Potatoes - the quest for processing quality

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Abstract

As an increasing proportion of the New Zealand potato crop is processed, the quality of the raw material has assumed increasing importance. The main quality characteristics of interest to both French fry and crisp producers are tuber size and shape, flesh colour, dormancy and storability, dry matter content and reducing sugar content.

The reasons for and importance of these characteristics are outlined, and the ability of potato breeding and agronomic management to influence the processing quality requirements of processed potatoes is discussed. Recent cultivar releases offer advantages in the quest for processing quality. Genetic material for the development of cultivars capable of being chipped after low temperature storage will be available in the future.

Additional key words: Solanum tuberosum, *dormancy/storage, dry matter content, reducing sugar content.*

Introduction

When the DSIR began potato breeding 50 years ago the main objectives were yield and resistance to late blight (*Phytophthora infestans*) (Genet, 1983). The rapid development of potato processing overseas during the 1960s was seen as a vanguard to similar developments in New Zealand. Although some varieties of that time would "process", the need for better processing types was acknowledged and objectives of the potato breeding programme expanded to include processing characteristics. Today, at least one-third of the New Zealand potato crop is processed and the proportion is rising. One of the major limiting factors to further expansion of potato processing is the lack of quality raw material.

This paper outlines the factors comprising potato quality, how potato breeding is providing improvements for the processor, how agronomic management can assist quality raw material for processing, and finally future directions for research in the quest for processing quality.

What is Processing Quality

Many traits influence the processing potential of a cultivar and different processes require different quality characteristics. In New Zealand, french fries and crisps are the major processed potato products. Minor processed products include dehydrated flake, canned baby potatoes and fried products like hashbrowns and croquettes. The main quality characteristics required for the manufacture of french fries and crisps are outlined in Table 1.

Tuber size and shape

For the production of french fries, the tuber shape most closely resembling a rectangle in cross-section results in minimum wastage (offcuts and slivers). Long tubers satisfy the demand of fast food chains for long fries. Hence, the common expression "the brick-shaped potato" fits the requirements of processor and customer.

End users of crisps are not overly concerned with crisp size. However, the dictates of processors' packaging and slicing equipment require round, medium-size (100-200 g) tubers. Large crisps are more prone to damage, and are more difficult to fit in small packs. As tubers cannot be orientated at the slicing stage, long tubers are difficult to cut.

Table 1. Specific quality characteristics for processed potato products.

Characteristic		Processed Product	
		French fry	Crisps
Tuber shape		Long	Round
Tuber size		Large	Medium
Flesh colour		White/yellow*	White/yellow*
Dormancy		Long	Long
Storability		Long	Long
Dry matter	%	Medium-high	High
	variation	Low	Low
Reducing sugar content		Low	Very low
	variation	Low	Very low
After cooking darkening		Low	-

* Depends on individual processors

Although early reports from Salaman (1926) suggested that tuber shape was controlled by a single gene for length, subsequent work suggests a polygenic relationship (Howard, 1970). The recent use of other *Solanum* spp., mainly to introduce genes for pest and disease resistance, may have further complicated the genetics of tuber shape. However, with the strong industry definition of tuber size and shape, breeders consciously select those required.

While the genotype has the major say in the shape of tubers, environment can have some effect. Bunkenberg (pers. comm.) has observed tubers of a number of cultivars to be longer when grown in silt soils north of Palmerston North compared with those grown in peat soils to the south.

Tuber size can be affected by changing plant density, nutrient applications, plant longevity, seed size and water supply.

Flesh colour

Potatoes grown in New Zealand have traditionally been white fleshed, however many European cultivars have yellow flesh. Processors have mixed views about the colour of their product. Present attitudes favour white-fleshed french fries and yellow crisps, but not exclusively so.

While yellow is dominant to white (Howard, 1970), the present requirement for both colours is easily met from within existing germplasm.

Dormancy/storage

Dormancy and storage considerations are unimportant in cultivars processed directly from the field. However, to best utilize plant and personnel, cultivars that can remain in top processing condition through the winter and spring are essential. Storage cultivars must remain dormant, maintain their processing quality and resist storage diseases and damage during harvesting, transporting and grading.

As with most multigenetically-inherited characters, use of identified parent and progeny testing is necessary to isolate the desired genotypes.

While the length of dormancy is genetically determined, and a large part of storability is related to disease resistance, management of storage temperature and humidity is important. High humidity to reduce respiration losses and constant temperatures of 9-10° for French fries, and 10-11°C for crisps to prevent sugar buildup and consequent darkening of processed product are necessary unless reconditioning is conducted.

Dry matter content

Dry matter content is important for both economic and quality reasons.

1. Yield of processed product is higher per unit fresh weight from higher dry matter potatoes. Lulai and Orr (1979) found that a 0.005 unit increase in the specific gravity of potato tubers resulted in a 1% increase in the yield of chips.

2. Particularly with crisps, lower dry matter contents require more energy to drive out the moisture and more oil to replace it (Lulai and Orr, 1979). If too much oil is required, ie dry matters are low, the resulting crisps are soggy and oily with a reduced shelf-life and increased production costs.

3. Higher dry matter results in better textured products, crisps are crunchier and french fries are more mealy and firmer.

4. Variation in dry matter content both between tubers and within tubers affects the uniformity of processed product, and thus the quality.

Most of the dry matter in potatoes consists of starch with small amounts of sugars, fibre, protein and ash (Lisinska and Leszczynski, 1989). In immature tubers the dry matter percentage is around 16 and rises depending on cultivar and environmental conditions to 18-28% (Appleman and Millar, 1926). The maximum dry matter content is achieved at different times and can fluctuate considerably during the latter stages of growth, often dropping slightly prior to haulm senescence (Genet, 1977). The reasons for this are not clearly understood but are thought to involve changing rates of increase in starch and cell wall material compared with water uptake. As the plant matures, starch deposition declines but water uptake is maintained. Losses due to respiration may also be involved (Gray and Hughes, 1978).

Johanssen *et al.* (1967) concluded from their study of the inheritance of dry matter content that both parents needed to have high dry matter contents if a high proportion of the resulting progeny were to acquire that characteristic. This theory plus the knowledge that dry matter content is correlated with late maturity are utilised in practical potato breeding.

The dry matter content of potato tubers is variable both between and within tubers. Some cultivars are reputed to be less variable than others. Russet Burbank has a reputation for evenness of dry matter content. Results from Lincoln confirm this (Table 2). In 1987-88 we also looked at within tuber variation of 4 cultivars by coring tubers and drying selected segments of tuber. In all cultivars the dry matter content of the centre of the cores was lower than the outer portions (Table 3) confirming work reported by Baijal and von Vliet (1966).

A number of factors affect dry matter content. To understand fully the effects of any cultural or environmental treatments on dry matter content the growth and activity of the foliage and tubers and crop maturity must be considered. Failure to interpret these complex interactions may explain the seemingly contradictory results reported in the literature.

Adequate levels of water during the early and active growing stages of the crop increase the final dry matter content of tubers because of increased starch production but irrigation late in the season can depress dry matter content (Smith, 1960).

Generally, as found by Martin *et al.* (1988), only small differences in dry matter percentage are found under different irrigation regimes when fully mature tubers are tested. In areas with high temperatures the effect of irrigation on soil temperature cooling and subsequent dry matter content can be important. Motes and Greig (1970) reported that in a year of high temperature, irrigation lowered soil temperature, and that high soil temperatures are associated with low specific gravity potatoes.

Table 2. Dry matter variation between 60 tubers of 4 cultivars grown side by side in two years. (Measured as standard deviation — a lower standard deviation signifying a less variable dry matter.)

Cultivar	Year 1986	1987
Tekau	0.0069	0.0087
Ilam Hardy	0.0065	0.0078
Kaituna	0.0073	0.0079
Russet Burbank	0.0055	0.0057

Table 3. Dry matter content of different portions of potato tubers. (Mean of 4 cultivars - Ilam Hardy, Tekau, Kaituna, Russet Burbank.)

	Rose End	Middle	Stem End
Outer	21.7	21.2	21.2
Center	17.0	15.3	17.1

Haulm killing. As potato plants slowly die, food reserves are translocated from the leaves to the tubers. These, mainly plant sugars, are converted to starch resulting in increased dry matter. Chemical or physical rapid haulm killing prevents the translocation of food reserves to the tubers and results in lower dry matter tubers than if left to mature naturally (Rowberry and Johnston, 1966).

Fertiliser. High rates of nitrogen and potassium can reduce dry matter content. Nitrogen, in particular, delays tuberisation and unless growing seasons are long the crop often does not achieve full maturity (Gray and Hughes, 1978).

Site

Many people have reported that potato cultivars grown in different locations regularly have higher or lower specific gravities. Location differences are probably a combination of soils and climate. Usually, potatoes grown on sandy soils produce tubers with higher dry matter content. As part of our breeding programme we conduct trials at Pukekohe and Lincoln every year. Ilam Hardy and Rua are grown as controls. Table 4 shows the consistently higher dry matter contents achieved at Lincoln with both cultivars.

Reducing sugar content

From a consumer point of view, colour, particularly with crisps, is the most important quality characteristic. The colour of crisps is related to the reducing sugar content - the higher the reducing sugar content the darker the crisp. The browning of crisps is a result of the Maillard reaction - between the reducing sugars, amino acids, ascorbic acid and other organic compounds. These last three groups are always present in potato tubers. Levels of reducing sugars vary depending on cultivar and environment. Reducing sugar levels above 0.1% make high quality crisps difficult to produce.

Table 4. Effect of site on dry matter of Rua and Ilam Hardy potatoes.

	Ilam Hardy		Rua	
Year	Lincoln	Pukekohe	Lincoln	Pukekohe
1990-91	20.7	16.8	23.1	19.3
1991-92	21.2	16.4	25.4	19.0
Mean	21.0	16.6	24.3	19.2

Studies on the inheritance of reducing sugar content have shown high heritability estimates. Loiselle *et al.* (1990) recommended that progeny testing be conducted for both specific parents and crosses in order to identify successful processing combinations and increase the chances of selecting valuable chipping clones.

In most potato cultivars, temperatures below 8°C result in an increase in reducing sugar levels preventing their use for chipping. In 1970, Lauer and Shaw reported a potato line capable of producing acceptable crisps direct from storage at 4-5°C. They also reported that crosses using a cold chipper as one parent in diploid populations gave 5.4% of the progeny that would chip successfully out of cold storage.

Ehlenfeldt *et al.* (1990) found similar rates from tetraploid crosses, the percentage being determined by the non- cold chipping parent.

Mackay *et al.* (1990) reported acceptable fry colour in some test clones even after 30 weeks storage at 4°C. The cultivar, 'Brodick', released in 1991 is capable of chipping from cold storage.

Factors influencing the maturity of potato tubers have a bearing on the resulting colour of processed product, and generally cultural and environmental factors that result in potatoes of high dry matter content also produce light-coloured product. (Talburt and Smith, 1967). The most easily influenced factors that affect sugar content include soil moisture or irrigation, fertiliser, length of growing season and haulm killing, which have been covered earlier.

Future

The future of the New Zealand processing industry is dependent on high quality products and low production costs. High yielding, consistent quality cultivars will allow production costs to remain low. The present specialist French fry cultivar, Russet Burbank, is expensive to produce and unreliable because of its susceptibility to a number of diseases, in particular late blight, and physiological disorders. The recent release of Warrior (Genet *et al.*, 1993) with its medium-high dry matter content, low sugars, oval-long shape and consistency of production and quality should assist French fry processors. Similarly, the release of Kaimai (Anderson *et al.*, 1993) with very high dry matter content, medium-low sugars and round shape should allow production of high quality crisps. Other cultivars will be required to extend the seasonal range, particularly early season.

The ability of some clones to maintain low reducing sugar content after storage at low temperatures offers significant advantages to processors. Incorporation of this characteristic into processing-type potatoes will be a major breeding objective over the next few years. The ability of genetic engineers to introduce similar advantages to the gene pool may be the next step.

As concluded by Holden (1981), few attributes of the potato are not susceptible to genetic manipulation and the principal difficulty facing the breeder is how to assign priorities to the many different selection criteria.

The broad principles affecting the growth of process quality potato crops are reasonably well understood. They include water, plant nutrients, plant density, and seed management. More specific information well be required to maximise quality and yield for the new cultivars produced by breeding programmes.

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