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Nutritionally enhanced potatoes and potato products

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1 Executive summary

This Interim Report summarises research progress and highlights from Sub-programmes 1 and 2 of the "Nutritionally Enhanced Potato and Potato Products Project", a 3-year project being conducted for Horticulture New Zealand by Plant & Food Research.

The research focus of the programme is the manipulation of the proportions of rapidly digested starch (RDS) and slowly digested starch (SDS) in potatoes. This is an important step towards developing potato cultivars and products that have minimal impact on blood glucose following ingestion, resulting in the production of a healthier product for the consumer.

The research funded in the first year was aimed at determining some of the factors that influence SDS and RDS levels as a guide to both experiments on potato starch and attempts to develop new food products. The research covered two Sub-programmes:

- Sub-programme 1: Effect of cultivar, site and storage on the capacity of potato tubers to form Slowly Digested Starch and Resistant Starch.
- Sub-programme 2: Processing variables affecting the formation of Slowly Digested Starch and Resistance Starch in potato products.

The research highlights described below are particularly focused on setting up the experiments and research conditions for the coming two years of research:

- Twelve potato cultivars and three sites have been chosen for the Sub-programme 1 experiment. Tubers from the Palmerston North site have been harvested, sampled and are in storage. Tubers from Pukekohe and Lincoln are about to be harvested, dependent on the weather.
- Tuber samples can be safely stored in raw, freeze dried form before subsequent measurement of changes in RDS and SDS. Therefore, samples taken from Sub-programme 1 will be safely stored in this form until analysis. This means that we can process tuber samples in a convenient way, according to research priorities.
- Potato samples that had been freeze dried and reconstituted before cooking and cooling also showed similar, or greater, SDS and resistant starch (RS) formation than whole potato samples. Therefore, not only is this method a suitable storage form before analysis, it may present opportunities to design new foods based on freeze-dried and reconstituted potato components that have significantly reduced glycaemic impact.
- The majority of SDS formation appears to occur within hours of cooling cooked potatoes, with levels continuing to rise more slowly over the next 2 days. Because most of the formation of SDS occurred within 24 h, we will give at least a 24 h cold treatment after cooking in future research on SDS formation. This discovery will improve the accuracy of our measurements of SDS in potato tubers.
- Differences in tissue structure between the periphery and the centre of the potato tuber have an impact on the availability of starch, but do not influence the proportion of SDS and RDS in the starch that is digestible. This means material throughout the tuber can be used with confidence for future SDS/RDS measurements.

- Controlled hydration of dried potato in food products can reduce the RDS content and substantially increase the amount of potentially fermentable (prebiotic) starch in the products. The addition of dried potato starch as an ingredient in food products with low water content, such as biscuits or even breads, could increase their nutritional value though limited RDS formation, the formation of some SDS, and the substantial formation of RS.

In summary, excellent progress has been made in the first year of the project. We are well positioned to continue with the next two years' research and to make rapid progress towards the design of low glycaemic impact potato-based foods.

2 Background

Potatoes are a staple part of the Western diet, and producers and marketers of potatoes are now realising that their product could provide health benefits to consumers. Because most of the available carbohydrate in potatoes is starch, and most of the starch in freshly cooked potatoes is rapidly digested, potatoes have a relatively high glycaemic index (rise in blood glucose in response to 50 g available carbohydrate in a food as a percentage of the rise due to 50 g glucose). Potatoes have therefore suffered adverse publicity, even though, because they are about 80% water, their glycaemic impact on a per equal weight of food consumed basis is not excessive (Monro & Mishra 2009). Nonetheless, consuming large quantities of potatoes, particularly as fast-foods, may contribute to the incidence of obesity, glucose intolerance and Type 2 diabetes, all of which are hallmark symptoms of 'metabolic syndrome'. There is, therefore, an international drive to improve the health characteristics of potato.

In view of our preliminary results, our access to a range of cultivars in a well-run potato breeding programme, and the availability of a well-tested system for assessing the glycaemic potency of foods by *in vitro* digestion, we have a great opportunity to conduct research that will identify some of the conditions that influence the distribution of total starch between the nutritionally distinct fractions rapidly digested starch (RDS), slowly digested starch (SDS) and resistant starch (RS). There is great potential to reduce the glycaemic potency of potato by understanding the processes during tuber growth, postharvest storage, and processing, that influence the formation of SDS and RS, both of which reduce glycaemic impact in potato because they are formed at the expense of RDS.

Recently, a study of commercially available potato cultivars from New Zealand has shown variation in the degree of RS and SDS production following cooking and cold storage (Monro et al. 2008). Furthermore, several selections from the Plant & Food Research potato breeding programme score highly for RS and SDS following this treatment, suggesting a genetic basis. Indeed there is already evidence that levels of amylose, which is less digestible and more susceptible to retrogradation to resistant starch than amylopectin, may be controllable by genetic manipulation of the enzymes involved in starch synthesis in potatoes (Schwall et al. 2000; Andersson et al. 2006). Current research being conducted in the FRST-funded Future Vegetables programme, in partnership with HortNZ, is investigating the biochemical and molecular basis for cultivar differences in RS content. However, several questions remain around the stability of RS and SDS content in cultivars when grown under different environmental and agronomic conditions and whether the RDS/SDS profile alters during postharvest storage.

Several cultivars with a high capacity to develop RS and SDS have already been identified, and can be used immediately to develop our knowledge of processing treatments that will enhance SDS and RS formation. Experiments on these cultivars are also helping to determine the potential use of potato SDS and RS in new food products with enhanced and defined nutritional attributes. This work is also critical in cultivar comparisons because it is identifying the optimal conditions for SDS and RS formation.

In order to maximise the production of RS and SDS in New Zealand's potatoes we aim to:

- assess a range of Plant & Food Research cultivars for RS and SDS content,
- determine how environmental conditions, agronomy and storage conditions influence RS and SDS,
- establish the best processing treatments for producing SDS and RS,
- explore the potential to manage SDS and RS in the design of new products.

Based on knowledge gained from this work, we will begin product development. In the long-term we envisage the production of a range of high-health RS and SDS-based products that will expand our current export markets for New Zealand's potatoes.

3 Sub-program 1. Effect of cultivar, site and storage on the capacity of potato tubers to form SDS and RS.

3.1 Background

We have previously shown that the capacity of potatoes to form slowly digested starch (SDS) and resistant starch (RS) after processing differs between cultivars, and that there may be variation between tubers within cultivars and between years. So far our work has provided a 'snap-shot' of differences between cultivars from single samplings (Monro et al. 2008). However, to select cultivars with a robust capacity to form SDS and/or RS it is important to more clearly define the effects of some basic variables on SDS and RS formation. This approach will allow us to select cultivars with a strong capacity to produce SDS and RS across a range of conditions, including site of growth and duration of tuber storage before processing.

Our original proposal was to select 8−10 potato lines from the Crop & Food Research (now Plant & Food Research) breeding programme based on our previous work and in consultation with the potato breeders. Our aim was to cover a range of RS/SDS formation after cooking and cooling, with several cultivars being high and several low in RS/SDS formation. The potato lines were to be sourced from three sites: Pukekohe, Palmerston North and Lincoln. Their tendency to form SDS and RS after cooking and cold treating were to be measured. Potato tubers were to be stored under three conditions (ambient, cold storage (8^{o}C) and longer-term ground storage), sampled at regular intervals, and cooked and cold-treated prior to measuring SDS and RS formation.

As we designed the experiment we assessed the potential risks associated with long-term ground storage of tubers from multiple cultivars, when the remainder of the crop had already been harvested. Unfortunately, it was not possible to access sites in three locations where the range of tubers we were interested in could be ground stored without disrupting other crop practices. Therefore, the decision was made to remove the ground storage treatment, and instead increase the numbers of cultivars we sampled from 8−10 to 12, and to extend the cool-store time to 8 months in order to better replicate the storage times used in industry. Ground storage experiments may be conducted in future years once we have assessed the other variables influencing SDS and RS production and have narrowed down the number of cultivars of interest.

3.2 Objective

To determine the effect of four variables (cultivar, growth site and duration and temperature of tuber storage) on the production of SDS and RS in potato tubers.

3.3 Methods

3.3.1 Potato cultivars

Several potato cultivars were assessed that, from our previous research, we knew covered a range of SDS and RS production, a range of end purposes (e.g. processing, salad, table) and were of particular interest to Plant & Food Research Potato Breeders John Anderson and Russell Genet.

The 12 cultivars selected are:

Agria	German yellow flesh potato with high reputation for eating quality. No. 2 in New Zealand seed area and used for both fresh and French fries. Widely grown worldwide.
Bondi	New CFR-bred main crop French fry potato, with medium temperature storage potential. Promising future in New Zealand, Australia and possibly worldwide.
Crop 20	Currently our most widely used parent, very high resistance to cold induced sweetening resistance and high dry matter, high RS.
Crop 22	Newly released yellow general purpose.
Crop 33	To be released main crop purple flesh.
Crop 34	Advanced general purpose line.
Crop 35	Advanced fresh wash selection.
Crop 36	French fry selection.
Golden Miracle (Crop 15)	Yellow fleshed crisper. Very high SDS.
Nadine	Significant worldwide as a fresh washing potato. Low DM high sugar. High RS and RAC.
Red Rascal	CFR-bred fresh, low RAC.
Russett Burbank	Industry standard for French fry processing.

3.3.2 Cultivation/sites

Three sites were selected at Palmerston North, Pukekohe and Lincoln. Plants from the 12 cultivars were grown in randomised blocks in triplicate at each site and cultivated using standard agronomic practices.

Some concern was raised about the potential for potato psyllid damage, particularly at Pukekohe and Palmerston North (John Anderson pers. com.). Tubers from each of these sites were to be carefully monitored for signs of psyllid damage during sampling.

3.3.3 Harvesting

Tubers were harvested from the Palmerston North site in early May 2009, and are about to be harvested from the Pukekohe and Lincoln sites. Tubers from each cultivar and replicate were inspected and any damaged, small or irregular grown tubers were discarded. Each replicate was stored in a separate onion bag before being transported back to the Food Industry Science Centre in Palmerston North. Tubers were stored at ambient temperature for 1 week to ‘wound-heal’ before sampling and further storage.

3.3.4 Sampling

An initial Time 0 sample was taken before storage began. Five tubers from each replicate were cleaned, and cut in half width-wise. A single 1 cm thick slice was taken from the middle of each tuber and inspected for signs of potato psyllid damage. Any tubers with obvious damage were discarded and another tuber sampled.

A single ‘chip’ (1 cm x 1 cm x tuber width), including the skin, was removed from the centre of each of the five tuber slices. These were diced, mixed, packed into two plastic containers and immediately frozen in liquid nitrogen before storage at -80°C. One container from each replicate was freeze dried and stored in preparation for SDS and RD analysis (sub-programme 1, year 2). The other pottle remains at -80°C storage as a back-up, or for further analysis.

3.3.5 Storage

The remaining tubers were treated with sprout inhibitor and placed in ambient storage (12°C, 85% humidity) or cold storage (8°C, 85% humidity). Samples will be taken, as above, after 4 and 8 months of storage.

4 Sub-program 2. Processing variables affecting the formation of SDS and RS in potato products.

4.1 Background

In a previous report we investigated in detail the influence of various treatments on SDS and RS formation to identify the effect of various sample handling methods as causes of variability. This research can now be extended to examine the effect of various processing variables on formation of SDS and RS as a preliminary to new product development.

The effect of several key variables on SDS and RS formation will be examined, including:

- duration of cooking,
- degree of hydration during cooking and during subsequent cold treatment,
- duration of cold treatment after cooking,
- temperature of cold treatment.

In addition, the effect of mixing potato starch with other cereal starches in various proportions on the formation of SDS and RS will be measured as a guide to possibilities for using potato starch as a functional ingredient in new composite products.

The temperature-stability of SDS and RS formed by cold treatment after cooking will be examined. This will involve establishing the degree of reversion of SDS and RS to RDS as a function of temperature, cultivar, and duration of storage. Cultivars with a high tendency to form SDS may form a more heat-stable SDS. Furthermore, a higher tendency to form SDS may lead to a greater progression to RS with storage. The interactions between temperature, storage duration, cultivar and degree of hydration will be used as a basis for new product development.

Six experiments have been conducted in Sub-programme 2 in this, its first year of research. Full details of these experiments will be included in the final report for this Sub-programme (due 30 May 2010.) For this interim report we have limited our discussion to the objectives and conclusions from each experiment, as outlined below. However, if further details of any experiments are required, we are happy to provide these.

4.2 Experiment 1. The effect of prolonged storage of freeze dried raw potato on formation of SDS and RS when the potato is subsequently rehydrated, cooked then stored cold.

4.2.1 Objective

To confirm that storing raw potato in freeze-dried form, and at low temperature, will prevent time-dependent changes in the digestibility of starch when the potato is rehydrated, cooked, and stored cold to induce formation of SDS.

4.2.2 Conclusion

Storage of potato in raw, freeze-dried form is suitable for subsequent measurement of changes in RDS and SDS as a result of processing or postharvest storage of the tubers. Therefore, samples taken from Sub-programme 1 will be safely stored in this form until analysis.

4.3 Experiment 2. The time course of changes in RDS, SDS and RS formation in Agria and Nadine potatoes after cooking then storing cold.

4.3.1 Objective

To determine the time course of changes in RDS and SDS during cold treatment of potato after cooking.

4.3.2 Conclusion

SDS formation may occur very rapidly upon cooling cooked potatoes. Most SDS forms within 24 h, but changes in the digestibility of potatoes through the formation of RS should be included in the analysis. We will give at least a 24 h cold treatment after cooking in future research on SDS formation.

4.4 Experiment 3. Changes in RDS and SDS in fresh potato and rehydrated freeze dried raw potato after cooking then storing cold.

4.4.1 Objective

To determine whether the form of potato cooked before cold-induction of SDS has any impact on SDS formation, or on changes in RDS.

4.4.2 Conclusion

Potato samples that have been freeze-dried and reconstituted before cooking and cooling showed similar, or greater, SDS and RS formation than whole potato samples. Therefore, not only is this method a suitable storage form before analysis, it may present opportunities for a significant reduction in glycaemic impact on ingestion.

4.5 Experiment 4. The effect of location in tuber on RDS and SDS formation in potatoes cooked then stored cold.

4.5.1 Objective

To determine the influence of tissue location within the potato tuber on the tendency of cooked potato to form SDS when cooled. To determine whether or not tissue location and mode of maceration interact to affect starch digestibility.

4.5.2 Conclusions

Tissue location does not appear to be an important determinant of the tendency of a given amount of starch to form SDS, but it may indirectly affect both RDS and SDS levels without affecting the relative proportions of each, by determining the amount of starch that is accessible for digestion.

4.6 Experiment 5. The effect of water content time of heating on the formation of nutritionally distinct starch fractions in rehydrated potato.

4.6.1 Objective

To determine the range of water additions to dehydrated potato that is required to limit the extent to which a heat-induced increase in digestibility occurs when the potato is cooked.

4.6.2 Conclusion

Limiting the degree to which starch gelatinisation is able to occur during cooking, by restricting the amount of water available, is a means of decreasing the glycaemic impact of potatoes. The dramatic reduction in digestible starch achieved using this process indicates that the use of potato as an ingredient in starchy products that contain less than about 50% water when cooked warrants further investigation, as a strategy for reducing the glycaemic impact and to increase the prebiotic potential of foods.

4.7 Experiment 6. Using controlled hydration of raw potato in food products to control their glycaemic-prebiotic balance.

4.7.1 Objective

To use *in vitro* digestion to determine the relative glycaemic impact of potato starch as a function of moisture content during cooking.

4.7.2 Conclusion

Controlling the degree of potato starch gelatinisation in food products may be a highly effective way of manipulating their nutritional attributes.

5 Acknowledgements

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