CHAPTER 5

EVALUATION OF GROWTH PERFORMANCE AND DRY MATTER PARTITIONING OF FOUR PROCESSING POTATO CULTIVARS

5.1 Introduction

The potato (*Solanum tuberosum* L.) crop is a weather-sensitive crop with a wide variation among cultivars (Pashiardis, 1987). The environment is one of the major variables affecting crop production in general but, in particular, potato crops. Hence, knowledge of how it influences potato crop development, growth and yield is of great interest to researchers. Successful potato crop production requires efficient use of the climatic resources, namely solar radiation, temperature and water, among many others.

The growth rate of a potato crop, that is well supplied with water and nutrients and free from pests and diseases, is about proportional to its light absorption (Spitters, 1987; Van Delden, 2001). The total biomass production and accumulation of potato cultivars are dependent on the absorbed PAR, which is directly proportional to the plant canopy cover (Spitters, 1987; Vos & Groenwold, 1989; Van Delden, 2001). Spitters (1987) indicate that tuber yield is determined by the fraction of total biomass that is partitioned to the tuber. Potato cultivar variation in yield can thus be analysed in terms of differences in cumulative light absorption, the efficiency with which the absorbed radiation is used for DM, and the fraction of dry matter allocated to the desired plant organ (Pashiardis, 1987; Spitters, 1987; Van Delden, 2001). According to MacKerron (1987), cultivar differences in conversion efficiency have shown that, for most of the growing season, there is a linear relation between TDM and integral of intercepted solar radiation. Hence, the potential DM is manipulated using the conversion efficiency, which is the slope of the relationship. MacKerron (1987) further explained that the potential yield of tubers could be estimated from the average value of dry matter concentration, partitioned to both the top and tubers of the crop.

Biomass production in crops, including potatoes, is dependent on the amount of photosynthate available, which is directly proportional to the photosynthetic rate of the crop and its LAI (Meyer & Green, 1980; Tekalign & Hammes, 2005b). High LAI usually indicate that the crop can intercept more solar radiation for photosynthetic activity. Many researchers (Potters & Jones, 1977; Meyer & Green, 1980) report that the relationship between leaf area and biomass accumulation is linear. The most important factors that affect the rapid establishment of the crop canopy are genotype, seed environment, planting date and plant density, temperature and water stress conditions, and the availability of plant nutrients in the soil. Drought and high temperatures affect leaf area development and its persistence. The relationships between LAI and the proportion of radiation intercepted by the crop indicate that a LAI of four would intercept more than 80% of the incident radiation (Potters & Jones, 1977; Meyer & Green, 1980; Pashiardis, 1987).

Leaf radiation absorption is governed by the rate of leaf appearance, leaf expansion, leaf size, geometry and direction (Pashiardis, 1987). Pashiardis (1987) further explains that, in the absence of water stress, temperature is the major environmental factor influencing the development of leaf surface. Potato cultivars differ in the production of leaves at low temperatures in such a way that horizontal leaves intercept more light than erect leaves at low leaf area indices, and most cultivars differ considerably in this character (Pashiardis, 1987; Kooman & Rabbinge, 1996; Kooman *et al.,* 1996a). Generally, a temperature of below 7°C and above 30°C reduces the development rate of the potato crop (Kooman & Rabbinge, 1996; Kooman *et al.*, 1996b; Juzl & Stefl, 2002; Onder *et al.*, 2005).

Temperature and day length are among the major environmental factors that influence the development rate of potatoes and, consequently, the distribution of dry matter to various plant organs (Pashiardis, 1987; MacKerron & Jefferies, 1988; Kooman & Rabbinge, 1996). At early growth stages, most of the dry matter is distributed in a fixed proportion between leaves (80%) and stems (20%) (Van Heemist, 1986; Cadersa & Govinden, 2000; Jenkins & Mahmood, 2003), and from the onset of tuber initiation, the portion of dry matter partitioned to the tuber would constantly be at a maximum.

Dry matter production and allocation to the sink, the tuber, vary greatly in potato cultivars. Many researchers (Haverkort & Harris, 1987; Deblonde & Ledent, 2000) indicate that the poor adaptation of potato cultivars may be due to unfavourable allocation of assimilates in the plant. One of the reasons for failure of proportional assimilate allocation could be attributed to high temperatures, since, for some cultivars, a temperature of above 23°C favours allocation of dry matter to the foliage at the cost of tuber growth (Haverkort & Harris, 1987; Jenkins & Mahmood, 2003). The variation in assimilate allocation in potatoes is related to maturity, (early or late,) because differences in life span of the crop in the field allow them to have extended time to produce and allocate more dry matter to the sink (Wolfe *et al.*, 1983; Van

Heemist 1986; Spitters, 1987). Hence, assimilate allocation is the result of genotype and climate interaction with appropriate cultural practices. Meyling & Bodlaender (1981) generalise that assimilate allocation is the combined result of genotype, growth and development, which are mutually interdependent and are difficult to analyse separately in an experiment.

With this background, the objective of this experiment was to evaluate two newly developed South African potato cultivars (Frodo and Darius) in comparison with two current commercial cultivars (Pentland Dell and Shepody) for their growth performance and dry matter partitioning to the sink, by efficient use of the microclimate of the specific growing location. Frodo was a new cultivar bred by the Agricultural Research Council (ARC), Roodeplaat, in South Africa and was not yet released during this experimentation. The result of this experiment has appraised the performance of this cultivar and hence, it was released in 2005 and licensed to McCain Foods (SA) (Pty) Ltd.

Darius was also developed by the ARC at Roodeplaat. It is characterised by medium maturity length and long-oval tuber shape with shallow eyes. The skin and flesh of this cultivar is white with a fairly high yield and good tuber size distribution. Darius has a high specific gravity (SG) and is generally used for french fries and crisping.

Pentland Dell was developed in the United Kingdom for its high yielding ability. Tubers are long and oval in shape, medium to large in size, white-skinned with cream flesh and shallow eyes (Van Niekerk, 1984). In South Africa, this cultivar is widely produced in the Gauteng, Limpopo, North West and Mpumalanga and Eastern regions. It is known to be excellent for boiling, wedges, baking, chipping and mashing (Van Niekerk, 1984). On the other hand, Shepody was developed in North America as a medium to high yielding cultivar (CSIDC, 2003). Plant type at full flower is upright with a good canopy and plant maturity at harvest has been rated as yellow before it finally dies completely. The tubers are characterised by medium to low SG compared to other potato cultivars. Tuber shape is mostly oblong with shallow eye depth. The skin colour is buff to white with a smooth to moderately smooth texture and the tuber flesh colour is white (Hutchinson *et al.*, 2001). The overall external tuber appearance was rated as poor to fair and the fry colour ranges from 00-3, where a rating of 3 is the maximum tolerance that processors accept under scarce supply situations (CSIDC, 2003). Shepody is known to be one of the high yielding cultivars with desirable processing quality in the areas where it was originally developed.

5.2 Materials and methods

Site description

The study was conducted from August 2003 to January 2004 at the Bronkhorstspruit McCain Experimental Station in South Africa. The station is located at a latitude of 25^o 44' 16" S, a longitude of 28^o 41' 03" E and an altitude of 1 490 m above sea level. The area receives an average rainfall of 709 mm per annum, with an average monthly maximum temperature of 26.4^{o}C and an average minimum temperature of 13.7^{o}C during the crop growth period. The seedbed preparation was performed following standard cultivation practices.

Field procedure and treatments

The four potato cultivars, Frodo, Pentland Dell, Darius and Shepody, were planted on 28 August 2003. All potato seeds were produced under the same conditions and stored at 4°C for about four months before planting. Each cultivar occupied six rows at a spacing of 0.9 m between rows and 0.3 m between plants. The experiment was arranged in a RCBD with three replicates. The experimental field was kept free of weeds, and no visible disease and insect pests were observed during the growing season. For other cultural practices, the station's standard methods were followed.

At planting, the crops received 80 kg ha^{-1} of nitrogen, 120 kg ha^{-1} of phosphorus and 160 kg ha^{-1} of potassium in a 2:3:4 (30) fertiliser blend. Three light doses, that added up to 140 kg ha^{-1} of nitrogen fertiliser in a form of limestone ammonium nitrate (28), were side-dressed 50-80 DAP, which gave an overall total of 220 kg ha^{-1} of nitrogen. No fertiliser deficiency and disease/pest symptoms were observed during the growth period of this crop.

Data recorded

Soil water content (WC) was measured with a neutron water meter model 503DR CPN Hydroprobe (Campbell Pacific Nuclear, California, USA). The neutron water meter was calibrated for the site and weekly readings were taken before irrigation. Measurements were made in the middle of each plot, at 0.2 m soil depth increments down to 1 m. Sprinkler irrigation was used to replenish water deficit to field capacity for all plots according to the average soil water deficit recorded.

Crop growth parameters were measured weekly on all the plots from 35 DAP onwards. FI of PAR was measured weekly with a Decagon Sunfleck Ceptometer (Decagon, Pullman, Washington, USA) making one reference reading above and 10 readings beneath each canopy. Growth analyses were carried out weekly by harvesting plant material from 1 m^2 of ground surface at representative sites on each plot. Harvestable fresh matter was measured directly after sampling and dry matter of plant organs after drying in an oven at 60^{o}C for four to five days. Four harvests were specifically considered to determine the proportion of dry matter partitioned to the different parts of the plant. The harvests were performed at 58 DAP (Harvest I), 72 DAP (Harvest II), 84 DAP (Harvest III) and 101 DAP (Harvest IV). Two records of percentage canopy cover were taken at 58 DAP (CC1) and 84 DAP (CC2). Leaf area was measured with an LI 3100 belt-driven leaf area meter (LiCor, Lincoln, Nebraska, USA) and LAI was calculated from the data. RD was estimated during the growing season from the WC measurement fluctuation in the profile. Phenological development was also monitored for each cultivar.

Weather data was collected using a Metos automatic weather station. Wind speed was measured by anemometer and solar radiation (Rs) with a photocell, which measures in the wavelength spectrum of 360 to 1 100 nm. Precipitation and irrigation were measured, using a tipping spoon rain gauge. The relative humidity (RH) sensor had a capacity of measuring RH from 10 to 95% RH.

Statistical analysis

Analysis of variance was performed using the SAS System for Windows, 2002 (the SAS Institute Inc., Cary, North Carolina, USA). Means were compared, using the

LSD test at the 95% probability level. Correlation between parameters was performed where applicable.

5.3 Results and discussion

Dry matter partitioning

Data on dry matter partitioning during the four consecutive harvests (Harvest I, II, III, and IV) are given in Tables 5.1, 5.2, 5.3 and 5.4 respectively. Dry matter partitioning to different plant organs, leaf (LDM), stem (SDM), tuber (HDM) and total (TDM) accumulation was determined for the four potato cultivars, namely Frodo, Pentland Dell, Darius and Shepody. At harvest I, the percentage of LDM and HDM partitioning was not significantly different among the cultivars, although Shepody had a comparably higher percentage of HDM (Table 5.1). This indicates that Shepody was already at the end of the vegetative growth stage and in transition to the tuber filling stage, while the rest of the cultivars were mainly partitioning dry matter to the canopy. This was substantiated by the fact that Shepody had the highest dry matter partitioned to the tubers (HDM), about 38% ($p>0.05$), compared to Darius, only about 10%.

Dry matter partitioning to the stem was significantly lower ($p<0.05$) for Shepody than for the remaining three cultivars that were still in the peak of vegetative development. Darius took a long time to emerge compared to the other cultivars and had less vegetative coverage during the harvest.

Table 5.1 Potato dry matter partitioning to leaves (LDM), stem (SDM), tuber/ harvestable (HDM), and total dry mass (TDM) for the four potato cultivars Harvest I (58 DAP)

Cultivars	LDM (%)	SDM (%)	HDM (%)	TDM kg m^{-2}
Frodo	58.95a	23.30a	17.75a	0.82ab
Pentland Dell	65.89a	20.09a	14.02a	0.84ab
Darius	65.88a	24.15a	9.96a	0.60b
Shepody	49.58a	11.98b	38.44b	1.65a
SEM	4.22	1.92	4.83	0.16
C V (%)	23.70	16.84	70.52	44.87

Means with the same letter are not significantly different

The TDM accumulation data revealed that Shepody produced significantly higher TDM ($p<0.05$) compared to Darius that had the lowest TDM accumulation (Table 5.1). At the first harvest, cultivars Frodo and Pentland Dell performed similarly and were second to the best performing cultivar (Table 5.1). Significantly higher tuber dry matter accumulation of Shepody during the first harvest indicated that it was an early maturing cultivar that had already advanced to the tuber bulking stage, while others were still in the vegetative stage.

During harvest II, cultivars Frodo and Darius were still allocating dry matter to leaves (Table 5.2) compared to the other two cultivars, which showed significantly lower partitioning to the leaves ($p<0.05$). On the other hand, dry matter partitioning to stem was still high for all cultivars, except for cultivar Frodo, which had significantly lower SDM values ($p<0.05$). The dry matter accumulation into the tuber was about 11% higher for Shepody, as compared to Darius, which indicated that Darius was still diverting a major quantity of assimilates to the production of new leaves and stems. At this harvest, Shepody again had the highest TDM accumulation ($p<0.05$), while Frodo still had the least (Table 5.2).

Table 5.2 Potato dry matter partitioning to leaves (LDM), stem (SDM), tuber/ harvestable (HDM) and total dry mass (TDM) for the four potato cultivars Harvest II (72 DAP)

Cultivars	LDM (%)	SDM (%)	HDM (%)	TDM kg m^{-2}
Frodo	37.70a	18.44b	43.86a	1.08b
Pentland Dell	12.85b	43.57a	43.57a	1.28ab
Darius	27.40a	36.30a	36.30a	1.15b
Shepody	6.22b	46.89a	46.89a	1.84a
SEM	4.04	3.59	2.25	0.11
C V (%)	26.09	15.83	16.94	23.55

Means with the same letter are not significantly different

The percentage of dry matter partitioned to stem did not vary significantly among cultivars during harvest III (Table 5.3), although the highest dry matter accumulation in the stem was observed for Shepody, compared to Frodo, which had the lowest accumulation. During this growth period, the proportion of dry matter translocated to leaf was significantly higher for Frodo and the lowest for Shepody ($p<0.05$). Once again, this indicated that Shepody was already undergoing leaf senescence, while stems and tubers remained the dominant sinks for dry matter allocation. Table 5.3 also reveals that the percentage of dry matter partitioned to tuber was significantly higher for Pentland Dell and Shepody ($p<0.05$). During this harvesting period, Frodo had the lowest proportion of dry matter translocated to tubers. Once again, Shepody had the highest ($p<0.05$) TDM accumulation and it was the lowest for Pentland Dell. Tubers had accumulated the highest proportion of assimilates during this time for all cultivars and the leaves accumulated the minimum share, followed by stems (except for Frodo).

Table 5.3 Potato dry matter partitioning to leaves (LDM), stem (SDM), tuber/ harvestable (HDM) and total dry mass (TDM) for the four potato cultivars Harvest III (84 DAP)

Cultivars	LDM (%)	SDM (%)	HDM (%)	TDM kg m^{-2}
Frodo	28.59a	28.86a	42.54b	1.38b
Pentland Dell	14.32bc	31.00a	54.68a	1.18b
Darius	18.47b	34.65a	46.88ab	1.47ab
Shepody	5.55c	40.40a	54.03a	1.78a
SEM	2.73	4.46	4.60	0.08
C V (%)	27.70	25.93	10.66	12.09

Means with the same letter are not significantly different

At harvest IV, most cultivars were already at the stage of senescing and Shepody had already completely senesced and had to be left out of the comparison. In general, dry matter partitioning to different plant parts was uniformly consistent among cultivars for all the parameters considered. Translocation of assimilates was lower for leaves and stems, and the highest for tubers. Frodo had the highest dry matter accumulation compared to remaining two cultivars, Pentland Dell and Darius (Table 5.4), where no significant differences were evident.

Table 5.4 Potato dry matter partitioning to leaves (LDM), stem (SDM), tuber/ harvestable (HDM) and total dry mass (TDM) for the four potato cultivars Harvest IV (101 DAP)

Cultivars	LDM (%)	SDM (%)	HDM (%)	TDM kg m^{-2}
Frodo	15.12a	13.46a	71.42a	1.89a
Pentland Dell	15.41a	12.29a	72.31a	1.35a
Darius	15.40a	13.99a	70.61a	1.46a
Shepody	-	-	-	-
SEM	1.76	0.95	2.52	0.12
C V (%)	15.28	15.94	5.37	20.51

Means with the same letter are not significantly different

These findings are in agreement with the results of Spitters (1987), who concluded that potato cultivars differed greatly in the proportion of dry matter allocation to the tuber over time. Spitters (1987) grouped potato cultivars into three categories with regard to the growth, development and dry matter allocation to the tuber. Group one were the cultivars in which tuber filling stars early and harvest index increases rapidly with time and, after the onset of tuber filling, assimilates were largely used for tuber growth. The second group was the cultivars in which tuber filling also started early, but harvest index increased less rapidly with time and a substantial fraction of current assimilates were still partitioned to the haulm growth. The third group was the cultivars in which tuber filling commenced later and showed a gradual increase in harvest index, with a continuous diversion of a major fraction of current assimilates to the production of new leaves and stem growth.

Number of stems, canopy cover and yield

Data on the number of stems, canopy cover, dry matter and fresh potato tuber yield, as well as average LAI is presented in Tables 5.5 and 5.6. Table 5.5 reveals average stem number and the percent canopy cover for two records, CC1 (58 DAP) and CC2 (84 DAP), for the four potato cultivars under comparison. From the results, Shepody was observed to be initially (at 58 DAP) the most vigorous potato cultivar, followed by cv. Frodo. The percentage canopy cover of these cultivars during CC1 was significantly higher relative to Pentland Dell and Darius ($p<0.05$). However, at the second canopy measurement date, Shepody had the lowest coverage, 8%, as compared to Frodo with 72% and Darius with about 67% canopy cover. This confirmed that for Shepody leaf senescence commenced very early, compared to the other cultivars (Table 5.5). Shepody had the highest average number of stems, which was significantly different from P. Dell & Darius at the 95% probability level. In general, Shepody is known as an early cultivar with more excessive vegetative growth and is less efficient in dry matter partitioning to the tuber. Many researchers (Pashiardis, 1987; Spitters, 1987; Kooman & Rabbinge, 1996; Kooman *et al.*, 1996a) agree that canopy cover is directly proportional to LAI as it enables crops to intercept adequate PAR and finally achieve a high biomass.

Table 5.5 Average stem number and percent canopy covers for the first (CC1) and the second (CC2) measurements for the four potato cultivars compared

Cultivars	Stem number (m^2)	CC1 (58 DAP) (%)	CC2 (84 DAP) (%)
Frodo	8.00a	69.39a	71.50a
Pentland Dell	5.17b	56.92b	49.28b
Darius	4.33b	47.55b	66.72a
Shepody	8.83a	79.11a	8.25c
SEM	0.71	4.230	7.788
C V (%)	23.56	6.80	12.13

Means with the same letter are not significantly different

From the potato cultivars compared, Shepody had produced the highest seasonal average LDM, which is significantly different ($p<0.05$) from Pentland Dell and Darius (Table 5.6). Shepody also produced the highest seasonal average CDM, though the difference is significant ($p<0.05$) only from Darius (Table 5.6). On the other hand, the fresh potato tuber yield record revealed that Shepody produced significantly lower tuber yield ($p<0.05$) as compared to the rest of the potato cultivars (Table 5.6). Of the four cultivars evaluated, Frodo significantly out-yielded the rest, followed by Pentland Dell and Darius with more or less similar dry matter yields. Shepody once again produced significantly lower HDM yield ($p<0.05$). Table 5.6 again revealed that Shepody produced the highest seasonal average LAI compared to the rest of the cultivars and the value is significantly higher than that of Pentland Dell and Darius ($p<0.05$).

Table 5.6 Comparison of average leaf dry mass (LDM), average canopy dry mass (CDM), fresh potato tuber yield (FTY) at final harvest, tuber/harvestable dry matter (HDM) at final harvest and average leaf area index (LAI) for the four potato cultivars compared

Varieties	LDM $kg\ m^{-2}$	CDM $kg\ m^{-2}$	FTY $ton\ ha^{-1}$	HDM $kg\ m^{2}$	LAI $m^{2}\ m^{-2}$
Frodo	0.11ab	0.18ab	52.23a	10.45a	1.86ab
Pentland Dell	0.10bc	0.16ab	43.86a	8.59b	1.25bc
Darius	0.07c	0.11b	40.84a	8.41b	1.11c
Shepody	0.15a	0.23a	25.07b	4.51c	2.31a
SEM	0.01	0.01	3.27	0.65	0.17
CV. %	17.53	15.76	10.34	9.96	16.15

Means with the same letter are not significantly different

This experiment clearly shows that the cultivar with the highest CDM and high leaf area index, Shepody, eventually had the lowest tuber yield, which indicates that this cultivar is less efficient in dry matter translocation to its end product, the tuber. Shepody is a high-yielding cultivar in North America, where it was originally developed. In South Africa, however, it is a lower yielding cultivar, compared to most commercial potato cultivars. This could be attributed to the high temperature and long days in South Africa. The advantage of this cultivar is that it is an early maturing cultivar with the capacity of possessing high tuber SG to fill the market gap in case of scarcity. This result, however, agrees with the finding of Pashiardis (1987) who concluded that yield is associated more with the duration of potato growth period and LAD than with its growth rate. This is further confirmed by Kooman and Rabbinge (1996), who conclude that DM is not only dependent on new leaf production but also on the longevity of leaves. Leaf longevity is cultivar-dependent and systematically shorter in early cultivars than in late cultivars. Therefore, Frodo was found to be a late-maturing potato cultivar that allows its leaves to take more time collecting dry matter and partitioning significantly more to the tuber as compared to other cultivars.

Leaf area index (LAI), leaf dry mass (LDM) and canopy dry mass (CDM)

Figures 5.1 to 5.3 present data on the LAI, LDM and CDM, or the above-ground plant part, during the growing period. The LAI is one of the physical parameters indicating performance of crop growth and partitioning of assimilates. LAI of the four tested potato cultivars uniformly increased until about 80 DAP (Fig. 5.1). After about 80 DAP, Frodo and Darius were still actively growing, with increasing LAI, while Shepody's LAI, in particular, dropped sharply and completely senesced by 106 DAP (Fig. 5.1). The LAI for Pentland Dell also gradually declined from about 80 DAP to its senescence at about 118 DAP. The long duration for which a potato crop maintains active leaves, indicating the length of time foliage remains photosynthetically active on the plant, is very important in tuber dry matter accumulation (Lahlou *et al.,* 2003). Higher values of LAI were observed at about 100 DAP for Frodo, followed by Darius. The duration of active leaf growth mainly determines potato yield and is a major limiting factor with early-maturing cultivars (Lahlou *et al.,* 2003). Other research also confirms that tuber yield might be limited by insufficient maximum LAI values and/or LAD (Potter & Jones, 1977; Jefferies & MacKerron, 1993; Lahlou *et al.,* 2003). Potter & Jones (1977) explain that the rate of leaf area expansion has a greater influence on DM production than the net assimilation rate. The LAI data of Shepody indicates that it reached a maximum value between 70 and 80 DAP, whereafter it declined sharply. As a result of this growth characteristic, the crop did not have enough time to intercept adequate solar radiation for sufficient photosynthesis and dry matter accumulation in the tuber.

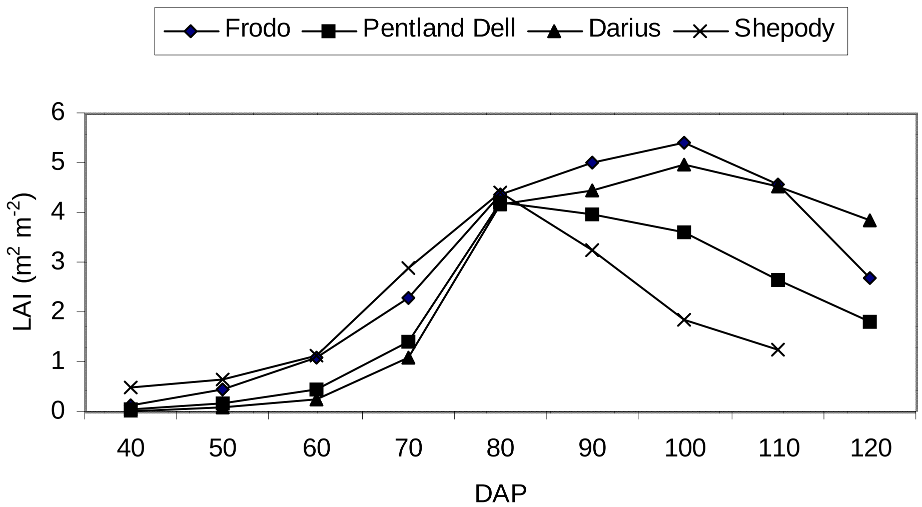

Figure 5.1 Leaf area index (LAI) of four potato cultivars during the days after planting (DAP)

This result, once again, is in agreement with that of Allen and Scott (1980), who drew the relationship between LAI and the proportion of radiation intercepted by the crop, indicating that a LAI of 4 and above intercepts more than 80% of the incident radiation for maximum photosynthetic activity and adequate dry matter partitioning to the tuber.

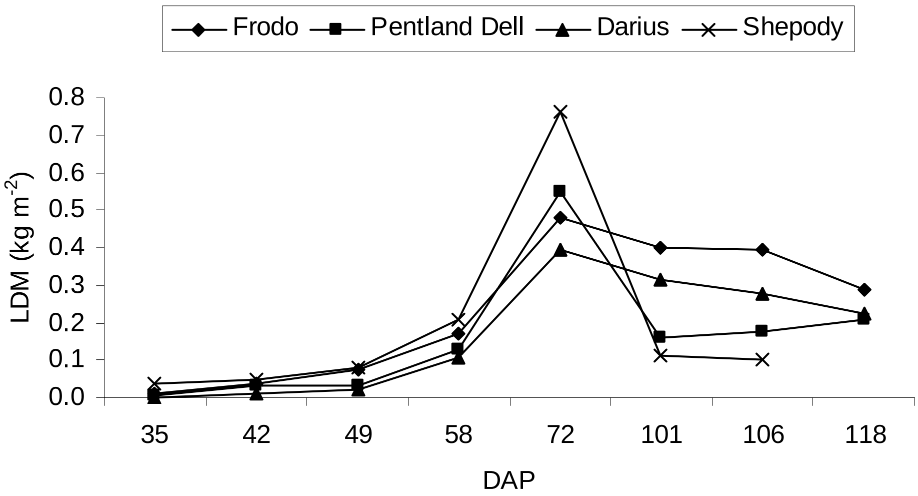

Figure 5.2 Leaf dry mass (LDM) of four potato cultivars during the days after planting (DAP)

Leaf dry matter (LDM) and CDM both followed the same trend as for LAI (Fig. 5.2 & 5.3). The LDM (Fig. 5.2) and CDM (Fig. 5.3) attained maximum values between 70 and 100 DAP for all cultivars and gradually declined to the same point at 118 DAP, except for Shepody, which died much earlier. This confirms the conclusion of many researchers (Allen & Scott, 1980; Lahlou *et al.*, 2003) that potato plant growth and DM are affected by the LAI and its duration.

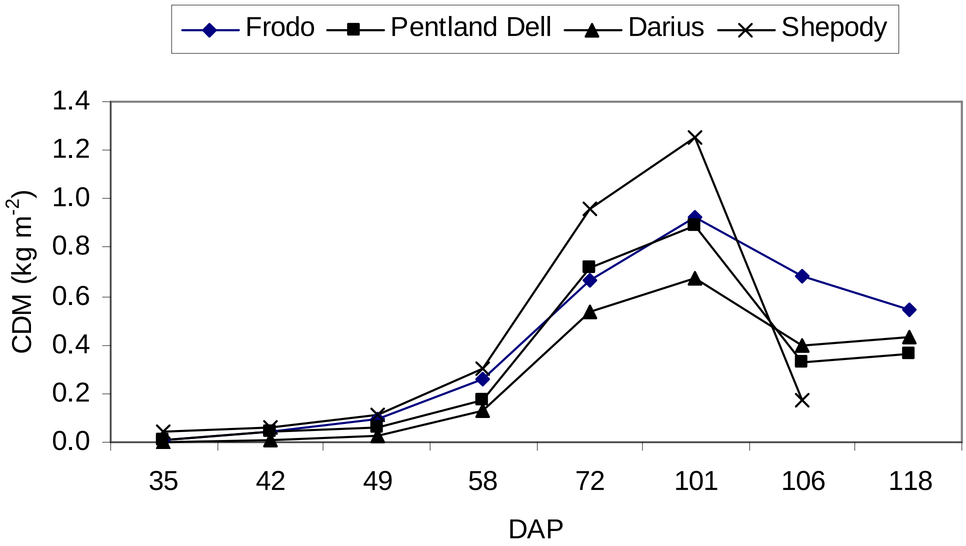

Figure 5.3 Canopy dry mass (CDM) of four potato cultivars during the days after planting (DAP)

Generally, Shepody produced high overall above-ground dry matter within a short growth period. This growth characteristic does not favour DM production and its allocation. Many researchers (Potter & Jones, 1977; Allen & Scott, 1980; Jefferies & MacKerron, 1993; Lahlou *et al.*, 2003) agree that long LAD is essential for high DM and high final yield.

5.4 Conclusions

The four potato cultivars were compared for their DM production and partitioning to the different plant parts, including the tubers. The main factor determining dry matter production is the length of the growth period. The results reveal that all cultivars performed differently at different harvests, even though Shepody had consistently higher TDM accumulation, with the most important contribution from the LDM. In addition, Shepody was found to be an early cultivar, performing all the growth activities and dry matter accumulation in a short period of time, compared to the remaining cultivars. Such a growth character, however, is not favourable for high tuber yield, since dry matter partitioning to tuber requires prolonged vegetative growth and high dry matter allocation efficiency, which is genotype-specific. The earliness of Shepody could be advantageous in rain-fed agriculture, where the rainfall duration is limited, but not under adequate irrigation, where maximum yield is expected. Another advantage is that earlier production enables processing factories to open their season earlier and get better use of their capital investment. This research finding reveals, however, that Frodo is the highest producer of fresh tuber yield, followed by Pentland Dell and Darius, which were significantly different from Shepody. The high average value of LAI for Shepody indicates that it is more efficient in translocation of dry matter to its canopy, as opposed to the ultimate goal of attaining high tuber yield. From the results, Frodo had effectively allocated most dry matter to the tubers, relative to others, which is the ultimate goal of potato crop production. From the tuber processing quality tests (data presented in Chapter 6), Frodo tubers exhibited good quality performance with minimum external and internal defects compared to the remaining cultivars. Its slow-growing nature and efficiency of partitioning dry matter to its tubers make Frodo a high-yielding cultivar with appropriate tuber characteristics. Hence, this newly developed potato cultivar is very suitable for the intended commercial production in South Africa.

CHAPTER 6

EVALUATION OF TUBER-PROCESSING QUALITY OF FOUR POTATO CULTIVARS

6.1 Introduction

The production of high-quality potatoes depends on the cumulative effect of various factors, including the genetic make-up of cultivars, the climate and the physical and biological properties of the soil (Brown, 1993). In addition, the external and internal tuber characteristics also affect the processing quality. According to David *et al.* (1983), a high-quality potato tuber should be turgid, well shaped, uniform and brightly coloured. These authors also refer to some external tuber characteristics for standardised quality grades, including being free from adhering soil, mechanical damage, greening, sprouts, disease and physiological defects. Quality traits important for cultivars used in potato chip manufacturing include high dry matter (specific gravity), low sugar levels and being free from defects (Hayes & Thill, 2002). The same authors report that the development of brown colour upon frying is the result of reactions between acids and sugars having a particular chemical structure or amino acids and the reducing sugars (glucose and fructose). In addition, though not a reducing sugar, sucrose is also an important indicator of processing quality because it can break down into glucose and fructose during cold storage, thus contributing to the development of brown colour during the frying process (Gary & Hughes, 1978). Standard limits for reducing sugars for chipping quality is less than 0.2% of fresh tuber mass. The concentration of reducing sugars above this level results in unacceptably dark fries (Cottrell *et al.*, 1995). The lower the content of reducing sugars, the lighter the chip colour.

Greater amounts of reducing sugars accumulate when tubers are stored at temperatures below 5°C, which is commonly known as low-temperature sweetening (Cottrell *et al.*, 1995). Cultivars that are resistant to low-temperature sweetening usually have lower activities of starch-degrading enzymes than those sweetening under low temperatures. However, sensitivity to low-temperature sweetening could also be related to starch granule degradation by endogenous enzymes (Cottrell *et al.*, 1995).

Specific gravity of potatoes is an important determinant of harvest quality. This attribute of a tuber is an indicator of maturation that the industry uses as a reference to judge fry quality, baking characteristics and storability. More importantly, specific gravity measurements reflect environmental factors and cultural management procedures during the production season.

The specific gravity of tubers is also an important quality criterion for processing. It is used as an estimate of the solids or dry matter content of tubers. The higher the dry matter content, the lower the water content and the higher the specific gravity. Processors and consumers like to recognise the ideal french fry as lighter in colour, crisp on the outside and fluffy or mealy on the inside with a minimum of oiliness.

Specific gravity standards range from less than 1.060 (very low) to greater than 1.089 (very high) for quality chips and french fries (Mosley & Chase, 1993). The same authors further explain that specific gravity values between 1.060-1.069 are regarded as low, 1.070-1.079 as medium and 1.080-1.089 as high. Specific gravity can be influenced by several physiological processes of which respiration, transpiration, photosynthesis and water absorption are the major ones. Temperature and solar radiation favours the continuity of photosynthesis for production of carbohydrates for faster tuber growth. The production of a high yield of high specific gravity is directly related to the length of the growing season (Hudson, 1975; Baritelle & Hyde, 2003). Early maturing cultivars typically have short storage dormancy and are usually processed at harvest or shortly afterwards. Cultivars that are relatively late maturing, have long storage dormancies and can be processed for several months. In addition, specific gravity of potatoes is highly dependent on fertilisation and optimum soil water content. Excess nitrogen or high vegetative proportion can lower specific gravity (Hegney, 2001). The same author also indicates that, although potatoes are more sensitive to shortage of chloride than many crops, some works have shown an association between chloride application and a decrease in specific gravity. It has been observed that excess or insufficient soil water, particularly when accompanied by a high temperature, can lower specific gravity (Baritelle & Hyde, 2003; Stark *et al*., 2003). On the other hand, these authors indicate that optimum soil water, as tubers approach maturity, can increase specific gravity.

In general, late maturing (frozen processing) cultivars are usually rather high in starch (high dry matter, high specific gravity) and low in reducing sugars. Tubers with dry matter ranging from 20-25% are preferable for quality chipping (Mosley & Chase, 1993). Tubers with less than about 18% dry matter are seldom used for frozen processing or chips because of their poor texture (Mosley & Chase, 1993). Approximately two-thirds of the water in french fries, using tubers with high water content, is replaced by oil during frying (Mosley & Chase, 1993). Therefore, cultivars with high water content or low dry matter produce oily and soggy (wet and soft) french fries, as more water has to be removed during processing (Mosley & Chase, 1993).

Cultivar is not the only factor responsible for reduced external and internal tuber quality. Proper water management during the growing period is crucial for high yield and high chipping standard of tubers. Research has shown that next to genetic variation, water is one of the most detrimental limiting factors to potato growth, yield and processing quality. Potatoes are particularly sensitive to water stress during tuber initiation and early tuber development (Steyn *et al.*, 1992). Water deficit during this period can substantially reduce quality tubers by increasing the proportion of rough and malformed tubers (Shock *et al.*, 1998). Early-season water stress can also reduce specific gravity and increase the proportion of translucent ends (Tourneux *et al.*, 2003; Bradley & Stark, 2005). Low soil water during the crop growth can result in tuber vascular discolouration, especially when the crop is close to maturity. In addition, rapid death of vines due to frost, mechanical destruction and stress from high temperatures can also result in tuber internal growth defects, including vascular discolouration (Pavlista, 2002). Other forms of internal growth defects, like brown centre and hollow heart, substantially reduce the processing quality of tubers. These disorders are mostly associated with the abrupt change of growth conditions during the season (Hochmuth *et al.*, 2001). Excessively rapid tuber growth after cool temperatures and soil water stress aggravates the formation of brown centres and hollow hearts (Hochmuth *et al.*, 2001). On the other hand, plants exposed to cool soil temperatures of less than 12 ^{o}C and high soil water of greater than 80% plant available water during tuber initiation and a few weeks thereafter enhances brown centres (Hochmuth *et al.*, 2001). McCann and Stark (1989) also report an association of stem-end hollow heart with potassium deficiency. Finally, the physiological disorders of tubers resulting from either a water deficit or an excess of water is a major concern, resulting in tuber-processing quality decline. The extent of quality deterioration, on the other hand, depends greatly on inherent cultivar variation.

Background information of Pentland Dell and Shepody cultivars are dealt with in Chapter 5.1.

6.2 Materials and methods

Site description, field procedures and treatments are explained in detail in Chapter 5.2.

External and internal tuber characteristics

Specific gravity and crisp fry colour were determined for all cultivars from tuber samples collected from each plot. For specific gravity (SG) determination, tubers were weighed in air (Ma) and water (Mw). The SG was calculated by the formula SG = Ma/(Ma-Mw) (USDA, 1997). The reading obtained from each specific gravity test is corrected for temperature variations according to the standards provided by the USDA (1997). Reducing sugars were determined according to USDA (1997) standards for grades of potatoes for chipping quality. Tuber form index (TFI) was evaluated for tubers categorised as large, medium and small. Tubers are categorised as large when the diameter is greater than 75 mm, medium when it is between 55 and 75 mm, and small when it is less than 55 mm. For each category, length, width and mass of tubers were measured and a TFI was computed using the formula:

$$\text{TFI} = \text{Length (large) / Width (large)} \qquad (6.1)$$

The scoring methods used and their respective values for external tuber characteristics are given in Table 6.1, and for internal tuber characteristics in Table 6.2.

Table 6.1 External tuber characteristics evaluated for the four potato cultivars under comparison (USDA, 1997)

Parameters	**Scoring methods used and their relative values**
Secondary growth	Scored from 1 to 5, where 1 = no tubers with secondary growth; 2 = less than 10% of the tubers had secondary growth; 3 = 10–30% of the tubers had secondary growth; 4 = 30–60% of the tubers had secondary growth; and 5 = more than 60% of the tubers had secondary growth
Malformation	Tuber malformation scored from 1 to 5, where 1 indicates tubers with no malformation; 2 = less than 10%; 3 = 10–30% tubers, 4 = 30–60% tubers and 5 = more than 60% tubers were malformed
Mechanical damage	Tuber mechanical damage scored from 1 to 5, where 1 indicates no visible damage on the tuber; 2 = less than 10% tubers; 3 = 10–30% tubers; 4 = 30–60% tubers and 5 = more than 60% tubers exhibiting visible mechanical damage
Growth cracks	Growth cracks scored from 1 to 5, where 1 indicates tubers without growth cracks; 2 = less than 10% tubers; 3 = 10–30% tubers, 4 = 30–60% tubers and 5 = more than 60% of the tubers exhibiting growth cracks
Stolon indent	Appearance and depth of stolon indent scored from 1 to 3, where 1 indicates the appearance of stolon indents superficially; 2 = indents with medium depth; and 3 = deep indents
Eye depth	Tuber eye depths scored from 1 to 3, where 1 indicates superficial depth; 2 = medium depth; and 3 = deep tuber eyes.
Skin colour	Tuber skin colour was identified and each colour represented by numbers from 1 to 5, where 1 represent white; 2 = yellow; 3 = white with markings; 4 = red; and 5 = russet

Table 6.2 Internal tuber characteristics used for evaluating the four potato cultivars under comparison (USDA, 1997)

Parameters	Scoring methods and their relative values
Hollow heart	Tubers with hollow heart were counted and expressed in percentage.
Brown spot	Tubers with brown spot were counted and expressed in percentage.
Vascular discolouration	Tubers with vascular discolouration counted and expressed in percentage.
Dry rot	Dry rot scored from 1 to 5, where 1 represents no tubers with dry rot; 2 = less than 10% tubers; 3 = 10-30% tubers; 4 = 30–60% tubers; and 5 = more than 60% tubers characterized with dry rot
Common scab (area)	The presence and area of common scab was scored from 1 to 5, where 1 represents tubers with no symptoms of common scab; 2 = 1–25%; 3 = 25–50%; 4 = 50–75%; and 5 = 75–100% of surface with symptoms of common scab.
Eelworm (root knot)	Symptoms of eelworm scored from 1 to 5, where 1 represents tubers with no symptoms of eelworm; 2 = 1–25%; 3 = 25–50%; 4 = 50–75%; and 5 = 75–100% of surface with symptoms of eelworm
Flesh colour	Tuber flesh colours represented from 1 to 4, where 1 = white; 2 = cream; 3 = light yellow; and 4 = intense yellow

Statistical analysis

An analysis of variance was performed using the SAS System for Windows, 2002 (SAS Institute Inc., Cary, NC, USA). Means were compared using the least significant difference (LSD) test at a 95% probability level. Correlation between parameters was performed where applicable.

6.3 Results and discussion

In potatoes, specific gravity plays an important role in determining crop maturity, harvest quality and possibly longer periods of storability. In practice, this attribute is the indicator of maturation that the industry uses to judge fry quality, bagging characteristics and storability (Shetty, 2005). From the cultivars compared in the experiment, Shepody was significantly inferior to the others in specific gravity and it is regarded as low (Fig. 6.1).

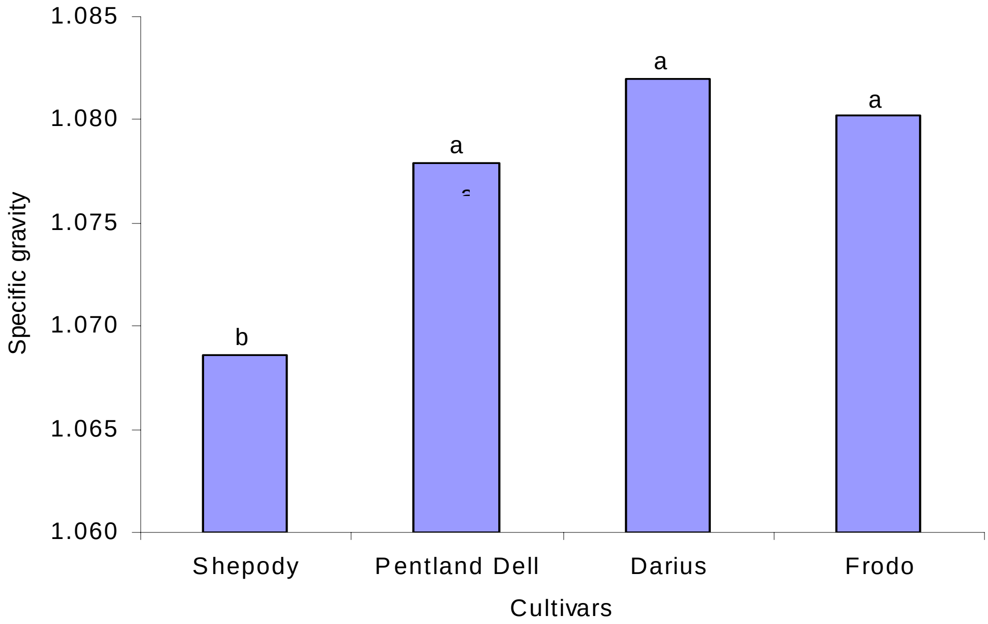

Figure 6.1 Tuber specific gravity of the four potato cultivars under comparison

The specific gravity of early-maturing cultivars is reported to be lower than those of late-maturing cultivars (Belanger *et al.*, 2002). Shepody is an early-maturing cultivar compared to Frodo, Pentland Dell and Darius, and this might partially explain its lower specific gravity in this study. The low specific gravity of this cultivar indicates that its dry matter percentage is also low. This cultivar is not encouraged to be used for chips and fries, as it becomes soggy (wet and soft) due to its low texture. On the other hand, Shepody is suitable for pan frying, salads, boiling and canning. From the specific gravity result, Pentland Dell is regarded as medium with a dry matter of about 20%. It is expected to bear a waxy texture after frying, but it is more ideal for boiling or mashing and would result into fair to medium chipping and canning qualities.

Frodo and Darius are late maturing cultivars with a high specific gravity that correlate to a high dry matter content of not less than 22%. These cultivars should result in a good mealy and dry texture chip when processed and are suitable for baking, chips and storage for several months, without producing reducing sugars when processed.

Specific gravity is not only a cultivar characteristic; the movement of water into and out of the tubers during the growing period also governs it. When the rate of transpiration exceeds water uptake, vines draw water from the tubers, causing them to decrease in mass and shrink, thereby increasing specific gravity. However, when the rate of water absorption by the roots exceeds water loss by transpiration, excess water can be stored in the tuber, leading to tuber expansion and increase in mass and therefore a decrease in specific gravity. Specific gravity is directly proportional to dry matter yield (Belanger *et al.*, 2002).

Reducing sugar content of tubers is the major factor influencing fry colour. According to Cottrell *et al.* (1995), fry colour depends mainly on the concentration of the reducing sugars (glucose and fructose) in the tubers, prior to processing. A higher concentration of reducing sugars in fresh tubers causes chips to become unacceptably dark when fried. Results of this experiment revealed that, although Pentland Dell and Shepody exhibited high reducing sugar levels that would result into high fry colour, they were still within the acceptable range of USDA standards (Fig. 6.2). Hence, as these cultivars are stored for longer periods, they will produce more reducing sugars when processed, and they should preferably be used at harvest or shortly afterwards. On the other hand, the new cultivars, Frodo and Darius, contain less than 0.1% (Fig. 6.2) reducing sugars that should result in bright fry colour, which indicates that the two cultivars well meet the required quality standards for processing french fries and crisps.

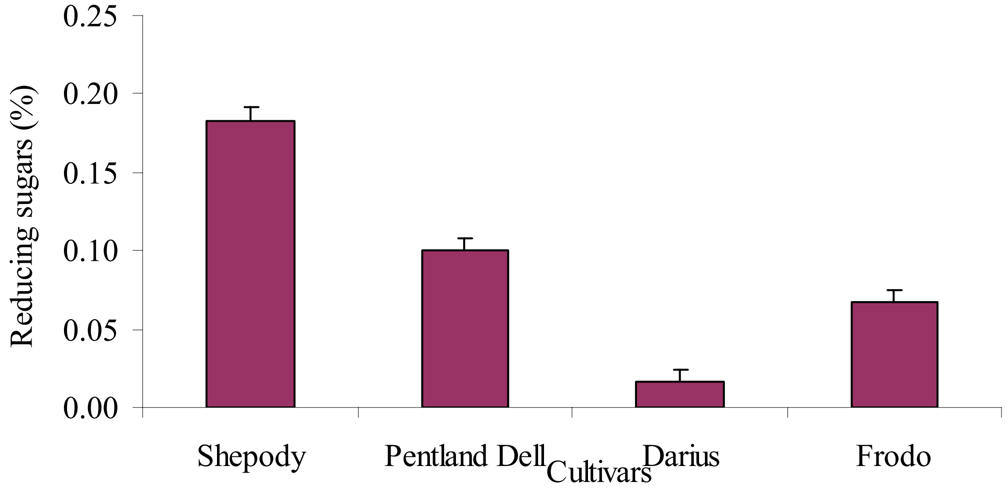

Figure 6.2 Reducing sugars (%) of USDA standard of the four potato cultivars under comparison

Pentland Dell and Shepody had acceptable reducing sugars that would result in high fry colour in the areas where they were developed. Since reducing sugars are influenced by many factors other than cultivar characteristics, such as environment, cultural practice, soil and plant nutrient management (Stark *et al.*, 2003), one of these factors could have influenced these cultivars to accumulate high reducing sugars in South Africa. These authors indicate that, when reducing sugar levels are too high during harvest, it is still possible to reduce to acceptable levels through manipulation of early storage temperatures.

An analysis of the TFI revealed that Frodo possesses significantly higher TFI for large and small tuber sizes, while Darius had consistently lower TFI values for all the three tuber sizes (Table 6.3). Pentland Dell and Shepody had similar TFI values for all the tuber sizes. This result implies that Frodo has longer tubers that are more suitable for fries, followed by both Pentland Dell and Shepody. Frodo is a newly developed South African cultivar, with superior tuber characteristics for fries. On the other hand, Darius was observed to have significantly lower TFI values for all the three tuber sizes, making them less suitable for fries.

Table 6.3 Average tuber form index (TFI) for large, medium and small-sized tubers of the four cultivars compared

Cultivars	TFI (large)	TFI (medium)	TFI (small)
Frodo	1.74a	1.55a	1.44a
Pentland Dell	1.65b	1.53a	1.33b
Shepody	1.64b	1.58a	1.34b
Darius	1.47c	1.41b	1.20c
LSD (0.05)	0.085	0.085	0.075
CV(%)	2.8	2.1	2.9

Means in the same column with the same letter are not significantly different.

The tuber size distribution into large, medium and small tubers indicates that Pentland Dell possessed significantly less large sized tubers (Table 6.4). For medium tuber sizes, however, the difference between cultivars was not significant. On the other hand, the small tuber size distribution for Frodo is significantly higher than that of Shepody and Darius. The total fresh tuber yield results also indicated that Shepody produced the lowest ($p<0.05$) total tuber yield compared to the other three cultivars (Table 6.4).

Table 6.4 Tuber size distributions for large, medium and small tubes, and total tuber yield of the four cultivars compared

Cultivars	Large (ton ha^{-1})	Medium (ton ha^{-1})	Small (ton ha^{-1})	*Total tuber Yield (ton ha^{-1})
Frodo	11.98a	20.45a	21.24a	52.23a
Pentland Dell	3.94b	24.79a	13.30ab	43.81a
Shepody	8.38a	18.23a	3.81b	25.07b
Darius	9.58a	25.39a	6.70b	40.84a
LSD (0.05)	4.20	10.14	9.02	11.40
CV%	26.7	23.5	45.1	10.34

Means in the same column with the same letter are not significantly different

* After Geremew, E.B., Steyn, J.M. and Annandale, J.G., 2007. *NZ. J. Crop Hort. Sci*, 35, 385-393.

Table 6.5 summarises the external and internal tuber characteristics as part of the quality indicators. From the results, all four cultivars had the same performance with regard to secondary growth, resistance to mechanical damage and growth cracks. Similarly, all cultivars were found to be free of tuber malformation except Shepody, which had less than 10% malformed tubers (Table 6.5). Cultivars Frodo and Darius were characterised by medium depth of stolon indent, while the remaining cultivars had superficial stolon indents. Frodo and Shepody had medium eye depths and the remaining two cultivars had superficial eye depths. In addition, Shepody and Darius possessed a white skin colour, whereas Pentland Dell and Frodo were yellow (Table 6.5).

Table 6.5 External and internal quality characteristics of the four potato cultivars under comparison

Cultivar Parameters (*)	Frodo	Pentland Dell	Darius	Shepody
External characteristics				
Secondary growth (1-5)	1	1	1	1
Malformation (1-5)	1	1	1	2
Mechanical damage (1-5)	2	2	2	2
Growth cracks (1-5)	1	1	1	1
Stolon indent (1-3)	2	1	2	1
Eye depth (1-3)	2	1	1	2
Skin colour (1-5)	3	3	1	1
Internal characteristics				
Dry rot (1-5)	2	2	2	1
Common scab area (1-5)	1	1	1	1
Eelworm (Root knot) (1-5)	1	1	1	1
Flesh colour (1-4)	1	1	1	1

1 = Superior, 5 = Inferior

(*) For details, refer to Tables 6.1 and 6.2

Internal characteristics of tubers for all the cultivars were also evaluated as standard criterion of quality assessment (Table 6.5, Fig. 6.3). The assessment revealed that cultivars Frodo, Pentland Dell and Darius contained less than 10% tubers affected by dry rot, while Shepody was free (Table 6.5). Furthermore, the result indicated that none of the cultivars showed any symptoms of common scab and eelworm and all of them had a preferential white flesh colour.

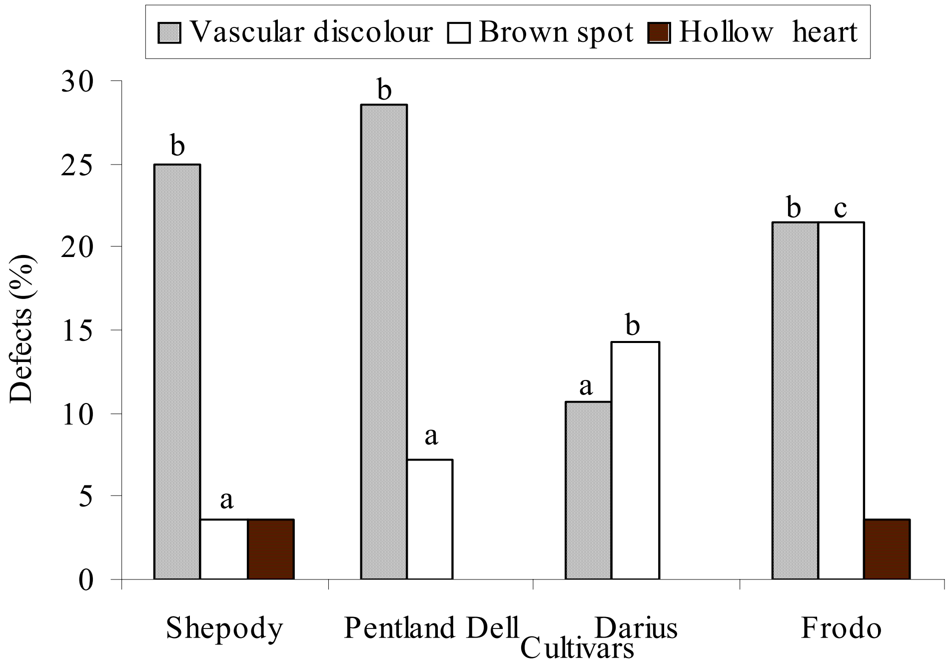

Figure 6.3 Vascular discolouration (%), brown spot (%), and hollow heart (%) recorded for the four potato cultivars under comparison

With regard to vascular discolouration, Pentland Dell had the highest incidence, close to 30%, followed by Shepody with 25% and Frodo with 20%. Darius had a relatively low percentage of vascular discolourations, about 10% (Fig. 6.3). On the other hand, Frodo showed the highest percentage of brown spot, about 20%, followed by Darius and Pentland Dell, while Shepody had the lowest percentage, less than 5% (Fig. 6.3). Furthermore, Pentland Dell and Darius were not characterised with hollow heart, while Frodo and Shepody were found to have a small percentage of hollow heart (<5%) (Fig. 6.3).

Generally, the cultivars investigated in this experiment were within acceptable low levels of tuber defects, with Frodo and Darius appearing to be good performers in most internal and external characteristics. Vascular discolouration, brown spot and hollow heart detects are results of improper management of the crop during the growing period. Proper management, such as water, and plant nutrient supply, and selection of the ideal climate for different cultivars, reduces the onset of tuber deformities and results in acceptable processing qualities.

6.4 Conclusions

Potato cultivars vary widely in internal and external tuber characteristics. Of the four cultivars tested for internal and external tuber characteristics and desirable processing quality, most adhered to acceptable quality standards. However, Pentland Dell and Shepody were found to have high proportions of vascular discolouration, between 25 and 30%, followed by Frodo with about 20%. Darius showed a low level of vascular discolouration, about 10%. Furthermore, Frodo contained a relatively high percentage of brown spots, about 20%, followed by Darius.

The current management level, mainly the water management, needs to be improved substantially in order to reduce the overall deformities. Specific gravity and dry matter percentage for Shepody is far below the USDA standard for chipping quality, while Pentland Dell is in an average position. Frodo and Darius had high specific gravity and low reducing sugars, which are the ideal characteristics for longer storage and quality frozen fries. Frodo possesses significantly higher TFI in all the size classes, while Darius possesses the least. Shepody seems to have relatively higher tuber malformation and deeper eye depths, but it is the least vulnerable cultivar to dry rot. In general, internal and external tuber characteristic results have followed the trend of the tuber fresh yield, with Shepody found to be significantly inferior to the remaining three cultivars. Hence, the experiment revealed that Frodo and Darius were within the acceptable range in terms of desirable tuber characteristics for processing as fries. On the other hand, Shepody and Pentland Dell had high reducing sugars, that could result in darker fry colours, though values are barely within the limits of the USDA standard. These results indicate that Frodo and Darius are more suitable for good mealy and dry texture fries due to high specific gravity and low reducing sugars, with characteristics that allow for long storability and frozen fries. On the other hand, Shepody, with low specific gravity, and Pentland Dell, with medium specific gravity, and both marginally within the standard ranges of reducing sugars, are rather to be used for pan frying, salads, boiling and canning and less for chipping and frying. Long storage of these cultivars will result in more reducing sugars being produced and an undesirable dark fry colour.