

**CHARACTERISATION OF “GLASSINESS” IN COMMERCIALY
PROCESSED FRENCH FRIED POTATOES**

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MASTER OF SCIENCE IN FOOD SCIENCE



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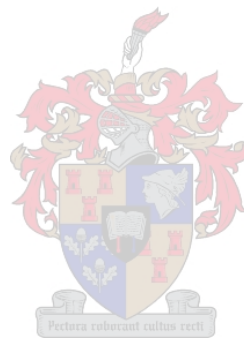
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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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ABSTRACT

The relationship between the “glassiness” defect in frozen French fries and the moisture, starch and reducing sugar content of the affected potato tuber was investigated. The effect of soil water quality, cultivar, soil depth, storage duration, specific gravity and blanching conditions during French fry production on the occurrence of “glassiness” was determined. Fourier transform near infrared (FT-NIR) spectroscopy was used to identify possible classifications of defected tubers.

No significant difference occurred between the moisture ($p=0.10$, trial 1 and $p=0.15$, trial 2), starch ($p=0.76$, trial 1 and $p=0.70$, trial 2) or reducing sugar ($p=0.05$, trial 1 and $p=0.51$, trial 2) content of potato sample with and without the “glassiness” defect. Samples of the cultivar Herta (Her) showed the lowest occurrence of the defect (23%, trial 1 and 0%, trial 2), while the cultivar Columbus (Col) showed the highest occurrence (70%, trial 1 and 84%, trial 2).

The soil water quality prevailing in the area of cultivation contributed to the amount of “glassiness” occurring in the samples of the cultivar Col. Col obtained from the Parys area (electrical capacity (EC) = 145 mS.m^{-1}) showed a 21% occurrence of “glassiness”. Col obtained from the Uitvlug (EC = 57 mS.m^{-1}) and Zandrug (EC = 25 mS.m^{-1}) areas showed a 91% occurrence of the defect. All samples cultivated in the Parys area during trial 1 showed a significantly lower occurrence of “glassiness” ($p=0.01$) than samples obtained from the areas Uitvlug and Zandrug. During trial 2 all samples obtained from the Thaaibos area (EC = 82 mS.m^{-1}) showed a lower occurrence of the defect than samples obtained from the area Witklip (EC = 178 mS.m^{-1}) although this difference was not statistically significant ($p=0.06$). Soil depth, specific gravity and storage duration did not contribute to a significant difference in the occurrence of “glassiness” between samples.

Modified blanching conditions of 62°C for 25 min instead of 80°C for 20 min during frozen French fry processing had a reducing effect on the occurrence of the defect in the cultivars Fianna (Fia) ($p=0.06$), Pentland Dell (Pen) ($p=0.05$)

and Col ($p < 0.01$). The modified blanching conditions improved the texture uniformity in the French fry strip, reducing oil absorption during frying and prevented fry strips from breaking during subsequent processing steps.

FT-NIR calibration models could not be successfully developed for the prediction of the moisture, starch and reducing sugar content in a potato sample. Principal component analysis (PCA) indicated no classification between potato samples affected by the “glassiness” defect and samples without the defect. The calibration models for moisture, starch and reducing sugar content yielded a standard error of prediction (SEP) of 1.62%, 2.28% and 0.07%, respectively. The respective correlation coefficients of these calibration models were 0.46, 0.42 and 0.41.

The “glassiness” defect was most prominent in the cultivar Col. The occurrence of the defect was reduced and French fry quality improved by adjusting blanching parameters to 25 min at 62°C. FT-NIR spectroscopy is not recommended for screening of potato quality prior to processing.



UITTREKSEL

Die ooreenkoms tussen die glaserigheidsdefek in bevrore Franse aartappelskyfies en die vog, stysel en reduserende suikerinhoud van die geaffekteerde aartappelknol is ondersoek. Die moontlike effek wat die grondwaterkwaliteit, kultivar, gronddiepte, opbergingstydperk, relatiewe digtheid en blansjeertoestande tydens die produksie van Franse aartappelskyfies op die teenwoordigheid van die glaserigheidsdefek kan hê, is bepaal. Fourier transformasie naby infrarooi (FT-NIR) spektroskopie is gebruik vir die moontlike klassifikasie van defektiewe aartappelknolle.

Geen beduidende verskille het voorgekom in die vog ($p=0.10$, proef 1 en $p=0.15$, proef 2), stysel ($p=0.76$, proef 1 en $p=0.70$, proef 2) of reduserende suikerinhoud ($p=0.05$, proef 1 en $p=0.51$, proef 2) van aartappelmonsters met en sonder die teenwoordigheid van die glaserigheidsdefek nie. Monsters van die kultivar Herta (Her) het die laagste teenwoordigheidssyfer van die defek getoon (23%, proef 1 en 0%, proef 2), terwyl die grootste hoeveelheid defektiewe monsters in die kultivar Columbus (Col) voorgekom het (70%, proef 1 en 84%, proef 2).

Die grondwaterkwaliteit in die area van verbouing het bygedra tot die teenwoordigheid van die defek in die kultivar Col. Col monsters van die Parys area (elektriese kapasiteit (EK) = $145 \text{ mS}\cdot\text{m}^{-1}$) het 21% teenwoordigheid van glaserigheid getoon. Col monsters van die Uitvlug (EK = $57 \text{ mS}\cdot\text{m}^{-1}$) en Zandrug (EK = $25 \text{ mS}\cdot\text{m}^{-1}$) areas het 'n 91% teenwoordigheid van die defek getoon. Verder het al die monsters verbou in die Parys area tydens proef 1 'n beduidende laer teenwoordigheid van glaserigheid ($p=0.01$) getoon as monsters verbou in die areas Uitvlug en Zandrug. Tydens proef 2 het al die monsters verbou in die Thaaibos area (EK = $82 \text{ mS}\cdot\text{m}^{-1}$) 'n laer teenwoordigheid van die defek getoon as monsters van die Witklip area (EK = $178 \text{ mS}\cdot\text{m}^{-1}$). Hierdie verskil tussen verbouingsareas was nie statisties beduidend nie ($p=0.06$). Gronddiepte, relatiewe digtheid en opbergingstydperk het nie bygedra tot

beduidende verskille in die teenwoordigheid van glaserigheid tussen monsters nie.

Gemodifiseerde blansjeertoestande van 62°C vir 25 min in plaas van 80°C vir 20 min tydens die produksie van bevrore Franse skyfies het 'n verminderde effek op die teenwoordigheid van die glaserighedsdefek in die kultivars Fianna (Fia) ($p=0.06$), Pentland Dell (Pen) ($p=0.05$) en Col ($p<0.01$) gehad. Die gemodifiseerde blansjeertoestande het verder 'n uniforme tekstuur in die Franse skyfie, 'n verlaagde olie absorpsie tydens diepvat braai en die voorkoming van gebreke skyfies na opeenvolgende prosesseringsstappe tot gevolg gehad.

FT-NIR kalibrasie modelle is nie suksesvol ontwikkel vir die bepaling van die vog, stysel en reduserende suikerinhoud van die aartappelmonster nie. Hoofkomponent analise (PCA) kon geen klassifikasie tussen glaserige en nie-glaserige monsters identifiseer nie. Die kalibrasie modelle vir vog, stysel en reduserende suikerinhoud het 'n standaardfout van voorspelling (SEP) van 1.62%, 2.28% en 0.07% onderskeidelik opgelewer. Die onderskeie korrelasiekoëffisiente (r) vir hierdie kalibrasie modelle was 0.46, 0.42 en 0.41.

Die glaserighedsdefek was mees prominent in die kultivar Col. Die teenwoordigheid van "glaserigheid" in Franse skyfies is verminder en die tekstuur verbeter deur gemodifiseerde blansjeertoestande van 62°C vir 25 min. FT-NIR spektroskopie word nie aanbeveel vir die bepaling van aartappelkwaliteit voor prosessering nie.

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Language and style used in this thesis are in accordance with the requirements of the *International Journal of Food Science and Technology*.

CHAPTER 1

INTRODUCTION

The industrial manufacturing of frozen French fries was initiated in the United States in 1945 (Lisińska, 1989). This industry developed much later in South Africa with a sudden explosion of frozen French fry production between 1991 and 1995 (Anon., 2004a). Today more than 20% of all potatoes (*Solanum tuberosum L.*) harvested annually in South Africa are used for the production of frozen French fries (Anon., 2004a). The increasing demand for convenience products and the popularity of French fried potatoes due to its characteristic colour, texture and flavour emphasises the production of a consistently high quality product (Talbert *et al.*, 1987; Burton, 1989; Lisińska, 1989; Anon., 2004a). A uniform product is, however, dependent on the quality of the raw material and the processing parameters during the fry production.

Reducing sugars contained within the tuber is responsible for the desired light cream to golden brown colour achieved in the French fry end-product (Baltes, 1982; Ashoor & Zent, 1984). An excess reducing sugars in the raw material (>0.5% (m/m) of the fresh weight of the tuber) will result in an undesirable dark discolouration ascribed to the Maillard reaction (Burton & Wilson, 1970; Cottrell *et al.*, 1995). The starch content of the potato, as indicated by the specific gravity of the tuber, is responsible for the textural characteristic of the French fry (Smith, 1977; Talbert *et al.*, 1987; Burton, 1989; McComber *et al.*, 1994; Golubowska, 2005). In the French fry industry the specific gravity of a potato tuber, indicative of its starch content, is often used as a measure for sorting potatoes into textural quality groups prior to processing (O'Beirne & Cassidy, 1990; Van Marle *et al.*, 1997; Thybo *et al.*, 2000; Thygesen *et al.*, 2001). A specific gravity (SG) higher than 1.080 is indicative of a mealy texture in the final French fry and preferred for frozen French fry production (Smith, 1977; Lisińska, 1989; McComber *et al.*, 1994, Anon., 2004b).

The processing suitability of potatoes depends on the prevailing environmental factors during physiological development and post-harvest storage of the tubers. These factors include cultivar, season, area, soil water quality, soil temperature, fertilisation and storage temperature and storage duration (Kumlay *et al.*, 2002). Among these, soil water quality is the most prominent factor distinguishing different areas in the Sandveld

region of South Africa. Cultivation of potatoes in these areas of differing soil water qualities results in distinct differences in the chemical composition of tubers, thereby continually challenging the processor to maintain a uniform product quality (Iritani, 1981).

A translucent-end defect known to affect the quality of the frozen French fry is extensively described in the literature (Iritani & Weller, 1973; Burton, 1989). This defect occurs mainly in potato tubers subjected to secondary re-growth when stress conditions during the physiological development are relieved (Ewing, 1981; Veerman & Van Loon, 1995). Translucent-end tubers have regions containing little or no starch, areas with low SG and high levels of reducing sugars (Marinus & Bodlaender, 1975; Iritani, 1981). The processing outcome is an uneven texture and colour in the French fry strip.

A similar defect described as “glassiness” exists in South African frozen French fries. The phenomenon of “glassiness” is characterised by a hard, raw and uneven texture in the processed French fry strip. As this defect is only detected in the end-product it is impossible to identify and eliminate the affected tubers prior to processing. An understanding of the mechanism of “glassiness” or the random appearance of the defect in tubers could be of great value to the processing industry.

As “glassiness” is a textural defect the possibility exist that fluctuations in one or more of the chemical components of the potato, being either moisture, starch or reducing sugars, are responsible for its occurrence. However, to determine the chemical content of potatoes, traditional methods are used which are both time consuming and sample destructive. For this reasons attempts have been made to development an alternative, rapid, non-destructive and on-line method to predict the chemical composition and optimum use of the potatoes prior to processing (Hartmann & Büning-Pfaue, 1998; Mehrübeoğlu & Côté, 1997; Scanlon *et al.*, 1999). By categorising the raw material it would be possible to optimise processing parameters for each specific group in order to obtain the best possible end-product (Thybo *et al.*, 2004). Fourier transform near infrared (FT-NIR) spectroscopy has previously been used to rapidly analyse and quantify the main chemical constituents in various agricultural products (Baker, 1985; Scanlon, 2004).

The aims of this study were to statistically correlate a variation in the chemical composition in the tuber to the occurrence of the “glassiness” defect; to identify the environmental conditions that give rise to the defect; and to develop a non-destructive

method for categorising affected tubers prior to processing by means of Fourier transform near infrared (FT-NIR) spectroscopy. The additional development of modified processing parameters might reduce the severity of the affected raw material.

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CHAPTER 2

LITERATURE REVIEW

A. BACKGROUND

Potatoes (*Solanum tuberosum* L.) are considered to be the world's third most important source of starch as it can successfully grow in a variety of soil and climatic conditions (McComber *et al.*, 1994; Christensen & Madsen, 1996). Raw potato starch is indigestible, therefore heat processing of some form is necessary to increase digestibility. Potatoes can either be cooked and consumed directly or processed to a variety of commercial products (Leszczyński, 1989a). Among these are dehydrated potato powder or flour, canned potatoes, potato alcohol, crisps and frozen French fries (Burton, 1989). Potato crisps and frozen French fries make up 39.44% and 40.92%, respectively of the total amount of processed potatoes in South Africa (Anon., 2004a).

An increase in the popularity of French fries over the last decade (Fig. 1) makes it necessary for the South African French fry industry to focus the purchase of potatoes on strict specifications that include tuber size, high specific gravity and low levels of reducing sugars in order to produce a good quality product (Talbert *et al.*, 1987a; Lisińska, 1989a; Horton & Anderson, 1992; Shock *et al.*, 1993; Eldredge *et al.*, 1996; Thygesen *et al.*, 2001; Thybo *et al.*, 2003; Anon., 2004a; Anon., 2004b). The French fry industry predominantly relies on farmers to produce and deliver potatoes suitable for French fry processing.

Environmental conditions have a major impact on the processing quality of potatoes (Kumlay *et al.*, 2002). Fry colour, texture and fry yield of French fries are quality aspects easily influenced by changes in the chemical composition of the potato due to different environmental conditions (Iritani, 1981). Fry colour and texture are important in consumer acceptability of the final product and is mainly influenced by the reducing sugar levels and starch content of the potato tuber. A high fry yield is dependent on a high specific gravity of the raw material and leads to higher profits (Lisińska, 1989a; L Slabber, Lamberts Bay Foods, Lamberts Bay, South Africa, personal communication).

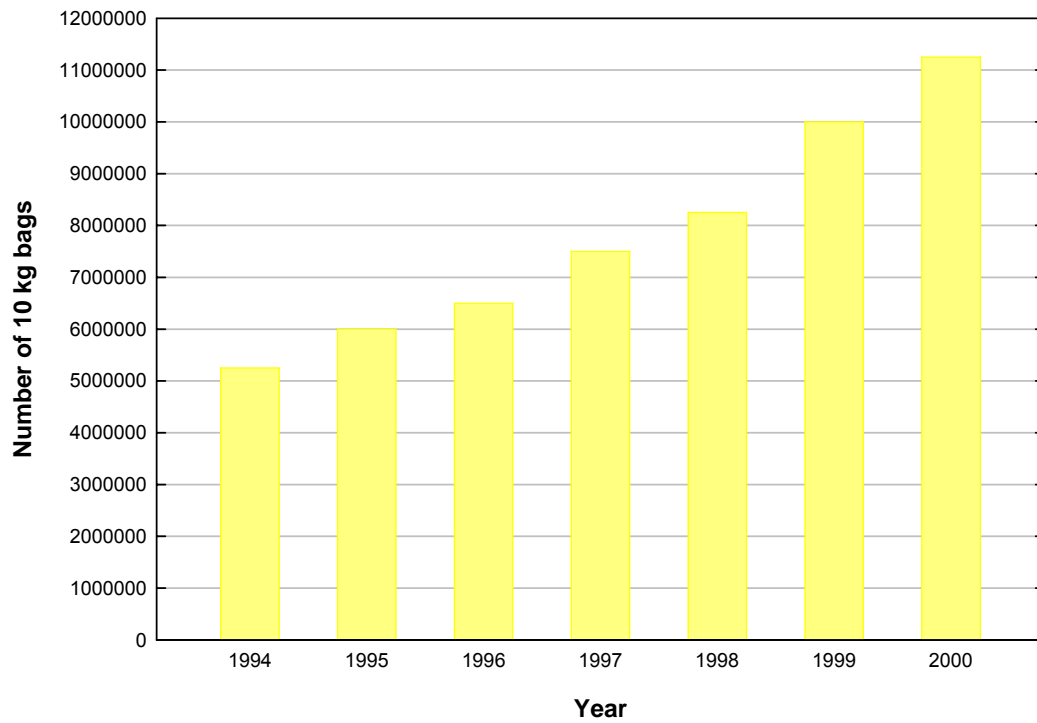


Figure 1. Frozen French fry consumption over the past decade in South Africa (Anon, 2004a).



B. THE POTATO TUBER

The potato tuber is a thickened underground stem, also described as the storage organ of the vegetative plant (Leszczyński, 1989a). The tuber is divided into a bud-end and stem-end region with the stem-end situated on the stolon of the potato plant (Fig. 2). These two regions differ in their chemical composition and cultivars can be distinguished from each other by the chemical composition of their stem-ends (McComber *et al.*, 1987; McComber *et al.*, 1988).

The outer skin of the potato tuber, known as the periderm protects the tuber tissue against moisture loss and fungal infections and plays no role in the storage of starch (Talbert *et al.*, 1987b). The periderm is white to yellow brown or reddish in colour depending on the carotenoid and anthocyanin concentrations (Burton, 1989; Storey & Davies, 1992). The thickness of the periderm varies between cultivars and is also influenced by the environmental conditions during growth (Smith, 1977). Small indents in the periderm, known as eyes, are spirally arranged around the tuber occurring more frequently in the bud-end region (Talbert *et al.*, 1987b; Leszczyński, 1989a). Each eye contains a scale leaf and three axillary buds and upon sprouting of the tuber the eyes in the bud-end region first resume growth (Cutter, 1992). Lenticels are formed in the periderm and are visible as circular craters on the surface (Burton, 1989; Cutter, 1992). These lenticels are pores that facilitate gas exchange and can allow the entry of pathogens (Adams, 1975).

The periderm is underlined by the cortex, a narrow strip of tissue that store starch (Smith, 1977). The cortex covers the vascular storage parenchyma that is the principle region of starch storage. A vascular ring consisting of xylem and phloem is present within the storage parenchyma (Talbert *et al.*, 1987b). The largest amount of starch is found in the thin layer of storage parenchyma between the cortex and the vascular ring (Johnston *et al.*, 1968).

The pith, also known as the water core, is found in the centre of the potato tuber and consists of large cells with a low starch and high water content and is translucent in appearance (Smith, 1977; Talbert *et al.*, 1987b). The pith and inner most storage parenchyma are grouped together and constitute the medulla (Burton, 1989). Thin branches of medullary parenchyma spread from the pith area to the eyes (Burton, 1989; Leszczyński, 1989a).

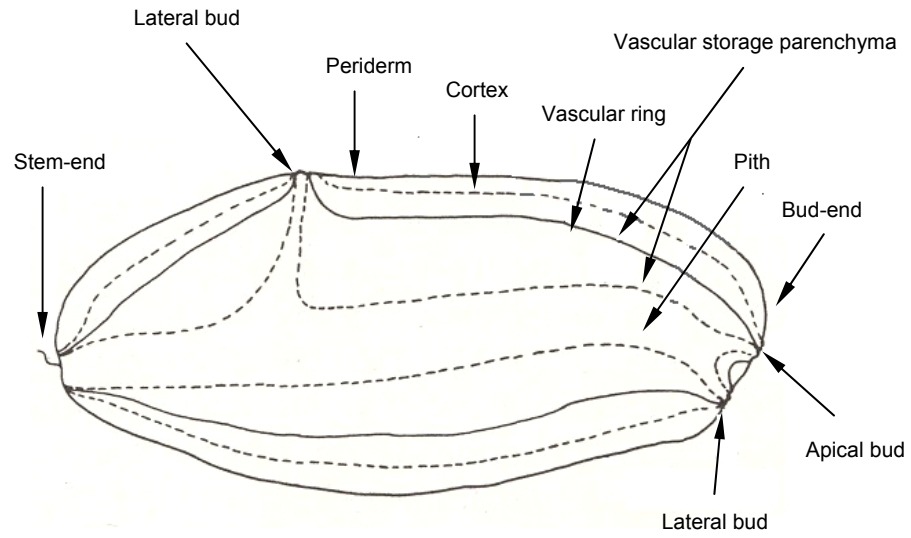
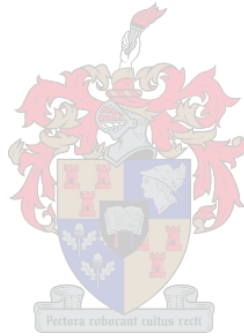


Figure 2. A longitudinal section of the potato tuber indicating the different tissue layers (Talbert *et al.*, 1978b).



C. CHEMICAL COMPOSITION

The potato is a good nutritional source of carbohydrates, proteins, vitamins and minerals (Burton, 1989). The main chemical constituents will be discussed in the following sections.

Moisture and dry matter content

Approximately 75% (m/m) of the fresh weight of the potato tuber consists of water (Leszczyński, 1989a). Eighty percent of the water is free water acting as a solvent for small hydrophilic compounds. This free water, together with the dissolved substances make up the juice of the potato.

The dry matter content of the tuber consists of starch, sugars, proteins, lipids and ash (Leszczyński, 1989a). Starch is the main component of the dry matter (between 60 and 80% (g.100 g⁻¹ dry mass)) and the starch content is generally indicated by the dry matter content of the potato (Leszczyński, 1989a). The starch content can rapidly, reliably and non-destructively be measured by the specific gravity of the tuber, due to the correlation between the specific gravity and the dry matter content (Whittenberger, 1951; Schippers, 1976; Burton, 1989; Kumlay *et al.*, 2002). The specific gravity of the potato tuber is measured by the flotation of the tubers in different concentrations of saline solution (Dalton, 1981). Specific gravity is then calculated as weight in air / (weight in air – weight in water) (Thybo *et al.*, 2003). This method is preferred over the gravimetric method for determining dry matter content, since the sample is not destroyed and less time is needed for the measurement (Thybo *et al.*, 2003).

Determination of the specific gravity prior to processing is of great importance as it gives an indication of the textural quality of the end-product (O'Beirne & Cassidy, 1990; Van Marle *et al.*, 1997; Thybo *et al.*, 2000; Thygesen *et al.*, 2001). This measurement determines the correct use of the raw material and possible adjustments to the processing procedure to achieve the optimal product quality (Linehan & Hughes, 1969a; Schippers, 1976; McComber *et al.*, 1994; Thygesen *et al.*, 2001; Thybo *et al.*, 2004). A high dry matter content, and thus a high starch content, indicated by a specific gravity above 1.080 is ideal for French fry production (Dalton, 1981; Lisińska, 1989a; L Slabber, Lamberts Bay Foods, personal communication). During pre-frying of high

specific gravity tissue, less oil is absorbed and moisture loss is limited resulting in higher fry yields (Lisińska, 1989a). A high specific gravity also results in a mealy texture in the heat processed potato tissue (Linehan & Hughes, 1969a; Schippers, 1976). This mealy texture is creamy, dry and granular, with visible starch particles and a glossy appearance, which produces the ideal French fry (Bettelheim & Sterling, 1955; Dalton, 1981; McComber *et al.*, 1988).

Starch

Starch is synthesised in the amyloplasts that are specialised plastids containing starch synthesising enzymes (Burton, 1989; Christensen & Madsen, 1996). Amyloplasts with the synthesised starch and surrounding membrane form the starch granules in the starch containing cells, the leucoplasts (Burton, 1989; Leszczyński, 1989b). Starch granules are spherical to oval shaped and 5 – 100 μm in diameter. The starch granule consists of starch (60 – 80%), water (13 – 21%) and trace amounts of organic and mineral substances, inclusive of crude protein (0.05 – 0.08%), lipids (0.02 – 0.04%), phosphorous (0.06 – 0.09%), calcium (0.058%), potassium (0.018%), sodium (0.008%) and silicon (0.069%) (Palasiński, 1969).

Potato starch is composed of two polysaccharide components, namely amylose and amylopectin (Smith, 1977; Burton, 1989). Amylose is a linear polymer of glucose residues linked by α -1, 4-glucosidic linkages. Amylopectin is a similar glucose polymer, but differ from amylose in being highly branched by α -1, 6 linkages (Smith, 1977; Burton, 1989). Amylopectin chains form crystals in the starch granule, while amylose is mainly amorphous (Svegmark *et al.*, 2002). Amylose and amylopectin occur in the tuber in a 1:3 ratio. Variations in this ratio can influence several of the functional properties of the starch, such as the gelatinisation temperature, swelling potential and peak viscosity (Fredriksson *et al.*, 1998; Noda *et al.*, 2004). A high amylose content inhibits the extent to which starch swells during gelatinisation, influencing the viscosity of the resulting starch paste (Smith, 1977; Noda *et al.*, 2004).

Potato starch is unique compared to rice, wheat and maize starch, as it has a larger granule size, longer amylose and amylopectin chains, a higher degree of phosphate esterification on the amylopectin molecules and a better swelling potential. Potato starch also has the ability to exchange cations including calcium and magnesium

exercising an influence on the viscosity of the gelatinised starch and the ability to form a viscous gel when exposed to heat with subsequent cooling (Hizukuri *et al.*, 1970; Swinkels, 1985; Leszczyński, 1989b; Vasanthan *et al.*, 1999).

The process of gelatinisation of potato starch describes the changes that occur in the structure of the starch granule, the swelling of the granule and increased solubility and gel formation of the starch when subjected to heat (Leszczyński, 1989b; Fredriksson *et al.*, 1998). Potato starch starts to gelatinise at temperatures between 60° – 65°C, depending on the size of the starch granule and the cultivar (Burton, 1989; Hermansson & Svegmarm, 1996; Fonck & Van Nuffel, 2003). When starch granules are exposed to this temperature range, the granules start to swell as water diffuses into them from the surrounding areas until an internal water content of 20 – 30% is reached (Smith, 1977; Burton, 1989; Leszczyński, 1989b). The swollen starch granules have an outward pressure on the cell walls of the leucoplasts. As the temperature range increases to 80° – 85°C the granules continue to swell with increased pressure on the cell walls (Leszczyński, 1989b; Fonck & Van Nuffel, 2003).

During swelling a highly viscose starch gel is formed within the granules with approximately 30% of the amylose in a solution (Leszczyński, 1989b). As amylose molecules are in the amorphous phase and contains weaker bonds than amylopectin, it gelatinises more easily (Leszczyński, 1989b; Svegmarm *et al.*, 2002). Small amounts of these soluble, linear molecules are able to diffuse through the granule membrane due to the outwards pressure of the swollen granule (Hermansson & Svegmarm, 1996; Svegmarm *et al.*, 2002). As the rising temperature exceeds the end-point of gelatinisation (>85°C) all the amylose molecules are in solution and the amylopectin fraction eventually becomes soluble (Hollo *et al.*, 1959). Starch loses its granular structure and results in a viscose, homogenous paste contained in the leucoplasts that stay intact throughout the cooking process (Hollo *et al.*, 1959, Hermansson & Svegmarm, 1996). On subsequent cooling amylose crystallises, forming gels or aggregated structures in a process known as retrogradation (Hermansson & Svegmarm, 1996; Fredriksson *et al.*, 1998; Svegmarm *et al.*, 2002).

The composition of the starch granule changes during the physiological development of the potato tuber. The starch content and granule size increase with the increasing maturity of the tuber, while the gelatinisation temperature of the starch

decreases (Smith, 1977; Reust & Escher, 1979; Christensen & Madsen, 1996; Liu *et al.*, 2003).

The physical and chemical properties of potato starch are determined by the cultivar, environmental conditions during growth and maturity of the tuber at the time of harvest (Wiesenborn *et al.*, 1994; Cottrell *et al.*, 1995; Kim *et al.*, 1995; Christensen & Madsen, 1996; Lui *et al.*, 2003; Noda *et al.*, 2004). These physicochemical properties include the size of the starch granules, the amylose concentration, the degree of branching of the amylopectin and the amount of covalently-bound phosphate in the amylopectin molecules (Christensen & Madsen, 1996; Lui *et al.*, 2003; Noda *et al.*, 2004). These physical and chemical properties of the starch, as well as the distribution of the starch in the different tissue layers of the tuber have a significant influence on the functional properties of the starch and the resulting textural quality of the heat processed tissue (Linehan & Hughes, 1969b; Burton, 1989; Cottrell *et al.*, 1995; Christensen & Madsen, 1996; Liu *et al.*, 2003; Noda *et al.*, 2004).

Of all the organic and mineral substances contained within the starch granule only phosphorous is covalently bound to the starch, more specifically to the amylopectin (Swinkels, 1985; Christensen & Madsen, 1996; Noda *et al.*, 2004). These bound phosphorous groups are mainly present as glucose-6-phosphate with the remaining phosphorous groups present as glucose-2-phosphate and glucose-3-phosphate (Hizukuri *et al.*, 1970). Wiesenborn *et al.* (1994) and Jacobsen *et al.* (1998) found that a higher phosphorous content leads to an increased viscosity of the gelatinised starch and a decrease in the gelatinisation temperature. Therefore, phosphorous plays a determining role in the quality of potato starch and tissue texture after heat processing. The amount of phosphorus increases when environmental and soil temperatures are low during tuber development and when the time of harvesting is delayed (Christensen & Madsen, 1996; Noda *et al.*, 2004).

Sugars

The sugar content of the potato tuber consists mainly of the non-reducing disaccharide, sucrose and the reducing monosaccharides, glucose and fructose (Leszczyński, 1989a). The reducing sugars are unevenly distributed throughout the potato tuber, compared to the even distribution of sucrose. The cortex is found to

contain the highest amount of reducing sugars, while very low levels are detected in the stem-end region (Weaver *et al.*, 1978).

The content of reducing sugars in the tuber is important in the intensity of frying colour in potato products (Marquez & Añon, 1986; Burton, 1989; Brown *et al.*, 1990; Pritchard & Adam, 1994). Glucose and fructose are both involved in the non-enzymatic Maillard reaction during high temperature frying of the potato tissue with a resultant undesirable dark discolouration when these sugars are present at high levels (Baltes, 1982; Ashoor & Zent, 1984). Non-reducing sugars also contribute to this discolouration through similar non-enzymatic browning reactions (Leszkowiat *et al.*, 1990).

Pectic substances

The non-starch polysaccharides contained within the potato tuber are cellulose, hemicellulose and pectic substances (Talbert *et al.*, 1987b). The potato tuber cells are surrounded by a cell wall consisting of hemicelluloses and celluloses imbedded in a pectic matrix (Burton, 1989). The middle lamella between two adjacent cells consists of a pectic layer acting as the intercellular adhesive. This layer contains the polysaccharide component, galacturonic acid, and is strengthened with calcium and magnesium bridges (Burton, 1989).

Pectic substances are divided into three groups: protopectin, soluble pectin and pectic acid (Talbert *et al.*, 1987b; Burton, 1989). Protopectin is associated with the cell wall structure and is insoluble, highly polymerised with a low degree of methylation among the carboxyl groups (Leszczyński, 1989a). With increasing maturity and prolonged storage of the potato tuber and upon heat processing of the potato tissue, protopectin is partially depolymerised to soluble pectin (Smith, 1977; Leszczyński, 1989a). Pectic acid is the main source of calcium and magnesium cations in the cell wall and middle lamella and is present as calcium or magnesium salts that have a strengthening effect on the cell and tuber tissue (Talbert *et al.*, 1987b; Leszczyński, 1989a).

D. THE EFFECT OF ENVIRONMENTAL AND STORAGE CONDITIONS

The chemical composition of the potato is affected by many factors, including cultivar, growing season, location, soil temperature, soil water quality, fertilisation, as well as the

duration and conditions of storage (Burton *et al.*, 1992; Kumlay *et al.*, 2002). Fluctuations in the chemical composition of potato tubers have a major impact on processing suitability and quality (Iritani, 1981; Burton *et al.*, 1992; Shock *et al.*, 1993; Kumlay *et al.*, 2002).

Reducing sugars

The cultivation region, stress conditions during tuber development, as well as storage conditions play an important role in the accumulation of excess reducing sugars (Shock *et al.*, 1993; Eldredge *et al.*, 1996). High temperatures and limited water availability during tuber development, followed by storage at temperatures below 10°C, leads to the accumulation of reducing sugars to levels higher than the optimum (Burton & Wilson, 1970; Cottrell, 1995; Eldredge *et al.*, 1996).

A high level of reducing sugars in the potato tuber and a resultant undesirable dark fry colour is generally associated with sugar-end defect (Isherwood, 1973; Burton, 1989). According to Sowokinos *et al.* (2000) tubers with sugar-end defect contain low levels of starch and sucrose and high levels of glucose. Water stress in the early stages of tuber growth promotes the development of sugar-end in the stem-end region of the tuber, while late season water stress gives rise to sugar-end in the bud-end region (Iritani, 1981). Reducing sugar accumulation induced by stress only becomes apparent after harvesting and storage of the mature tuber (Eldredge *et al.*, 1996).

Four factors contributing to the accumulation of reducing sugars in potato tubers after harvesting have been identified. This includes immaturity of the tubers at harvesting; rapid sprouting of tubers during storage; low temperature storage prior to processing; and senescence (Iritani, 1981; Weaver & Timm, 1983; Storey & Davies, 1992). The accumulation of reducing sugars during postharvest storage is dependent on the storage temperature and cultivar (Talbert *et al.*, 1987b; Hertog *et al.*, 1997). Cultivars with a low specific gravity accumulate more sugars during storage than cultivars with a high specific gravity (Talbert *et al.*, 1987b). A higher sugar accumulation is also observed in cultivars with rapid sprout growth (Storey & Davies, 1992).

Cold storage can inhibit sprouting, but leads to cold-induced sweetening. During storage at temperatures below 10°C, endogenous amylolytic enzymes convert starch to reducing sugars with an increase in the rate of accumulation as the temperature decreases (Schwimmer *et al.*, 1954; Smith, 1977; Smith, 1987; Talbert *et al.*, 1987b;

Burton, 1989; Brown *et al.*, 1990). When reducing sugars accumulate to levels higher than the optimum, the process is known as cold-induced sweetening. Fructose accumulates more rapidly than glucose, while little of the non-reducing sugar, sucrose is accumulated (Smith, 1977). Cold-induced sweetening can be reversed by the conditioning of affected tubers at a temperature range of 10° – 20°C applied for 2 – 3 weeks (Burton, 1989; Lisińska, 1989a).

Storage of unsprouted tubers for prolonged periods at higher temperatures (5 – 6 months at 10° – 20°C) leads to senescent sweetening (Burton, 1989). Senescent sweetening is accompanied by changes in and breakdown of the amyloplast membrane (Isherwood & Burton, 1975; Isherwood, 1976; Kozempel *et al.*, 1982). The rate at which this type of sweetening occurs is dependent on the cultivar and environmental conditions to which the tuber was exposed during physiological development (Dwelle & Stallknecht, 1978). Although senescent sweetening in contrast to cold-induced sweetening is irreversible, the breakdown of the tissue makes the leaching of reducing sugars possible during blanching (Isherwood, 1976). The decreased reducing sugar levels in this instance will improve the colour quality of the final fried product, but a poor texture is expected due to the disrupted tissue.

Starch

Preferential enzymatic hydrolysis of large starch granules during prolonged storage of tubers leads to increased levels of small sized starch granules (Golachowski, 1985). The smaller starch granules enhance the gelling capacity of the starch, leading to increased tissue firmness during heat processing (Jane & Shen, 1993). A larger proportion of small starch granules is therefore characteristic of a waxy texture and is not ideal for French fry processing (Briant *et al.*, 1945; Lisińska, 1989a).

Short periods of unfavourable environmental conditions during the development of the potato tuber induce secondary growth (Ewing, 1981; Veerman & Van Loon, 1995). The products of photosynthesis are first used for vegetative growth of the potato plant and then diverted to the growth of the tuber (Burton, 1989). If the environment changes, as is the case during short periods of high temperature and water stress, these photosynthesis products are diverted back to vegetative growth. Secondary growth can be seen as renewed tuber growth in the bud-end of the tuber and occurs when the environment changes back to conditions favouring tuberisation (Burton, 1989). During

this re-growth, starch is mobilised in the stem-end and translocated to the region of new growth, depleting the stem-end of its starch content (Iritani & Weller, 1973; Burton, 1989). This gives rise to a defect described as glassy or translucent-end tuber. The affected part of the tuber has a translucent appearance and contains little or no starch, with a low specific gravity and high levels of reducing sugars (Van der Zaag, 1958; Marinus & Bodlaender, 1975; Iritani, 1981). The uneven distribution of starch in the tuber leads to an unacceptable texture and uneven distribution or lack of mealiness in the French fry strip (Iritani, 1981; Agblor & Scanlon, 1998).

Lugt (1960) observed glassiness not only in secondary tubers, but also in primary tubers and characterised it as tissue that remained hard even when cooked for up to one hour. As in the case of secondary translucent-end tubers, the affected regions in the primary tubers contain little starch and a low specific gravity (Lugt, 1960). The glucose content was found to be high in the affected glassy areas indicating that the absence of starch is due to the hydrolysis of the starch to sugars (Smith & Davis, 1963a). In certain cultivars, tubers with a specific gravity below 1.055 are glassy and the defect is easily detected by separations of the tubers according to specific gravity (Van der Zaag, 1958).

Other factors

Environmental stress during tuber development may also lead to uneven growth that cause growth cracks, hallow heart and misshaped tubers (Iritani, 1981). Water deficiency that persists throughout the entire growing season of the crop will reduce tuber yield, size and quality (Hane & Pumphrey, 1984).

E. EFFECT OF HEAT PROCESSING ON POTATO TISSUE

Three changes occur when potato tissue is exposed to heat: Starch becomes gelatinised; the cell walls are weakened with an increased permeability; and intercellular adhesion between adjacent cells is reduced resulting in a softening of the tissue (Linehan & Hughes, 1969a; Burton, 1989; Fredriksson *et al.*, 1998). The weakening of the cell walls and increased permeability is the result of the partial de-polymerisation of protopectin to soluble pectin (Leszczyński, 1989a; Binner *et al.*, 2000). The de-polymerisation of the protopectin is due to the β -eliminative mechanism as the cell wall

is hydrated during heat processing (Jarvis & Duncan, 1992; Jarvis *et al.*, 1992). The soluble pectin becomes dissolved in the hydrated cell wall and the concentration of the protopectin is reduced (Hughes *et al.*, 1975a).

Gelatinised starch is contained within the weakened cell walls, causing a 4% expansion of the cell as a result of the increasing internal pressure (Burton, 1989; Jarvis *et al.*, 1992). Intercellular adhesion between adjacent cells is reduced due to the breakdown of calcium and magnesium bridges in the middle lamella (Smith, 1977; Binner *et al.*, 2000). The tissue cells become spherical and partially unattached, resulting in cooked potatoes with a mealy texture (Fig. 3 and 4) (Smith, 1977; Burton, 1989; Freeman *et al.*, 1992; Binner *et al.*, 2000).

In the presence of calcium the cell walls are not weakened during heat processing (Warren & Woodman, 1974; Agblor & Scanlon, 2002). High concentrations of calcium ions present in the cell surroundings, strengthens the cell walls against the outwards pressure of the gelatinising starch (Bettelheim & Sterling, 1955; Keijbets *et al.*, 1976). Most of the calcium contained within the tissue is present in the starch granules (Smith, 1977). When the cells have a high starch content, the availability of the calcium ions are decreased (Smith, 1977). This improves the mealy texture and partly explains the correlation between a high starch content and mealiness.

The firmness of the tissue is increased by delaying the solubilisation of protopectin at temperatures between 88° – 100°C (Reeve, 1972; Keijbets *et al.*, 1976). At a pre-cooking temperature range of 50° – 70°C both the divalent cations, calcium and magnesium, have a firming effect (Haydar *et al.*, 1980; Dalton, 1981; Tzeng *et al.*, 1986). The firming of the cell wall at the mentioned pre-cooking temperature range is ascribed to the de-esterification of the cell wall pectin by pectin methyl-esterase (PME) (Bartolome & Hoff, 1972; Taylor *et al.*, 1981). After de-esterification, pectin contains carboxyl groups that are free to react with calcium and magnesium ions, forming more rigid structures and promoting the firmness of the tissue (Linehan & Hughes, 1969b; Hughes *et al.*, 1975a; Binner *et al.*, 2000).

When PME activity is restricted at temperatures above 70°C, the occurrence of a mealy texture is increased (Bartolome & Hoff, 1972). When the chelating agent, phytic acid is present in the potato tissue, the calcium and magnesium ions become unavailable for the formation of rigid structures and the tissue firmness is decreased during heat processing (Thygesen *et al.*, 2001).

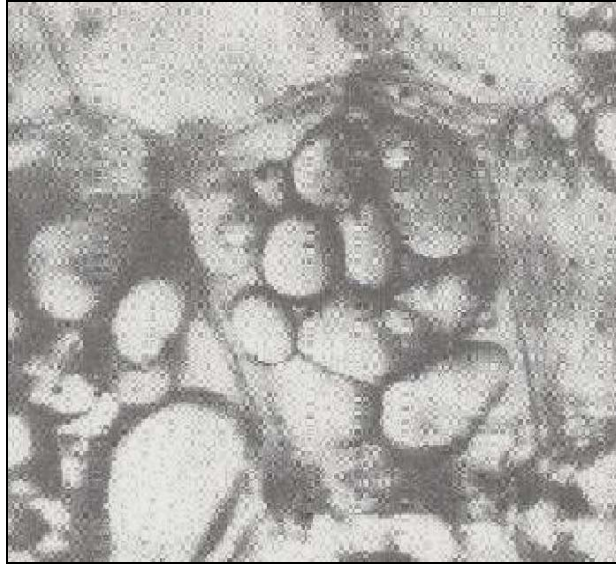


Figure 3. Intercellular adhesion between cells of the raw potato tissue containing the starch granules (Burton, 1989).

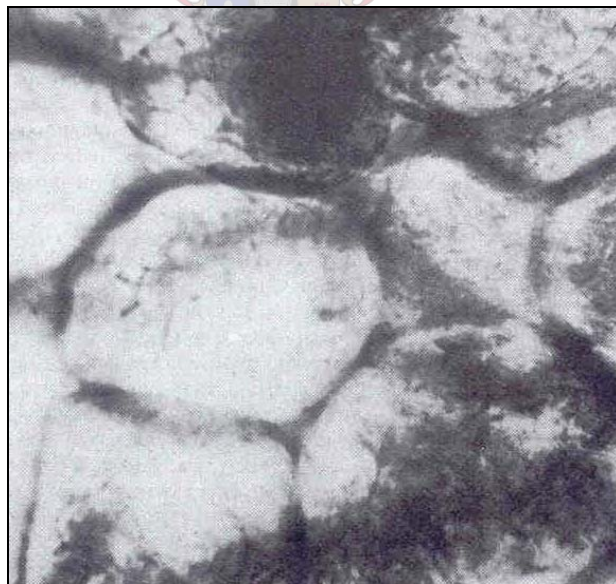


Figure 4. Spherical cell structure of mealy potato tissue engorged with gelatinised starch after heat processing (Burton, 1989).

The monovalent ions, sodium and potassium show the opposite effect to calcium and magnesium by weakening the cellular structure during heat processing (Hughes *et al.*, 1975a; Hughes *et al.*, 1975b). In the presence of these ions, pectic substances become more susceptible to solubilisation due to the extraction of calcium ions from the pectin, either through ion exchange or the breakage of hydrogen bonds.

Raw potato tissue resulting in a mealy texture when heat processed contains larger cells with larger starch granules and a low pectic content (Smith, 1977; McComber *et al.*, 1994). The larger cells and starch granules in tubers with a mealy characteristic contribute to a higher specific gravity and partially explain the relationship that exists between specific gravity and mealiness (Smith, 1977). When this tissue is exposed to heat the cells are entirely filled with gelatinised starch. These starch filled cells show better water retention, leading to the characteristic dryer mouthfeel of the mealy tissue (McComber *et al.*, 1994). In contrast to a mealy texture, a texture described as waxy can be found. The latter contains cells maintaining their raw shapes and staying attached after heat processing (Fig. 5) (Burton, 1989). The raw cells of waxy tubers are small in size with a high percentage of small starch granules (Briant *et al.*, 1945). During heat processing, the cell walls do not weaken and intercellular adhesion is not reduced to the extent of ensuring the separation of cells (Burton, 1989). The cells are also filled with less gelatinised starch (McComber *et al.*, 1994). Tubers with a specific gravity between 1.055 and 1.065 have been found to have a waxy textural characteristic (Van der Zaag, 1958; Anon., 2004c). Instead of the desired creamy, dry mouthfeel experienced with a mealy texture a waxy texture is moist, smooth and gummy (Charley, 1982; McComber *et al.*, 1988). Waxy potatoes can be used for commercial products where cohesiveness is important for example potato salad, canning or boiling (Charley, 1982).

F. FRENCH FRY PROCESSING

The production of frozen French fries includes the following processes: blanching, drying, partial frying and freezing (Talbert *et al.*, 1987a; Burton, 1989; Lisińska, 1989a). Each step in the production line contributes to the quality of the final French fry in terms of texture, colour, oil absorption and structural integrity (Talbert *et al.*, 1987a; Burton, 1989; Lisińska, 1989a). Variations in the chemical composition of cultivars and tubers

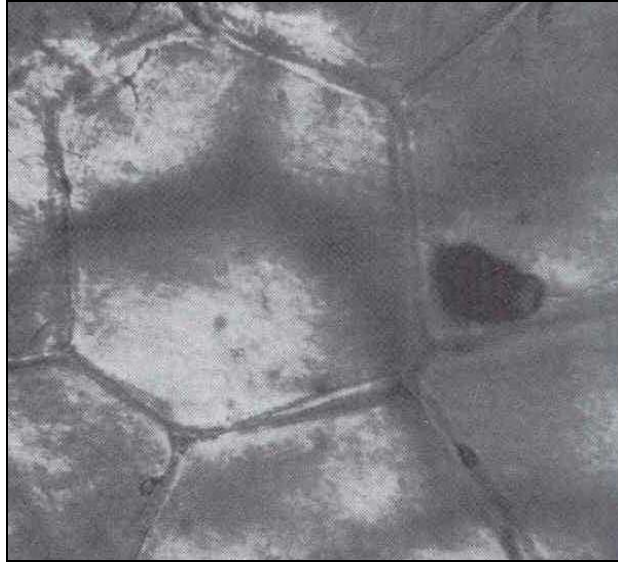


Figure 5. Angular cell structure of waxy potato tissue containing little gelatinised starch after heat processing (Burton, 1989).



from the same crop or plant make the production of a high quality and uniform product challenging (Iritani, 1981; Agblor & Scanlon, 2000; Thygesen *et al.*, 2001; Agblor & Scanlon, 2002). By mixing good and poor quality raw material, the minimum specifications for an acceptable French fry product can be met. By adjusting the parameters of each processing step, French fries with less variation in textural and colour quality can be produced.

Blanching

The pre-heating procedure during frozen French fry processing involves a low-temperature long-time (LTLT) blanching step in steam or water at a temperature range of 60° - 85°C for 20 - 40 min (Agblor & Scanlon, 1998). The exact time and temperature set are largely determined by the reducing sugar content and textural characteristics of the specific cultivar (L Slabber, Lamberts Bay Foods, personal communication). At the pre-heating temperature range starch is partially gelatinised, but intercellular adhesion stays intact. This reduces the final preparation time of the product and improves the firmness of the tissue due to the formation of rigid structures by the enzyme, PME, and the presence of calcium ions (Bartolome & Hoff, 1972; Talburt *et al.*, 1987a; Burton, 1989; Lisińska, 1989a; Aquilar *et al.*, 1997).

Blanching at LTLT conditions have advantages. Textural differences that may exist in fries made from different sections of the tuber or due to uneven distribution of the dry matter in the tuber are reduced, creating textural uniformity (Scanlon, 2004). The long time period of submersion in the water during LTLT blanching also allows for leaching out of excessive reducing sugars from the tissue, resulting in a better end-product frying colour (Kaymak & Kincal, 1994). LTLT conditions prevent excessive oil absorption during subsequent frying process by the gelatinisation of starch contained within the thin tissue layer on the surface of the French fry strip (Talburt *et al.*, 1987a).

Several adjustments can be made to this blanching step to improve the quality of the final French fry. When very low levels of reducing sugars are present in the raw material, dextrose is added to the blanching water to improve the colour quality of the final fried product (Burton, 1989). Calcium or magnesium salts can also be added to the water to improve the firmness of the tissue (Smith, 1977; Lisińska, 1989a). The addition of sodium acid pyrophosphate (SAPP) prevents the grey discolouration of the tissue

after blanching due to oxidation and improves mealiness to some extent (Smith & Davis, 1963b; Sapers *et al.*, 1997).

The main difference in the appearance of blanched tissue compared to cooked potato tissue is that, in the case of blanching, the cells remain in the original angular shape and maintain this shape even after processing (Reeve *et al.*, 1968). Therefore, the final textural quality of the French fry can be based on the texture of the fry after blanching (Golubowska, 2005; Reeve, 1972).

Drying

Drying is done in order to remove excess surface water on the fries after blanching. The drying of the tissue prevents excess oil absorption during partial frying as a result of a decrease in the oil temperature (Talbert *et al.*, 1987a).

Partial frying

At the high frying temperatures (170° – 190°C for 2 min), water is evaporated from the tissue and oil is absorbed, replacing the evaporated water (Bunger *et al.*, 2003). The French fry is sealed by the formation of a crisp crust. Oil absorption must be kept to a minimum for economical and health reasons. This can be achieved by sufficient blanching prior to frying and by maintaining optimum oil temperatures (Talbert *et al.*, 1987a).

Oil temperatures and frying duration must be carefully controlled to avoid over cooking during the partial frying step. A dark discoloration due to the Maillard reaction and a thick crust not exceeding the ideal thickness of 1-2 mm must be prevented (Burton, 1989).

Freezing

The internal structure and texture of the French fries are negatively influenced by slow freezing due to the disruption of cellular components as large extracellular ice crystals are formed (Fuchigami *et al.*, 1995). Textural losses and oil absorption during final frying are kept to a minimum when French fries are subjected to quick freezing at -40°C for 10 min (Burton, 1989; Fuchigami *et al.*, 1995). A blast freezer is used in the last step of the production line to achieve these freezing conditions.

G. FRENCH FRY QUALITY

Fry colour and texture are the primary quality characteristics of French fried potatoes (Talbert *et al.*, 1987; Burton, 1989; Lisińska, 1989a). The ideal French fry have a light cream to golden brown crust of 1-2 mm in thickness and a firm, mealy interior with no separation between the crust and the core (Lisińska, 1989a). The colour of the French fry is determined by the reducing sugar levels in the raw potato and the extent to which the Maillard reaction occurs during high temperature frying (Baltes, 1982; Ashoor & Zent, 1984). A reducing sugar content between 0.2 – 0.5% of the fresh weight will produce a French fry with a good colour quality (Burton & Wilson, 1970; Cottrell *et al.*, 1995).

The texture is affected by the starch content and cell wall components of the potato tuber as indicated by the specific gravity (Smith, 1977; Talbert *et al.*, 1987a; Burton, 1989; McComber *et al.*, 1994; Golubowska, 2005). Several predictions can be made directly from the specific gravity of a potato tuber and this measure is often used in the industry to sort potatoes into textural quality groups prior to processing (O'Beirne & Cassidy, 1990; Van Marle *et al.*, 1997; Thybo *et al.*, 2000; Thygesen *et al.*, 2001).

H. CONCLUSION

The internal quality differences that exist in potatoes from different locations and cultivars impose great challenges upon the French fry processing industry. Combined with this, the awareness of food quality by the consumer is increasing, thereby emphasising the importance of producing a product of high and uniform quality.

Environmental conditions have a major influence on the chemical composition of potatoes and the resulting quality of French fries (Iritani, 1981). Apart from manipulating the processing conditions during French fry production thereby increasing colour, textural quality and fry yield, little can be done to decrease the effect of unfavourable environmental conditions on the quality of the raw material and thus on the eventual end-product. Through improvements in technology, an increasing control can be placed on environmental conditions during tuber growth to decrease the deterioration effect of environmental stress on the quality and yield of potatoes (Agblor & Scanlon, 2002). Possible improvements include modifications of agricultural practices, adjustments in

growth patterns and the development of new cultivars that are less sensitive to changes in the environment (Iritani, 1981). The selection of potatoes for specific production practices and control of storage conditions could also assist in improving the consistency of the end-product quality (Agblor & Scanlon, 2002).

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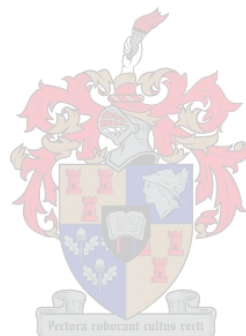
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CHAPTER 3

RELATIONSHIP BETWEEN THE CHEMICAL COMPOSITION OF POTATOES CULTIVATED IN DIFFERENT AREAS OF THE SOUTH AFRICAN SANDVELD AND THE “GLASSINESS” DEFECT IN FROZEN FRENCH FRIES

Abstract

A textural defect known as “glassiness” is found in South African frozen French fries. The aim of this study was to determine the chemical composition of five potato cultivars cultivated in five different areas in the Sandveld region and to determine if a relationship exists between these chemical components in the potato tuber and the “glassiness” defect in frozen French fries. No significant differences occurred in the moisture ($p=0.10$, trial 1 and $p=0.15$, trial 2), starch ($p=0.76$, trial 1 and $p=0.70$, trial 2) and reducing sugar ($p=0.05$, trial 1 and $p=0.51$, trial 2) content of samples with and without the “glassiness” defect. The cultivar Herta had the lowest occurrence of the defect (23%, trial 1 and 0%, trial 2) and the cultivar Columbus the highest (70%, trial 1 and 84%, trial 2). All samples cultivated in the Parys area during trial 1 showed a significantly lower occurrence of “glassiness” ($p=0.01$) than samples obtained from the areas Uitvlug and Zandrug. During trial 2 all samples obtained from the Thaaibos area showed a lower occurrence of the defect than samples obtained from the area Witklip, although this difference was not statistically significant ($p=0.06$). Modified blanching conditions of 62°C for 25 min reduced the occurrence of “glassiness” in the cultivars Fianna ($p=0.06$), Pentland Dell ($p=0.05$) and Columbus ($p<0.01$). The stem-end section of all potato samples was scanned by means of Fourier transform near infrared (FT-NIR) spectroscopy. Principal component analysis (PCA) indicated no classification between samples with and without the “glassiness” defect. Calibration models for moisture, starch and reducing sugar content were developed using the raw data and showed a standard error of prediction (SEP) of 1.62%, 2.28% and 0.07% respectively. The respective correlation coefficients (r) of these calibration models were 0.46, 0.42 and 0.41.

Introduction

Texture and frying colour are the most important quality aspects of commercially processed French fried potatoes (Talbert *et al.*, 1987a; Burton, 1989; Lisińska, 1989). Potatoes with a high starch content, high specific gravity (SG) and low levels of reducing sugars are required for the production of good quality French fries (Talbert *et al.*, 1987a; Lisińska, 1989; Shock *et al.*, 1993; Eldredge *et al.*, 1996; Thygesen *et al.*, 2001; Thybo *et al.*, 2003). A SG higher than 1.080 and a reducing sugar level between 0.2 – 0.5% (m/m) of the fresh weight will ensure the production of the ideal French fry (Dalton, 1981; Lisińska, 1989; Shock *et al.*, 1993; Cottrell *et al.*, 1995). Changes in the concentration of these components will have a major impact on the processing suitability of the potato. These changes in the chemical composition of the potato can be caused by various environmental conditions including cultivar, season, soil temperature, cultivation region, soil water quality, fertilisation, as well as the duration and conditions of storage (Burton *et al.*, 1992; Kumlay *et al.*, 2002).

A defect known as translucent-end or glassy tuber is described in literature (Iritani & Weller, 1973; Burton, 1989). The occurrence of this defect is mainly ascribed to secondary re-growth of the potato tuber when stress conditions during the physiological growth of the tuber are reduced (Ewing, 1981; Veerman & Van Loon, 1995). Translucent-end tubers have regions containing little or no starch, areas with low SG and high levels of reducing sugars resulting in an uneven texture and colour of the French fry strip (Marinus & Bodlaender, 1975; Iritani, 1981).

A similar defect described as “glassiness” appears in South African frozen French fries. This defect appears randomly among tubers and is characterised by a hard texture in the cooked French fry. The severe impact of the random appearance of this defect on economical losses in the French fry industry has resulted in the “glassiness” defect being added to the list of quality specifications.

The aim of the study was to determine the moisture, starch and reducing sugar content of the potatoes harvested from five different areas in the Sandveld region and to investigate the possible relationship between these parameters and the “glassiness” defect. Furthermore, the possible detection of “glassiness” prior to processing by means of Fourier transform near infrared (FT-NIR) spectroscopy and the influence of different

blanching conditions during frozen French fry production on the occurrence of “glassiness” were investigated.

Materials and methods

Sample and variable selection

Trial 1

Four potato cultivars (Pentland Dell (Pen), Fianna (Fia), Columbus (Col) and Herta (Her)) that were harvested at a shallow and deep soil depth from three different areas in the Sandveld region, Western Cape, South Africa, were obtained from First Potato Dynamic, Piketberg, South Africa, in July 2003 (Table A1) (Tables A1 – A4 and Figures A1 – A14 are shown in the Appendix). The three areas were represented by the farms Parys, Uitvlug and Zandrug and mainly differed from each other in terms of soil water qualities. These soil water qualities are expressed as electrical capacity (EC) ($\text{mS}\cdot\text{m}^{-1}$) and were 145, 57 and 25 $\text{mS}\cdot\text{m}^{-1}$ for Parys, Uitvlug and Zandrug, respectively.

Twenty four samples (4 cultivars X 2 depths X 3 areas), consisting of approximately 5 kg potatoes each, were collected and subsequently categorised into high and low SG groups. This was done by separating floating and sinking tubers in a 12% (m/v) NaCl solution according to the method described by Dalton (1981) and Burton (1989). The separations were performed at room temperature as the SG value is characteristic to a salt water solution at 20°C (Burton, 1989). Potato tubers that floated were categorised as the low SG group ($\text{SG} < 1.0857$) and tubers that sunk were categorised as the high SG group ($\text{SG} \geq 1.0857$).

Trial 2

Five potato cultivars (Pen, Fia, Col, Her and Shepody (She)) that were harvested at a shallow and deep depth from two different areas in the Sandveld region were obtained from First Potato Dynamic in January 2004 (Table A2). The two areas were represented by the farms Thaaibos and Witklip and differed from each other and the areas analysed during trial 1 in terms of soil water quality. The EC values for Thaaibos and Witklip were 82 and 178 $\text{mS}\cdot\text{m}^{-1}$, respectively.

Twenty samples (5 cultivars X 2 depths X 2 areas) consisting of approximately 5 kg potatoes each, were collected and subsequently categorised into high, medium and low SG groups. Floating and sinking tubers in a 10% (m/v) NaCl solution were separated at room temperature (Dalton, 1981; Burton, 1989). These floating tubers were categorised as the low SG group ($SG < 1.0707$). Sinking tubers were then subjected to separation in a 12% (m/v) NaCl solution. The tubers that sunk were categorised as the high SG group ($SG \geq 1.0857$). Tubers that floated were categorised as the medium SG group (SG between 1.0707 and 1.0857).

Variables analysed

Area, cultivar, depth and SG were the variables analysed throughout trials 1 and 2. Each combination of these variables represented a sample set of which four repetitions of the analytical procedure were done over a period of two months. Sample sets and repetitions were randomly ordered allowing each an equal storage duration at 12°C (Table A3 and A4). With the first two repetitions of all sample sets completed before the third and fourth repetitions were executed the data could be separated into two storage time groups (storage time 1 and storage time 2) (Table A3 and A4). By doing so, storage time was added as a variable to take into consideration the possible change in the chemical composition of the potato tuber during storage at 12°C for the duration of the analytical period (*ca.* 2 months) (Talbert *et al.*, 1987b; Shock *et al.*, 1993).

Analytical tests performed

Moisture content

A single tuber was randomly selected from the appropriate sample set (represented by area, cultivar, depth, SG and storage time). The unpeeled sample was longitudinally divided into two halves. One half (the other half retained for further tests) was homogenised with a household handblender (Braun Multiquick Advantage) for 2 min at high speed. Five grams of the homogenised sample was dried overnight at 72°C in a vacuum oven (James, 1995). The moisture content was indicated by the difference in weight between the wet and dried sample.

Starch

Approximately 0.4 g of the homogenised sample was used to determine the total starch content. Sample preparation and determination were executed by using the Boehringer Mannheim enzymatic starch kit (AEC Amersham, Germany) and performed according to the manufacturer's instructions. Starch is converted to D-gluconate-6-phosphate, reduced nicotinamide adenine dinucleotide phosphate (NADPH) and H^+ in a three step enzymatic hydrolyses process. NADPH concentration was estimated through absorbency measurements at 340 nm in a Spectronic® 20 Genesys™ spectrophotometer.

Reducing sugars

Reducing sugar content was determined according to a modified colorimetric dinitrophenol method (Anon., 2003). Solution I was prepared by dissolving 7.145 g of 2,4-dinitrophenol (Merck, Cape Town, South Africa) in 230 ml of 5% (m/v) NaOH (Merck) with a magnetic stirrer on a heated plate. To the clear yellow solution 2.5 g phenol (Merck) was added with further heating until the solution was transparent. Solution II was made by dissolving 100 g sodium potassium tartrate (Rochelle salt) (Merck) in 500 ml distilled water. The two solutions were mixed in a volumetric flask and filled with distilled water to 1000 ml.

A dilution series were prepared consisting of 0.28, 0.40, 0.52, 0.60, 0.72 and 0.80 mg glucose. ml^{-1} using a 1% (m/v) glucose solution. Two millilitres of the dinitrophenol reagent was added to one millilitre of each of the serial glucose solutions, as well as to one millilitre distilled water (the control), mixed thoroughly and heated in a boiling waterbath for 15 min. After cooling, the absorbion of each glucose solution was measured at 600 nm in a Spectronic® 20 Genesys™ spectrophotometer. A linear regression graph was compiled for the serial glucose solutions and their respective absorbencies.

The juice of the remaining homogenised sample was drained by means of a muslin cloth and used to determine the reducing sugar content. Two millilitres of this potato juice were centrifuged at 3000 rpm for 10 min (Eppendorf Centrifuge 5415 D). The supernatant and distilled water were used to make 1:3 and 1:4 dilutions of samples of the first and second storage times, respectively. Two millilitres of the dinitrophenol

reagent was added to one ml of the dilution, mixed in a vortex and heated for 15 min in a boiling water bath. After cooling, the absorbency was measured at 600 nm in a Spectronic® 20 Genesys™ spectrophotometer. The reducing sugar concentration in each potato sample was determined by means of corresponding absorbencies on the standard curves.

Additional tests performed

Fourier transform near infrared (FT-NIR) measurements

The stem-end section of the retained half of the potato sample was scanned using a Perkin Elmer Spectrum IdentiCheck FT-NIR spectrophotometer. Spectral data was collected by reflectance measurement in the near infrared region of 700 nm – 2500 nm at 2 nm intervals (901 data points) using Spectrum IdentiCheck software (version 2.00).

Calibration development

Calibration models were developed from the spectral data using The Unscrambler® 6.11 (CAMO ASA) software package. The total data set (trials 1 and 2) of 268 samples was used to develop calibrations. One third of this data set was selected and used for independent validation. The validation set covered the same variation and reference range as the calibration set with the highest and lowest values included in the calibration set.

Principal component analyses (PCA) were performed for three wavelength ranges (700 nm – 2500 nm, 700 nm – 1100 nm and 1100 nm – 2500 nm) on the raw data set to evaluate possible spectral differences between samples with and without the “glassiness” defect. Partial least squares (PLS) regression was done on the three respective wavelength ranges to develop calibration models for the moisture, reducing sugars and starch content. Results obtained by standard analytical methods for moisture, reducing sugars and starch content determination were used as reference data.

The accuracy of the calibration models was evaluated by performance indicators including standard error of prediction (SEP) (Formula 3.1), root mean square error of prediction (RMSEP) (Formula 3.2), bias, coefficient of correlation (r) (Formula 3.3) and

the ratio of the standard deviation of reference data to SEP (RPD) (Formula 3.4) (Williams, 2001). Where possible, SEP values were compared to the standard error of laboratory (SEL) (Formula 3.5) to determine the predictive potential of the calibration models.

$$SEP = \sqrt{\frac{\sum_{i=1}^n (\hat{y}_i - y_i - bias)^2}{n-1}} \quad \dots 3.1$$

where \hat{y}_i = predicted property of the i^{th} standard of the independent validation sample set
 y_i = actual property of the i^{th} standard
 n = number of spectra
 $bias$ = the average differences between reference and predicted values

$$RMSEP = \sqrt{\frac{\sum_{i=1}^n (\hat{y}_i - y_i)^2}{n-1}} \quad \dots 3.2$$



$$r_{jk} = \frac{\sum x_{ij} x_{jk}}{\sqrt{(\sum x_{ij}^2 \sum x_{jk}^2)}} \quad \dots 3.3$$

where x_{ij} = absorbance value (nm) of the i^{th} wavelength for spectra j
 x_{jk} = absorbance value (nm) of the i^{th} wavelength for spectra k

$$RPD = \frac{SD_x}{SEP} \quad \dots 3.4$$

where SD_x = standard deviation of reference data

$$SEL = \sqrt{\frac{\sum (y_1 - y_2)^2}{2n}} \quad \dots 3.5$$

where y_1 and y_2 = values of duplicate determinations
 n = number of samples analysed

Determination of “glassiness” in samples subjected to industrial blanching conditions

Following the NIR spectroscopy analysis a 13 mm thick strip was removed from the retained half of the sample for determining the presence of the “glassiness” defect. The strip was blanched at 80°C for 20 min in tap water followed by deep fat frying at 180°C for 3.5 min using a household deep fat fryer. The presence of “glassiness” was determined by manually feeling the intensity of hardness in the tissue (L Slabber, Lamberts Bay Foods, Lamberts Bay, South Africa, personal communication). The occurrence of the defect was indicated by a positive or negative score (Yes/No).

Determination of “glassiness” in samples subjected to modified industrial blanching conditions

A total of 163 Fia, 222 Col and 130 Pen samples (unrelated to the samples previously analysed) were analysed under modified blanching conditions. Two adjacent fry strips were taken from the centre of each sample cut along the longitudinal axis of the tuber. One strip was subjected to the industrial blanching conditions as discussed and the other strip was blanched at modified conditions of 62°C for 25 min using tap water. Both blanching conditions were followed by deep fat frying at 180°C for 3.5 min. The presence of “glassiness” was again identified by manually feeling the intensity of hardness of the tissue. The number of observations of “glassiness” present in the fry strips subjected to this modified blanching conditions were statistically compared to the occurrence of this defect in the strips subjected to the industrial blanching conditions.

Effect of modified industrial blanching conditions on the quality of commercially processed frozen French fries

The modified blanching conditions were introduced to the frozen French fry production line in the processing unit at Lamberts Bay Foods (Pty) Ltd, Lamberts Bay,

South Africa, to determine the overall effect of these conditions on the textural quality of the commercially processed frozen French fries. The blanching process in the production line at the plant is presently performed by feeding the product through three blanchers. The conditions that prevailed on the production line for both the industrial and modified blanching methods were as indicated in Table 1. Both blanching methods were followed by air drying at 180°C for 1 min, frying at 180°C for 3 min and eventually blast freezing. The production of frozen French fries using the modified blanching conditions was completed for three samples, namely the cultivars Her, Col and a combination of She and Pen. The end-product of this modified blanching method was evaluated in terms of the frequency of the occurrence of “glassiness”, textural quality in the absence of the defect and general appearance of the end-product.

Statistical analysis

Differences in the chemical content of the sample combinations of the independent variables (area, cultivar, depth, SG and storage time) were determined by analysis of variance (ANOVA) and categorised regression tree (CART) analyses. The graphs were compiled by using Statistica software (Version 6). Each point on the graph indicated the average value of four repetitions with each repetition representing the average of two duplicates. In some cases, variables were eliminated during the statistical analysis, as it played no role in the differences that occurred between the chemical composition of samples. In these cases the point of the graph indicating the average value were calculated with more than four values. Significant differences were determined by using a 5% significance level ($p < 0.05$) as guideline.

Results and discussion

Sample and variable selection

During separation of the samples into two SG groups, 8 of the initial 24 samples (4 cultivars X 2 depths X 3 areas) of trial 1 could not be characterised as a high SG group, resulting in a total of 40 (instead of 48) combinations of the variables area, cultivar, depth and SG. These combinations of variables are referred to as sample sets. Sample separations into three SG groups in trial 2 resulted in a total of 44 (instead of 60) sample sets. Ten of the initial 20 samples (5 cultivars X 2 depths X 2 areas) could not be

Table 1. Industrial and modified blanching conditions of the frozen French fry production line.

Blanchers	Industrial blanching method		Modified blanching method	
	Time (min)	Temperature (°C)	Time (min)	Temperature (°C)
1	6	88	6	61
2	19	88	18	61
3	19	88	17	60



characterised as a low SG group, one sample not into a medium SG group and five not into a high SG group.

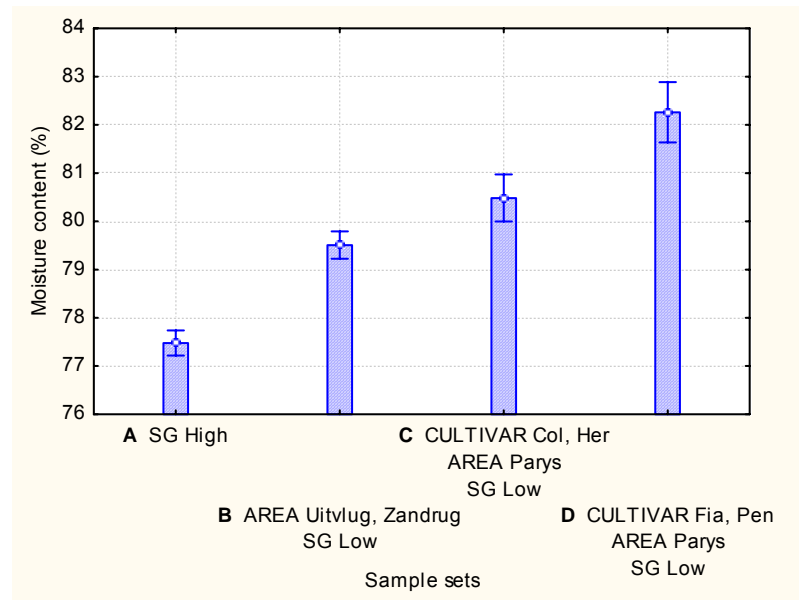
Moisture content

The average moisture content for sample sets of the independent variables area, cultivar and SG for trial 1 is indicated in Fig. 1A. The independent variables depth and storage time played no role in the differences that occurred in the moisture content between the samples and were omitted when statistical analysis was performed.

Throughout trial 1, samples with a high SG, independent of the cultivar or area in which it was grown (sample set A, Fig. 1A), had a low average moisture content compared to the average moisture content of samples in the low SG group (sample sets B, C & D, Fig. 1A). Differences occurred in the average moisture content of samples in the low SG group in trial 1 (sample sets B, C & D, Fig. 1A) and these differences are mainly determined by the area and cultivar. Samples of all four cultivars (Pen, Fia, Col and Her) with a low SG and grown in the areas of Uitvlug and Zandrug (sample set B, Fig. 1A), had a lower average moisture content compared to samples of the same cultivars with a low SG grown in the area of Parys (sample sets C & D, Fig. 1A). This tendency showed that potatoes react uniquely in terms of dry matter accumulation when grown in areas with different soil water qualities as represented by the three different areas. The average moisture content of cultivars Col and Her with a low SG, grown in Parys (sample set C, Fig. 1A) were lower than the average moisture content of cultivars Fia and Pen with a low SG, grown in Parys (sample set D, Fig. 1A). From these results it is clear that the moisture content of the potato tuber also tend to differ between cultivars grown under the same soil water qualities (sample sets C & D, Fig. 1A), indicating that the cultivar also plays a determining role in the moisture content of potatoes.

The average moisture content for sample sets of the independent variables cultivar and SG in trial 2 is indicated in Fig. 1B. The independent variables area, depth and storage time were omitted during the statistical analysis of the data as it made no contribution to the differences that occurred in the moisture content between samples. From Fig. 1B it is clear that samples with a high SG (sample set A), independent of the cultivar, had a low average moisture content compared to that of samples with a medium and low SG (sample sets B, C and D).

A



B

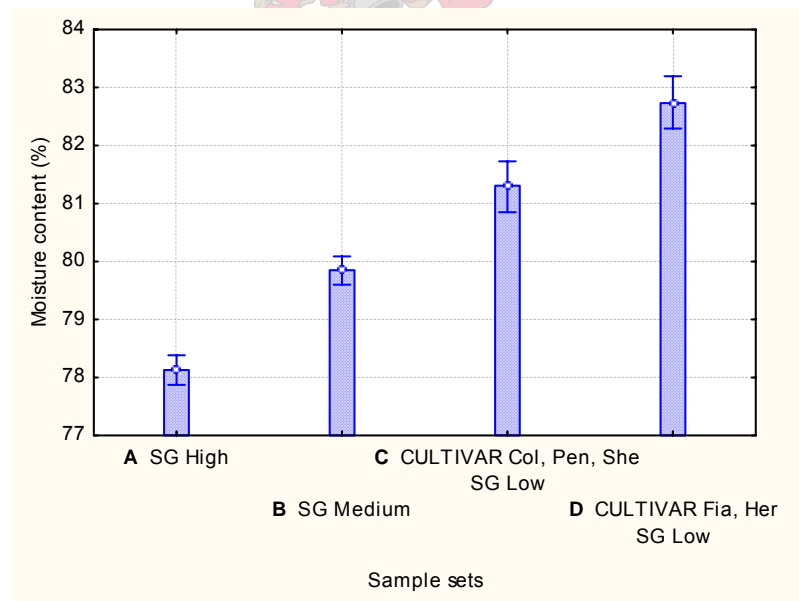


Figure 1. The average moisture content (%) for sample combinations of the independent variables area, cultivar and SG for trials 1 (A) and 2 (B). Groups were selected using CART analysis and vertical bars denote 0.95 confidence intervals.

During trial 2 (Fig. 1B) the average moisture content of all samples in the medium SG group (sample set B), differed from that of samples in the high (sample set A) and low SG groups (sample set C & D). Furthermore, the average moisture content of samples in the low SG group differed according to cultivar (sample set C & D, Fig. 1B). The cultivars Fia and Her with a low SG (sample set D, Fig. 1B) tend to have a high average moisture content compared to cultivars Col, Pen and She with a low SG (sample set C, Fig. 1B). Therefore, as in trial 1, differences in the moisture content and thus the dry matter accumulation in the potato tuber is dependent on the cultivar.

Moisture content and SG

During separate ANOVA analyses, the average moisture content in samples of the high SG group throughout trial 1 (sample set A, Fig. 1A) were found to be significantly lower than the average moisture content of samples in the low SG groups ($p < 0.01$) (Fig. A2A). The same was apparent in trial 2 where the average moisture content in samples of the high SG group (sample set A, Fig. 1B) were significantly lower than that of samples of the medium and low SG groups ($p < 0.01$) (Fig. A2B). Additionally a statistically significant difference was found in the average moisture content of samples in the medium and low SG groups throughout trial 2 ($p < 0.01$) (Fig. A2B). These statistically significant differences in the average moisture contents of SG groups confirm the relationship between moisture content (dry matter content) and the SG of potatoes (Schippers, 1976; Burton, 1989; Kumlay *et al.*, 2002).

Moisture content and “glassiness”

The moisture content found in samples with and without the presence of “glassiness” clearly indicated no correlation between the average moisture content of the potato and this defect (Fig. A3). During trial 1 all samples where the “glassiness” defect were absent showed a slight tendency to a higher moisture content than the defected samples although this tendency were not statistically significant ($p = 0.10$) (Fig. A3A). The opposite was found in trial 2 where samples with the “glassiness” defect tended to have higher average moisture content than potatoes without the defect. These differences were again not statistically significant ($p = 0.15$) (Fig. A3B). Therefore, the moisture content in the potato tuber has no relation to the occurrence of the “glassiness” defect in the samples tested.

Total starch content

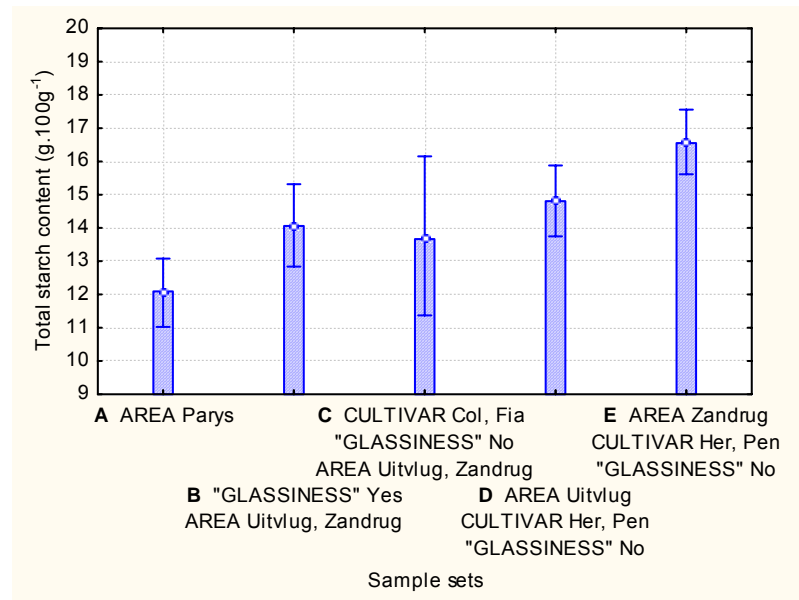
The average starch content for sample sets of the independent variables area, cultivar and “glassiness” in trial 1 are indicated in Fig. 2A. The sample sets were also selected according to the presence and absence of the “glassiness” defect as this variable played a role in the differences that occurred in the starch content of the samples. The independent variables depth, SG and storage time were omitted during the statistical analyses of the data as these variable made no contribution to the differences that occurred in the average starch content of the samples.

The average starch content of samples obtained from Parys (sample set A, Fig. 2A) in trial 1 was lower than that of samples obtained from other areas (sample sets B, C, D & E, Fig. 2A). The low average starch content found in samples from Parys correlated positively with the high average moisture content found in samples with a low SG obtained from Parys (sample sets C & D, Fig.1A). The high moisture content and resultant low dry matter content of these samples is indicative of a low starch content, with starch being the primary component of the dry matter in potato tubers (between 60 and 80%) (Leszczyński, 1989).

Sample sets B and C (Fig. 2A) did not differ from each other or from other sample sets in their starch content. The sample sets D and E (Fig. 2A) indicated that samples of the cultivars Her and Pen without the “glassiness” defect obtained from Uitvlug and Zandrug had a higher starch content compared to samples grown in Parys (sample set A, Fig. 2A). A separate ANOVA analysis performed on the average starch content of all samples obtained from the three different areas of cultivation during trial 1 confirmed that the tendency of the starch content of samples to differ between areas of cultivation (sample set A, D & E, Fig. 2A) were statistically significant. The average starch content of samples obtained from the Parys area was significantly lower ($p=0.01$) than that of potatoes grown in Uitvlug and Zandrug. Therefore, the soil water quality may play a determining role in the starch accumulation in potato tubers.

The average starch content for sample sets of the independent variables area and SG in trial 2 is indicated in Fig. 2B. SG as an independent variable of analysis during trial 2 may be due to the more pronounced distinction between the high and low SG samples through the inclusion of a medium SG groups. During this trial the variables cultivar, depth and storage time were negated during the statistical analyses of the data as it proofed not to influence the average starch content.

A



B

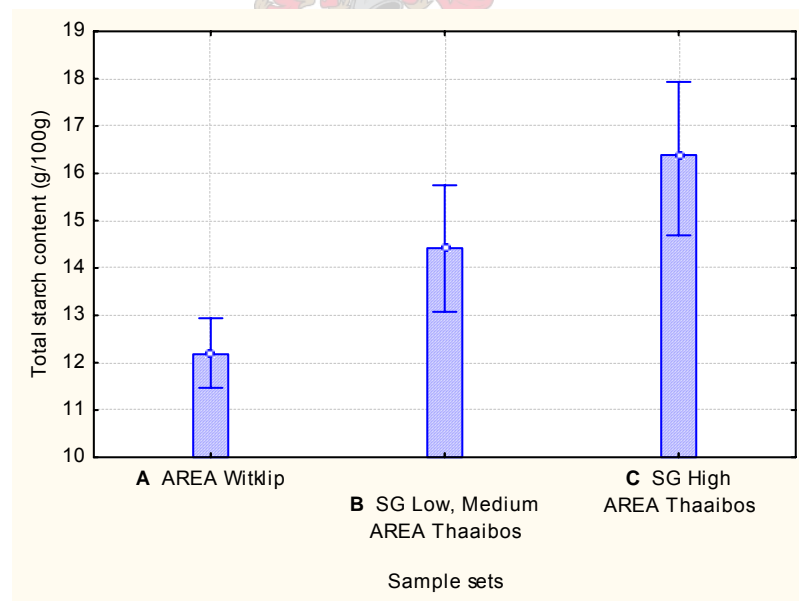


Figure 2. The average starch content (g.100g⁻¹) for the independent variables area, cultivar, SG and “glassiness” for trial 1 (A) and 2 (B). Groups were selected using CART analysis and vertical bars denote 0.95 confidence intervals.

In trial 2 all samples obtained from Witklip (sample set A, Fig. 2B) had a lower average starch content compared to samples obtained from the Thaaibos area (sample sets B & C, Fig. 2B). In an independent ANOVA analysis on the average starch content of all samples obtained in trial 2, a statistically significant lower average starch content was found in samples from the Witklip area ($p < 0.01$) (Fig. A4). This again indicated that the soil water quality contribute to the starch accumulation in the potato tuber.

The average starch content of the samples obtained from the Thaaibos region differed depending on the SG of the sample. Samples from the high SG group obtained from this area (sample set C, Fig. 2B) had a higher average starch content than samples from the medium and low SG groups (sample set B, Fig 2B). With the inclusion of SG as a relevant variable during trial 2 it became clear that the SG gives a true reflection of the starch content in potatoes confirming the results of previous studies (Schippers, 1976; Burton, 1989; Kumlay *et al.*, 2002).

Very little information regarding the tendency of potato cultivars to react differently in terms of dry matter and starch accumulation when cultivated in different areas, is available to the potato processing industry. The latter focuses the purchase of their raw material on strict specifications including a high starch content as indicated by a high SG (Talbert *et al.*, 1987a; Lisińska, 1989; Shock *et al.*, 1993; Eldredge *et al.*, 1996; Thygesen *et al.*, 2001; Thybo *et al.*, 2003; Anon., 2004a; Anon., 2004b). The SG of a potato tuber is often used in the French fry industry for predicting the fry yield and textural quality of the end-product and a SG above 1.080 is positively correlated with an ideal mealy French fry texture and a high fry yield (Smith, 1977; Dalton, 1981; Lisińska, 1989; O'Beirne & Cassidy, 1990; Van Marle *et al.*, 1997; Thybo *et al.*, 2000; Thygesen *et al.*, 2001). The moisture and total starch results presented in Figs. 1 and 2 can be useful as a guideline in determining the best intended use and processing suitability of the harvested potatoes.

Total starch content and SG

An ANOVA analysis for the average starch content of samples in the two respective SG groups during trial 1 indicated a higher starch content in samples from the high SG group than from the low SG group (Fig. 3A). Although this difference was not significant ($p = 0.20$), this tendency of samples from the high SG group having a higher starch content in contrast to samples from the low SG group were as expected (Burton,

1989). This insignificant difference can possibly be ascribed to the indefinite distinction between the high and low SG groups (Burton, 1989). The starch content of samples with a SG equal to or just above 1.0857 differed only slightly from that of tubers with a SG just below 1.0857. For this reason potato samples were divided into three SG groups (high, medium and low) during the second trial in an attempt to increase the distinction in starch content between the samples. Figure 3B indicates that the separation of the samples into three SG groups during trial 2 did result in a statistically significant distinction ($p=0.01$) between the average starch content of the high and low SG groups.

Total starch content and “glassiness”

An ANOVA analysis was used to determine the difference in the starch content of samples with and those without the “glassiness” defect. No tendencies or significant differences were found in trial 1 ($p=0.76$) or trial 2 ($p=0.70$) (Fig. A6). As this was not the case, it may be that the amount of starch accumulated within the potato tuber is not responsible for the occurrence of the “glassiness” defect. To be able to draw a correlation between “glassiness” and the translucent-end defect described in literature, a low starch content were expected in the cases where “glassiness” were present (Marinus & Bodlaender, 1975; Iritani, 1981).

Reducing sugars

The average reducing sugar content of sample sets of the independent variables area and cultivar for trial 1 are indicated in Fig. 4A. The independent variables depth and storage time made no contribution to the differences that occurred in the reducing sugar content between samples. Throughout trial 1 the cultivars Col, Fia and Her contained low levels of reducing sugars independent of the area from which these samples were obtained (sample set A, Fig. 4A). Exceptionally high levels of reducing sugars were found in the cultivar Pen obtained from all three areas of cultivation (sample sets B & C, Fig. 4A).

Sample sets of the independent variables cultivar and SG contributed to the differences in the reducing sugar content of the samples in trial 2 (Fig. 4B). The independent variables area, depth and storage time did not influence the differences

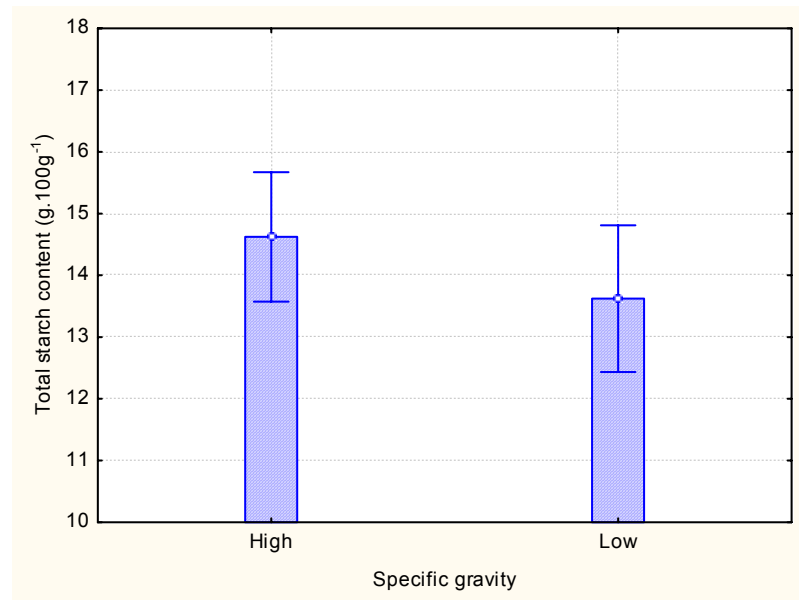
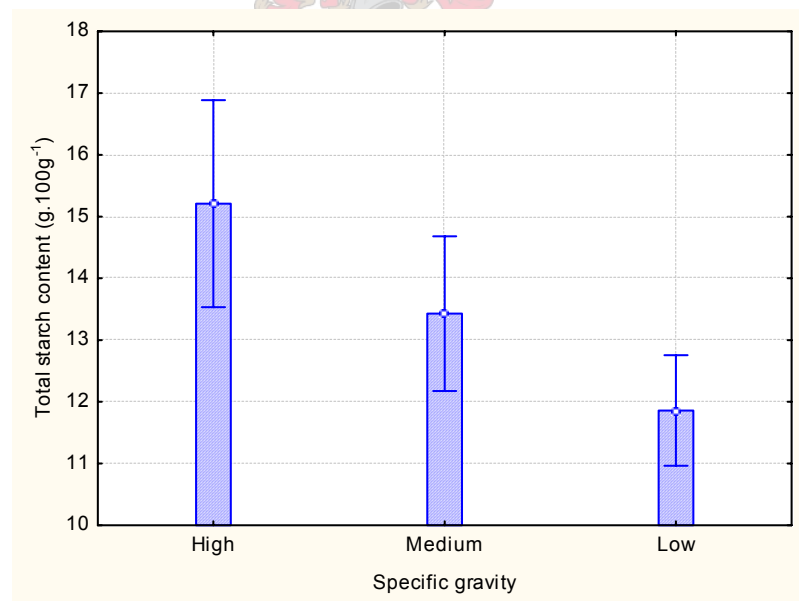
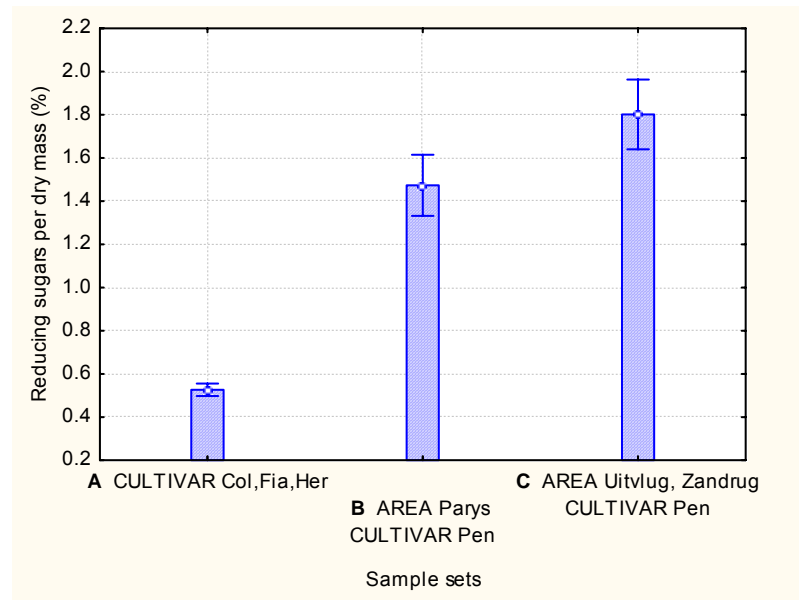
A**B**

Figure 3. The average total starch content (g.100g⁻¹) for the SG groups during trial 1 (**A**) ($p=0.20$) and 2 (**B**) ($p=0.01$). Vertical bars denote 0.95 confidence intervals.

A



B

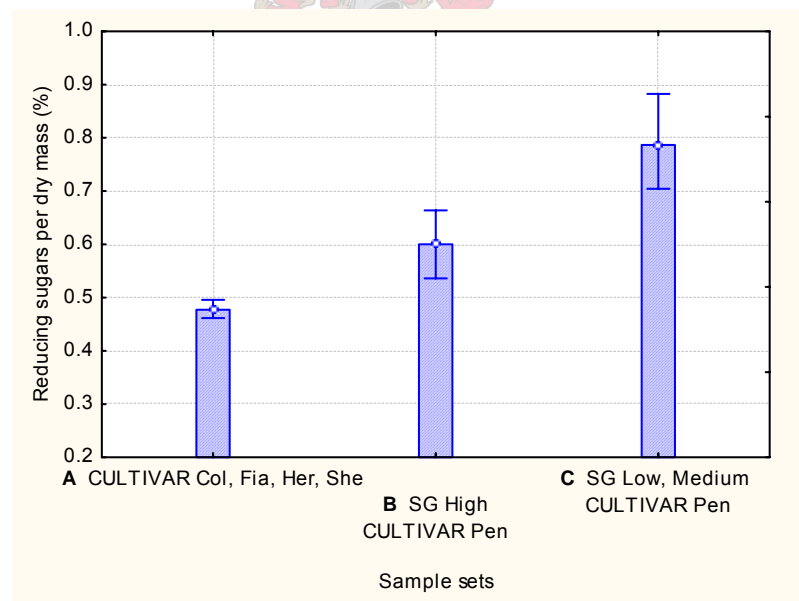


Figure 4. The average reducing sugar content per dry mass (%) for the independent variables area, cultivar and SG for trial 1 (A) and 2 (B). Groups were selected using CART analysis and vertical bars denote 0.95 confidence intervals.

between the potato samples. Throughout trial 2 samples of the cultivars Col, Fia, Her and She contained very low levels of reducing sugars (sample set A, Fig. 4B). As was the case in trial 1, samples of the cultivar Pen contained noticeably high levels of reducing sugars. Samples of the cultivar Pen with a medium and low SG (sample set C, Fig. 4B) contained higher levels of reducing sugars than that of Pen with a high SG (sample set B, Fig. 4B). An ANOVA analysis confirmed that the reducing sugar content of the Pen samples from the medium and low SG groups in trial 2 were significantly higher than that of the samples of other cultivars ($p < 0.01$) (Fig. 5).

The remarkably higher reducing sugar content in samples of the cultivar Pen during trial 1 (sample sets B & C, Fig. 4A) and 2 (sample sets B & C, Fig. 4B) can be explained. Based on the fact that samples of all cultivars were subjected to the same atmospheric and soil conditions prevailing in a specific area, the cultivar Pen appears to be more susceptible to minor changes in these conditions resulting in higher levels of reducing sugars in the mature tuber. Iritani (1981) found cultivars to differ in their susceptibility to fluctuations in environmental conditions for instance high and low temperatures, low moisture availability and fertiliser imbalances and stated that stress conditions during tuber development cause increased reducing sugar accumulation during storage of tubers of the stress-sensitive cultivars.

The reducing sugar content of potatoes are of great importance in the French fry processing industry as it is considered one of the primary factors influencing the quality of the end-product (Talbert *et al.*, 1987a; Burton, 1989; Lisińska, 1989; Shock *et al.*, 1993). High levels of reducing sugars (more than 0.5% of the fresh weight) will lead to an undesirable dark discoloration in the final fried product due to the non-enzymatic Maillard reaction (Baltes, 1982; Ashoor & Zent, 1984). The accumulation of reducing sugars in the potato tuber is easily influenced by uncontrollable environmental conditions, including region of cultivation, soil water quality and availability, soil temperature, cultivar and the duration and conditions of post-harvest storage (Iritani, 1981; Cottrell *et al.*, 1995; Eldredge *et al.*, 1996; Kumlay *et al.*, 2002). The statistical analyses indicated that the area of cultivation, cultivar and SG play an important role in the reducing sugar accumulation of the tuber (Fig. 4). Information on how different cultivars perform in different areas in terms of reducing sugar accumulation, as indicated in Fig. 4, can be useful when selecting potatoes for the production of high quality French fries.

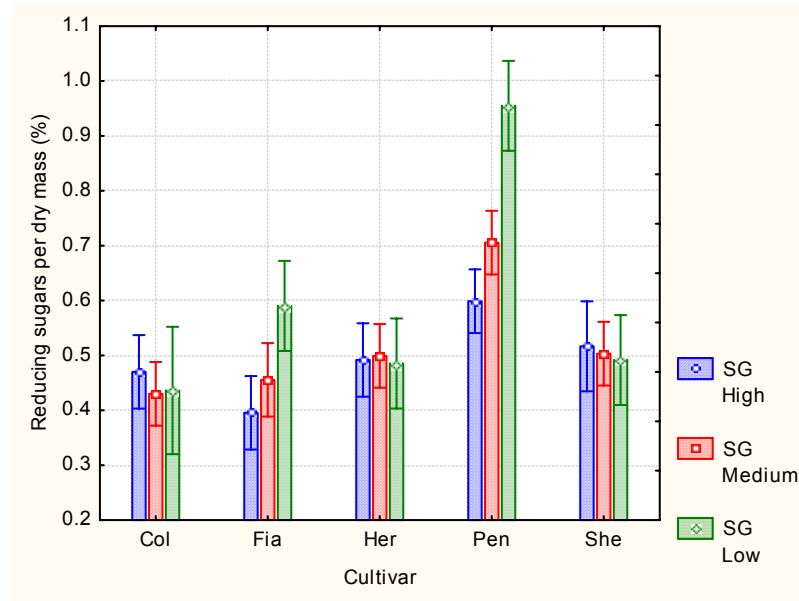
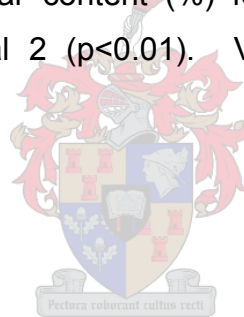


Figure 5. The reducing sugar content (%) for cultivars in the three different SG groups during trial 2 ($p < 0.01$). Vertical bars denote 0.95 confidence intervals.



Pen was found to be the problematic cultivar in terms of reducing sugars as very high levels occurred in samples of this cultivar. Therefore, it was most likely to produce an end-product with an undesirable dark frying colour. The average reducing sugar content per fresh weight (data not shown) showed that none of the Pen samples exceeded the index of 0.5% per fresh weight indicated as the upper limit for ensuring a fried product with good colour quality (Baltes, 1982; Ashoor & Zent, 1984). As reducing sugars tend to accumulate to very high levels in this particular cultivar it is advised that prolonged storage is avoided and samples are processed immediately after reception if possible.

Reducing sugars and “glassiness”

An ANOVA analysis showed that those samples in trial 1 without the “glassiness” defect had a strong tendency to have a higher reducing sugar content than the affected samples, although these differences in reducing sugar levels were not significant ($p=0.05$) (Fig. A8). The observed tendency is opposite to what is expected if “glassiness” is to be compared to the translucent-end tuber defect described in literature. The reducing sugar levels were found to be high in tubers affected by the translucent-end defect (Marinus & Bodlaender, 1975; Iritani, 1981). During trial 2 no statistical significant difference existed in the reducing sugar content of samples with and without the “glassiness” defect ($p=0.51$). Therefore, the conclusion can be made that “glassiness” is not correlated with the translucent-end defect and that the reducing sugar content in potato tubers is not responsible for the occurrence of this defect in South African frozen French fried potatoes.

Effect of the variables analysed on the occurrence of “glassiness”

No statistically significant differences were found between the chemical composition (moisture, starch and reducing sugar content) of samples with and without the “glassiness” defect (Fig. A3, A6 and A8). A classification tree analysis were done to determine if the independent variables area, cultivar, depth, SG and storage time had an effect on the occurrence of “glassiness” in samples subjected to the industrial blanching conditions.

The occurrence of “glassiness” during trial 1 was plotted against the number of observations for the independent variables area and cultivar in a classification tree

analysis (Fig. 6). The independent variables depth, SG and storage time were not included in the statistical analysis, as it did not contribute to the occurrence of the “glassiness” defect. Cultivars Fia, Her and Pen had a low tendency to give rise to “glassiness”, independent of the area from which they were obtained (sample set A, Fig. 6). The defect occurred in only 25% of samples from these cultivars. The occurrence of “glassiness” in the cultivar Col differed between the areas of cultivation with only 21% of Col samples grown in the Parys region (sample set B, Fig. 6) being affected, compared to a total of 91% defected Col samples grown in Uitvlug and Zandrug (sample set C, Fig. 6). Therefore, the area and the soil water quality play a contributing role in the occurrence of the “glassiness” defect during trial 1.

“Glassiness” was observed in a sample during trial 1 and the severity of the defect was expressed as the affected percentage of the French fry strip. These percentages were plotted against sample sets of the independent variables region and cultivar in a CART analysis (Fig. 7). Comparing these results to that in Fig. 6 it is clear that when the number of observations of “glassiness” is low, the percentage of “glassiness” in the French fry strip are also low. In the cultivars Fia, Her and Pen only 25% of the samples showed “glassiness” (sample set A, Fig. 6) and on average only 5% of the strip was affected (sample set A, Fig. 7) compared to the cultivar Col grown in region Uitvlug and Zandrug where “glassiness” occurred in 91% of the samples (sample set C, Fig. 6) and an average of 35% of the strip was affected (sample set C, Fig. 7). It is clear that the area of cultivation and the cultivar affects the occurrence, as well as severity of the “glassiness” defect.

The number of observations of the “glassiness” defect was also compared to sample sets of the independent variables cultivar and SG for trial 2 as determined by a classification tree analysis (Fig. 8). From Fig. 8 (sample set A) it is clear that the cultivars Col and Fia had the highest occurrence of “glassiness” as 73% of the samples were affected. The cultivar Her showed a 100% absence of the “glassiness” defect (sample set D, Fig. 8). In the cultivars Pen and She, the number of observations of “glassiness” differed between SG groups (sample sets B & C, Fig. 8). Samples of these two cultivars in the high and medium SG groups had a lower occurrence of the defect as only 30% of the samples were affected compared to 63% of the samples of these cultivars in the low SG group.

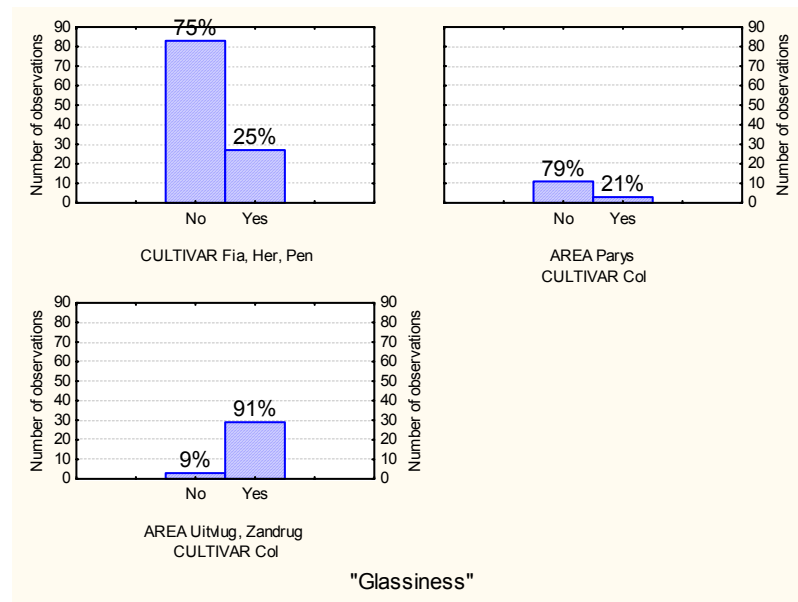


Figure 6. The occurrence of "glassiness" for sample combinations of the independent variables region and cultivar during trial 1. Groups were selected using a classification tree analysis.

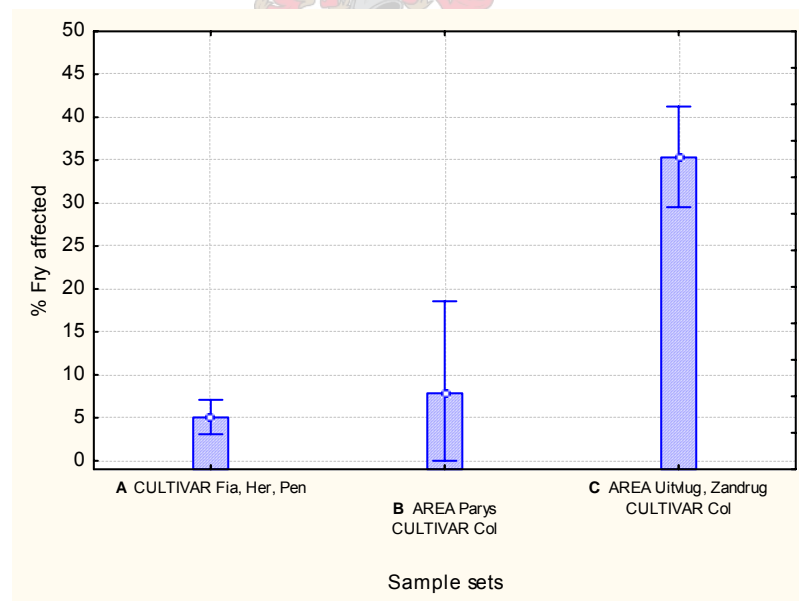


Figure 7. The severity of "glassiness" (%) in the French fry strip for sample combinations of the independent variables region and cultivar during trial 1. Groups were selected using CART analysis and vertical bars denote 0.95 confidence intervals.

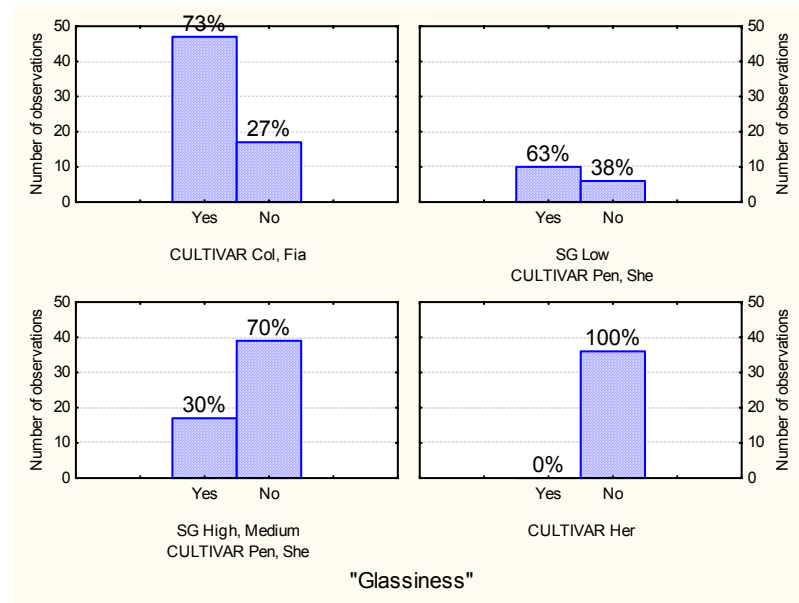


Figure 8. The occurrence of “glassiness” for sample combinations of the independent variables cultivar and SG during trial 2. Groups were selected using a classification tree analysis.



Figs. 6 and 8 indicated that the area, cultivar and SG did contribute to the occurrence of the “glassiness” defect, but these results are mere tendencies determined by a classification tree analysis, with no statistical support. In order to determine if these factors did indeed significantly contributed to the occurrence of “glassiness” in the final product, the occurrence of “glassiness” for the independent variables area, cultivar and SG was calculated in an ANOVA analysis. The significance of the analysis was determined using a chi-square test.

“Glassiness” and area

The “glassiness” defect in the different areas of cultivation during trials 1 and 2 were determined. Throughout trial 1 the occurrence of “glassiness” was similar in the areas Zandrug and Uitvlug (Fig. A9A). Compared to the 44% occurrence of the defect in these two regions, the occurrence of 18% in the Parys area was significantly lower ($p=0.01$). As the mentioned areas of cultivation differed from each other in terms of soil water quality, this may be a contributing factor to the occurrence of the defect. However, different cultivars tend to react uniquely in different regions of cultivation (Fig. 6).

During trial 2 the area represented by Witklip showed 50% defected and 50% non-defected samples, while the defect was less likely in the Thaaibos area where only 36% of the samples showed the “glassiness” defect (Fig. A9B). This difference in the occurrence of “glassiness” between the two regions of cultivation during trial 2 was not significant ($p=0.06$).

“Glassiness” and cultivar

The occurrence of the “glassiness” defect for the cultivars investigated during trial 1 is indicated in Fig. A10A. Very high numbers of the defect (70%) was found in the cultivar Col. As seen in Fig. 6 the defect occurred mostly where Col was grown in the Uitvlug and Zandrug areas. The occurrence of the defect in other cultivars investigated during trial 1 were equally low being 24%, 28% and 23% for Pen, Fia and Her, respectively (Fig. A10A).

During trial 2 Col showed the highest occurrence of the defect (84%), followed by Fia in which a 63% occurrence was observed (Fig. A10B). The occurrence of “glassiness” was lower for Pen (38%) and She (38%) and as indicated by the

classification tree analysis for trial 2 (Fig. 8) tended to differ depending on the SG of the sample. Throughout trial 2, the defect was absent in Her (Fig. A10B).

“Glassiness” and SG

No significant differences existed in the occurrence of “glassiness” between the high and low SG groups of trial 1 ($p=0.66$) (Fig. A11A) and the three SG groups of trial 2 ($p=0.09$) (Fig. A11B). This confirmed the tendency of samples of the cultivars Pen and She in the high and medium SG groups to have a lower occurrence of the “glassiness” defect (30%) (sample set C, Fig. 8) compared to samples of these cultivars in the low SG groups (63%) (sample set B, Fig. 8) to be insignificant.

Effect of variables on the occurrence of “glassiness”

With the exception of the cultivar Her in trial 2, the “glassiness” defect occurred in all sample sets of the independent variables, with no defect-free combination of area, cultivar, depth, SG and storage time. “Glassiness” was in most cases observed in the stem end of the French fry strip. The stem-end and bud-end of potato tubers differ in their chemical composition and cultivars can be distinguished from each other by the chemical composition of their stem-ends (McComber *et al.*, 1987; McComber *et al.*, 1988). As “glassiness” is a textural problem in frozen French fries the possibility exist that the defect can be ascribed to the physical, chemical and functional properties of starch rather than total starch content in the tuber. The physical and functional properties of starch contained in the stem ends of tubers have been found to differ between cultivars and are easily affected by different environmental factors including soil water quality, soil temperature and storage conditions (McComber *et al.*, 1994; Wiesenborn *et al.*, 1994; Cottrell *et al.*, 1995; Kim *et al.*, 1995; Christensen & Madsen, 1996; Lui *et al.*, 2003; Noda *et al.*, 2004). This explains why the defect is more prominent in certain cultivars and areas than in others and include the possibility that a “glassiness” defect are most probably due to differences in starch properties of the stem-ends of tubers.

Determination of “glassiness” in samples subjected to modified industrial blanching conditions

Statistical analysis to determine the difference in the occurrence of “glassiness” in Fia samples subjected to the industrial and modified blanching conditions was done. The results showed that “glassiness” occurred in 15% of the samples subjected to the industrial blanching conditions, while the defect occurred in only 7% of the samples when adjacent fry strips were subjected to modified blanching conditions (Fig. A12). Although the results showed a definite decrease in the occurrence of the defect at the modified blanching conditions, these differences were not statistically significant ($p=0.06$). In an uncontrolled experiment (not included in the statistical analysis), blanching temperatures were kept at 65°C, whilst fry strips from the cultivar Fia were subjected to this temperature for 40 min. All fry strips were found to be hard in texture indicating that the starch reacted in a different manner when exposed to temperatures above 62°C for a period longer than 30 min.

In the case of the cultivar Col a 40% occurrence of “glassiness” was observed under the industrial blanching conditions used presently, while only 19% tested positive when adjacent fries were subjected to the modified blanching conditions (Fig. A13). This observed difference were highly significant ($p<0.01$) as determined by the McNemar test. The conclusion can be made that the modified blanching conditions have a statistically significant decreasing effect on the occurrence of “glassiness” in the cultivar Col.

In the case of the cultivar Pen the occurrence of the defect was decreased from 18% under industrial blanching conditions to 10% under the modified blanching conditions (Fig. A14). This difference in the occurrence of the defect was a strong tendency but not significant ($p=0.05$).

The modified blanching conditions were responsible for the decrease in the occurrence of the “glassiness” defect. The severity of the decrease was dependent on the cultivar with the most significant decrease in the cultivar Col. This cultivar is most problematic with the highest overall occurrence of the defect (Fig. A10A and Fig. A10B). The change in blanching conditions may, therefore, be of great value to French fry producers preferring the use of Col for possible quality attributes offered by this cultivar such as shape, size and low reducing sugar content.

Effect of modified industrial blanching conditions on the quality of commercially processed frozen French fries

The cultivar Her was tested in the production line in an industrial processing unit under the modified blanching conditions. The occurrence of “glassiness” in the cultivar Her was previously not present. These samples, however, allowed a comparison between the overall quality of the product industrially blanched and the product produced under the modified blanching conditions. After evaluation of the two treatments the sample subjected to the modified conditions had an improved appearance. The fries were found to be puffed-up with the desired mealy texture throughout the fry strip. The texture was less oily than normal, indicating decreased oil absorption during the frying process. In the case of the original product, the texture varied throughout the fry strip. The bud-end of the fry strip tended to soften more easily upon heat processing than the stem-end due to the uneven distribution of dry matter in the potato tuber (Scanlon, 2004). The French fries produced under the modified blanching conditions had an even texture throughout the fry strip. Therefore, the modified blanching method produced a more desirable end-product with good textural quality. In a study done by Agblor and Scanlon (1998) similar results were found. These authors showed that low-temperature long-time (LTLT) blanching conditions had a reducing effect on the textural difference that may occur in a French fry strip or between strips made from different sections of the tuber.

The second sample tested on the production line to determine the effect of the modified blanching conditions consisted of a combination of the cultivars She and Pen. A low incidence of “glassiness” existed in this batch of potatoes and the test run did not allow the evaluation of the effect of the modified blanching conditions (61°C) on the occurrence of the defect in these cultivars. Other improvements in product quality were observed as a result of the modified blanching method. Fry strips normally tend to break during the processing steps following blanching at 88°C. In this instance the fry strips remained intact throughout the entire production process. The number of full length fries were thus increased and the quality of the final end-product more desirable.

The third sample subjected to the modified blanching conditions consisted of the cultivar Col, normally presenting a very high incidence of “glassiness”. A decrease in the occurrence of “glassiness” was observed in the fries produced under the modified blanching conditions. In the cases where “glassiness” was present the defect was

described as a firmer area in the fry strip rather than the characteristic hard, raw parts found in the fries produced under the industrial blanching conditions. Apart from a decreased occurrence of the “glassiness” defect in fry strips that were subjected to the modified blanching conditions, other improvements in terms of the textural quality of the French fry were observed. The texture of the product was satisfactory and evenly distributed through the fry strip.

The modified blanching conditions showed numerous improvements in the final quality of frozen French fries depending on the cultivar used. The desirable firming of the potato tissue and the even distribution of a mealy texture in the French fry strip that was observed at these lowered blanching temperatures (61 – 62°C) can be ascribed to the activation and action of pectin methylesterase (PME) which is normally deactivated at the industrial blanching temperatures of 88°C (Bartolome & Hoff, 1972). PME de-esterifies the cell wall pectin increasing its availability to react with calcium and magnesium ions, forming more rigid structures and promoting the firmness of the tissue (Linehan & Hughes, 1969; Hughes *et al.*, 1975; Binner *et al.*, 2000).

Complications brought upon by the modified blanching conditions were identified as the oxidation of the potato tissue during blanching and a resultant grey discolouration, as well as reduced leakage of reducing sugars from the tissue resulting in excess reducing sugars during frying and an undesirable dark fry colour. These were not severe and were corrected by the addition of sodium acid pyrophosphate (SAPP) to the blanching water in order to reduce oxidation and by adjustments the temperature and time parameters of the frying process to control the fry colour (Sapers *et al.*, 1997).

NIR calibration development

A typical NIR spectrum of the stem end tissue of the potato tuber is shown in Fig. 9. The absorption of water is indicated as three prominent peaks at 970 nm, 1450 nm and 1940 nm (Thybo *et al.*, 2000). The high absorption of water at these wavelengths can be problematic for the measurement of other chemical constituents in the wet potato tissue as valuable information in this spectral range may be concealed (Mehrübeoğlu & Coté, 1997). No spectral differences between samples with and without the “glassiness” defect were illustrated when applying PCA (Figs. 10, 11 and 12).

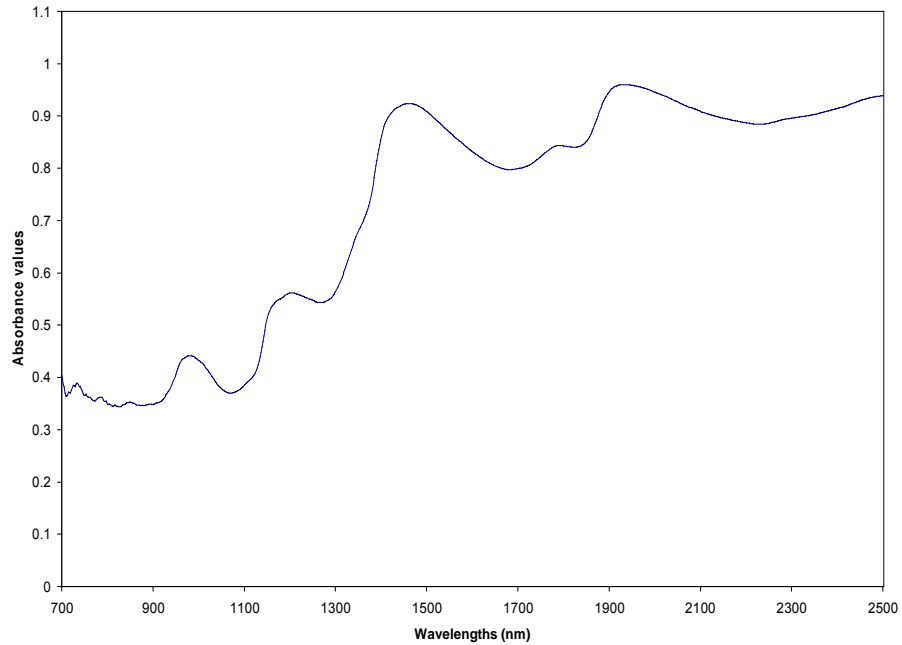


Figure 9. Typical spectrum of the stem end tissue of the potato tuber.

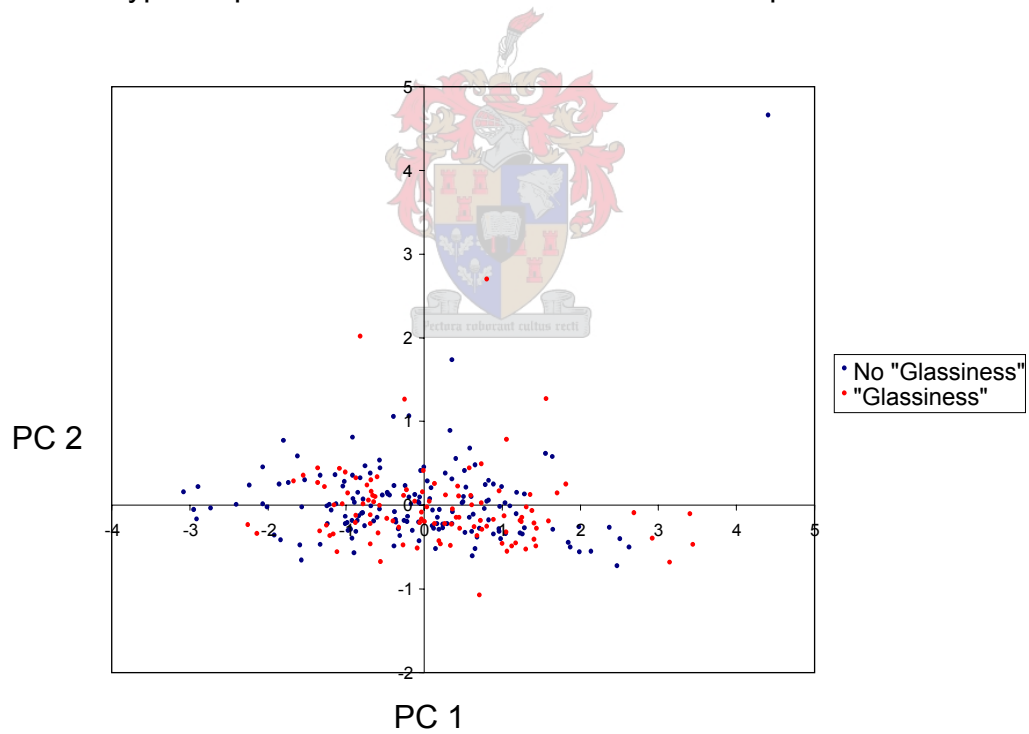


Figure 10. PCA plot of raw spectral data of stem end tissue of the potato tuber in the wavelength range of 700 – 2500 nm.

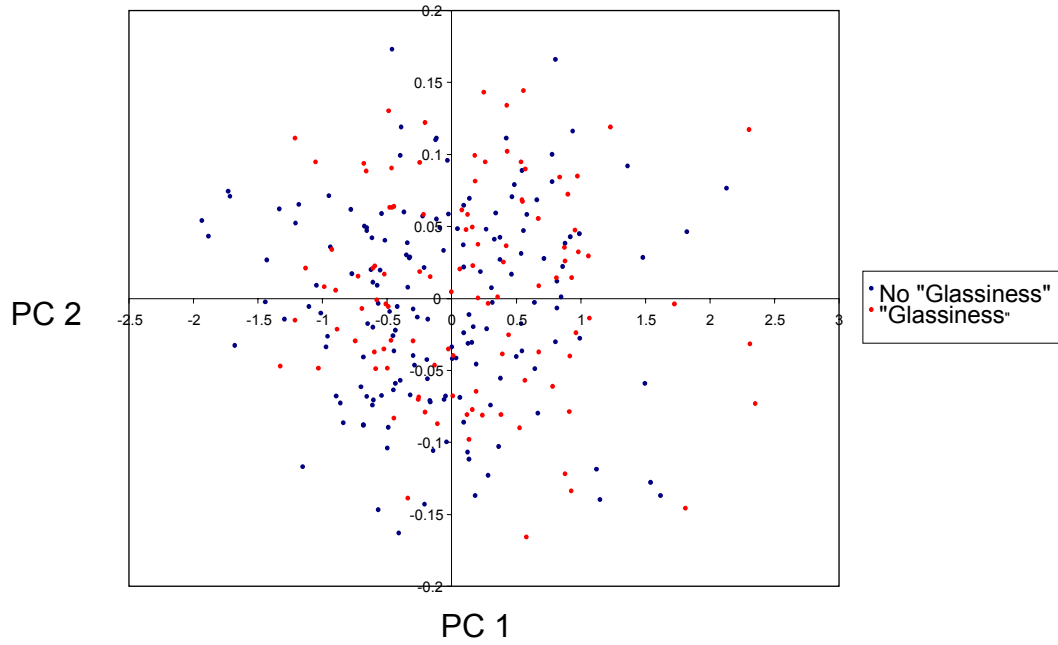


Figure 11. PCA plot of raw spectral data of stem end tissue of the potato tuber in the wavelength range of 700 – 1100 nm.

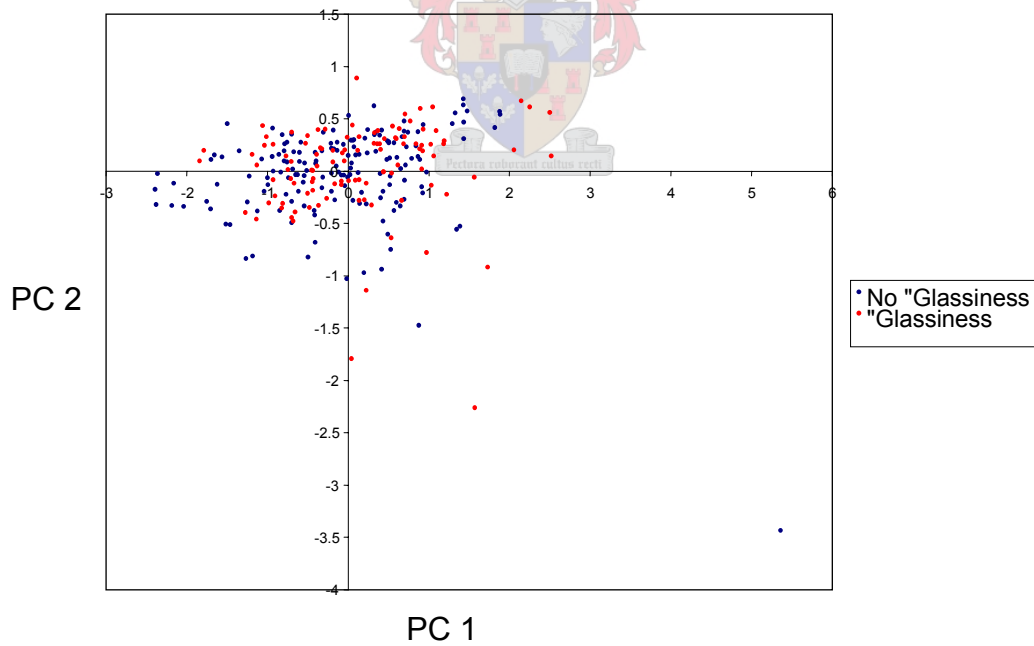


Figure 12. PCA plot of raw spectral data of stem end tissue of the potato tuber in the wavelength range of 1100 – 2500 nm.

A calibration model for the moisture content was build across the entire NIR wavelength range (700 – 2500 nm) using the raw data (Table 2). An independent validation set (n=89) was selected to represent the moisture content between 75.42 and 83.96%. The SEP of this model was 1.62% and the correlation coefficient was 0.46. The SEP was not comparable to the applied conventional reference method (SEL=0.4%). The potential of the calibration model to predict the SG in an unknown sample had an accuracy of ± 0.01 SG units (Burton, 1989). This compares to an accuracy of ± 0.003 SG units for conventional bulk (9 kg) SG determinations (Scanlon *et al.*, 1999). The frozen French fry industry requires raw material with a SG between in the narrow range of 1.080 and 1.100 for the production of a product with a good textural quality (Lisińska, 1989; Anon., 2004c). For this reason the predictive potential of the calibration model for determination of SG prior to processing, is poor. This conclusion is supported by the RPD of 1.12 indicating that the calibration model is not recommended for application in a screening or quality control process (Williams, 2001).

For starch content the best calibration model was build across the entire NIR range (700 – 2500 nm) using the raw data. The selected independent validation set (n=16) represented a starch content between 10.48 and 19.01 g.100g⁻¹. The SEP (2.28 g.100g⁻¹) and correlation coefficient (0.42) were determined using four PLS factors (Table 3). The calibration model had the potential to predict the SG in an unknown sample with an accuracy of ± 0.01 SG units (Burton, 1989). When comparing this to the accuracy of ± 0.003 SG units for conventional bulk (9 kg) SG determinations and the RPD of 1.12, the calibration model is discarded as a possible predictive measurement of SG and textural quality prior to processing (Scanlon *et al.*, 1999; Williams, 2001).

The reducing sugar content was best described using the raw data (700 – 2500 nm) to build a calibration model. A SEP of 0.07% and a correlation coefficient of 0.41 were attained (Table 4). The SEP was not comparable to the applied conventional reference method (SEL=0.006%). Frozen French fry processors require raw material with a reducing sugar content within the range of 0.20% – 0.50% of the fresh weight for optimal colour quality in the end-product (Burton & Wilson, 1970; Cottrell *et al.*, 1995). Although the analytical error indicates a reliable determination of reducing sugar levels in raw material, the screening or quality prediction potential of the calibration model was eliminated by a RPD of 1.20. The low correlation coefficient can be explained by the

Table 2. Statistical results for the moisture content (%) calibrations.

	Raw Data		
	Wavelength range (nm)		
	700 – 2500	700 – 1100	1100 – 2500
Calibration set (n)	179	179	179
Validation set (n)	89	89	89
SEP (%)	1.62	1.63	1.62
Bias	0.04	-0.05	0.06
RMSEP (%)	1.62	1.63	1.61
r	0.46	0.45	0.46
PLS factors (n)	6	7	5
Calibration set range (%)	75.41 – 84.37	75.41 – 84.37	75.41 – 84.37
Validation set range (%)	75.42 – 83.96	75.42 – 83.96	75.42 – 83.96
SEL (%)	0.4	0.4	0.4
RPD	1.12	1.12	1.12

SEP = Standard error of prediction corrected for bias

RMSEP = Root mean standard error of prediction

r = Correlation coefficient

SEL = Standard error of laboratory

RPD = Ratio of the standard error of performance to the standard deviation of the reference data

Table 3. Statistical results for the total starch content (%) calibrations.

	Raw Data		
	Wavelength range (nm)		
	700 – 2500	700 – 1100	1100 – 2500
Calibration set (n)	32	32	32
Validation set (n)	16	16	16
SEP (%)	2.28	2.38	2.48
Bias	0.28	0.37	-0.29
RMSEP (%)	2.23	2.33	2.42
r	0.42	0.31	0.10
Calibration set range (%)	9.29 – 19.78	9.29 – 19.78	9.29 – 19.78
Validation set range (%)	10.48 – 19.01	10.48 – 19.01	10.48 – 19.01
PLS factors (n)	4	2	2
RPD	1.12	1.08	1.03

SEP = Standard error of prediction corrected for bias

RMSEP = Root mean standard error of prediction

r = Correlation coefficient

RPD = Ratio of the standard error of performance to the standard deviation of the reference data

Table 4. Statistical results for the reducing sugars content (% per wet weight) calibrations.

	Raw Data		
	Wavelength range (nm)		
	700 – 2500	700 – 1100	1100 – 2500
Calibration set (n)	179	179	179
Validation set (n)	89	89	89
SEP (%)	0.07	0.07	0.07
Bias	0.002	-0.0008	0.002
RMSEP (%)	0.07	0.07	0.07
r	0.41	0.38	0.37
PLS factors (n)	4	4	6
Calibration set range (%)	0.02 – 0.52	0.02 – 0.52	0.02 – 0.52
Validation set range (%)	0.03 – 0.45	0.03 – 0.45	0.03 – 0.45
SEL (%)	0.006	0.006	0.006
RPD	1.20	1.20	1.20

SEP = Standard error of prediction corrected for bias

RMSEP = Root mean standard error of prediction

r = Correlation coefficient

SEL = Standard error of laboratory

RPD = Ratio of the standard error of performance to the standard deviation of the reference data

reducing sugar range (0.02 to 0.52% per fresh weight) represented by the sample set (n=268). This narrow range makes regression analysis difficult. The correlation can possibly be increased by developing individual calibration models for different cultivars or by homogenising the sample before scanning.

Conclusion

The phenomenon of “glassiness” appear in potatoes from the same crop or even from the same plant and certain cultivars are more severely affected than others depending on the region of cultivation. During this study this defect could not be ascribed to a specific chemical component present in the potato tuber. Adjustments in the blanching conditions (62°C for 25 min) during frozen French fry production can reduce or eliminate the occurrence of the defect. Although a decline in the occurrence of the defect was not that drastic for all cultivars tested, the modified blanching conditions gave rise to an improved and more uniform textural quality in the end-product, a higher incidence of full length fries, less oil absorption during the par-frying production step and reduced production costs at the lowered blanching temperatures.

It can be recommended that the cultivar Her is used for the production of high quality frozen French fries. The cultivar Col is problematic in terms of the “glassiness” defect. It is suggested that this cultivar is not used for the production of products where the “glassiness” defect is considered as a quality parameter. If this cultivar is, however, preferred for the production of frozen French fries on the account of other attributes such as shape, size, SG or reducing sugar content, it is best cultivating this cultivar under soil water conditions prevailing in the Parys area (EC=145.57 mS.m⁻¹). Processing under the modified industrial blanching conditions of 25 min at 62°C will lead to a reduction in the occurrence of glassiness and improved product quality.

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CHAPTER 4

GENERAL DISCUSSION AND CONCLUSIONS

The increased popularity and consumption of convenience products in South Africa has placed the focus, amongst others, on the frozen French fry industry to produce a product of uniform textural and colour quality (Talbert *et al.*, 1987; Burton, 1989; Lisińska, 1989; Anon., 2004). The quality of the French fry texture and colour are mainly determined by the dry matter, starch and reducing sugar content in the potato tuber (Lisińska, 1989; Shock *et al.*, 1993). The content of these chemical components is in turn easily affected by the prevailing environmental conditions during physiological development and post-harvest storage of the tuber (Burton *et al.*, 1992; Kumlay *et al.*, 2002).

A textural defect referred to as “glassiness” occurs in frozen French fries. The impact of “glassiness” on the frozen French fry industry and the lack of information concerning the origin of the defect motivated this study. The aim was to determine the relationship between “glassiness” and the moisture, starch, and reducing sugar content of the defected potato tuber in order to develop an effective calibration model for prediction of the defect through Fourier transform near infrared (FT-NIR) spectroscopy prior to processing. The effect of the soil water quality, cultivar, soil depth, storage duration, specific gravity (SG) and blanching conditions during frozen French fry production on the occurrence of “glassiness” was investigated.

No significant differences were found between the moisture, starch and reducing sugar concentrations of samples with and without the “glassiness” defect. In consequence of these findings it was accepted that the “glassiness” defect present in frozen French fries was not related to the concentration of a specific chemical component.

Differences in the occurrence of “glassiness” in the samples were present depending on the soil water quality (area of cultivation) and cultivar. Samples of the cultivar Herta (Her) had the significantly lowest occurrence of the “glassiness” defect, whereas the cultivar Columbus (Col) was most problematic. During trial 1 the occurrence of “glassiness” in Col samples was further influenced by the soil water quality in the area of cultivation. Col samples obtained from the Uitvlug (electrical capacity (EC) = 57 mS.m⁻¹) and Zandrug (EC = 25 mS.m⁻¹) areas were highly affected

compared to Col samples obtained from the Parys ($EC = 145 \text{ mS.m}^{-1}$) area. All samples obtained from the Parys area during trial 1 showed a significantly lower occurrence of the defect compared to samples from the Uitvlug and Zandrug areas. During trial 2 samples from the Thaaibos ($EC = 82 \text{ mS.m}^{-1}$) area showed a lower occurrence of “glassiness” than samples from the Witklip ($EC = 178 \text{ mS.m}^{-1}$). Other cultivars analysed during the study, including Fianna (Fia), Pentland Dell (Pen) and Shepody (She) did not show an exceptionally high occurrence of “glassiness” with the exception of Fia during trial 2. The soil depth, specific gravity and storage duration did not contribute to the differences on the occurrence of “glassiness” in a significant manner. This defect can therefore, be ascribed to variations in the chemical and physical starch properties as affected by cultivar and environmental conditions such as soil water quality.

Blanching at modified conditions of 62°C for 25 min during frozen French fry processing caused a reduction in the occurrence of the “glassiness” defect in the cultivars Fia, Pen and Col. These modified conditions also improved the uniformity of the texture in the French fry strip, reduced oil absorption during frying and prevented the French fry strips from breaking during subsequent processing steps.

FT-NIR calibration models were not successfully developed to predict the moisture, starch and reducing sugar content in a potato sample. No clear distinctions could be made between samples with and without the “glassiness” defect when principal component analysis was applied. Inclusion of FT-NIR spectroscopy in a quality control system for monitoring the moisture, starch and reducing sugar content and the occurrence of the “glassiness” defect in potatoes has therefore, been proven to be inaccurate. The use of homogenised instead of intact samples can possibly improve the accuracy of these predictions.

From the results obtained it may be proposed that the cultivar Her is ideal for the production of a French fry product where “glassiness” is considered a quality aspect. The cultivar Col should be avoided for the production of frozen French fries as this cultivar show an exceptionally high occurrence of the “glassiness” defect. If Col is, however, preferred for French fry production due to other quality attributes including tuber size, specific gravity or flesh colour it is suggested that this cultivar is cultivated under soil water conditions prevailing in the area Parys ($EC = 145.57 \text{ mS.m}^{-1}$) or processed under the modified blanching conditions. According to the results of this

study a reduced occurrence of the “glassiness” defect and an improved French fry quality can be expected by adjusting blanching parameters to 25 min at 62°C.

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APPENDIX

Detailed results and the complete statistical analyses are presented in the Appendix.

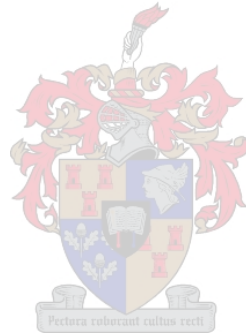


Table A3. Analytical results during trial 1.

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Parys	Col	Shallow	High	59	1	1	78.86	0.57	-	No
Parys	Col	Shallow	High	35	2	1	78.78	0.51	-	No
Parys	Col	Shallow	Low	30	1	1	81.11	0.56	-	No
Parys	Col	Shallow	Low	48	2	1	80.57	0.49	-	Yes
Parys	Col	Shallow	Low	17	3	2	80.41	0.47	-	No
Parys	Col	Shallow	Low	31	4	2	80.18	0.59	-	Yes
Parys	Col	Deep	High	15	1	1	76.79	0.24	-	No
Parys	Col	Deep	High	39	2	1	78.28	0.48	-	No
Parys	Col	Deep	High	78	3	2	77.30	0.46	-	No
Parys	Col	Deep	High	90	4	2	77.64	0.47	-	Yes
Parys	Col	Deep	Low	49	1	1	79.13	0.42	-	No
Parys	Col	Deep	Low	23	2	1	79.48	0.53	-	No
Parys	Col	Deep	Low	51	3	2	78.87	0.34	-	No
Parys	Col	Deep	Low	49	4	2	79.02	0.42	-	No
Parys	Pen	Shallow	Low	55	1	1	81.72	1.36	12.02	No
Parys	Pen	Shallow	Low	73	2	1	81.91	1.62	-	No
Parys	Pen	Shallow	Low	16	3	2	81.20	1.23	-	No
Parys	Pen	Shallow	Low	20	4	2	81.12	1.62	-	No
Parys	Pen	Deep	Low	74	1	1	82.49	1.58	12.08	Yes
Parys	Pen	Deep	Low	77	2	1	81.50	1.25	-	No
Parys	Pen	Deep	Low	34	3	2	80.21	1.48	-	No
Parys	Pen	Deep	Low	32	4	2	80.79	1.63	-	No
Parys	Fia	Shallow	Low	50	1	1	83.50	0.61	9.35	No
Parys	Fia	Shallow	Low	91	2	1	83.27	0.52	-	Yes
Parys	Fia	Shallow	Low	21	3	2	84.37	0.80	-	No
Parys	Fia	Shallow	Low	57	4	2	82.88	0.61	-	No
Parys	Fia	Deep	Low	96	1	1	81.94	0.81	-	No
Parys	Fia	Deep	Low	27	2	1	82.48	0.64	-	No
Parys	Fia	Deep	Low	60	3	2	83.96	0.56	-	No
Parys	Fia	Deep	Low	37	4	2	82.81	0.95	-	No
Parys	Her	Shallow	Low	36	1	1	81.07	0.52	11.36	No
Parys	Her	Shallow	Low	41	2	1	81.10	0.68	-	No
Parys	Her	Shallow	Low	44	3	2	80.99	0.61	-	Yes
Parys	Her	Shallow	Low	3	4	2	81.52	0.64	-	No
Parys	Her	Deep	Low	40	1	1	81.53	0.66	-	No
Parys	Her	Deep	Low	29	2	1	81.57	0.74	-	Yes
Parys	Her	Deep	Low	82	3	2	80.41	0.82	-	No
Parys	Her	Deep	Low	27	4	2	80.79	0.47	-	No
Zandrug	Col	Shallow	High	8	1	1	78.25	0.13	-	Yes
Zandrug	Col	Shallow	High	28	2	1	78.48	0.48	13.10	Yes
Zandrug	Col	Shallow	High	8	3	2	77.08	0.45	-	Yes
Zandrug	Col	Shallow	High	29	4	2	77.05	0.56	-	Yes
Zandrug	Col	Shallow	Low	65	1	1	80.02	0.74	-	Yes
Zandrug	Col	Shallow	Low	24	2	1	81.71	0.60	-	Yes
Zandrug	Col	Shallow	Low	62	3	2	78.73	0.45	-	Yes

Table A3. Continue...

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Zandrug	Col	Shallow	Low	63	4	2	79.42	0.44	-	Yes
Zandrug	Col	Deep	High	46	1	1	76.14	0.52	-	Yes
Zandrug	Col	Deep	High	86	2	1	76.07	0.43	-	Yes
Zandrug	Col	Deep	High	74	3	2	76.25	0.55	-	Yes
Zandrug	Col	Deep	High	26	4	2	76.17	0.48	-	Yes
Zandrug	Col	Deep	Low	64	1	1	78.29	0.55	-	Yes
Zandrug	Col	Deep	Low	3	2	1	79.20	0.33	-	Yes
Zandrug	Col	Deep	Low	28	3	2	79.03	0.74	-	Yes
Zandrug	Col	Deep	Low	6	4	2	79.65	0.46	-	No
Zandrug	Pen	Shallow	High	1	1	1	78.50	2.41	-	No
Zandrug	Pen	Shallow	High	56	2	1	77.67	1.67	15.17	No
Zandrug	Pen	Shallow	Low	52	1	1	78.86	2.07	12.30	Yes
Zandrug	Pen	Shallow	Low	4	2	1	78.67	2.02	-	No
Zandrug	Pen	Shallow	Low	40	3	2	79.67	1.71	-	Yes
Zandrug	Pen	Shallow	Low	24	4	2	78.39	2.16	-	No
Zandrug	Pen	Deep	Low	57	1	1	78.68	1.52	16.16	No
Zandrug	Pen	Deep	Low	62	2	1	77.18	1.89	-	Yes
Zandrug	Pen	Deep	Low	76	3	2	79.29	1.32	-	No
Zandrug	Pen	Deep	Low	85	4	2	77.94	1.40	-	No
Zandrug	Fia	Shallow	Low	67	1	1	79.08	0.58	16.80	Yes
Zandrug	Fia	Shallow	Low	83	2	1	79.14	0.46	-	Yes
Zandrug	Fia	Shallow	Low	93	3	2	78.90	0.64	-	No
Zandrug	Fia	Shallow	Low	68	4	2	80.28	0.83	-	No
Zandrug	Fia	Deep	High	38	1	1	76.98	0.58	14.05	No
Zandrug	Fia	Deep	High	54	2	1	78.16	0.76	-	No
Zandrug	Fia	Deep	High	22	3	2	76.59	0.65	-	No
Zandrug	Fia	Deep	High	47	4	2	78.00	0.49	-	No
Zandrug	Fia	Deep	Low	9	1	1	79.04	0.18	-	Yes
Zandrug	Fia	Deep	Low	21	2	1	79.67	0.69	10.48	No
Zandrug	Fia	Deep	Low	48	3	2	78.85	0.45	-	No
Zandrug	Fia	Deep	Low	18	4	2	79.44	0.52	-	No
Zandrug	Her	Shallow	High	63	1	1	78.24	0.62	-	No
Zandrug	Her	Shallow	High	42	2	1	77.47	0.52	-	Yes
Zandrug	Her	Shallow	High	81	3	2	78.17	0.54	-	No
Zandrug	Her	Shallow	High	88	4	2	78.94	0.54	-	Yes
Zandrug	Her	Shallow	Low	66	1	1	78.43	0.61	-	No
Zandrug	Her	Shallow	Low	31	2	1	79.69	0.84	-	Yes
Zandrug	Her	Shallow	Low	19	3	2	80.62	0.59	-	No
Zandrug	Her	Shallow	Low	13	4	2	81.60	0.80	-	No
Zandrug	Her	Deep	High	82	1	1	78.47	0.53	-	No
Zandrug	Her	Deep	High	92	2	1	77.31	0.72	-	No
Zandrug	Her	Deep	High	56	3	2	78.59	0.55	-	No
Zandrug	Her	Deep	High	66	4	2	76.80	0.51	-	No
Zandrug	Her	Deep	Low	16	1	1	78.91	0.34	-	No
Zandrug	Her	Deep	Low	34	2	1	77.81	0.52	-	No

Table A3. Continue...

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Zandrug	Her	Deep	Low	54	3	2	78.92	0.58	-	No
Zandrug	Her	Deep	Low	15	4	2	79.45	0.61	-	No
Uitvlug	Col	Shallow	High	20	1	1	76.79	0.53	13.74	Yes
Uitvlug	Col	Shallow	High	17	2	1	77.85	0.13	-	Yes
Uitvlug	Col	Shallow	High	12	3	2	77.85	0.52	-	Yes
Uitvlug	Col	Shallow	High	79	4	2	78.23	0.48	-	Yes
Uitvlug	Col	Shallow	Low	68	1	1	80.11	0.58	-	Yes
Uitvlug	Col	Shallow	Low	11	2	1	78.81	0.40	-	Yes
Uitvlug	Col	Shallow	Low	2	3	2	80.57	0.48	-	Yes
Uitvlug	Col	Shallow	Low	67	4	2	78.17	0.43	-	Yes
Uitvlug	Col	Deep	High	61	1	1	76.33	0.39	-	Yes
Uitvlug	Col	Deep	High	13	2	1	78.37	0.20	-	Yes
Uitvlug	Col	Deep	High	39	3	2	75.42	0.47	-	No
Uitvlug	Col	Deep	High	91	4	2	75.41	0.51	-	Yes
Uitvlug	Col	Deep	Low	5	1	1	80.36	0.12	-	No
Uitvlug	Col	Deep	Low	43	2	1	79.59	0.42	-	Yes
Uitvlug	Col	Deep	Low	50	3	2	76.54	0.36	-	Yes
Uitvlug	Col	Deep	Low	7	4	2	79.82	0.45	-	Yes
Uitvlug	Pen	Shallow	High	60	1	1	78.03	1.70	-	No
Uitvlug	Pen	Shallow	High	44	2	1	78.26	1.91	-	No
Uitvlug	Pen	Shallow	High	41	3	2	77.70	1.74	-	Yes
Uitvlug	Pen	Shallow	High	33	4	2	79.01	2.50	-	No
Uitvlug	Pen	Shallow	Low	87	1	1	80.98	1.77	-	Yes
Uitvlug	Pen	Shallow	Low	19	2	1	81.98	1.51	-	No
Uitvlug	Pen	Shallow	Low	70	3	2	80.72	1.85	-	No
Uitvlug	Pen	Shallow	Low	77	4	2	80.42	1.88	-	No
Uitvlug	Pen	Deep	High	58	1	1	78.35	1.30	16.64	No
Uitvlug	Pen	Deep	High	32	2	1	76.34	1.30	-	Yes
Uitvlug	Pen	Deep	High	64	3	2	78.91	1.12	-	No
Uitvlug	Pen	Deep	High	53	4	2	78.47	1.52	-	No
Uitvlug	Pen	Deep	Low	76	1	1	81.38	2.39	14.07	No
Uitvlug	Pen	Deep	Low	12	2	1	80.46	1.43	-	No
Uitvlug	Pen	Deep	Low	38	3	2	82.04	2.56	-	Yes
Uitvlug	Pen	Deep	Low	23	4	2	80.07	2.20	-	No
Uitvlug	Fia	Shallow	High	26	1	1	76.64	0.45	-	No
Uitvlug	Fia	Shallow	High	53	2	1	78.26	0.62	-	Yes
Uitvlug	Fia	Shallow	High	10	3	2	77.43	0.50	-	No
Uitvlug	Fia	Shallow	High	43	4	2	79.00	0.78	-	Yes
Uitvlug	Fia	Shallow	Low	93	1	1	78.46	0.59	-	Yes
Uitvlug	Fia	Shallow	Low	33	2	1	80.45	0.74	-	Yes
Uitvlug	Fia	Shallow	Low	59	3	2	79.08	0.46	-	Yes
Uitvlug	Fia	Shallow	Low	14	4	2	79.01	0.53	-	No
Uitvlug	Fia	Deep	High	14	1	1	75.78	0.19	-	Yes
Uitvlug	Fia	Deep	High	81	2	1	77.44	0.39	17.23	No
Uitvlug	Fia	Deep	High	65	3	2	77.33	0.38	-	No

Table A3. Continue...

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Uitvlug	Fia	Deep	High	1	4	2	76.53	0.44	-	No
Uitvlug	Fia	Deep	Low	94	1	1	77.83	0.65	-	No
Uitvlug	Fia	Deep	Low	10	2	1	79.18	0.14	-	No
Uitvlug	Fia	Deep	Low	83	3	2	78.14	0.56	-	No
Uitvlug	Fia	Deep	Low	42	4	2	79.76	1.02	-	No
Uitvlug	Her	Shallow	High	90	1	1	79.01	0.42	-	No
Uitvlug	Her	Shallow	High	25	2	1	77.77	0.63	-	Yes
Uitvlug	Her	Shallow	High	96	3	2	76.11	0.53	-	No
Uitvlug	Her	Shallow	High	92	4	2	77.46	0.48	-	No
Uitvlug	Her	Shallow	Low	78	1	1	80.57	0.52	-	No
Uitvlug	Her	Shallow	Low	18	2	1	80.89	0.16	-	Yes
Uitvlug	Her	Shallow	Low	75	3	2	81.29	0.56	-	No
Uitvlug	Her	Shallow	Low	36	4	2	80.15	0.64	-	Yes
Uitvlug	Her	Deep	High	51	1	1	76.39	0.52	-	No
Uitvlug	Her	Deep	High	85	2	1	77.29	0.46	-	No
Uitvlug	Her	Deep	High	87	3	2	76.10	0.34	-	No
Uitvlug	Her	Deep	High	46	4	2	75.78	0.44	-	No
Uitvlug	Her	Deep	Low	80	1	1	79.10	0.42	12.51	No
Uitvlug	Her	Deep	Low	47	2	1	79.26	0.70	-	No
Uitvlug	Her	Deep	Low	5	3	2	79.94	0.59	-	Yes
Uitvlug	Her	Deep	Low	72	4	2	78.75	0.60	-	No

^a All repetitions were randomly ordered allowing each sample an equal chance for storage at 12°C.

^b Values indicated with (-) were not determined.

Table A4. Analytical results during trial 2.

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Thaaibos	Col	Shallow	High	109	1	1	78.84	0.39	-	Yes
Thaaibos	Col	Shallow	High	73	2	1	79.31	0.55	-	No
Thaaibos	Col	Shallow	High	70	3	2	76.51	0.43	17.54	No
Thaaibos	Col	Shallow	High	40	4	2	76.95	0.52	-	Yes
Thaaibos	Col	Deep	High	85	1	1	78.79	0.55	-	Yes
Thaaibos	Col	Deep	High	39	2	1	79.39	0.42	-	Yes
Thaaibos	Col	Deep	High	89	3	2	78.12	0.52	13.38	Yes
Thaaibos	Col	Deep	High	104	4	2	77.77	0.45	-	Yes
Thaaibos	Col	Shallow	Medium	77	1	1	81.19	0.50	-	No
Thaaibos	Col	Shallow	Medium	106	2	1	82.13	0.39	-	Yes
Thaaibos	Col	Shallow	Medium	7	3	2	80.46	0.47	-	No
Thaaibos	Col	Shallow	Medium	115	4	2	77.96	0.41	16.08	Yes
Thaaibos	Col	Deep	Medium	111	1	1	79.16	0.43	-	Yes
Thaaibos	Col	Deep	Medium	68	2	1	79.97	0.41	-	Yes
Thaaibos	Col	Deep	Medium	26	3	2	79.34	0.61	17.15	Yes
Thaaibos	Col	Deep	Medium	30	4	2	80.66	0.54	-	Yes
Thaaibos	Pen	Shallow	High	22	1	1	77.81	0.63	-	No
Thaaibos	Pen	Shallow	High	120	2	1	79.74	0.65	-	No
Thaaibos	Pen	Shallow	High	84	3	2	77.66	0.70	19.16	Yes
Thaaibos	Pen	Shallow	High	109	4	2	77.43	0.51	-	No
Thaaibos	Pen	Shallow	Low	1	1	1	82.25	0.58	-	Yes
Thaaibos	Pen	Shallow	Low	119	2	1	79.07	0.75	-	Yes
Thaaibos	Pen	Shallow	Low	55	3	2	81.93	1.38	11.85	No
Thaaibos	Pen	Shallow	Low	6	4	2	81.56	1.15	-	Yes
Thaaibos	Pen	Deep	High	67	1	1	77.58	0.45	-	No
Thaaibos	Pen	Deep	High	20	2	1	78.54	0.80	-	Yes
Thaaibos	Pen	Deep	High	76	3	2	76.77	0.77	14.86	No
Thaaibos	Pen	Deep	High	112	4	2	77.14	0.54	-	No
Thaaibos	Pen	Shallow	Medium	118	1	1	81.23	0.73	-	No
Thaaibos	Pen	Shallow	Medium	49	2	1	81.07	0.73	-	No
Thaaibos	Pen	Shallow	Medium	4	3	2	79.33	0.73	17.89	No
Thaaibos	Pen	Shallow	Medium	36	4	2	80.80	0.55	-	No
Thaaibos	Pen	Deep	Medium	112	1	1	79.93	0.61	-	No
Thaaibos	Pen	Deep	Medium	36	2	1	78.20	0.67	-	No
Thaaibos	Pen	Deep	Medium	20	3	2	79.25	0.80	-	Yes
Thaaibos	Pen	Deep	Medium	119	4	2	80.81	0.55	11.89	No
Thaaibos	Fia	Shallow	High	101	1	1	80.31	0.40	-	No
Thaaibos	Fia	Shallow	High	113	2	1	79.88	0.44	-	No
Thaaibos	Fia	Shallow	High	60	3	2	76.83	0.43	16.38	No
Thaaibos	Fia	Shallow	High	57	4	2	76.93	0.36	-	Yes
Thaaibos	Fia	Shallow	Low	43	1	1	83.79	0.79	-	Yes
Thaaibos	Fia	Shallow	Low	79	2	1	81.92	0.45	-	Yes
Thaaibos	Fia	Shallow	Low	18	3	2	82.05	0.59	-	Yes
Thaaibos	Fia	Shallow	Low	85	4	2	81.75	0.78	12.04	No
Thaaibos	Fia	Deep	High	38	1	1	76.94	0.28	-	Yes
Thaaibos	Fia	Deep	High	81	2	1	77.40	0.37	-	No

Table A4. Continue...

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Thaaibos	Fia	Deep	High	68	3	2	75.63	0.50	18.67	No
Thaaibos	Fia	Deep	High	77	4	2	75.37	0.45	-	No
Thaaibos	Fia	Shallow	Medium	13	1	1	80.17	0.49	-	Yes
Thaaibos	Fia	Shallow	Medium	82	2	1	80.04	0.43	-	No
Thaaibos	Fia	Shallow	Medium	52	3	2	79.73	0.58	16.91	Yes
Thaaibos	Fia	Shallow	Medium	81	4	2	80.48	0.54	-	Yes
Thaaibos	Her	Shallow	High	76	1	1	79.08	0.48	-	No
Thaaibos	Her	Shallow	High	29	2	1	79.00	0.47	-	No
Thaaibos	Her	Shallow	High	9	3	2	77.71	0.57	19.01	No
Thaaibos	Her	Shallow	High	25	4	2	78.93	0.60	-	No
Thaaibos	Her	Deep	High	54	1	1	78.08	0.58	-	No
Thaaibos	Her	Deep	High	90	2	1	77.43	0.49	-	No
Thaaibos	Her	Deep	High	106	3	2	77.65	0.53	11.86	No
Thaaibos	Her	Deep	High	74	4	2	76.89	0.47	-	No
Thaaibos	Her	Shallow	Medium	52	1	1	80.75	0.59	-	No
Thaaibos	Her	Shallow	Medium	97	2	1	80.08	0.42	-	No
Thaaibos	Her	Shallow	Medium	114	3	2	78.79	0.49	14.75	No
Thaaibos	Her	Shallow	Medium	82	4	2	78.71	0.52	-	No
Thaaibos	Her	Deep	Medium	12	1	1	80.32	0.67	-	No
Thaaibos	Her	Deep	Medium	24	2	1	79.93	0.57	-	No
Thaaibos	Her	Deep	Medium	47	3	2	79.69	0.55	14.89	No
Thaaibos	Her	Deep	Medium	120	4	2	79.69	0.46	-	No
Thaaibos	She	Shallow	High	51	1	1	78.06	0.65	-	No
Thaaibos	She	Shallow	High	94	2	1	78.72	0.48	-	No
Thaaibos	She	Shallow	High	53	3	2	78.77	0.45	13.00	No
Thaaibos	She	Shallow	High	58	4	2	78.74	0.47	-	No
Thaaibos	She	Deep	High	48	1	1	77.37	0.45	-	No
Thaaibos	She	Deep	High	41	2	1	78.49	0.53	-	No
Thaaibos	She	Deep	High	3	3	2	77.24	0.53	19.78	No
Thaaibos	She	Deep	High	2	4	2	77.97	0.58	-	No
Thaaibos	She	Shallow	Medium	10	1	1	80.34	0.64	-	Yes
Thaaibos	She	Shallow	Medium	114	2	1	78.34	0.42	-	Yes
Thaaibos	She	Shallow	Medium	13	3	2	79.10	0.48	-	Yes
Thaaibos	She	Shallow	Medium	117	4	2	80.39	0.36	11.27	No
Thaaibos	She	Deep	Medium	98	1	1	79.39	0.44	-	Yes
Thaaibos	She	Deep	Medium	107	2	1	78.36	0.45	-	No
Thaaibos	She	Deep	Medium	67	3	2	77.74	0.64	13.93	No
Thaaibos	She	Deep	Medium	27	4	2	79.45	0.56	-	No
Witklip	Col	Shallow	Low	57	1	1	82.10	0.41	-	Yes
Witklip	Col	Shallow	Low	19	2	1	81.95	0.52	-	Yes
Witklip	Col	Shallow	Low	69	3	2	80.17	0.40	13.64	Yes
Witklip	Col	Shallow	Low	113	4	2	81.02	0.42	-	Yes
Witklip	Col	Deep	High	2	1	1	79.20	0.43	-	Yes
Witklip	Col	Deep	High	37	2	1	79.81	0.53	-	Yes
Witklip	Col	Deep	High	42	3	2	79.28	0.43	12.18	Yes
Witklip	Col	Deep	High	90	4	2	77.88	0.43	-	Yes

Table A4. Continue...

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Witklip	Col	Shallow	Medium	59	1	1	80.28	0.35	-	Yes
Witklip	Col	Shallow	Medium	31	2	1	79.47	0.38	-	Yes
Witklip	Col	Shallow	Medium	98	3	2	79.72	0.39	11.44	Yes
Witklip	Col	Shallow	Medium	108	4	2	78.93	0.38	-	Yes
Witklip	Col	Deep	Medium	5	1	1	80.30	0.43	-	Yes
Witklip	Col	Deep	Medium	4	2	1	79.84	0.44	-	Yes
Witklip	Col	Deep	Medium	63	3	2	79.25	0.40	10.61	No
Witklip	Col	Deep	Medium	21	4	2	79.90	0.37	-	Yes
Witklip	Pen	Shallow	High	45	1	1	78.74	0.52	-	Yes
Witklip	Pen	Shallow	High	96	2	1	79.24	0.44	-	No
Witklip	Pen	Shallow	High	116	3	2	79.08	0.38	10.81	Yes
Witklip	Pen	Shallow	High	88	4	2	79.06	0.70	-	No
Witklip	Pen	Shallow	Low	92	1	1	82.64	0.90	-	Yes
Witklip	Pen	Shallow	Low	84	2	1	82.49	0.87	-	Yes
Witklip	Pen	Shallow	Low	75	3	2	81.15	1.29	11.90	No
Witklip	Pen	Shallow	Low	56	4	2	82.10	0.72	-	No
Witklip	Pen	Deep	High	91	1	1	79.07	0.57	-	Yes
Witklip	Pen	Deep	High	18	2	1	78.25	0.57	-	No
Witklip	Pen	Deep	High	102	3	2	78.55	0.81	12.30	No
Witklip	Pen	Deep	High	110	4	2	77.00	0.56	-	No
Witklip	Pen	Shallow	Medium	35	1	1	79.33	0.67	-	No
Witklip	Pen	Shallow	Medium	11	2	1	81.26	1.04	-	Yes
Witklip	Pen	Shallow	Medium	17	3	2	81.45	0.71	16.00	No
Witklip	Pen	Shallow	Medium	33	4	2	78.68	0.54	-	Yes
Witklip	Pen	Deep	Medium	47	1	1	80.64	0.68	-	Yes
Witklip	Pen	Deep	Medium	50	2	1	81.04	0.95	-	No
Witklip	Pen	Deep	Medium	97	3	2	79.35	0.58	11.83	No
Witklip	Pen	Deep	Medium	62	4	2	79.41	0.76	-	Yes
Witklip	Fia	Shallow	High	34	1	1	77.90	0.39	-	Yes
Witklip	Fia	Shallow	High	80	2	1	79.01	0.37	-	No
Witklip	Fia	Shallow	High	100	3	2	77.96	0.35	13.81	Yes
Witklip	Fia	Shallow	High	41	4	2	78.47	0.41	-	Yes
Witklip	Fia	Shallow	Low	61	1	1	83.00	0.43	-	Yes
Witklip	Fia	Shallow	Low	56	2	1	83.90	0.72	-	Yes
Witklip	Fia	Shallow	Low	24	3	2	82.55	0.55	10.78	Yes
Witklip	Fia	Shallow	Low	16	4	2	82.61	0.41	-	No
Witklip	Fia	Shallow	Medium	64	1	1	81.31	0.42	-	Yes
Witklip	Fia	Shallow	Medium	27	2	1	78.90	0.41	-	Yes
Witklip	Fia	Shallow	Medium	80	3	2	80.46	0.48	12.87	Yes
Witklip	Fia	Shallow	Medium	46	4	2	80.47	0.60	-	Yes
Witklip	Fia	Deep	Medium	87	1	1	77.20	0.32	-	Yes
Witklip	Fia	Deep	Medium	3	2	1	76.58	0.52	-	No
Witklip	Fia	Deep	Medium	118	3	2	78.71	0.27	12.09	Yes
Witklip	Fia	Deep	Medium	19	4	2	78.50	0.41	-	No
Witklip	Her	Shallow	Low	99	1	1	82.03	0.38	-	No
Witklip	Her	Shallow	Low	110	2	1	83.21	0.40	-	No

Table A4. Continue...

Area	Cultivar	Tuber soil depth	SG	Random sample order ^a	Repetition	Storage time group	Moisture content per wet weight (%)	Reducing sugar content per dry weight (%)	Total starch content (g/100g) ^b	Occurrence of "glassiness"
Witklip	Her	Shallow	Low	14	3	2	83.80	0.62	-	No
Witklip	Her	Shallow	Low	51	4	2	83.04	0.50	12.14	No
Witklip	Her	Deep	High	103	1	1	77.83	0.44	-	No
Witklip	Her	Deep	High	70	2	1	78.54	0.42	-	No
Witklip	Her	Deep	High	78	3	2	77.76	0.52	15.42	No
Witklip	Her	Deep	High	103	4	2	77.52	0.34	-	No
Witklip	Her	Deep	Low	89	1	1	84.37	0.54	-	No
Witklip	Her	Deep	Low	40	2	1	80.72	0.43	-	No
Witklip	Her	Deep	Low	45	3	2	81.93	0.56	11.91	No
Witklip	Her	Deep	Low	35	4	2	82.94	0.45	-	No
Witklip	Her	Shallow	Medium	108	1	1	80.16	0.35	-	No
Witklip	Her	Shallow	Medium	58	2	1	80.53	0.46	-	No
Witklip	Her	Shallow	Medium	39	3	2	80.65	0.42	-	No
Witklip	Her	Shallow	Medium	105	4	2	80.30	0.42	13.60	No
Witklip	Her	Deep	Medium	60	1	1	81.27	0.48	-	No
Witklip	Her	Deep	Medium	7	2	1	80.23	0.67	-	No
Witklip	Her	Deep	Medium	111	3	2	79.61	0.47	9.30	No
Witklip	Her	Deep	Medium	11	4	2	80.86	0.46	-	No
Witklip	She	Shallow	Low	66	1	1	80.60	0.36	-	No
Witklip	She	Shallow	Low	53	2	1	82.32	0.48	-	No
Witklip	She	Shallow	Low	43	3	2	82.34	0.50	12.91	Yes
Witklip	She	Shallow	Low	83	4	2	80.06	0.45	-	Yes
Witklip	She	Deep	Low	86	1	1	80.98	0.56	-	Yes
Witklip	She	Deep	Low	8	2	1	80.41	0.54	-	No
Witklip	She	Deep	Low	64	3	2	80.66	0.42	9.56	Yes
Witklip	She	Deep	Low	99	4	2	80.10	0.63	-	Yes
Witklip	She	Shallow	Medium	62	1	1	80.47	0.77	-	Yes
Witklip	She	Shallow	Medium	105	2	1	80.17	0.36	-	No
Witklip	She	Shallow	Medium	54	3	2	81.39	0.37	9.29	No
Witklip	She	Shallow	Medium	59	4	2	79.45	0.31	-	No
Witklip	She	Deep	Medium	44	1	1	80.10	0.75	-	No
Witklip	She	Deep	Medium	102	2	1	80.31	0.51	-	No
Witklip	She	Deep	Medium	44	3	2	79.22	0.43	13.34	Yes
Witklip	She	Deep	Medium	49	4	2	80.00	0.57	-	Yes

^a All repetitions were randomly ordered allowing each sample an equal chance for storage at 12°C.

^b Values indicated with (-) were not determined.

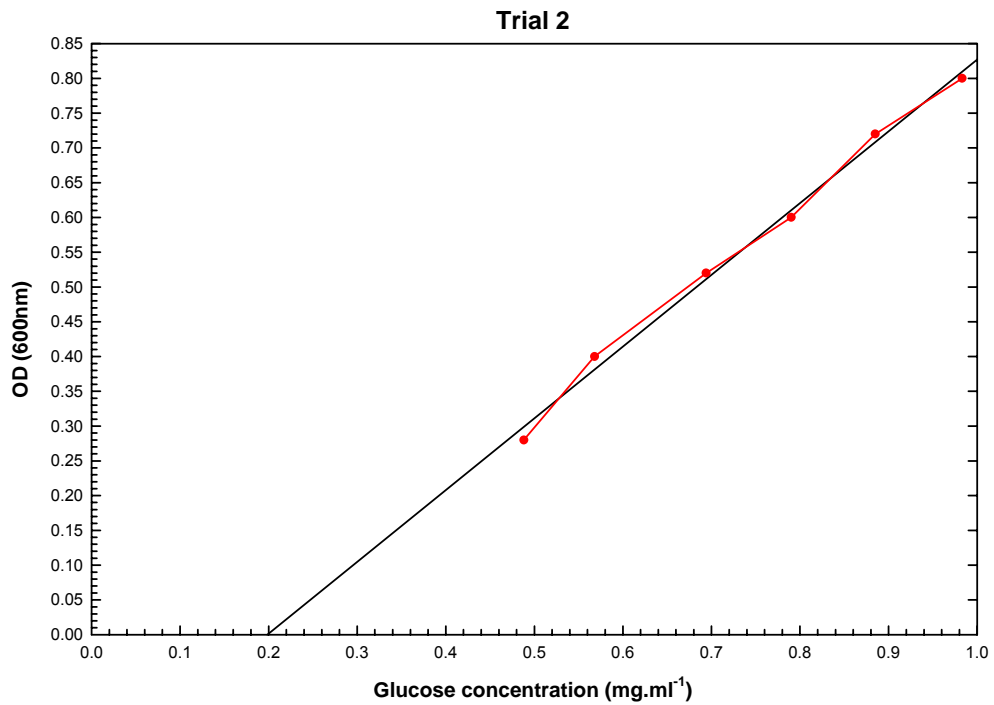
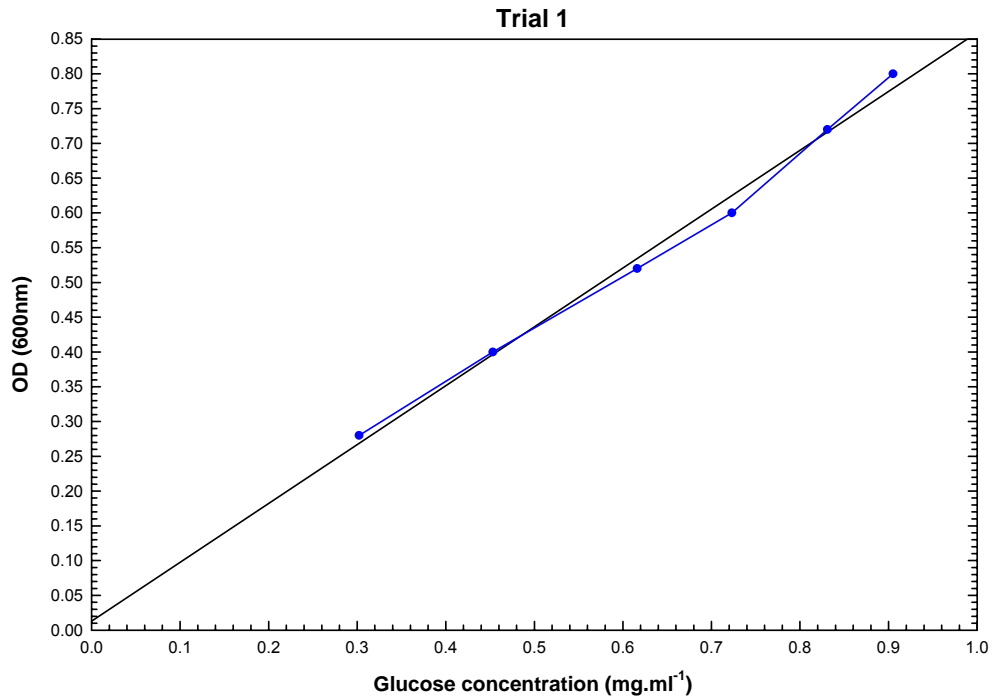


Figure A1. Linear regression graph for glucose concentration (mg.ml⁻¹) and absorbency values (600 nm) performing as standard curve for the determination of the reducing sugars content in trail 1 (A) and 2 (B).

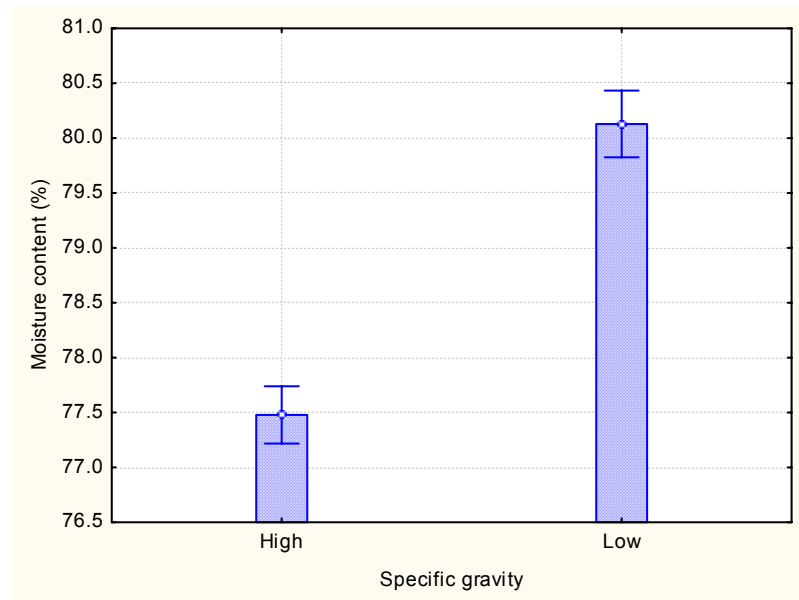
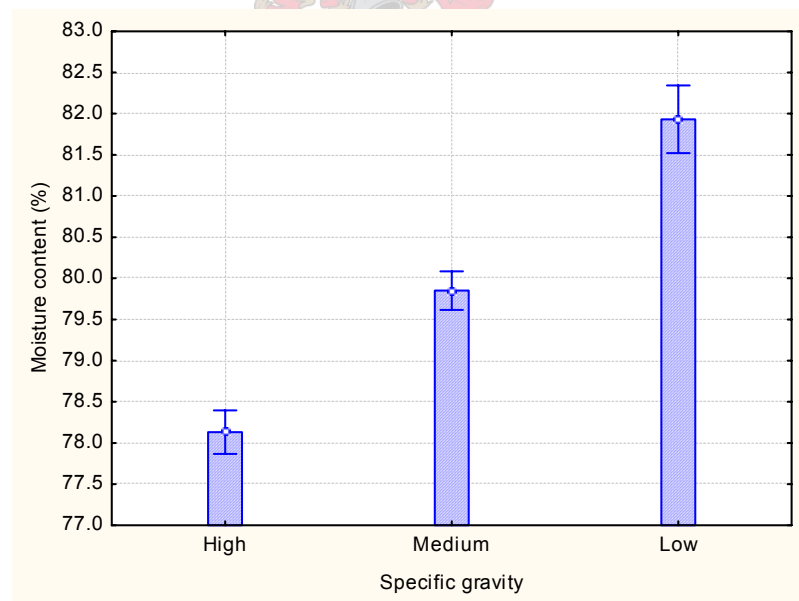
A**B**

Figure A2. Moisture content of specific gravity groups during trial 1 (**A**) ($p < 0.01$) and 2 (**B**) ($p < 0.01$) as determined by an analysis of variance (ANOVA). Vertical bars denote 0.95 confidence intervals.

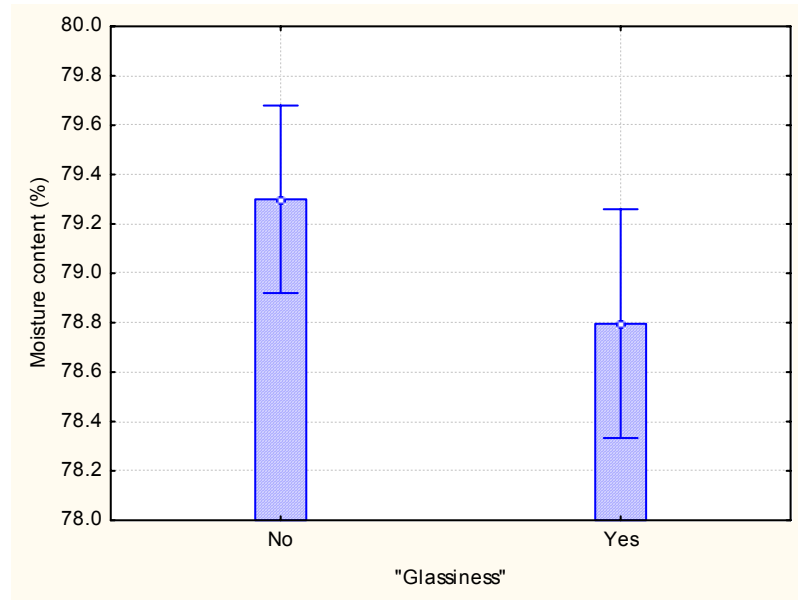
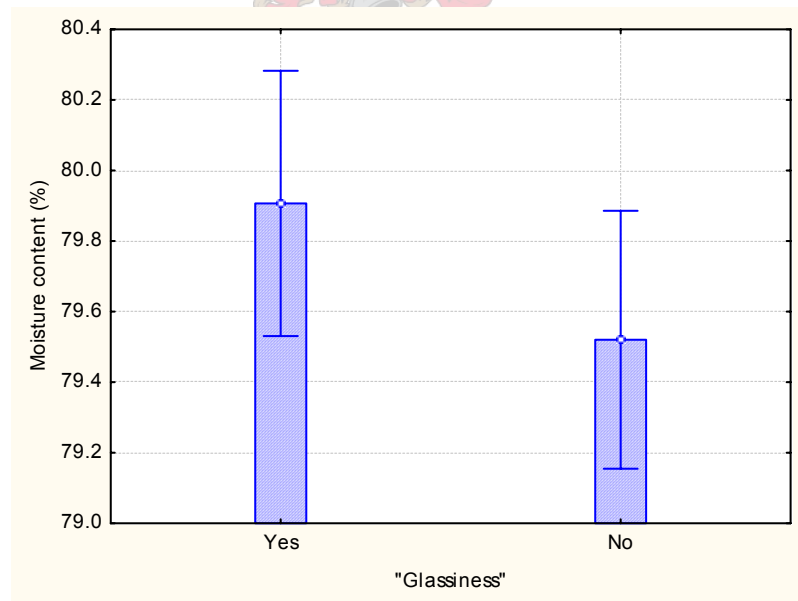
A**B**

Figure A3. Moisture content (%) for the “glassiness” defect in trial 1 (**A**) ($p=0.10$) and 2 (**B**) ($p=0.15$) as determined by an analysis of variance (ANOVA). Vertical bars denote 0.95 confidence intervals.

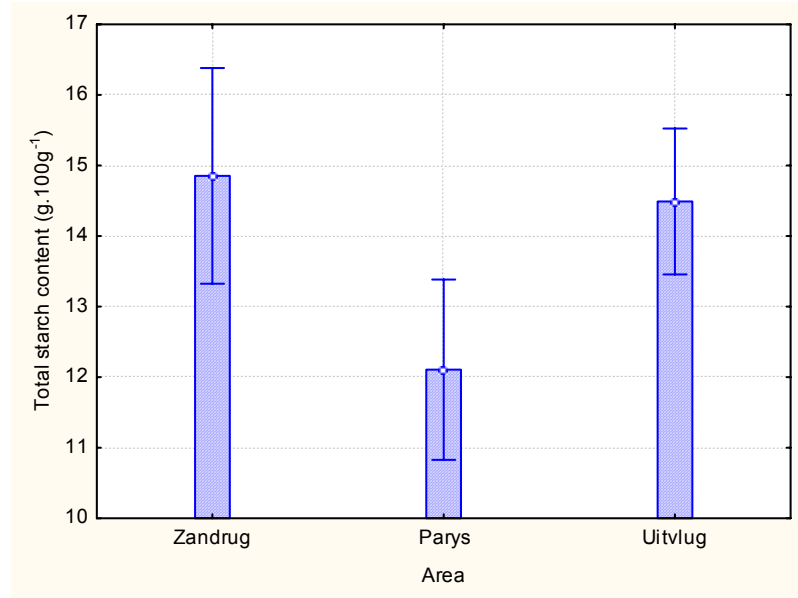
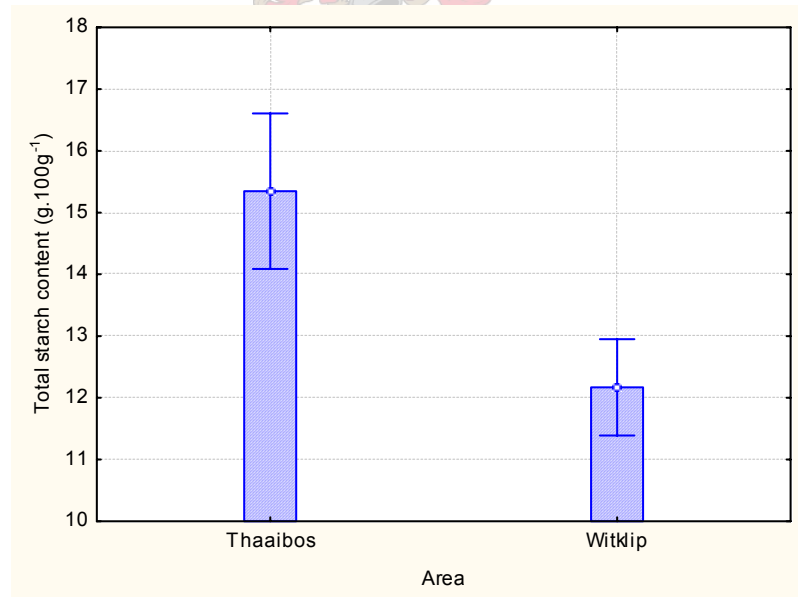
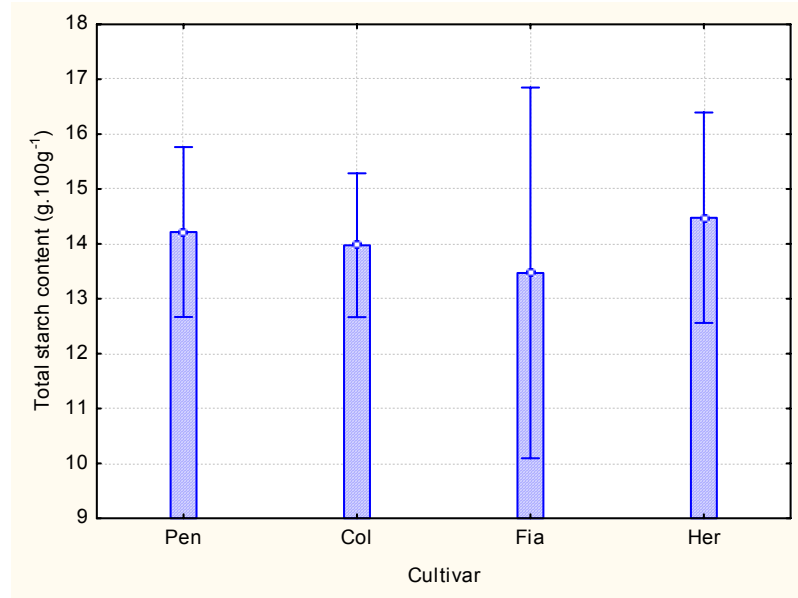
A**B**

Figure A4. The average total starch content (g.100g⁻¹) for different regions during trial 1 (**A**) (p=0.01) and 2 (**B**) (p<0.01) as determined by an analysis of variance (ANOVA). Vertical bars denote 0.95 confidence intervals.

A



B

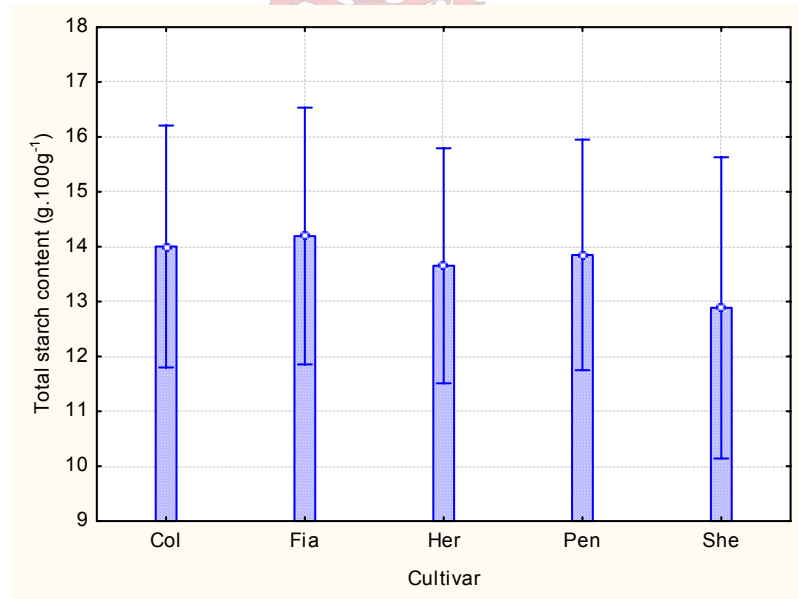


Figure A5. The average total starch content (g.100g⁻¹) for cultivars during trial 1 (**A**) ($p=0.87$) and 2 (**B**) ($p=0.91$) as determined by an analysis of variance (ANOVA). Vertical bars denote 0.95 confidence intervals.

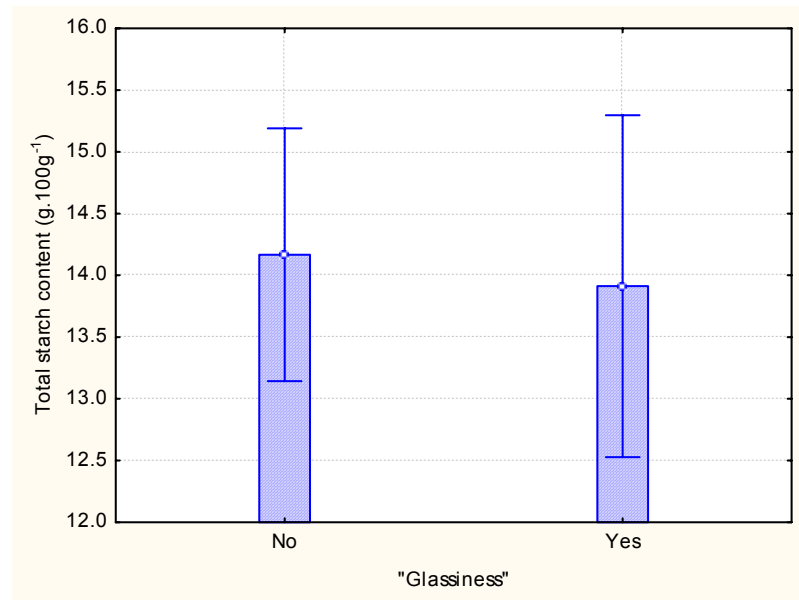
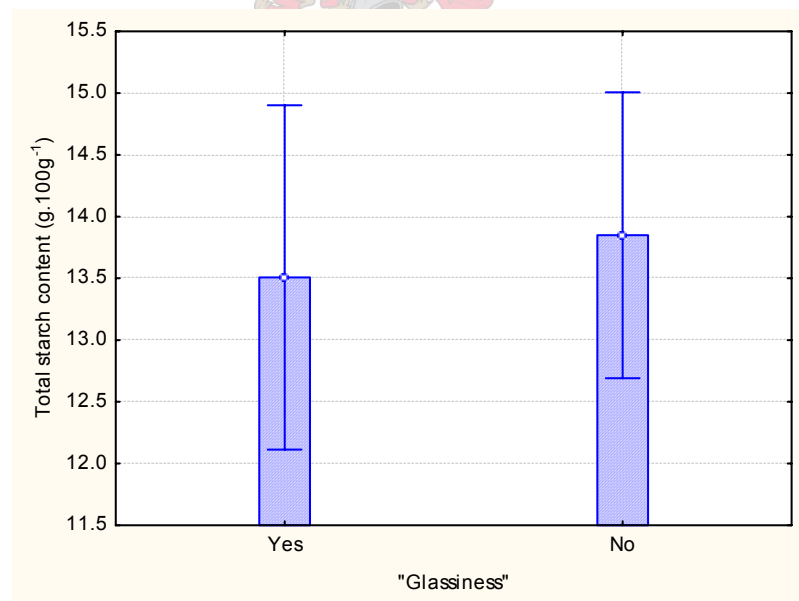
A**B**

Figure A6. Total starch content (g.100g⁻¹) for the “glassiness” defect in trial 1 (**A**) (p=0.76) and 2 (**B**) (p=0.70) as determined by an analysis of variance (ANOVA). Vertical bars denote 0.95 confidence intervals.

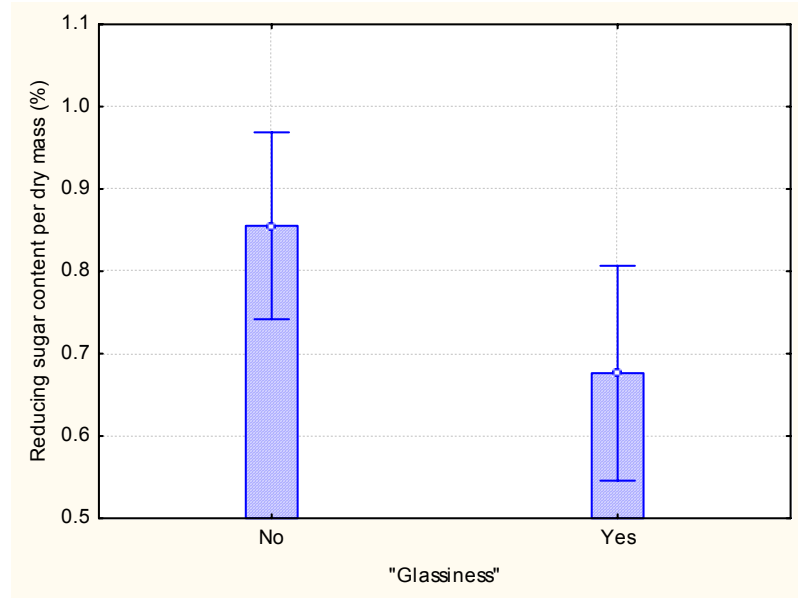
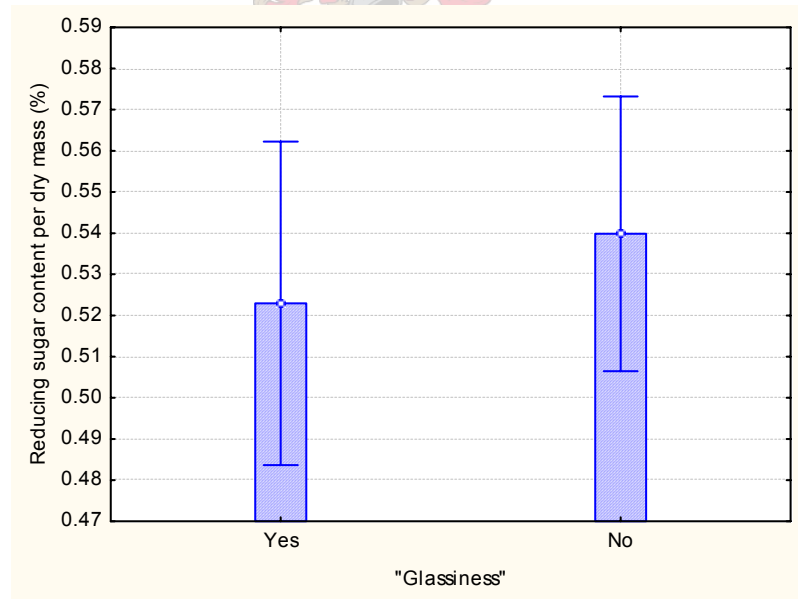
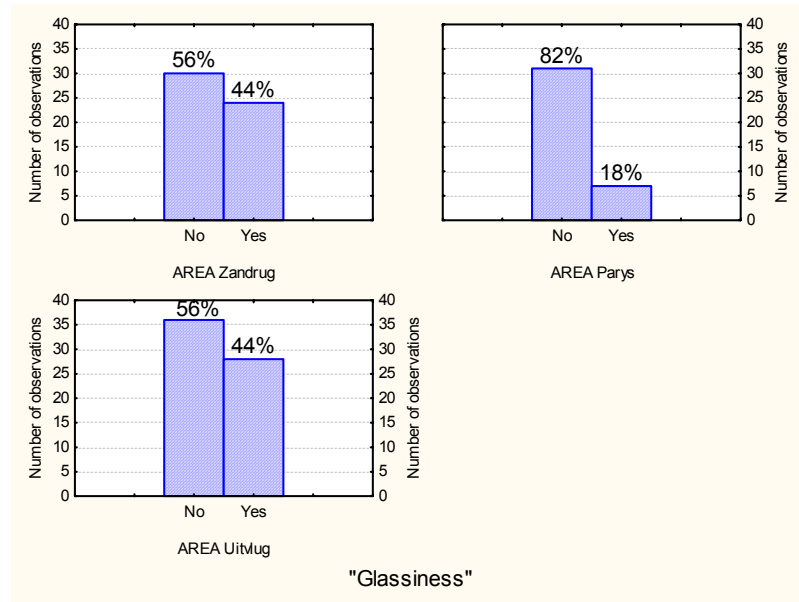
A**B**

Figure A8. The reducing sugar content per dry mass (%) for the “glassiness” defect in trial 1 (**A**) ($p=0.05$) and 2 (**B**) ($p=0.51$) as determined by an analysis of variance (ANOVA). Vertical bars denote 0.95 confidence intervals.

A



B

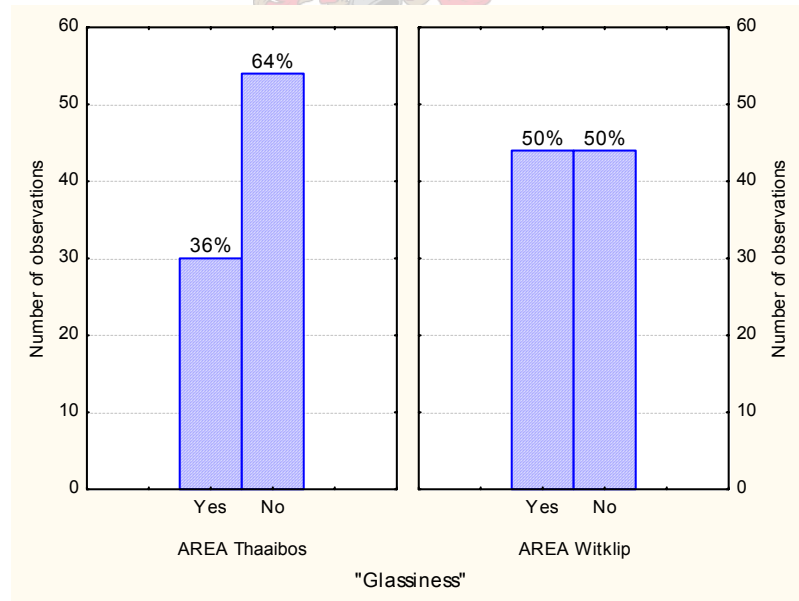
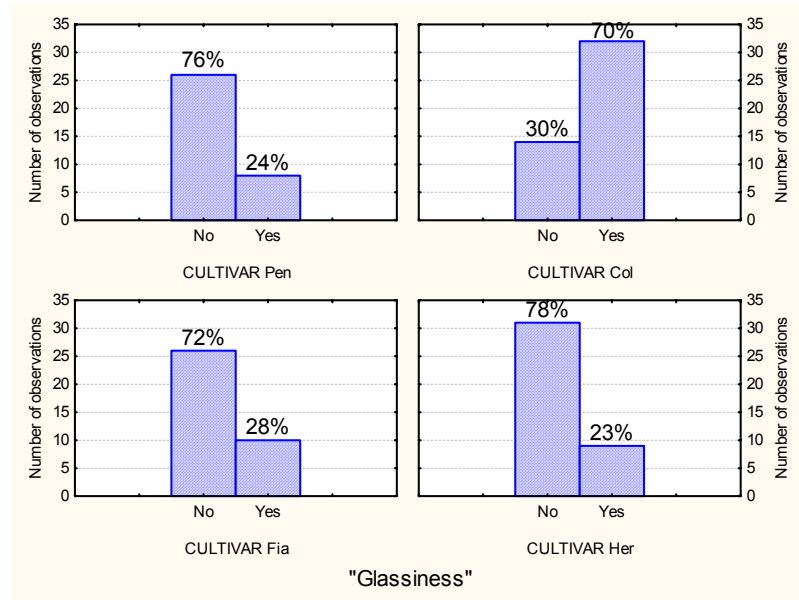


Figure A9. The occurrence of the “glassiness” defect in the regions of cultivation during trial 1 (**A**) ($p=0.01$) and 2 (**B**) ($p=0.06$).

A



B

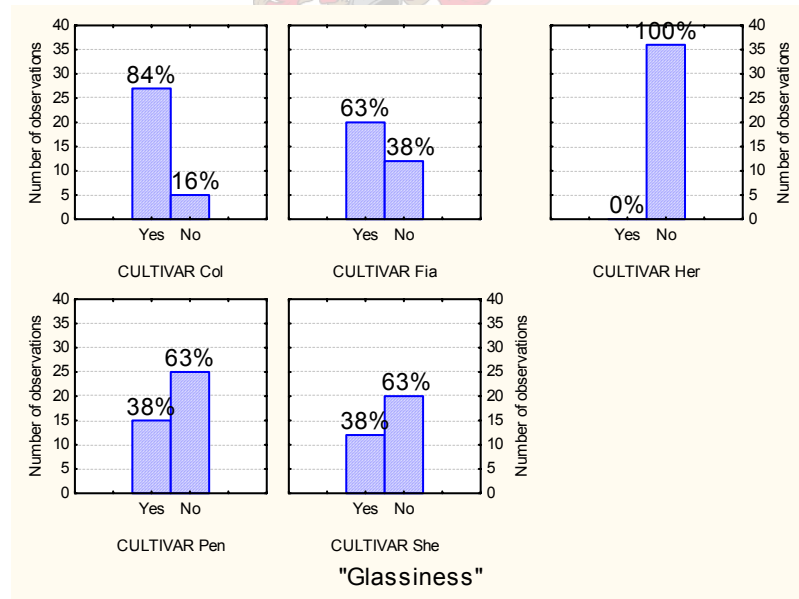
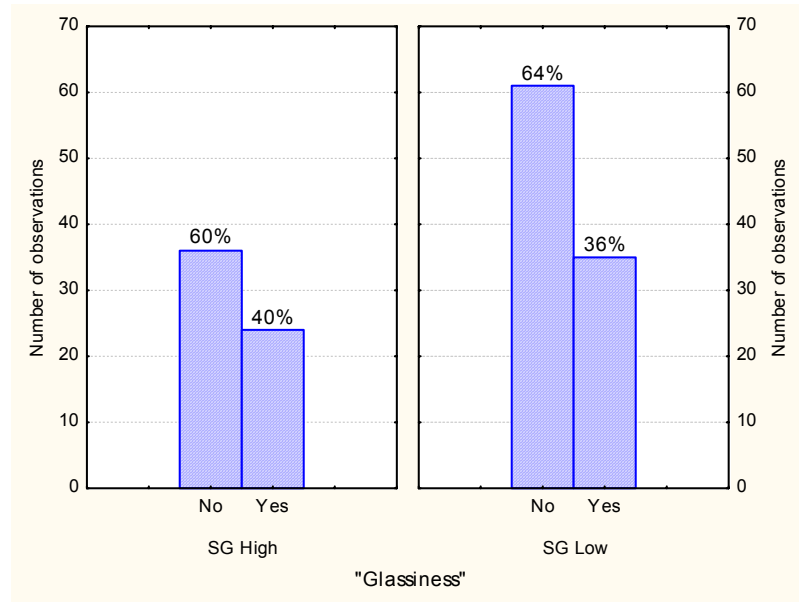


Figure A10. The occurrence of the “glassiness” defect in the cultivars analysed during trial 1 (**A**) ($p < 0.01$) and 2 (**B**) ($p < 0.01$).

A



B

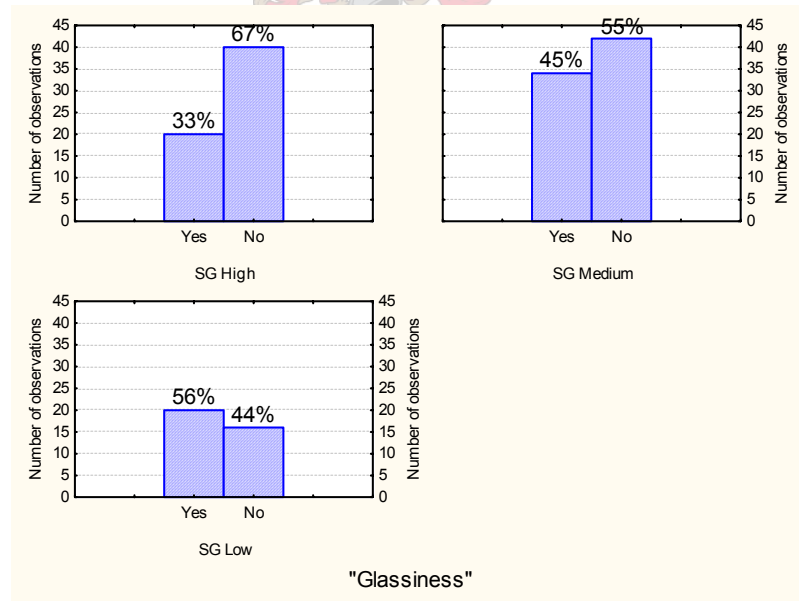


Figure A11. The occurrence of the “glassiness” defect in the specific gravity groups analysed during trial 1 (A) ($p=0.66$) and 2 (B) ($p=0.09$).

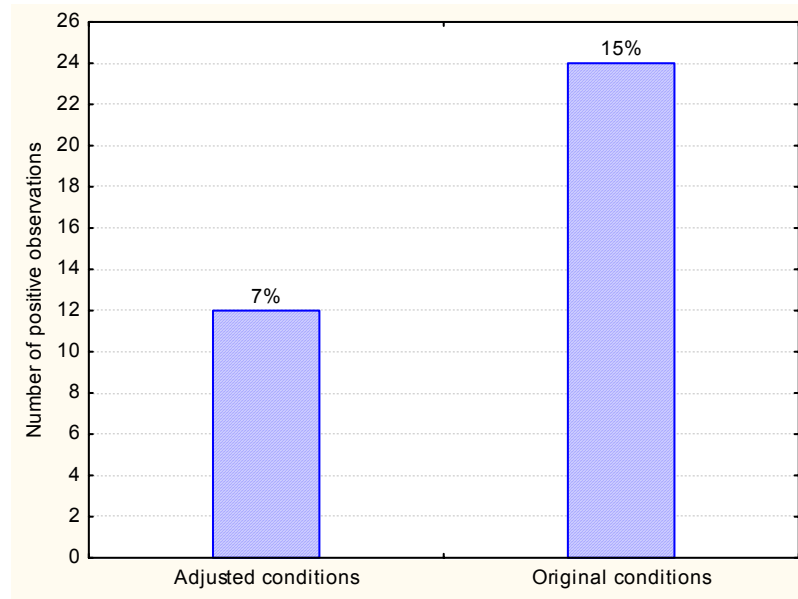


Figure A12. The percentage of the 163 samples of the cultivar Fia in which the “glassiness” defect occurred for the original and adjusted blanching conditions ($p=0.06$).

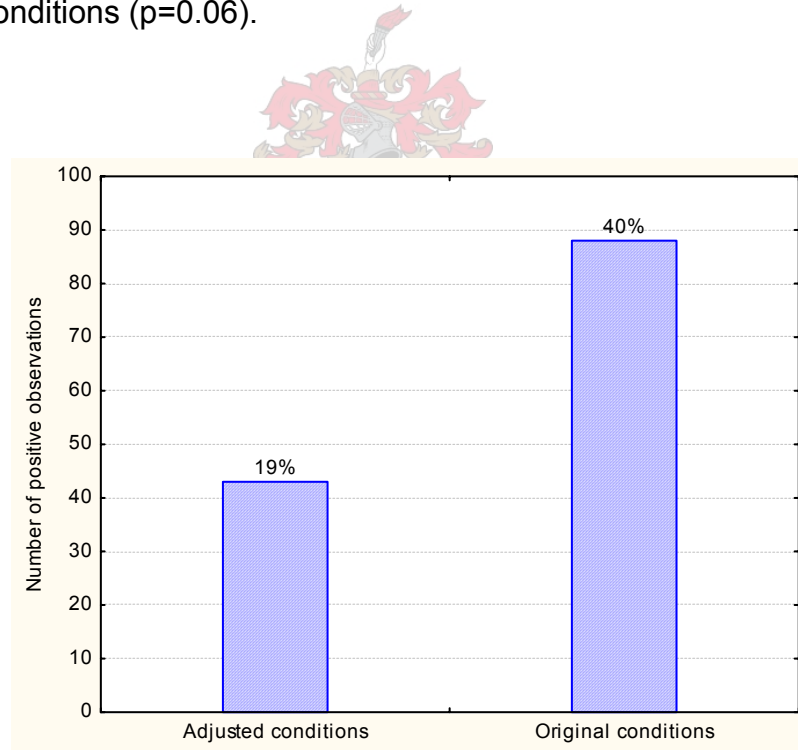


Figure A13. The percentage of the 222 samples of the cultivar Col in which the “glassiness” defect occurred for the original and adjusted blanching conditions ($p<0.01$).

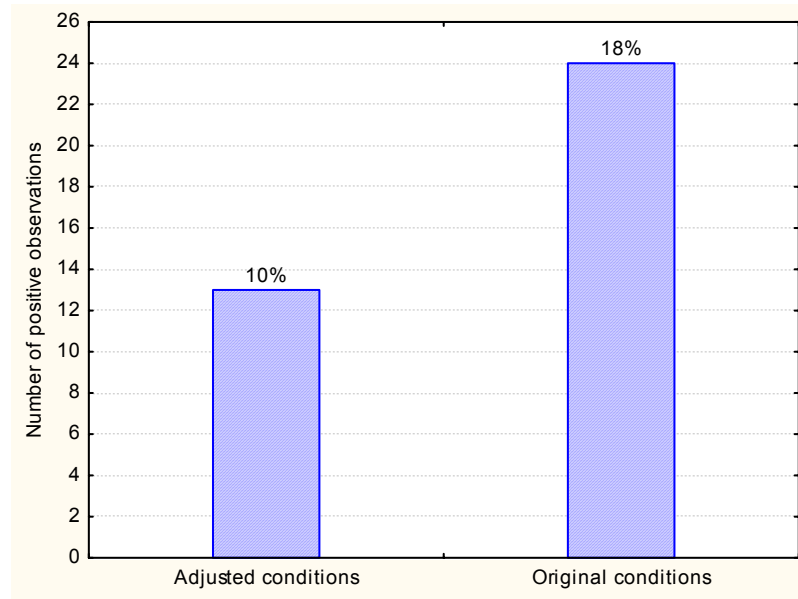


Figure A14. The percentage of the 130 samples of the cultivar Pen in which the “glassiness” defect occurred for the original and adjusted blanching conditions ($p=0.05$).

