SERIES: Effect of nitrogen management on tuber initiation

V: How nitrogen management influences quality

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Introduction

A look at market reports indicates that potato prices can fluctuate tremendously at any given time. It is primarily attributable to differences in the quality of products offered for sale. The consumer prefers an attractive product (nice looking) that will last long (good internal quality) and is regularly prepared to pay a premium for a high quality product. If the product has a longer shelf-life, it means that more time is available to sell it, and there is less wastage. In general distributors also have a faster turn-over and get a better price, because the product is visually more enticing. Quality is determined by various factors. The internal quality aspects that were investigated in this study included specific gravity (SG), hollow heart and chip colour (sugar content).

Specific gravity

Specific gravity is the most accepted practical method to determine the internal quality of potatoes. There is a very high correlation between the specific gravity and the starch accumulation, as well as percentage dry matter or total solids of the tuber. Specific gravity is also an indication of ripening and is used by the industry to evaluate frying quality, baking characteristics and storing ability. The higher the dry matter content, the lower the water content and thus a higher specific gravity. When tubers with a high water content is used for chips, about two thirds (Mosley & Chase, 1993) of the water is replaced with oil during the frying process. Chips made from tubers with a high water content will thus be oily. A specific gravity of 1.075 and higher is acceptable to the formal processing industry to ensure optimum quality products and recovery rate. Local research, however, has shown the informal market prefer potatoes that are oily and make “slap” chips. Specific gravity is a cultivar characteristic, but also reflect environmental factors and production practices (availability of ground water, fertiliser and growing period) during the season. Tuber size and shape, as well as defects such as the malformation and hollow heart, also
influence specific gravity.

Specific gravity can be determined by making use of the mass-in-air and mass-in-water method. The tubers are first washed to remove any soil from the surface. When the tubers are dry, a randomised sample of at least 3 kg tubers is weighed in the air, whereafter the same sample is weighed in a wire basket submerged in water (Figure 1). The specific gravity is then determined by using equation 1.

\[
\text{Specific gravity} = \frac{\text{Mass of tubers in air}}{\text{Mass of tubers in air} - \text{Mass of tubers submerged in water}}
\]

Equation 1

**Chip colour**

Chip colour is another important quality aspect. The development of a brown colour and bitter taste in chips during the frying process, is the result of the Maillard reaction (Figure 2) between amino acids and reducing sugars (glucose and fructose). The less reducing sugars there are in the tuber, the lighter the chip colour which is what the industry requires. Some studies have also indicated that a negative correlation exists between reducing sugar content and specific gravity. The reducing sugar content is primarily influenced by the cultivar, crop maturity, environmental conditions (especially air temperature) and production practices (e.g. fertiliser and irrigation) during the growing season and some post-harvest and storing factors. A chip colour of higher than 50 is considered acceptable for the processing industry.

**Hollow heart**

Some potato cultivars (such as BP1) are inclined to the development of internal tuber deviations such as hollow heart. Although the specific cause of hollow heart defects is not completely understood, it has been determined that cultivar, environmental conditions and N imbalances have an influence. Hollow heart occurs during drastic changes in growing conditions such as excessive application of N, which causes the tuber to grow much faster. This causes the tissue to tear, which...
leads to the development of internal cracks or hollows (Figure 3). However, no hollow heart symptoms are externally observable. Fifteen large tubers in the study were taken and cut in half to visually determine the appearance of hollow heart in each treatment.

**The effect of cultivar and N fertilisation on internal quality**

The study on three selected potato cultivars was executed during two seasons (spring and autumn plantings) to investigate the effect of N management (N level and application time) on tuber initiation as well as the effect on internal tuber quality. Internal tuber quality included specific gravity, chip colour and hollow heart. A summary of all the treatments is indicated in the block below. The information will make the choice in respect of optimal production practices possible, in this case N fertilising management, to not only ensure the efficient use of nutrients and environmentally friendly practices, but also to produce a better product sustainably and thereby increase profitability.

**Results**

**Specific gravity**

Significant differences in specific gravity took place in respect of cultivar, N level, N application time, as well as in respect of the interaction between cultivar and N application time.

<table>
<thead>
<tr>
<th>Summary of treatments</th>
</tr>
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<tbody>
<tr>
<td>• 3 cultivars: BP1 (C1; standard), Eos (C2) and Lanorma (C3)</td>
</tr>
<tr>
<td>• 3 different N levels, based on the soil’s clay content and potential yield:</td>
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<tr>
<td>- Spring season: 160 kg/ha N (R1), 240 kg/ha N (R2) and 320 kg/ha N (R3).</td>
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<tr>
<td>- Autumn season: 140 kg/ha N (R1), 220 kg/ha N (R2) and 300 kg/ha N (R3).</td>
</tr>
<tr>
<td>• 3 N application times (identical in both seasons):</td>
</tr>
<tr>
<td>- 30% N with planting and 70% after tuber initiation (T1).</td>
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<tr>
<td>- 50% N with planting and 50% after tuber initiation (T2).</td>
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<tr>
<td>- 70% N with planting and 30% after tuber initiation (T3)</td>
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</tbody>
</table>

Additional details about the treatments, as well as methods are available in the first article of the series in CHIPS Vol. 32 No.1 January/February 2017 edition.
season the plants grow from warmer towards cooler
days and previous research has proven that such
conditions normally deliver better quality tubers.

**Effect of nitrogen levels**

Specific gravity decreased significantly as the N
level increased. The specific gravity was thus at the
highest N level (320 kg/ha) significantly lower than
that of the lowest (160 kg/ha) N level (Figure 5). As
discussed in-depth in the previous article (CHIPS Vol
32 No 4, July/August 2018, pp. 20-27) in this series,
excessive nitrogen (highest N level) stimulated and
extended the foliage growth, which in turn shortened
the tuber bulking stage and delayed tuber maturity.
Starch synthesis is then negatively affected, and as
there is a high correlation between starch synthesis
and total dry matter accumulation, the high N levels
lead to lower specific gravity.

**Effect of nitrogen application times**

Nitrogen application times also had a significant
effect on the specific gravity of tubers with the
treatment that received 50% N at planting and 50%
N after tuber initiation, and which showed the highest
specific gravity values for two of the three cultivars
(Eos and Lanorma) (Figure 6). An N shortage early
in the season (30% at planting and 70% after tuber
initiation) resulted in a decrease in photosynthesis
and foliage growth, and thus a smaller leaf canopy
which led to the early die-off of the plant. The plant
thus depleted most of its N reserves before the tubers
bulk sufficiently. The excessive N that was applied
late in the season, delayed tuber maturity (and thus
specific gravity) as a result of the stimulation of foliage
growth at the expense of tubers. Although there was a
decrease in specific gravity when 70% N was applied
at planting and 30% after tuber initiation, the specific
gravity values were still above the acceptable norm of
1.075. The reason for the decrease in specific gravity
when 70% N was applied with planting and 30%
after tuber initiation is, however, unclear.

**Interaction effect**

Significant interaction between cultivar and N
application time (Table 1) was observed. Cultivar BP1
exhibited no significant differences regarding specific
gravity between the three N application times. On the
other hand, the specific gravity of Eos and Lanorma
decreased with the treatments 30% N with planting;
70% N after tuber initiation and 70% N with planting;
30% N after tuber initiation.

These results could possibly be explained by studying
the start and duration of tuber initiation between
cultivars. The treatment with 30% N with planting

* Values followed by the same letter do not statistically differ at $P < 0.05$ according to the Tukey test
* CV% = 0.2  * LSD (cultivar) = 2.43  * SE (Cult) = 0.000354
Figure 4: Specific gravity as influenced by cultivars (BP1, Eos and Lanorma) in both spring (orange block) and
autumn (green block) season where the horizontal dotted line represents the acceptable norm ($\geq 1.075$).
and 70% N after emergence affected the specific gravity of cultivars Eos and Lanorma because these two cultivars initiated the bulk of their tubers early in the season and only limited quantity initiated later in the season, whereas BP1 initiated tubers throughout the season. More immature tubers are thus expected from BP1 as a result of initiation late in the season and which led to lower specific gravity.

**Chip colour**

No significant effect on chip colour in respect of N level and N application time was observed, which corresponds with various studies. However, other studies have found that large quantities N, as well as high quantities N late in the season, increased the reducing sugar levels in tubers, which would affect

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*Values followed by the same letter do not statistically differ at P <0.05 according to the Tukey test*

*CV% = 0.2  *LSD (Rate) = 0.001343  *LSD (Ratexcultivar) = 0.002160  *SE (Rate x Cultivar) = 0.000756

Figure 5: Specific gravity as influenced by N level for cultivars BP1, Eos and Lanorma where the horizontal dotted line represents the acceptable norm (≥1.075).

Table 1: The interaction effect of cultivars (BP1, Eos and Lanorma) and N application times on specific tuber gravity.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Timing of application</th>
<th>Specific gravity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>30% met plant; 70% 3-4 weke na opkoms</td>
<td></td>
</tr>
<tr>
<td>BP1</td>
<td>1.076 a</td>
<td>1.075 a</td>
</tr>
<tr>
<td>Eos</td>
<td>1.066 d</td>
<td>1.07 c</td>
</tr>
<tr>
<td>Lanorma</td>
<td>1.075 a</td>
<td>1.077 b</td>
</tr>
</tbody>
</table>

*Values followed by the same letter do not statistically differ at P <0.05 according to the Tukey test*

*SE = 0.000335  *LSD= 0.000974  *CV% = 0.1
the chip colour negatively. Results on how N affect the reducing sugar content and consequently chip colour, is thus still inconsistent. According to Kunkel and Holstad (1971) this variation in results can be ascribed to environmental conditions (climate), cultivar and fertiliser placement. Cultivar, however, led to significant differences in chip colour. BP1 reached a higher average chip colour compared to Eos, whereas Lanorma did not significantly differ from BP1 or Eos (Figure 7). Genetics is thus one of the factors that influences chip colour.

Figure 6: Specific gravity, as influenced by N application time for cultivars BP1, Eos and Lanorma where the horizontal dotted line represents the acceptable norm (≥1.075).

Figure 7: Chip colour as influenced by cultivars BP1, Eos and Lanorma where the dotted line represents the acceptable norm (≥50).

* Values followed by the same letter do not statistically differ at P <0.05 according to the Tukey test
* CV% = 0.2    * LSD (Time) = 0.001343    * LSD (Time x Cultivar) = 0.002160    * SE (Time x Cultivar) = 0.000756

Figure 6: Specific gravity, as influenced by N application time for cultivars BP1, Eos and Lanorma where the horizontal dotted line represents the acceptable norm (≥1.075).
**Hollow heart**

**Cultivar effect**

The incidence of hollow heart differed significantly between cultivars, N levels and N application times. Cultivar BP1 exhibited a significantly higher incidence of hollow heart compared to Eos and Lanorma (Figure 8). Eos and Lanorma, however, did not meaningfully differ from one another. Hollow heart incidence differ from cultivar to cultivar because of environmental conditions, as well as production practices. It is also known that BP1 is more prone to develop hollow heart defects. From the results it also seems that Eos and Lanorma are not really prone to hollow heart defects.

**Effect of nitrogen levels**

Significant differences in hollow heart appearance, as influences by N levels, were observed between the two lowest N levels (160 kg/ha and 240 kg/ha) and the highest N level (320 kg/ha) for the cultivars BP1 and Eos. The highest N level reflected the highest hollow heart appearance for all three cultivars (although not meaningful in respect of Lanorma) (Figure 9). Large quantities N cause the tubers to grow faster and that tissues are torn apart, which leads to hollow heart.

**Effect of nitrogen application times**

The N application time that received more N later in the season (30% N at planting and 70% N after tuber initiation), reflected significantly higher hollow heart appearances in cultivars BP1 and Eos compared to the two other treatments (Figure 10). The higher proportion (70%) N after tuber initiation caused the tubers to grow too fast, which led to increased hollow heart appearance. Hollow heart is known to develop when excessive N is applied between the tuber initiation phase and when the tubers reach a mass of about 60 g.

**Discussion**

In respect of internal quality, the cultivar had an extremely important effect on all three quality factors (specific gravity, chip colour and hollow heart). Each cultivar reacted differently to factors such as climate, soil conditions and production practices.

Although yield increases as the N level increases, it is often at the expense of the quality of the final product. The highest N level extended the vegetative growing stage of potatoes, but delayed tuber maturity and starch accumulation which led to lower specific gravity of tubers. The appearance of hollow heart also increased as the N level increased. In respect of nitrogen application times with large qualities N being applied late in the season (30% N with planting and 70% after tuber initiation) in combination with a high N level, lead to an extension of the vegetative stage at the expense of tuber growth. As a result of the extended vegetative stage the maturity of the tuber is

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* Values followed by the same letter do not statistically differ at P <0.05 according to the Tukey test
* KV% = 37.2  * KBV (Cultivar) = 1.1517  * SE (Cultivar) = 0.1235

Figure 8: Hollow heart frequency as influenced by cultivar (BP1, Eos and Lanorma).
* Values followed by the same letter do not statistically differ at $P < 0.05$ according to the Tukey test.

* CV% = 37.2 * LSD (Rate) = 5.07 * LSD (Cult) = 4.87 * SE (Rate) = 0.07 * SE (Cultivar) = 0.127

Figure 9: Hollow heart frequency at final harvesting, as influenced by N levels for cultivars BP1, Eos and Lanorma.

delayed, which can lead to poor skin set and lower specific gravity, which is in turn decrease tuber quality and shelf life. Sufficient N early in the growing season is also important to support sufficient early vegetative growth.

* Values followed by the same letter do not statistically differ at $P < 0.05$ according to the Tukey test.

* CV% = 37.2 * LSD (Rate) = 5.07 * LSD (Cultivar) = 4.87 * SE (Rate) = 0.07 * SE (Cultivar) = 0.127

Figure 10: Hollow heart appearance during final harvesting, as influenced by N application times for cultivars BP1, Eos and Lanorma.
A high percentage N (e.g. 70% of the total quantity N) later in the growing season may result in the tubers growing too fast, which lead to an increase in hollow heart appearance. Hollow heart is known to develop when excessive N is applied late in the season (between the tuber initiation stage and when the tubers reach an approximate mass of 60 g). In this project no relation was found between N treatments and chip colour, whereas other studies did find differences. The results regarding chip colour are thus still inconsistent and further studies are necessary in instances where environmental conditions (climate), cultivars and fertiliser placement are taken into account.

Summary

The effect of the N level and N application time on the quality and size group distribution of the three cultivars can be summarised as follows (Table 2):

- Cultivar has a significant effect on all three quality factors (specific gravity, chip colour and hollow heart).
- Although yield increases as the N level increases, excessive N stimulates yield at the expense of product quality.
- Excessive N extends the vegetative stage and delays maturity and starch accumulation in tubers, which leads to lower specific gravity.
- Hollow heart appearance increases as the N level increases.
- Large quantities N late in the season (30% at planting and 70% after tuber initiation) in combination with a high N level, leads to the extension of the vegetative stage at the expense of tuber growth. As a result of the extended vegetative stage the maturity of the tubers is delayed, which leads to poor skin set and lower specific gravity, which again decrease tuber quality and shorten shelf life.
- A sufficient quantity N early in the season is important to support sufficient early vegetative growth.
- A high ratio N (70% of the total) later in the growing season causes tubers to grow too fast, which leads to an increase in hollow heart appearance.
- A positive interaction between cultivar and N application time was observed. Eos and Lanorma exhibited the best specific tuber gravity with the treatment that received 50% N with planting and 50% N after tuber initiation, whereas N application times did not influence the specific gravity of BP1.

In the next CHIPS article we shall address how different nitrogen management treatments influence nitrogen use efficiency.

### Table 2: Opsomming van die effek van kultivar, N-pyl en N-toedieningstyd op kwaliteit.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nitrogen rate</th>
<th>Nitrogen timing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R1 (Deficient)</td>
<td>R2 (Recommended)</td>
</tr>
<tr>
<td></td>
<td>160 kg/ha N</td>
<td>240 kg/ha N</td>
</tr>
<tr>
<td>Canopy</td>
<td>Early in season</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Final yield</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Size group distribution</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Harvest index</td>
<td>Early</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Maturity</td>
<td>Delayed</td>
<td>Delayed</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>Acceptable</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Hollow heart</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Chip colour</td>
<td>Inconsistant results</td>
<td>No effect</td>
</tr>
</tbody>
</table>