber quality on local markets, sellers claimed to sell locally grown potatoes. However, there has been lots of rumours that plenty of Chinese potatoes were in circulation on local markets in Lam Dong. Official news articles confirm these rumours. At this stage it is not clear which assessed potatoes are locally grown or from Chinese origin.

5 Chapter 5: Conclusion and future perspectives

The findings of this study reaffirmed potato production constraints in Lam Dong. However, it also uncovers other considerable problems and opportunities.

In contrast with the RRD, potato production in Lam Dong is predominated by men. Male farmers prove to produce significant higher yields in comparison with female farmers. Despite several research and trainings institutes exist, the smallholder farmers have little knowledge of these training programs in their neighbourhood, let alone that they participate them. However, in other studies, these trainings have shown enhancement of potato production.

Potato farmers in Lam Dong have the basic knowledge of potato cultivation but lack some fundamental principles. They understand the favourable properties of choosing F1 cultivars as seeds but overlook to remove diseased plants from the field. They see the advantages of crop rotation with mainly (Chinese) cabbage. In fact, these advantages, in terms of yield, were found to be statistically significant. However, they lack understanding in amending their fertilizer usage. Consistently, areal fields are over-fertilized although. Overall, farmers are unaware of advisory services in relation to soil fertility. They have not, therefore, got tested their soil to know the right amount and type of fertilizer. Additionally, irrigation management is not strictly respected.

When farmers in Lam Dong seek for seed tubers, one third looks at the plant, one third to the tuber and one third considered both. They don't favour a seed size and choose their planting distance independently of seed size. 'Positive selection' has shown favourable results in previous literature and can also enhance potato production in Lam Dong. Seeds are stored for eight to nine months since most farmers only grow in dry season. Hot, humid storage conditions do not seem any good to seed tuber quality. Whereas cold-storage of seed can be a long-term investment, improved diffuse-light-storage can enhance seed tuber quality.

Their pesticides are eagerly combined, mainly to combat late blight, leaf miner flies and bacterial wilt. However, losses due to diseases and pests remain high. Still, farmers manage to harvest relatively large yields mainly intended for fresh consumption. It might well be that they prefer high yields above quality. Nonetheless, they receive relatively high but fluctuating prices, depending on the season. Higher prices are received in rainy season due to lower yields. The high price of potatoes in Lam Dong appears a negligible parameter for consumers to buy potatoes. They consider low pesticide residue twice as important. Unfortunately, pesticides are clearly the first, and often only, remedy to combat pests and diseases. While consumers seem to focus on quality, potato farmers attach more importance to yield. Consumers experience bad quality on local markets and tend to buy potatoes more often if quality improves.

Chances are that besides locally grown potatoes, also imported Chinese potatoes were assessed to determine tuber quality. Therefore, the conclusion of this assessment covers quality of tubers, available on local markets in Lam Dong. Available potatoes on local markets in Lam Dong are predominantly yellow or brown-reddish and medium sized, which is in line with consumer's needs. Depth of eyes differs significantly for the four researched districts. Tubers exhibit light to moderate common scab and have not appeared to suffer greening. DM content is measured very low compared to Europe, thus, tubers are not suitable for industrial use. Cooked tubers were not crumbly, rather firm and a fairly humid. Mealiness was the only attribute for cooking behaviour which significantly differs for the researched districts of Lam Dong. The sensory analysis of French fries proofed a significant difference for attribute 'colour' for the four districts.

Even though our current knowledge may provide a foundation to improve potato production and quality in Lam Dong, much remains to be learned. First, potato farmers can be visited at the right time of the year when they have their harvested potatoes available for research. In this way, a correlation can be made between their farming practices and tuber quality. Since there is a marked difference between dry and rainy season, and the seasons will be more pronounced due to climate change, a distinction between the two can be made in future research. Furthermore, the relevance of the fact that training services are not visited too often, can be researched. As concerns potatoes, DM content is seem as an important quality parameter for both fresh market and industrial use. Therefore, further research is required to increase DM content in potatoes in Vietnam.

No matter how important research of this subject is, much responsibility rests with the government who can play an active role by regulating pesticides and fertilizers, as well as controlling good quality seed supply. As Belgium is a major player in the potato market, substantial new market opportunities for Belgian companies, which also benefit potato production in Vietnam, can be searched.

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Appendix 1: Farmers' questionnaire

Questionnaire: Potato management in Dalat Region (*Bảng câu hỏi: Quản lý khoai tây ở khu vực Đà Lạt*)

Respondent name (*Tên người trả lời*):

Date & time of interview (*Ngày & giờ phỏng vấn*):

Location (*Địa chỉ*):

Nr. (*số điện thoại*):

I. General background of farmer (*Thông tin chung của nông dân*)

1. Gender *(Giới tính):*
   - □ Male (*Nam*)
   - □ Female (*Nữ*)

2. Age (*Tuổi*)
   - □ < 21
   - □ 21-30
   - □ 31-40
   - □ 41-50
   - □ 51-60
   - □ > 60

3. What is you highest education level? (*Trình độ văn hóa cao nhất?*)
   - □ College or university (*Cao đẳng hay đại học*:)
   - □ High school (*Trung học*):
   - □ Middle school (*Trung học cơ sở*):
   - □ Primary school (*Tiểu học*)
   - □ Home schooled (*Học tại nhà*):
   - □ Illiterate (*Không biết chữ*)

4. Did you follow any training about potato crop husbandry?
   (Ông/Bà đã từng được tập huấn về trồng khoai tây chưa?)
   - □ Yes (*Có*)
   - □ No (*Không*)

5. Are you aware of any training programs in your neighbourhood?
   (Ông/Bà có biết về bất kỳ một chương trình tập huấn nào tại địa phương của mình không?)
   - □ Yes (Có)
   - □ No (Không)

6. How many members of your family work at the farm? (*Nhà ông/bà có bao nhiêu người làm việc ở tại trang trại?)* _____

7. Do you employ labourers on your farm? (*Ông/bà có thuê lao động không?*)

□ Yes (*Có*)

□ No (*Không*)

a. If yes, how many labourers do you hire during each periods (*Nếu có, ông/bà thuê bao nhiêu lao động cho mỗi giai đoạn?)*

□ Flowering season/Growing period (*Giai đoạn trồng*): _____

□ Hilling up 1 (*Lên luống lần 1*): _____

□ Hilling up 2 (*Lên luống lần 2*): _____

□ Harvest *(Thu hoạch*): _____

8. If you encounter agricultural problems, is there a service you can contact for advice? *(Nếu ông/bà gặp vấn đề về trồng trọt, có các dịch vụ để ông/bà có thể liên hệ tư vấn không?)*

□ Yes (*Có*)

□ No (*Không*)

□ I don't know (Tôi không biết)

a. Which service did you contact? (*Loại dịch vụ nào mà ông/bà đã liên hệ?*)

□ Government (*Chính quyền/Nhà nước*)

□ Potato retailer (*Cửa hàng thuốc BVTV)*

□ Potato company (*Công ty khoai tây*)

□ Neighbour (*Hàng xóm*)

□ Center of Agriculture (*Trung tâm nông nghiệp*)

□ Internet (*Internet/mạng*)

□ Other (*Khác*): _____

b. If yes, have you contacted this service before? (*Nếu có, ông/bà đã có liên hệ với dịch vụ này trước đây chưa?)*

□ Yes (*Có*)

□ No (*Không*)

II. General farming system and practices

9. What is your total potato production area? (*Diện tích trồng khoai tây của ông/bà là?)*

□ < 5 sào

□ 5 – 10 sào

□ 10 – 15 sào

□ > 15 sào

10. How many times a year you plant potato (rainy season as well as dry season)? What is the normal planting date (Ông/Bà trồng khoai tây bao nhiêu mùa một năm (mùa khô và mùa mưa), thường trồng vào ngày nào?

_____

11. What is the usual plant density (plants per 1000 m^2) *(Mật độ trồng là bao nhiêu?)*

_____

12. Where did you get your seed tubers? (*Ông/bà mua củ giống từ đâu?*)

□ Neighbour/*Hàng xóm*
□ Market (*Chợ*)
□ Own seed production (*Tự sản xuất củ giống*)
□ Government (*Chính quyền*)
□ Other (*Khác*): _____

a. Which were the criteria for choosing varieties? *(Tiêu chí lựa chọn củ giống là)*

□ Availability/*Giống sẵn có*
□ Productivity/*Năng suất*
□ Resistance to diseases/*Kháng bệnh*
□ Shape of tree/*Hình dạng cây*
□ Recommendation by neighbours/*Khuyến cáo của nông dân khác*
□ Other/*Khác*:

b. Do you know anything about their disease and pest resistance levels of varieties?(*Ông/bà có biết gì về mức độ kháng sâu bệnh của các giống?)*

□ Yes/*Có*
□ No/*Không*

13. Which size of seed tubers are used/*Kích cỡ củ giống được sử dụng là*?

□ 25-35mm
□ 36-55mm

14. Do you use fertilizers to maintain your soil fertility? (*Ông/bà có sử dụng phân bón để duy trì độ phì của đất không?)*

□ Yes/*Có*
□ No/*Không*

a. Which fertilizers do you use? (If not known: Can you show us the packaging material?)/*Ông bà sử dụng loại phân bón nào? (Nếu không biết: Ông/bà có thể cho chúng tôi xem bao bì được không?)*

Name of fertilizer used/*Tên loại phân bón*	Composition (N, P, K)/ *Thành phần N, P, K*	Frequency of use (times per year)/*Tần suất sử dụng (số lần/năm)*	Amount per application (*Khối lượng/lần bón)*

b. How do you decide when to use fertilizer? / *Dựa vào đâu để Ông/bà quyết định khi nào nên sử dụng phân bón?*

□ Calendar schedule/*Lịch trình*
□ Analysis of leaves/*Kết quả phân tích lá*
□ Analysis of soil/*Kết quả phân tích đất*
□ Visual examination of potato plants (*Quan sát cây khoai tây*)
□ Random/*Bón hú họa, không chắc chắn*
□ Depending on the rain/*Phụ thuộc vào mưa*

c. How much do you spend on fertilizers each year? /*Ông/bà tốn bao nhiều chi phí phân bón mỗi năm*

d. Do you know if any advisory services exist in relation to soil fertility? *Ông/bà có biết bất kỳ dịch vụ tư vấn nào liên quan đến phân tích đất và hướng dẫn bón phân không?*

□ Yes/Có
□ No/Không

e. Who organizes this service? (*Ai tổ chức dịch vụ này?*)

□ Government/*Chính quyền*)
□ Research institute (*Viện nghiên cứu*)
□ Agro chemical retailer/*Cửa hàng thuốc BVTV*
□ Private company/*Công ty tư nhân*
□ Other/*Khác* : _____

f. Have your soil or leaves been analysed to known if they need more fertilizer? / *Ông/bà phân tích đất và lá để biết khi nào cây cần bón phân chưa?*

□ Yes/Có
□ No/Không

15. Do you apply irrigation? / *Ông/bà có tưới tiêu không?*

□ Yes/*Có*
□ No/*Không*

a. If yes, how do you apply irrigation? (*Nếu có, Ông/bà có sử dụng cách tưới nào?*)

□ Sprinkler from top/*Tưới phun*
□ Drip irrigation at the base of the trees (*Tưới nhỏ giọt*)
□ Other (*Khác*) _____

b. When do you apply irrigation? (*Khi nào thì Ông/bà tưới*)

□ Regular time points/*Tưới thường xuyên*: _____ times/*lần* _____(day/week/season) / (trên một ngày/tuần/mùa)
□ When the soil looks dry/*Khi đất có vẻ khô*
□ When it has not rained for/*Khi trời không mưa trong* ____ days/*ngày*
□ Other/*Khác* _____ .

16. Which crop are grown in your potato rotation?/ *Ông/bà luân canh khoai tây với loại cây trồng khác không*

_____

17. Do you own livestock? / *Ông/bà có chăn nuôi không?*

Species/*Loại gia súc*	**Yes/*Có***	**Number/*số lượng***
Poultry/*Gà*		
Pig/*Heo*		
Buffalo/*Trâu*		
Cow/*Bò*		
Goat/*Dê*		
Sheep/*Cừu*		

III. Occurrence of pests and diseases */ Sự xuất hiện của sâu bệnh*

18. Can you describe which pests or diseases you encounter in your field? (*Ông/bà có thể mô tả các loại sâu bệnh mà ông bà gặp trên ruộng khoai tây*

Name of pest or disease / *Tên loại sâu bệnh*	**Description of pest or disease/*Mô tả***	**Most important (choose one)/ *quan trọng nhất (Chọn 1)***

a. Can you estimate the income you lost because of disease or pests by looking at the previous season?(*Ông/bà có thể ước tính thu nhập bị tổn thất do sâu bệnh ở mùa trước là bao nhiêu?*

_____

19. Per disease of pest following questions?/ *Trả lời các câu hỏi sau về các loại sâu bệnh*

a. Do you recognize the following symptoms caused by Phythophthora infestans? (Show pictures of typical symptoms)/ *Ông/bà có nhận biết các triệu chứng sau đây do bệnh mốc sương do Phythophthora infestans gây ra không?(Cho xem hình)*

□ Yes/Có

□ No/Không

b. Do you know that this is caused by a fungus/mould?(*Ông/bà có biết bệnh này gây ra do nấm hay không?*)

□ Yes/*Có*

□ No/*Không*

c. How many plants displayed these symptoms in general? (*Nhìn chung, có bao nhiêu phần trăm khoai tây bị triệu chứng này?*)

□ 0 %
□ 1-2 %
□ 3-10 %
□ 10-25%
□ 25-50%
□ 50-75%
□ >75%

d. In which growing stage did you see the symptoms? *(Ông/bà nhìn thấy triệu chứng này ở khoai tây ở giai đoạn phát triển nào?)*

□ Flowering season/*Khi ra hoa*
□ Berry development/*Khi hình thành củ*
□ Harvest season/*Khi thu hoạch*

e. What do you do when you see these symptoms? (*Ông/bà làm gì khi thấy các triệu chứng này)*

□ Nothing/Không làm gì
□ Apply pesticides/Phun thuốc
□ Remove affected plant parts/Nhổ bỏ các cây bị bệnh
□ Other/Khác

IV. Crop protection measures / *Biện pháp bảo vệ*

20. When you see diseased or insect affected plant parts, how do you handle them?/ *Khi thấy khoai tây bị sâu bệnh, ông/bà xử lý như thế nào*

□ Do nothing/*Không làm gì*
□ Treat the plant parts with pesticides / *Xử lý các cây bị sâu bệnh bằng thuốc bảo vệ thực vật*
□ Remove the plant parts from the field / *Loại bỏ các cây bị sâu bệnh ra khỏi đồng ruộng*
□ Burn the affected plant parts / *Đốt cháy các phần cây bị nhiễm*
□ Other:/Khác _____

21. If pesticides were applied:/*Nếu phun thuốc thì*

Name of pesticide / *Tên thuốc*	**Amount of pesticide per application/ *Tổng số thuốc cho 1 lần phun***	**Frequency of application (number per month or year)/ *Tần suất phun (số lần/tháng hoặc năm)***
1.		
2.		
3.		
4.		
5.		

6.		
7.		
8.		

22. Why did you choose these particular pesticides? *(Tại sao ông/bà chọn những thuốc bảo vệ thực vật này)*

□ Own decision based on pest / *tự quyết định tùy theo loại sâu bệnh*

□ Price/*Giá cả*

□ Effectiveness/*Hiệu quả*

□ Recommendation by neighbour/*Theo các nông dân khác*

□ Recommendation by government/*Theo khuyến cáo của chính quyền*

□ Recommendation by agro chemical retailer/ *Theo khuyến cáo của người bán lẻ*

□ Other:/*Khác* _____

23. Was the pesticide application effective last season?/*Ông bà thấy có loại thuốc bảo vệ thực vật nào có hiệu quả trong mùa vừa rồi)*

□ Yes/Có

□ No/Không

□ I don't known/Tôi không biết

24. Have you used these pesticides before? (*Ông/bà đã sử dụng các loại thuốc này trước đây chưa?)*

□ Yes/Có

□ No/Không

a. **If yes**, has the effectiveness changed compared with former applications?/*Nếu có, nó có hiệu quả so với các loại đã sử dụng trước đó không?*

□ Yes/*Có*

□ No/*Không*

□ I don't know/*Tôi không biết*

25. Did you apply the pesticides by yourself? (*Ông/bà có tự phun thuốc không?*)

□ Yes/Có

□ No/Không

a. What outfit did you (or the other person) wear to apply the pesticides? (*Loại bảo hộ nào mà ông/bà (hoặc người khác) mặc khi phun thuốc)*

	Always/ *Luônluoo*	Often/*Thường xuyên*	Sometimes/*Thỉnh thoảng*	Never/*Không bao*
Gloves/*Găng tay*				
Hat/*Mũ*				
(eye) Mask/*Kính mắt*				
Face shield / face mask/*Khẩu trang*				

Googles/*Kính*				
Full mask + respirator/*Mặt nạ phòng độc*				
T-shirt/*Áo thun*				
Short trousers /*Quần ngắn*				
Long trousers/*Quần dài*				
Impermeable clothes/*Quần áo chống thấm*				
Barefoot/*Chân trần*				
Normal shoes/*Giày thường*				
Boots/*Ủng*				

26. How much do you spend on pesticides each year*?(Ông/bà tốn bao nhiêu chi phí cho thuốc bảo vệ thực vật mỗi năm*)

_____

27. Do you know any organisms that are beneficial for the potato plants? *(Ông/bà có biết loại vi sinh vật nào có lợi cho cây khoai tây không?)*

□ Yes/Có

□ No/Không

a. **If yes**, do you take measures to promote the beneficial organisms?/*Nếu có, ông/bà có biện pháp nào để thúc đẩy các vi sinh vật có lợi này không?*

□ Yes/Có

□ No/Không

28. Are you aware of any training on pest management conducted in your area?/*Ông/bà có biết bất cứ một khóa tập huấn nào về quản lý sau bệnh tại địa phương không?*

□ Yes/Có

□ No/Không

a. If yes, have you attended this training?/Nếu có, ông/bà có tham gia và lớp tập huấn này không?

□ Yes/Có

□ No/Không

V. Economic information/ *Thông tin về kinh tế*

29. What was the average price for potatoes last season?/*Giá khoai tây trung bình mùa trước là bao nhiêu*? _____

a. How is this price decided?/*Giá này được quyết định như thế nào?*

□ Local market/Chợ địa phương

□ Retailer/Người bán lẻ

□ Other/Khác

30. What was your total yield last year?/*Sản lượng khoai tây năm ngoái của ông/bà là bao nhiêu?*

_____

31. Do you process potatoes on the farm or do you sell them as fresh product?(*Ông/bà có chế biến khoai tây ở trang trại không hay bán tươi?)*

□ Sell immediately as fresh product/*Bán tươi ngay lập tức*

□ Sell after storing on the farm (to wait for higher price)/ *Bán sau khi trữ tại trang trại (để chờ giá cao)*

□ Sell after processing on the farm /*bán sau khi chế biến tại trang trại*)

□ Other/*Khác*: _____

32. What is your total annual income? *Tổng thu nhập hàng năm của ông/bà là bao nhiêu*

_____

a. Which percentage originates from potato production?/*Trong đó, bao nhiêu phần trăm thu nhập từ trồng khoai tây*

□ <25%

□ 26-50%

□ 51-75%

□ 76-99%

□ 100%

VI. Quality aspects/Chất lượng

33. Mean usage of potatoes? Do you sell to commercial or for processing usage or for breeding? Ông/bà bán khoai tây để ăn tươi hay để chế biến hay để làm giống? Khoai tây được sử dụng để

□ Consumption: Fresh market/ Bán ra chợ

□ Consumption: Processing infustry/ Bán cho các công ty chế biến

□ Seed cultivation/ làm giống

□ Other/ *Khác*:

34. What are according to you the most important quality parameters?/Theo ông/bà tiêu chí chất lượng quan trọng nhất của khoai tây là gì?

_____

35. Do you take crop husbandry measures to improve quality? /Ông bà có thực hiện các biện pháp quản lý cây trồng để cải thiện chất lượng không?

_____

36. How are potatoes stocked? Do you use germination inhibitors or other chemicals*?/Ông/bà có trữ khoai tây không? Ông/bà có sử dụng các hóa chất ngăn ngừa nảy mầm hay các hóa chất khác không?*

_____

37. How are the seed potatoes stored? At what time? How long? / Khoai tây giống được lưu trữ như thế nào? Vào thời gian nào? Trong bao lâu?

_____

38. *If the farmer search for seed potatoes, does he look to the plant or to the tuber?/ Khi ông/bà mua khoai tây giống, ông/bà dựa vào cây hay củ để mua?* _____

39. Is price calculate based on quality parameters?/*Giá cả có được tính dựa trên chất lượng khoai không?*_____

Appendix 2: Adresses of interviewed farmers

Nr.	Name	Adress	District	Date	Mobile Nr.
1	Nguyen Duy Hoa	186 Tran quang khai street	Dalat	06-08-2018	+84 93 7949137
2	Dinh Phu	238 Ngo Tal To, P8	Dalat	07-08-2018	+84 98 6299664
3	Lé Thi Huyen	34 Cong Duia Ngoc Han	Dalat	10-08-2018	+84 126 4950615
4	Nguyen Thi Kim	36 Thanh Mau	Dalat	10-08-2018	+84 263 3667354
5	Lé Ngoc Quang	41 Cong chua Ngoc Han. P7	Dalat	10-08-2018	+84 91 8208226
6	Nguyen Duy Tam	98 Thanh Mau	Dalat	10-08-2018	+84 97 9677082
7	Tran Quang Tri	104 Thanh Mau	Duc Truong	11-08-2018	+84 166 2349236
8	Nguyen Quang Trung	112 Thanh May	Dalat	16-08-2018	+84 93 9792858
9	Nguyen Dinh Huy	32 Cong Chia Ngor Hon	Dalat	16-08-2018	+84 127 3281022
10	Bui Dac Thing	32A Thanh Mau	Dalat	19-08-2018	+84 166 3598220
11	Nguyen Quoc Khanh	36A Thang May	Don Duong	19-08-2018	+84 97 7399710
12	Nguyen Tuong Huy	25A Thanh May	Don Duong	19-08-2018	+84 91 8865574
13	Ho Thi Thuc	127 To Hai	Dalat	19-08-2018	+84 263 3570434
14	Dinh Thi Hong Nhung	Thai Phun, 12 Ward, Dalat	Dalat	20-08-2018	+84 93 3083938
15	Phan Thi Thu Ba	To 1 thon Da Quy Xa Xuan Tho	Dalat	26-08-2018	+84 94 4377561
16	Tran Ngoc Hung	To 1. Do Quy. Xuan Tho	Dalat	26-08-2018	+84 163 6454600
17	Dan Thi Dan	To 2, Da Quy. Xuan Tho	Dalat	26-08-2018	+84 163 9638102
18	Dang Phuoc Thanh Hung	To 1, Da Quy	Dalat	26-08-2018	+84 166 7319642
19	Nquyen Van Son	To 2, Than Da Quy, Xuan Tho	Dalat	26-08-2018	+84 168 4038495
20	Nguyen Van Son	Tap Doon 6. Xuan Tho	Dalat	27-08-2018	+84 97 3974007
21	Than Van Ngoan	Thon Phu Tranh, xa Hiep	Duc Truong	13-09-2018	+84 168 6218279
22	Nguyen van Hanh	Phu Hoi	Duc Trung	13-09-2018	+84 123 2501729
23	Ptan Truong Tuan	-	Don Duong	13-09-2018	-
24	Pham xan Thu	Da Ron	Don Duong	13-09-2018	+84 98 4409354
25	Van Bac Thanh	-	Don Duong	17-09-2018	-
26	Dagout Bill	234 LangBiang	Don Duong	17-09-2018	-
27	Dagout Guel	15 Dam Sam	Don Duong	17-09-2018	+84 94 8340758
28	Ka Tan Den	So 7 Dam Sam	Don Duong	17-09-2018	-

Appendix 3: Letter for potato sellers at local markets

Hello,

I am a Belgian student who is doing research about the potato cultivation in the Lam Dong Region. In order to improve the quality of the potatoes I'd like to do lab test on the potatoes you are selling. Are the potatoes you sell imported or locally grown?

- □ Imported
- □ Locally grown (in Lam Dong)
- □ Other Region: .....

Thank you for your help,

Pieter-Jan

Xin chào ông/bà:

Tôi là sinh viên người Bỉ đang nghiên cứu về canh tác khoai tây ở khu vực tính Lam Dong. Để nâng cao chất lượng khoai tây, tôi muốn làm một số thử nghiệm trên khoai tây bạn đang bán. Tôi có thể mua 1 kg khoai tây không? Câu hỏi liên quan đến nguồn gốc khoai tây.

Khoai tây của bạn đang bán là khoai tây nhập khẩu hay trồng tại Lam Dong?

- □ Nhập khẩu
- □ Trồng tại địa phương (Lam Dong)
- □ Khu vực khác .....

Xin chân thành cám ơn!

Pieter-Jan

Appendix 4: Consumers' questionnaire

1. Gender:

□	Male	□	Female	□	Other

2. Age

□	< 21	□	21-30	□	31-40
□	41-50	□	51-60	□	> 60

3. What is you highest education level?

□	College or university	□	High school	□	Middle school
□	Primary school	□	Home schooled	□	Illiteratee

4. Family size?

□	1	□	2	□	3
□	4	□	5	□	6
□	7	□	>7		

5. Do you live in Lam Dong region?

□	Yes	□	No

6. Do you agree or disagree the following; Potatoes are ...

	Agree	Disagree
Delicious	□	□
Quick and easy to prepare and cook	□	□
A filling meal on their own	□	□
Versatile	□	□
Healthy	□	□
Fattening	□	□
High in calories	□	□
Expensive	□	□
Cheap	□	□

7. Why do you eat potatoes?

	Not important	Neutral	Important
Good source of carbohydrates	□	□	□
Affordable	□	□	□
High in calories	□	□	□
Quick and easy to prepare	□	□	□

Essential part of diet	□	□	□
Contain no fat	□	□	□
Delicious	□	□	□
Versatile	□	□	□
Filling	□	□	□
Healthy / nutritional	□	□	□

8. What is the main use of the potatoes you buy?

□ Mashed potatoes	□ Baked potatoes	□ Roasted potatoes
□ Fried chips	□ In a stew with other food	

9. How often do you purchase potatoes in Lam Dong?

□ Depending on the season	□ Daily (5 – 7 times a week	□ 2 – 4 times a week
□ 1 time a week	□ 2 – 3 times a month	□ 1 time a month
□ Less frequent than once a month		

10. Where do you buy your potatoes?

□ Local market	□ Supermarket	□ Other

11. How important are the following parameter when you buy potatoes?

	Not important	Neutral	Important
Origin of potatoes	□	□	□
Size	□	□	□
Use of pesticides	□	□	□
Price	□	□	□
Shelf life	□	□	□
Fair price for farmers	□	□	□
Quality	□	□	□

12. Do you know that potatoes, sold in Lam Dong, are sometimes imported from China?

□ Yes	□ Maybe	□ No

13. Can you notice the difference between local grown or imported potatoes?

□ Yes	□ Maybe	□ No

14. Do you prefer to buy local grown or Chinese potatoes?

□	Local grown	□	Chinese

15. When buying potatoes, how often do you experience quality problems?

□	Often	□	Sometimes	□	Never

16. What is important according quality of potatoes?

	Not important	Neutral	Important
Smell	□	□	□
Skin must look good / good appearance	□	□	□
Weight	□	□	□
Size	□	□	□
Freshness	□	□	□
Shape	□	□	□
Colour of skin	□	□	□
Taste	□	□	□
Feel	□	□	□
Price	□	□	□

17. What is your preferred size of potatoes?

□	Small	□	Medium
□	Large	□	It does not matter

18. Would you buy more potatoes if the quality is better?

□	Yes	□	No	□	Maybe