Horticulture Innovation Australia

Final Report

Development of a new blanching technology for vegetables

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VG07177

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Simplot's request for confidentiality of project ***VG07177: Development of a new blanching technology for vegetables*** was formally approved by HAL for a requested period of life of project (up to 6/07/2009) and an additional 4 years (up to 6/07/2013) for the reasons outlined in the project proposal. The media summary below shall therefore remain confidential for this granted period of time unless otherwise formally approved (in writing) by Simplot Australia.

Media Summary

There is increasing demand for minimally processed products that have the attributes of freshly prepared food but still have an extended shelf-life and superior nutritional quality. Current conventional pasteurization and commercial sterilization processes involving extended exposure to heat cannot provide these desired attributes. This project explored the application of high power microwave heating (HPMH) technology as a means to alternatively pasteurise vegetables whilst maximizing product quality. The net result is significant profitable top-line growth for our business, greater local investment in raw materials and labour and an improved contribution to the satisfaction of Australian processed vegetable consumers.

The project was a collaborative effort between Simplot and the University of Wollongong (Faculty of Engineering).

The project which forms part of a larger project was composed of two key stages (I) Laboratory development work and (II) Prototype development and validation.

- Laboratory development work - This stage was primarily concerned with establishing the process conditions required to achieve successful blanching, leading to some design concepts.
- The prototype development and validation stage was concerned with developing a prototype processing system. The work focused on microwave aspects involved in achieving uniform heating, materials handling challenges and materials flow trials and ultimately the construction and validation of semi-continuous processing unit delivering 30-40kg product/hr.

Stage I yielded significant results on the (i) electrical properties of locally grown vegetables (ii) enzymes inactivation with varying process regimes (iii) energy and heat penetration modelling and (iv) preliminary understanding of vegetable quality after

treatment with these varying microwave conditions.

Stage II yielded a prototype microwave blanching system and process which returned many key and positive results including:

- Close to 100% enzyme (peroxidase) inactivation for a given processing time;
- High level of vegetable quality retention;
- Fast processing times, and;
- No textural loss during chilled storage.

Future research will concentrate on developing and validating the technology and process on a larger commercial scale and ultimately implementation if the research is successful. From the results of this project a conceptual commercial design for validation has been proposed with the following features:

- Mechanised unloading, cleaning and processing movements;
- Throughputs exceeding 600kg/hr;
- Improved microwave E-field uniformity, yielding more uniform heating and improved energy efficiency.

Technical Summary

Traditional blanching systems use steam to transfer heat by conduction from the outer surface of the vegetable inwards. This creates an inconsistent texture throughout the product with the core part having a firmer texture and a lesser degree of enzymes inactivated.

To overcome these discrepancies this project evaluated the use of high power microwave heating (HPMH) and its unique volumetric heating properties to blanch three vegetables, namely broccoli, carrots and corn kernels.

This project which forms part of a larger project was divided into two stages (Stages I and II).
Stage I, ***Laboratory development work***, was primarily concerned with establishing the process conditions required to achieve successful blanching, leading to design concepts.
During this stage important processing parameters, such as the ones listed below, were investigated:

- power density limits,
- applicator/process power profile,
- applicator type,
- materials handling issues,
- heating rate window limits,
- process limits,
- energy requirements.

Some of the specific technical challenges encountered during this stage were:

- impedance matching to ensure maximum power transfer,
- ensuring even heating; (i) penetration depth, (ii) electric field distribution and (iii) dielectric properties of vegetables,
- distribution of power density to ensure desired outcomes,
- development of a suitable microwave applicator.

Prototype development and validation, stage II, involved microwave applicator and materials handling demonstrative studies via both physical verification and software modelling based upon the conceptual design established in Stage I. Pilot scale continuous trials were undertaken on each of the specified vegetables with specific focus on applicator performance, materials handling product configuration and orientation**.**

Industrial (922MHz) and commercial (2.45GHz) microwave generators or magnetrons were tested for their different penetration depths. Industrial magnetrons, as expected, delivered a more uniform blanching throughout the vegetables and yielded a product with a firmer texture and higher levels of inactivate peroxidases than currently achieved with traditional methods.

In addition to delivering a superior product, the HPMH technology will also use less energy, water and will save factory floor space making it very attractive to the food industry in general.

Further research will be carried out on stage III and IV of this project to firmly validate the opportunities mentioned above and to fully understand their potential. The three main elements involved in the conceptual design of the microwave blanching unit for Stage III are:

- Determining the suitable microwave power, batch size and batch times;
- Producing a concept for the cavity, including methods of loading, mixing and unloading batches, and;
- Performing electromagnetic modelling of the proposed cavity to assess the microwave field pattern and coupling abilities of the loaded proposed cavity.

Stages III and IV should see further gains made in processing techniques, blanching parameters as well as equipment quality and setup, leading to a process that consistently and efficiently delivers crisp superior quality blanched vegetables with improved texture, higher nutrient and flavour retention and the potential for extended shelf life.

The results from stages III and IV will be communicated to HAL via informal updates within 12 months of the completion of this project and again within 12 months of the completion of the entire commercialization project (as state under VG07177's Schedule 1 'Outcomes' section).

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1 INTRODUCTION (including review of literature – Stage I and II)

There is increasing demand for minimally processed products that have the attributes of freshly prepared food but still have an extended shelf-life and superior nutritional quality. Current conventional pasteurization and commercial sterilization processes involving extended exposure to heat cannot provide these desired attributes. Simplot's corporate strategy is to venture into new frontiers, which includes entering the chilled market with a range of ready-to-eat/cook chilled minimally processed vegetables. This will result in a new range of vegetable products in the chilled vegetable segment, thus resulting in an increase in the size of this market. This could ultimately take share away from categories where off-shore vegetables are being marketed.

Microwave technology uses electromagnetic waves that pass through material and cause its molecules to oscillate, generating heat. Microwave heating generates heat within the material and heats the entire volume at about the same rate. This leads to a very rapid and more uniform heating when compared to conventional surface conduction heating, where the food surface heats first and then the heat moves inward. This technology has significant potential for food blanching where high pasteurization or sterilization temperatures can be achieved within seconds. This is expected to result in less product damage (i.e. textural and nutritive) than conventional water and steam blanching processes and assist in achieving attributes desired by consumers. HPMH is also reported to be up to 70% more energy efficient than conventional heating due to its volumetric penetration and requires no water for heat processing. Another advantage of the technology is that it is possible to transport and contain large amounts of energy in confined spaces resulting in minimal floor space for processing (reported to be ~ $1/5^{th}$ floor space of conventional heating process).

This literature review reports on the research undertaken regarding the implementation of, and issues relevant to microwave blanching technologies. Basic theory regarding dielectric properties is summarised as relevant to blanching, research on microwave blanching effects is reviewed, and compared with conventional techniques.

1.1 Dielectric properties of foods

Dielectric represents a class of materials which, although insulators, exhibit a number of effects when placed in an electrical field. The rate of the heat generated inside of a material when exposed to the microwave energy depends on the magnitude of its dielectrics properties.

The dielectric properties of any material are the main parameters that influence how microwave energy is coupled into the material and how efficiently this energy is then converted into thermal energy. These properties are described by the following complex equation:

$$\varepsilon = \varepsilon' - j\varepsilon''$$

The complex dielectric constant (ε) consists of a real part of the equation (ε'), the dielectric constant, which represents the ability of the material to store energy when a microwave field is applied. The imaginary part of the equation (jε''), the loss factor, determines how readily the microwave energy is converted into heat within the material. These values are typically obtained from literature and/or measured using a variety of specialised microwave techniques.

When materials are subjected to electromagnetic fields, there are various mechanisms which provide energy storage and conversion to heat. The dominant mechanisms for foods at microwave frequencies are ionic conduction and dipole rotation (Ryynänen, 1995).

The dielectric properties of foods are influenced by many factors, these include frequency, temperature, moisture content, and food compositions (salt content in particular) (Schubert & Regier, 2005). This means that during any microwave heating process, the dielectric properties of foods will inevitably change. The nature of this change depends on the influences mentioned above. For example walnut kernels at 3% moisture experience a decrease in loss factor with temperature increase (Schubert & Regier, 2005). This means that the hotter kernels will absorb less energy and thus overall heating uniformity is improved. In moist foods which contain salt, however, the loss factor will likely increase with increased temperature. This can lead to an effect known as thermal runaway, where hotter parts of the workload are heated preferentially, which in turn increases the loss factor, thus promoting non-uniform heating (Metaxas & Meredith, 1983).

Every food product to be processed in a microwave system has a different molecular makeup, and properties unique to it. Only after the identification of the dielectric properties of a material, knowledge of its size, shape and other properties such as specific heat can a system be designed to fully exploit the advantages of microwave heating technology (Schubert & Regier, 2005).

1.2 Microwave processing options

When considering the processing of vegetables with microwave technology there are two main applicator types:

- Single Mode, and
- Multi-mode**.**

The single mode applicator is the most efficient type of microwave processing (Schubert & Regier, 2005) as there is only one field pattern that resonates within the cavity, which allows the work load to be passed through the high field portion of the cavity.

The multi-mode applicator is the most common type used in both industry and domestic markets. This is particularly due to the greater flexibility it offers with continuous feed options such as conveyor belt systems. Achieving even field distributions and hence even heating, is not as straightforward in multi-mode ovens as in single mode. The multiple fields set up within the cavity require complex computer modelling to accurately predict the field distribution, particularly when dielectrics are present and moving within the cavity.

1.3 Microwave blanching: comparison to conventional methods

Blanching of vegetables is performed to preserve qualities such as flavour, colour, aroma and nutrient levels. It is important to compare the advantages, disadvantages and unique features of microwave blanching with conventional methods such as steam and water blanching.

The main features of microwave blanching which set it part from conventional methods include volumetric heating with reduced temperature gradients and rapid inactivation of enzyme complexes leading to reduced leaching of flavours, pigments, vitamins, and carbohydrates (de Ancos *et al.,* 1999). Microwave blanching also offers faster processing times, energy savings, instantaneous process control and no additional water is required in the process, which reduces the waste from the process (Schubert & Regier, 2005). In this section the literature regarding microwave blanching in the important areas of processing time, heating uniformity, enzyme inactivation, nutrient retention, as well as texture and colour retention are reviewed.

1.3.1 Process times

The direct coupling of microwave energy into heat volumetrically within a dielectric results in a more rapid heating than can be achieved with conventional blanching techniques. This results in reduced process times. Collins and McCarthy (1969) demonstrated that microwave blanching of potato tubers reduced the process time to inactivate peroxidase from 13 minutes with boiling water to 4.7 minutes. This more rapid heating results in a better quality product in terms of flavour, texture, colour, vitamin content (Dorantes-Alvarez *et al.,* 2000) and higher levels of heat-labile nutrients post treatment (Mudgett, 1989).

Ramesh *et al.* (2002) found that the time required for blanching was substantially different for different types of vegetables, and that water blanching was more effective for vegetables with high surface area to volume ratio (For example: Spinach).

1.3.2 Heating uniformity

Even heating is both a large advantage of microwave technology and its greatest challenge. The volumetric nature of microwave heating means that rapid heating and low temperature gradients are possible, leading to the vast array of benefits discussed in this review, however varying dielectric properties, specific heats, and the shape and size of products combine with the limited penetration depth of microwave energy to cause varied energy distribution within the food. Therefore an important requirement in any microwave system design in the food industry is the ability to control the heating homogeneity (Ringle & Donaldson, 1975).

1.3.3 Enzyme inactivation

Peroxidase is the most durable and heat resistant of the enzymes which catalyse reactions that reduce food quality. As such, it is a suitable indicator to assess whether successful blanching has been achieved. If peroxidase has been inactivated it can be assumed that all other enzymes of interest are also inactivated (Gunes & Bayindirli, 1993). Most blanching methods can successfully inactivate peroxidase but often the energy applied to achieve complete inactivation causes reduction of other product qualities.
Microwave blanching to inactivate peroxidase is not as harsh as conventional methods, and therefore results in improvements in flavour, colour, texture and nutrient levels (Gunes & Bayindirli, 1993).

There are a few parameters useful in the quantitative assessment of enzyme inactivation:

- D-value: This represents the heating time in minutes required to inactivate 90% of the enzyme activity at a particular temperature (Ramaswamy & Abbatemarco, 1996).
- *Z-value*: Indicates the range of temperatures which the D value passes through in one complete logarithmic cycle. It indicates the temperature sensitivity of the product.
- Thermal Inactivation Time (TIT):
  This is the time required to ensure no residual activity of an enzyme is measurable. This is usually performed on the most heat resistant enzyme (likely peroxidase).

Studies have shown that D-value can be very significantly reduced by using microwave blanching compared to conventional techniques such as steam or water bath. Analysis of enzyme deactivation in orange juice (Tajchakavit and Ramaswamy, 1997) heated in a continuous flow with 700W of microwave energy found that he D- values ranged from 38.5 seconds at 55°C to 1.32 seconds at 70° C. These results are much lower than the 10

– 390 seconds at 55° C and 6 – 36 seconds at 70° C for conventional heating methods. The microwave heating D-values are smaller by an order of magnitude than conventional methods.

1.3.4 Higher retention of nutrients

Microwave blanching, as mentioned above, often leads to reduced blanching time and in turn, higher soluble nutrient retention. Due to the fact that ascorbic acid is one of the most labile nutrients in fresh food products, its retention during processing is an indication of maintained food quality. Research has conflicted as to whether microwave blanching increases ascorbic acid retention compared to conventional methods. Some research found demonstrated reduced levels (Drake *et al.,* 1981; Ramesh *et al.,* 2002); however the majority of research found demonstrated higher ascorbic acid retention when microwave blanching was employed. A study on blanching of banana puree showed increased ascorbic acid retention when microwave blanching was performed compared with water bath blanching (Premakumar & Khurdiya, 2002). Another study showed higher ascorbic acid retention in microwave blanched artichokes (Ihl *et al.,* 1998).

Microwave blanching of carrots returned great ascorbic acid values, higher carotene and sucrose than conventional methods (Kidmose & Martens, 1999). This study compared continuous microwave blanching performed on a conveyor at 10kW total power, with steam and water blanching. Carotenoid retention has also been shown to be 35% greater than when blanched traditionally (Ramesh *et al.,* 2002).

Water, steam, convection and microwave methods were used to blanch green beans (Muftugil, 1986). It was found that Ascorbic acid and chlorophyll levels were highest in the microwave blanched samples.

1.3.5 Vegetable Texture

Kidmose and Martens (1999) in their study of microwave blanching of carrots did not find any marked improvement in the texture of the carrots when compared with conventional blanching techniques. A study by Quenzer and burns (1981) however did indicate differences. The study compared the texture of freeze-dried spinach when blanched by water, steam and microwaves. The microstructures of the leaves were observed after blanching through an electron microscope. It was noted that the microwave blanching kept the cell walls intact through coagulation of the protoplasmic material surrounding the cell walls. The microwave blanched samples had acceptable textural quality and produced a superior freeze-dried product as compared with conventionally blanched products. It is expected that spinach would possess different dielectric properties than the vegetables under investigation in this project but because of the lack of publications in this area it serves to support the microwave blanching theory for different vegetables. It also contributes to the elucidation of the changes occurred during microwave processing on a cell wall level.

1.3.6 Colour retention

Colour is an important quality factor. Microwave blanching has been shown to improve colour stability and retention of ascorbic acid in strawberry juice (Wrolsatd *et al.,* 1980). Microwave blanching of kiwi fruit successfully inactivated the peroxidase with almost no loss of the 'bright green' colour and with only small degradation of chlorophylls (de Ancos *et al.,* 1999). Microwave blanching has also been shown to improve colour retention in Brussels sprouts (Dietrich *et al.,* 1970). In general the literature search revealed no significant colour loss due to microwave blanching and in some cases improved retention.

1.3.7 Non thermal and enhanced thermal effects

The mechanism by which microwave radiation contributes to the inactivation of enzymes in food is unclear (Schuber & Regier, 2005). There is considerable division in literature as to whether non thermal effects associated with microwave enzyme inactivation exist. Studies involving the processing of apple and orange juices via conventional and microwave methods (Tajchakavit & Ramaswamy, 1995), observed the kinetic parameters (D-values and z-value) of enzyme inactivation. This study demonstrated a difference of an order of magnitude between the D values for conventional (154 seconds) and microwave (7 – 12 seconds) processes. This difference is potential evidence for the non-thermal effects of microwave enzyme inactivation.

Tajchakavit (1997) performed further tests at sub lethal temperatures (<40° C) to attempt to identify whether non-thermal effects were substantial. Insufficient inactivation occurred to confirm the existence of non thermal effects.

Further tests were carried out with the same equipment to assess the 'enhanced thermal effects' of microwaves versus thermal processes. To quantify these effects microwave enhancement ratio (MER) was created. This ratio simply compared inactivation under microwave heating (including thermal effects) to that due to calculated thermal effects. A MER of greater than 1 indicated enhanced thermal effects. The MER for the inactivation of pectin methyl esterase was up to 20, which strongly indicates the existence of enhanced thermal effects, but no non-thermal effects were observed at the sub-lethal temperatures. Other studies (Kermasha, *et al., 1993 a, b)* observed non thermal effects. These studies suggested that the proteins in the products have polar or charged molecules which could be affected in the microwave field and that the electrostatic, hydrophobic and hydrogen bonds may be disrupted, causing more immediate inactivation.

Overall, the literature suggests that even if non-thermal effects occur, the vast majority of inactivation during microwave blanching is due to direct thermal effects and thus during process design any non-thermal effects should only be taken as a possibly mechanism for increasing enzyme inactivation (Datta & Anantheswaran, 2001, Schubert & Regier, 2005).

1.4 Hybrid oven concept

As can be seen from the literature, microwaves provide significant advantages over conventional heating techniques due to the rapid and volumetric nature of the heating. However there is also evidence to suggest that systems that incorporate both microwave and conventional heating methods produce superior results. A study on the blanching of spinach leaves (Ponne *et al.,* 1994) compared steam, water, microwave and steam-microwave combination blanching as well as infrared and radio frequency techniques. The study compared the texture, colour, ascorbic acid content, nitrate content and sensory quality of the leaves after blanching, freezing and thawing. Of all the techniques microwave or steam-microwave combination produced the highest texture quality.

Ascorbic acid retention was highest in microwaves, steam or the combination processed leaves. The steam-microwave blanching also produced the highest sensory score.

There are numerous studies which analyse various microwave combination blanching techniques. Chen *et al.* (1971) studied the effect of the combination of microwave and water blanching of white potatoes. Various times combinations of each method were tested to determine the optimum processing combination. Chen *et al.* found that the best results for minimising peroxidase inactivation time were achieved with 2 mins of microwave processing followed by two minutes of water blanching.

Canet and Hill (1987) compared several blanching methods and observed effect on the texture and ascorbic acid content of frozen potatoes. It was found that a combination method, where microwave heating replaced the first step of the stepwise blanching technique, produced texture quality equal to that of the regular stepwise method but higher than conventional methods. The combination process reduced processing times and improved ascorbic acid retention.

A study on the processing of asparagus compared the effect of conventional methods against a hybrid microwave-circulated water combination (MCWC) method (Sun *et al.,* 2005). The study found that the MCWC method produced asparagus with higher antioxidant levels and a greener colour than the conventional techniques.

Another study reported on the use of hybrid technology on yellow peas (Kadlec *et al.*, 2001). Microwave energy was applied first followed by a period in an oven at 80°C. It was found that the hybrid processing produced superior texture.

Viña *et al.,* (2007) studied the effects of blanching method on the quality of Brussels sprouts. Pre blanching treatment of the Brussels sprouts with microwaves before being placed in boiling water was compared with several methods of water blanching. It was found that the microwave combination treatment had no deleterious effects in terms of texture compared to the other treatments and that the loss of colour factor L* was reduced, chlorophyll conservation was increased, and higher levels of radical scavenging activity and ascorbic acid content were increased. It was concluded that this combination method could be used as a technique to improve the health properties of Brussels sprouts.

Metaxas & Meredith (1988) state that in most heating processes there are distinct phases, and that while microwave heating would commonly be capable of performing all of them, the optimum system is often one in which microwave heating is used only for the part where its unique advantages are exploited. The rest of the process is then able to be performed by the cheaper (in capital cost) conventional methods. This literature leads to the conclusion that in order to achieve the highest quality, and most efficient blanching process, a hybrid system must be considered during the design process.

1.5 Dielectric properties

The dielectric properties of materials vary widely, not only with composition, but also with density, temperature and frequency. Knowledge of dielectric data is essential in the design of any microwave heating system because it allows estimates to be made of the power density, the associated electric field stress and penetration depth in the processing material.

1.5.1 Penetration Depth

The penetration depth refers to a wave passing into a dielectric material, whose amplitude is diminishing owing to power absorption as heat into the material. The wave's field intensity and power flux density fall exponentially with distance from the surface. The rate of decay is a function of the complex dielectric constant ε, which comprises the real component ε' and the loss factor ε''.

$$\varepsilon = \varepsilon' - j\varepsilon''$$

The penetration depth is defined as the depth into the material at which the power flux has fallen to 37% of its original value on entering the surface. The dielectric constants of the material being processed will provide reliable insight into the electromagnetic behaviour of the wave inside the material and allow design criteria to be defined.

The depth of penetration (Dp) is calculated using the following well-known equation for low loss dielectrics.

$$D_P \approx \frac{\lambda_0 \sqrt{\varepsilon'}}{2\Pi\varepsilon''}$$

Where: λ_0 = Free space wavelength (m)

The majority of academic research on the dielectric properties of fruits and vegetables has been performed at 2.45 GHz due to the compact sizing and lower cost of this equipment. Therefore during literature research the dielectric properties of corn and broccoli could be found at 2.45 GHz but not in the 915 MHz frequency. Using the properties of other vegetables whose dielectric properties had been found at both frequencies, a correlation was found and used to determine the approximate loss factor and dielectric constant for corn and broccoli at 922MHz. The dielectric properties of the vegetables are presented in table 1.1 below along with the penetration depth as calculated from equation above.

Table 1.1. Estimated Dielectric Properties at 23°C

Material	Frequency	ε'	ε"	D_P (mm)
Carrot	2.45GHz 922MHz	56 59	15 18	8.3 22.2
Corn	2.45GHz 922Mhz	59.7 62.6	16.4 19.9	9.1 20.7
Broccoli	2.45GHz 922MHz	71.1 74.6	20.5 24.9	8.0 18.1

Literature was found that related the dielectric properties of vegetables at 922MHz with temperature (Brinley *et al.*, 2008, Kumat *et al.*, 2008). From these studies the data demonstrated a high level of consistency in terms of gradient and trend line fitting. It was therefore determined that from this data reasonable estimates could be made regarding the dielectric properties of carrots, corn and broccoli versus temperature. The graph below shows the calculated properties.

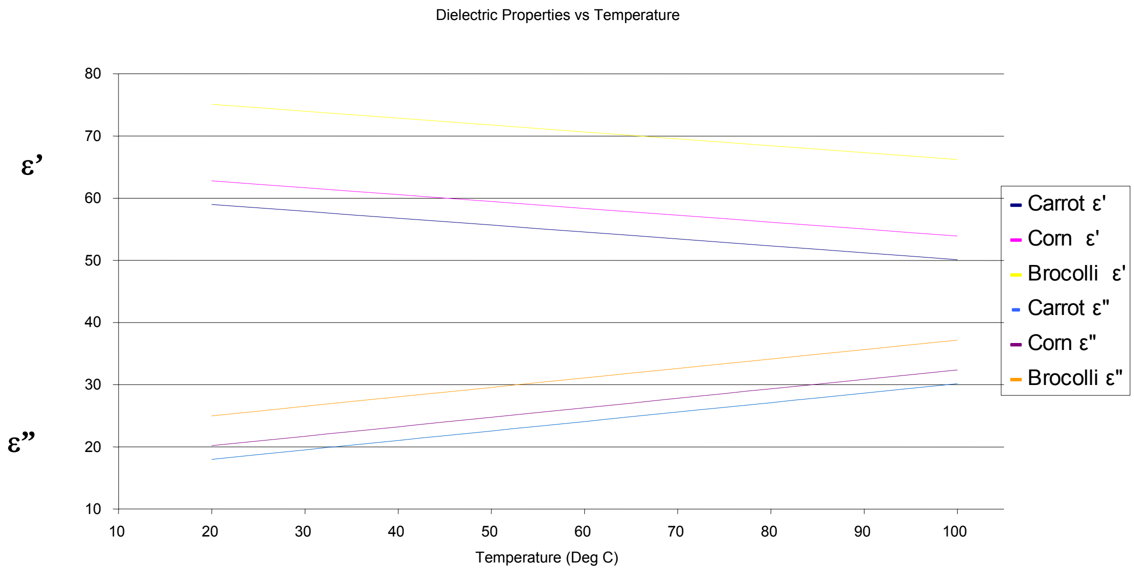


Figure 1.1: Dielectric property estimates (922MHz)

From the information above the penetration depths could easily be calculated. The results are shown in figure 1.2.

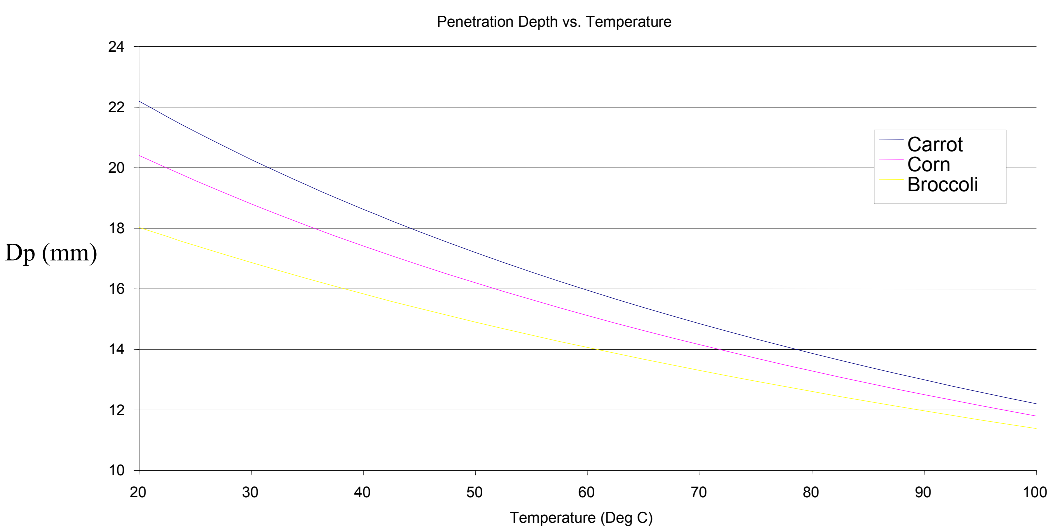


Figure 1.2: Penetration depth estimates (922MHz)

Figure 1.2 demonstrates that a significant decrease in penetration depth will occur during the blanching of the vegetables as the processing temperature increases.

1.5.2 Technical Considerations

One of the main concerns in any microwave heating system is the penetration depth of the power flux into the workload. It gives a direct understanding to the heat distribution within the material and hence heating uniformity. It is important to remember that the penetration depth only refers to the distance into the material where the power flux density has decreased to 37% of its surface value and that the corresponding temperature will be directly related to the exponentially decay in power the deeper into the food surface.

Following are some general conclusions derived from the dielectric values of carrot, corn and broccoli:

- The decrease in penetration depth demonstrated in figure 1.2 means that even heating of the product may become increasingly difficult as the temperature increases during processing. These penetration depths will be taken into account during the design of the applicator in order to ensure even heating

- It can be seen from table 1.1 that the penetration depths at 922 MHz are more than double those at 2.45 GHz. This is mainly due to the difference in frequency rather than the difference in dielectric properties. At 100°C the penetration depths at 922 MHz are still greater than those at 20°C at 2.45 GHz. This is one advantage of processing at 922MHz.

- These set of results represent a generalised set of loss factors ε'' that may be encountered. For a given electric field **E** the absorption of energy depends on ε''. The effectiveness of heating will depend as much on the design of the applicator (oven) as on the loss factor of the material.

1.5.3 Choice of Frequency

The choice is basically between using multiple magnetrons operating at either 2.45GHz maximum rated power 30kW or larger power magnetrons operating at 922MHz rated maximum power 100kW. Some facts about each approach are listed below.

- Magnetron efficiencies are between 50-70% for 2.45GHz compared to 80 to 87 % for high power 922MHz,
- Applicator dimensions and complexity increases as the number of individual magnetron sources increases,
- In multiple magnetron installations, magnetron life is reduced due to cross coupling of power,
- Multiple magnetron systems provide a high degree of redundancy,
- Penetration depths are significantly larger at 922MHz than at 2.45GHz.

In this instance, both 922Mz and 2.45GHz could be effectively used. 922Mz would be the frequency of choice due to its higher power range, greater penetration and better magnetron efficiency.

1.6 Microwave energy aspects

If a fixed continuous source of microwave power is dissipated into a material, the average temperature will rise linearly with time. This is a distinguishing feature not associated with conventional heating, in which the average temperature would rise asymptotically until it reaches the oven temperature, and cannot rise above it. As the material warms up, the dielectric properties of the water and the effect that other food components (ie, proteins, carbohydrates, oils/fats and salts) have on it will change, altering the penetration depth.

The power dissipated in a vegetable is a function of the loss factor (ε''), given by:

$$\text{Power /unit volume} \qquad \mathbf{P = \omega\varepsilon'' E^2}$$

Where E is the electric field and $\omega = 2\pi f$. where the operating frequency is either 2450MHz or 922MHz. The loss component of the complex dielectric constant is difficult to quantify, as it will vary with, temperature, frequency, density, packing factors, orientation and time.

The electric wave decreases in magnitude as it penetrates a lossy dielectric and consequently the power density will also decrease. This is shown in equation below, where **α** is the attenuation constant and **z** is distance in the direction of the moving wave.

$$\mathbf{P \, \alpha \; \varepsilon^{-2\alpha z}}$$

The power penetration depth, D_p, is defined as the distance where the electric power density has decayed to 1/ε =1/2.718 (= 0.37%) from the surface value. This corresponds to the condition where the exponent -2αz is equal to –1.

Again it is important to note that the energy per unit volume is reduced to 37 % of that at the surface. Hence the energy absorbed in the top or side layer of this thickness is 1-0.37 = 63%. Note that at this depth, the electric field is 0.61 of its value at the surface.

1.6.1 Theoretical Energy Calculations

When energy is dissipated in a particular constituent, heating takes place. The temperature rise of the individual constituents will depend on their specific heat capacity, C_p. Hence the relative temperature rise per unit time, assuming no heat transfer is,

$$\mathbf{\Delta T \propto f\, [\varepsilon''/C_p]}$$

The energy input required for the blanching of carrots, corn and broccoli is presented in table 1.2 assuming heating begins at 5°C and ends at 92°C.

Table 1.2: Energy breakdown: Vegetables

Physical Process	Calculation	Energy	Notes
	Mass x C_p x ΔT		
Carrots ΔT=87°C	1 x 3.81 x 87	**331 kJ/kg**	C_p = 3.81 kJ/kg/°C
Corn ΔT=87°C	1 x 2.03 x 87	**177 kJ/kg**	C_p = 2.03 kJ/kg/°C
Broccoli ΔT=87°C	1 x 3.85 x 87	**335 kJ/kg**	C_p = 3.85 kJ/kg/°C

The above calculated values when converted to microwave powers are listed in the following table.

Table 1.3: Microwave power required for an IDEAL process:

Through Put (kg/hour)	Carrot (kW)	Corn (kW)	Broccoli (kW)
1000	92	49	93
2200	202	108	205

Note: these values are for the **ideal** case only. In reality other losses will occur from heat transfer, cavity inefficiencies, uneven heating and possible temperature holding period.

1.7 Technical considerations involved with microwave food processing

The following literature review is concerned with the practicalities of heating vegetables successfully using microwave energy. This information is useful in the experimental trial and conceptual design stages of the project. The processing of food products via microwave interaction creates a large range of technical issues to be identified, analysed and addressed. This section briefly reviews some of these areas as found in the literature studied. The issues are largely related to the challenge of uniform heating within the food. This review addresses electromagnetic issues, heat transfer, cavity effects and dielectric effects.

1.7.1 Material factors

Power absorption into a food is affected by the size, shape, surface area, volume and positioning of the food. In conventional heating, power absorption increases with the increase of surface area of the product. This is not the case with microwave heating, where due to finite power penetration, food volume increases cause the power absorption per unit volume to decrease (Datta & Anantheswaran, 2001) and with increasing volume the volumetric advantages of microwave heating decrease. Studies have shown that for very small and large product volumes, the efficiency of microwave absorption is decreased (Zhang & Datta, 2000). This phenomenon is largely related to the penetration depth of microwaves (governed by the dielectric properties of the food), and the microwave cavity used.

The most critical factor in microwave heating is not how much energy is dissipated within the food but rather the uniformity of this dissipation within the food. A common problem with microwave heating of foods is corner and edge overheating. Greater field intensities are formed at the corners of the product causing more rapid heating. It is the refraction of incident waves on the edges of food products that results in this concentration of the fields (Datta & Anantheswaran, 2001). The angle of refraction is governed by the dielectric properties of the food, thus foods with smaller values of dielectric properties will experience less corner and edge overheating. One method for reducing these effects is using products with edge angles of over 90° because edges sharper than 90° experience more severe electric field concentration (Risman & Ohlssen, 1992).

Microwave heating can result in an internal heating concentration within the product. This phenomenon is often called focusing. Focusing is one of the effects that clearly distinguish microwave heating technology from conventional methods (Datta & Anantheswaran, 2001). It is largely determined by the wavelength of the microwaves, the penetration depth and the size of the heated material. For smaller sizes of product (less than 1 cm), the amount of focusing depends on the wavelength in the material. As the size of the product increases the focusing becomes more dependent on the penetration depth as well as wavelength (Zhang & Datta, 1999). As could be predicted, cylindrical shaped products experience less intense focussing than do spherical shapes due to the curved edge only occurring in one dimension.

Different foods absorb microwave energy at different rates. These differing rates add challenges if attempting the heat these products simultaneously. The dielectric properties, size and placement of the constituents all affect the rates of heating. Studies analysing these effects found that at lower volumes, constituents with lower values of dielectric properties absorbed less than the products with higher dielectric properties. At higher volumes, however, the lower dielectric loss material absorbed more energy (Zhang & Datta, 2000). These effects would vary significantly depending on the properties of the materials used. Testing and modelling would be required to predict trends in energy absorption for particular materials.

1.7.2 Cavity effects

In addition to the electromagnetic effects experienced within the work load, the field patterns (modes) that occur during processing in a microwave cavity have a large affect on the uniformity and magnitude of the energy dissipated into the material. This topic will only be briefly mentioned here because cavity effects are very specific to the design and will therefore be assessable at a later stage in the project. Here general effects and common cavity features are mentioned.

1.7.3 Load placement

Placement within any cavity is a critical factor in energy absorption and uniformity. In multimode cavities field intensity varies with location within the cavity. As microwave theory dictates, areas with higher field intensity lead to higher rates of energy absorption into the work load. Jackson and Barmatz (1991), however, showed that the highest rates of heating in a loaded oven occurred at the locations where field intensity was at a minimum in the unloaded oven. While this research likely only indicates the fact that placing a dielectric material within a microwave field changes the modes set up within a cavity, it does demonstrate the importance of correct field analysis and subsequent placement of the load in the microwave cavity.

1.7.4 Oven size

The number of modes established within a cavity increase with cavity size, and generally the uniformity of heating increases with the number of modes (Metaxas & Meredith, 1988). One study (Perch & Schubert, 1995) observed the magnitude of energy absorbed into varying volumes of water placed within a range of multimode cavity sizes. The study showed that larger cavity volume generally resulted in a higher level of energy absorption. However this would likely be due to higher levels of reflection from the cavity walls in the smaller sizes, which could be reduced or eliminated with the inclusion of a tuner or an impedance matched system.

1.7.5 Product displacement

The movement of the workload during processing is one of the most simple and effective methods of improving heating uniformity. This movement effectively ‘blurs’ the field heating patterns as it is displaced through microwave field.
Common methods used are turntables (as used in domestic microwave ovens) and conveyor systems.

1.7.6 Mode stirring

Mode stirring is achieved via a rotating steel blade assembly inside the microwave cavity. The movement of the assembly is intended to disperse and vary the modes set up within the cavity, thereby improving the heating uniformity. While it has been demonstrated that mode stirrers do change, and potentially improve the modes within a cavity (Bradshaw *et al.,* 1997), this change may not be significant enough to effectively improve heating homogeneity.

1.1.7 Microwave feed geometries

The number, position and orientation of microwave feed ports in to the cavity all effect the number and type of modes established. Multiple port feeding is performed with the intent to increase the number of modes resonant within the cavity and thereby increase heating uniformity. Quantifying this increase in modes and uniformity is difficult. Simulation techniques provide the best way to optimize feed arrangements (Fu & Metaxas, 1994).

1.7.8 Heat and moisture transfer

The vast majority of advantages of microwave heating in terms of product quality are either related to the reduced processing time, reduced temperatures, or the temperature distribution. The transfer of both heat and moisture within the food product affect all of these factors. More specifically; properties such as density, specific heat, thermal conductivity as well as cavity conditions, determine how heat and moisture are transported within the product and therefore its time-temperature history. Here some of the issues associated with heat and moisture transport that are relevant to microwave blanching are briefly discussed.

Dielectric properties of foods vary with temperature. As mentioned previously, in some situations this can lead to either an increase or decrease in heating homogeneity. If dielectric loss increases with temperature, this often results in increase energy dissipation into heat known as thermal runaway. If the dielectric loss is reduced with temperature, the cooler areas of the food are preferentially heated leading to an inherently more even product temperature.

In foods with a high percentage of water such as vegetables, the temperatures achieved during blanching only slightly exceed the boiling temperature for water. Therefore even if thermal runaway occurs the temperature differential is limited (Datta & Anantheswaran, 2001).

The temperature rise of heated products can be used to estimate the local electric field over short periods of time where heat diffusion can be neglected. This is given in equation below.

$$E_{rms} = \sqrt{\frac{\rho c_p}{2\Pi f \varepsilon_0 \varepsilon''_{eff}} \frac{\partial T}{\partial t}}$$

Where:

	E_{rms}	= electric field strength (V/m);
	ρ	= Material density (kg/m^3);
	c_p	= Product specific heat (kJ/kgK);
	ε_0	= Permittivity of free space;
	ε''_{eff}	= Dielectric loss factor;
	f	= Frequency (Hz); and
	T	= Temperature (°C).

1.8 Materials handling

Controlling the flow of bulk materials in any application warrants thorough calculation and design. Bulk solid flow on a continuous basis through a processing vessel with the addition of water further complicates the scenario.

Continuous process flow can be achieved by many different methods. The most common method used in the food industry is simple conveyor transport. Conveyor transports for continuous blanching processes have been in existence for many years. Guthier (1944) patented a continuous steam blancher based on conveyor belt transportation. More recently a continuous food heating apparatus design using microwaves was patented that used conveyor transport (Koch, 1990). This design required food to be pre-packaged and then continuously fed under sensors and direct microwave inputs. While conveyor belt transport avoids the design challenge of requiring slip between the product and the conveying medium, it only moves the workload in one direction at any one time. This one dimensional flow, while providing some improvement to the heating uniformity from microwave energy, does not utilise this feature as well as displacement through 2 or 3 dimensions.

Some improvements can be made to conveyor systems to increase product flow randomisation. Conveyor feeds built to include fall sections or tumbling sections (Ledet and Johnson, 1995) create potential movement in three dimensions during transport. This movement increases the uniformity achievable via microwave and steam heating.

An alternative method of continuous processing is the rotary drum technique. This involves a cylindrical rotating drum which is mounted on an angle. Product is fed in one end, the drum rotation causes slipping and thus forward movement of the workload through the cylinder and out the discharge end. This technique is much less widely used in heating applications, but there are examples of barrel style pasteurisers (Jwala Engineering, 2008) and barrel blanching systems (Jwala Engineering, 2008). More common in barrel style processors are continuous vegetable washing systems (Tong Peal, 2008). Rotary style systems rely on the workload sliding, tumbling or falling from the barrel surface, this can potentially be a significant design hurdle, especially when the workload is wet and includes small pieces such as carrot or corn. Water can create a suction effect between the barrel wall and the vegetable. To avoid such processing complications, rotary designs often employ low friction textured linings and internal baffles to encourage and control flow. Rotary systems potentially provide a very high level of mixing and 3 dimensional flow, leading to inherently uniform microwave heating.

Other potential conveying methods include pressurised vessel processing, in liquid (Goldhahn, 1983) or mechanical augur conveying. However, these two methods cause a reduction in product quality due to nutrient leaching and mechanical damage respectively.

1.9 Microwave safety

An industrial microwave applicator requires a method of loading and/or unloading the workload. Applicators may also require other openings such as rotating joints, vapour removal ducting or other mechanical attachment points. Any of these parts create potential areas for microwave leakage. Through microwave engineering design, choking sections are created to reduce microwave leakage at these points to within Australian standards. This can be achieved via correctly dimensioned tube sections, metal to metal contact, or active choking sections with quarter wavelength dimensions or lossy material placement.

Microwave radiation has no effect on the body other than normal consequences due to momentary heating (Meredith, 1998, Willert-Porada, 2006), however it is important to minimise or eliminate radiation leakage levels to comply with international and Australian Standards.

The IEC: 2002 60519-6 requires that the radiation from a microwave system must meet the safety standards at various extreme conditions of load and no load. These are:

- Normal Operation with load
- Abnormal Operation (doors open) with load
- Abnormal Operation (doors open) without load.

Radiation can be measured using authorised handheld devices while permanent sensors can monitor radiation levels on a continuous basis and be interlocked with the control system, ensuring ongoing safety and protection of staff.

The microwave leakage at any point 50mm or more from the external surface of the appliance shall not exceed 50W/m2 (5mW/cm2), TI: AS/NZ 60335.2.25 (AS/NZ 3350.2.25).

In a situation where access is required the following criteria must be adhered to.
If a door or cover is removed allowing microwave levels to exceed specified values, at least two interlocks per opening must be used to stop microwave operation. At least one interlock must be concealed to prevent direct physical over ride. Operation must be stopped in the case of a mechanical or electrical interlock failure. (IEC 60519-6: 2002)

1.10 Implementation costs

The costs to implement a microwave blanching system are currently higher than a conventional steam blanching system which approximately costs US$ 500K for a 10 Tons/h unit.
It is expected this gap will decrease as microwave systems become more popular due to their faster processing time, less energy requirements leading to a smaller carbon footprint, less water usage, and a final product with superior texture and nutrient contents. All these advantages will contribute to offset the higher initial implementation costs required by the microwave blanching system.

The overall objective of this project is to explore the potential of HPMH technology to effectively pasteurise vegetable and related products with minimal damage to the vegetable tissue and matrix (close to fresh as possible). The technology will primarily be evaluated to process vegetable products for entry into the chilled market. The technology may be explored to replace the existing steam blanching process for manufacture of frozen product.

This project is composed of two main sections:

- Section 1: Laboratory and prototype development and validation phase and

- Section 2: Scale-up development and validation phase

Section 1, the only section sponsored by HAL, was composed of two key stages:

- Stage I - Laboratory development work and

- Stage II - Prototype development and validation

Materials and methods, results and discussion for both stages are outlined in the proceeding sections of this report.

Development of a new blanching technology for vegetables

Stage I - Laboratory development work

2 MATERIALS & METHODS

Four phases of trials were undertaken during stage I of this project. These trials endeavoured to establish approximate processing parameters from which a conceptual design could be produced. The aim of the trials was to determine the effects of temperature, ramp time and dwell time on the inactivation and texture of the vegetables.

In phases 1 to 3 of the initial trials, the uniformity of heating was not the primary concern, rather, the trials focussed on the level of enzyme activity and vegetable quality at the location of the temperature probe for each sample. This emphasis in the method produced accurate and repeatable results since the temperature was known for the individual section of interest in the vegetable. Sensory ratings given in the first three phases of trials were to act only as a guide in development not as conclusive results, whereas the textural and sound tests performed on the fourth phase samples provided more accurate results. In the fourth phase, greater heating uniformity was required for technical analysis, but temperature monitoring and control were less critical. This section presents and analyses the results from these trials.

2.1 Sample preparation

Corn kernels, carrot sticks (Julienne style, 6x10x75 mm) and broccolis (40-50 mm diameter and 50-60 mm length) were used in section 1, stage I and II, of this project. Vegetables were locally sourced in Wollongong (NSW) and cut to specification one day prior to the microwave blanching process. Controls were either raw vegetable or Simplot's steam-only blanched vegetables processed as per manufacturing guidelines.

During phases 1 to 3 only one vegetable piece could be appropriately processed at time. This limitation was mainly due to the large variation in the electromagnetic field caused by the stationary mode applicator. In phase 4 a rotational system was developed and a substantially larger batch size of approximately 300g was processed.

A small but acceptable variation in vegetable quality is expected in section 2 (non-sponsored by HAL) when the microwave blancher prototype will be transferred to one of Simplot's processing plants, possibly in another state. Minor adjustments will occur as necessary to ensure the same level of enzyme inactivation and product quality are comparable to the results in section 1 of VG07177.

The majority of the experimental work carried out in stage I and II were of qualitative nature where assessors informally scored the microwave treated samples against control (raw and untreated vegetable). The quantitative texture measurements were performed using a texture analyser (Lloyd Instrument, model NEXYGEN MT with 2.5 KN load cell and sound analyser program). Unless otherwise stated experiments were carried out at least in triplicates with the averages and standard deviations calculated and plotted accordingly in the results section of each stage.

2.2 Test apparatus

The test equipment used to conduct trials on vegetable products is shown below in a schematic diagram. The apparatus comprises the following main components.

- Generator
- Circulator
- Directional coupler
- Tuner
- Simgle mode applictor

The experimental equipment consists of a number of components in series with each other. The first and most important is the generator containing the power supply and magnetron, this device provides microwave power output levels of between 0–30kW at a frequency of 922MHz. Power is then transmitted to each device via hollow rectangular tubing called waveguide.

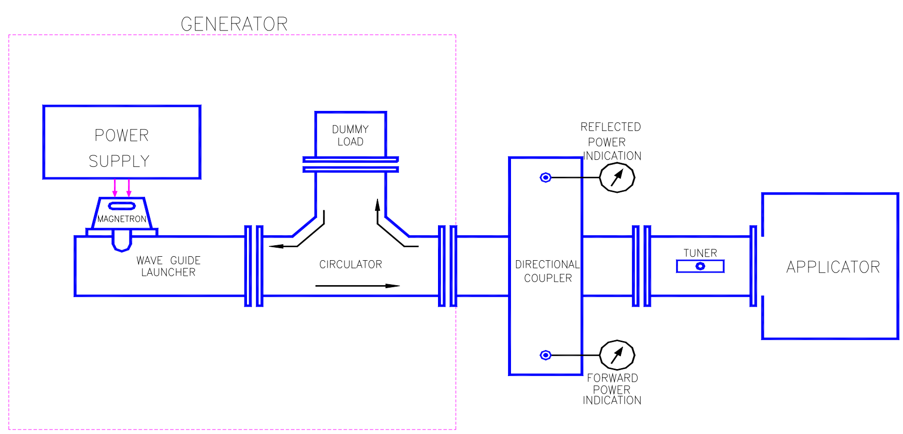


Figure 2.1: Schematic Diagram of the Microwave Test Apparatus.

If we follow the flow of power from the magnetron, the next component is the circulator, which eliminates problems associated with microwave applicators that are prone to reflected energy (i.e. empty cavity). If allowed back to the launcher the reflected energy can be reabsorbed by the magnetron causing premature ageing and hence device failure. A circulator is placed directly after the magnetron. The circulator acts as a one-way valve allowing energy to pass from the magnetron to the rest of the circuit but prevents any reflected energy from being returned to the magnetron. The reflected energy is directed into the dummy load and is dissipated into a constant flow of water.

The circulator is followed by a directional coupler, which enables the measurement of the forward and reflected powers at that point. The difference being the net power to the remaining circuit components. The directional coupler samples a portion of the power in each direction, this is then measured and the power determined from the "coupling factor".

The next device in series is the tuner. This allows a wide range of varying load/applicator impedances to be matched to the microwave network. Reflected power is due to impedance mismatches and the tuner acts as a matching element allowing an impedance transformation to take place, thus reducing the reflected power and improving the net power transfer to the applicator/load. The tuner consists of shorting stubs mounted on the wave guide, which when varied affect both the series and parallel reactance.

2.2.1 Applicators

Following the tuner is the applicator containing the load. For the initial 3 trials on the vegetables a single mode applicator was fabricated. This applicator had the following features:

- easy access, quick release door, with viewing holes;
- moveable choke design to allow maximum coupling into the product;
- adjustable polyethylene turntable; and a
- tapered waveguide to spread the electric field, and allow larger sample sizes.

The figure below shows the design of this equipment:

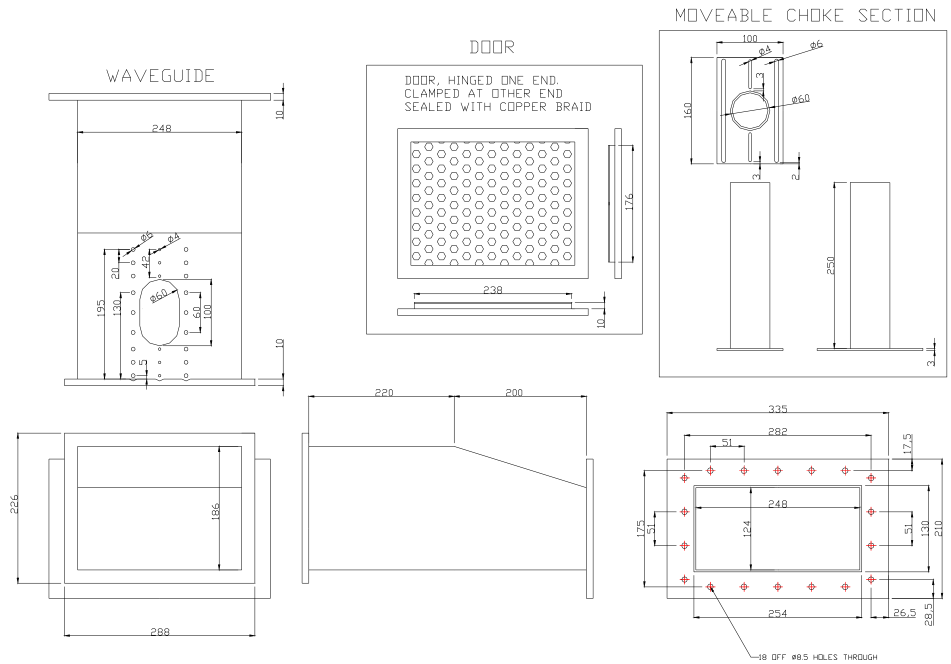


Figure 2.2: Single mode applicator design

The following image shows the fabricated applicator.

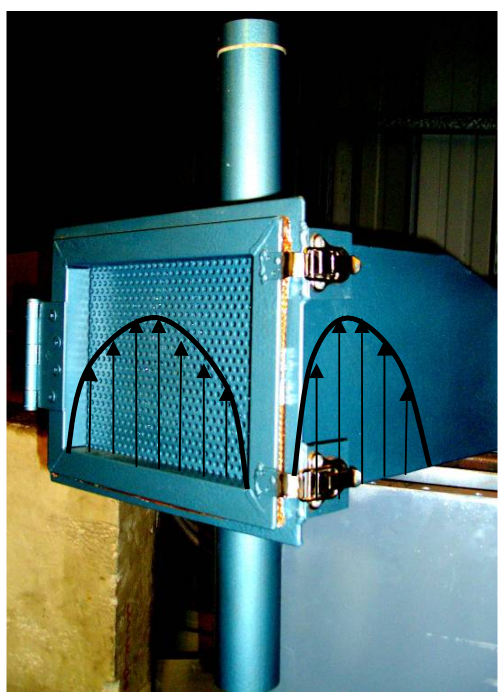


Figure 2.3: Single mode applicator

This applicator is a single mode style, meaning that only one set of field patterns occur in the empty cavity. Using a single mode applicator means the variation of electric field is known. The arrows in figure 2.3 indicate the variation in electric field strength along the plane on which they lie. That is the peak electric field strength occurs in the centre of the front face and ¼ of a wavelength back along the waveguide. By positioning the workload strategically within the cavity, the rate of energy absorption can be controlled.

The fourth phase of trials used a multimode applicator. The electric field patterns within multimode applicators are very difficult to predict, but can provide a reasonably uniform field if the dimensions are suitably chosen. This applicator included a rotating glass bowl, in which the vegetables were placed and which steam could be passed through to aid processing if necessary. This applicator is shown in the figure below.

Figure 2.4: Multimode applicator with glass bowl

In the second image of figure 2.4, the glass bowl is shown. The blue arrow indicates where steam enters the bowl and the red arrow the direction of bowl rotation.

2.2.2 Temperature measurement

During the first phase of trials, j-type thermocouples were used to measure temperature within the vegetables. These could not be placed within the microwave cavity as they would cause changes in the microwave field. During phases 2 and 3, Neoptix™ Reflex™ optic fibre temperature measurement and monitoring equipment was used. This allowed for the placement of the probes within the microwave cavity, and continuous temperature monitoring, so that exact temperature profiles were obtained.

2.3 Phase 1 - Initial microwave trials

The first phase of trials was used to establish rough parameters from which the later trials would be shaped. This phase included testing varying positions and orientation within the cavity, amounts of the product in the cavity for each vegetable, initial vegetable sizing and cut plane orientation for peroxidase testing.

2.3.1 Objectives

The objectives of the first phase of trials were:

- To establish initial method,
- determine approximate parameters for future trials, and
- briefly compare microwave blanching effectiveness with conventional methods.

2.3.2 Method

Phase 1 trial method:

(i) Microwave heating (in single mode 922 MHz applicator),
(ii) Temperature measurement (post microwave heating),
(iii) Hold/dwell period in 100°C oven, 90°C water bath, or via application of steam,
(iv) 30 second quench in cold water,

(v) Peroxidase activity testing using a modified version of the Bergmeyer (1974) method where the rate of decomposition of hydrogen peroxide, with guaiacol as hydrogen donor, is determined by the degree of colour development in a given time,

(vi) Photo taken to record colour of sample.

2.4 Phase 2 - Intermediate trials

The second phase of testing was used to consolidate the testing method for each of the vegetables. This would later aid in achieving consistent results in the third testing phase. Continuous temperature measurement was performed using a Neoptix^{TM} optical temperature probe.

2.4.1 Objective

The main objective of the second phase of trials was

- To gain understanding of the effects of temperature, heating rate and dwell time on the inactivation of peroxidase and the texture of the vegetable.

2.4.2 Method

Phase 2 trial method:

(i) Microwave heating (in single mode 922 MHz applicator),

(ii) Temperature measurement (during microwave heating) using fibre optic temperature probe located in target vegetable piece,

(iii) Hold/dwell period at specified temperature using pulsed microwave application,

(iv) Quench in cold water,

(v) Peroxidase activity testing as described on 2.3.2 (v),

(vi) Photo taken to record colour of sample.

2.5 Phase 3 - Detailed trials

The third phase of trials was performed to obtain useful results using the refinements in method and analysis achieved during the first two phases. The emphasis of the trials shifted during this third stage. The first two stages demonstrated that the peroxidase enzyme could quickly be inactivated by microwave heating of the vegetable, but the level of inactivation required for chilled shelf stable vegetables will not be known until later in the project. Instead, the trials focussed more on the textural quality of the vegetables, with the level of inactivation as a secondary test.

2.5.1 Objectives

The objectives of the third phase of trials were:

(i) to determine the effect of temperature, heating rate and dwell time on texture and inactivation, and

(ii) to establish estimates of optimum values for each of these parameters.

2.5.2 Method

Phase 3 trial method:

1. Microwave heating (in Single mode 922MHz applicator),
2. Temperature measurement (during microwave heating) using fibre optic temperature probe located in target vegetable piece,
3. Quench in cold water,
4. 6 – 12 runs performed using steps 1 – 3 at a range of settings,
5. Sensory ratings given to each sample (Ratings given by UOW technical staff, based on tasting tests: overall rating given out of 5),
6. Group images taken of peroxidase inactivation,
7. Colour change recorded for each target sample as described on 2.3.2 (v).

2.6 Phase 4 - Trials for product evaluation

The fourth round of trials was performed in a 2.45 GHz multimode applicator and processed larger amounts of vegetables than the previous trials. Movement of the vegetables during processing, combined with a small addition of steam, created more uniform heating within the pieces.

2.6.1 Objectives

The objectives of the fourth phase of trials were:

(i) Produce higher volumes of test samples in order to perform textural and sensorial evaluations, and

(ii) Increase heating uniformity within the vegetable samples.

2.6.2 Method

Phase 4 trial methods:

(i) Microwave heating (2.45 GHz) in rotating glass vessel (Batch sizes: 100 – 400g),

(ii) Application of steam through vessel during microwave heating,

(iii) Quench in cold water,

(iv) Test selection of batch with peroxidase testing solution to confirm heating uniformity as described on 2.3.2 (v),

(v) Sensory ratings given to each sample.

3 RESULTS

3.1 Phase 1- Initial microwave trials

It was determined that for each vegetable, a narrow cylindrical (~35mm diameter) vessel filled with multiple vegetable pieces returned consistent results. In the centre of the vessel one vegetable piece was monitored for temperature and was used to test for peroxidase activity.

In the first phase of trials, photos were taken of each test sample in order to compare the results to the test parameters. The following image shows the test samples of carrots from the trials, the samples were processed at a range of settings, and the images below illustrate the range of inactivation results observed.

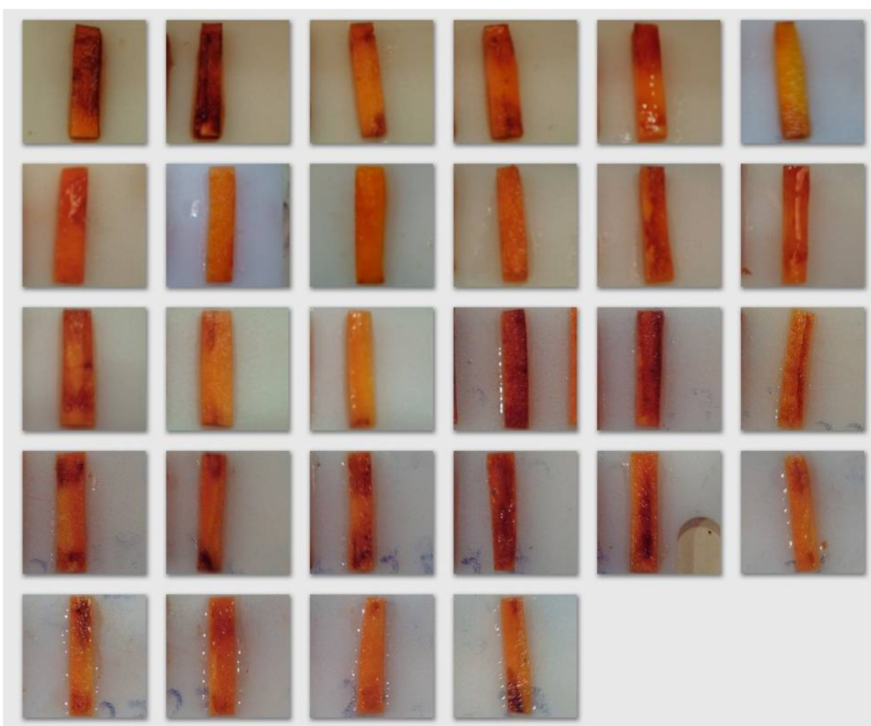


Figure 3.1: Phase 1 trials carrot peroxidase results

The images above were taken after the enzyme testing solution had been applied. The brown areas indicate areas in which complete inactivation did not occur. From these images the level of inactivation achieved in each test was given a rating out of 5. This rating system, while not highly accurate, did provide useful information from which trends could be illustrated in this early stage of work.

The figure below compares the inactivation of the enzymes within the carrot with the temperature reached. The area of interest was the carrot centres. The trials compared when microwaves were used with no dwell time, with when either water or steam was used to hold the temperature of the carrot after microwave treatment. The steam was applied at 100° C and the water bath at a temperature of approximately 90° C. The temperature along the horizontal axis in the figure shows the temperature at the end of the microwave heating (before the hold period). Conventional methods of holding the temperature had to be used during phase 1 trials because the optic fibre temperature monitoring equipment was not available and thus temperatures could not be monitored during microwave heating.

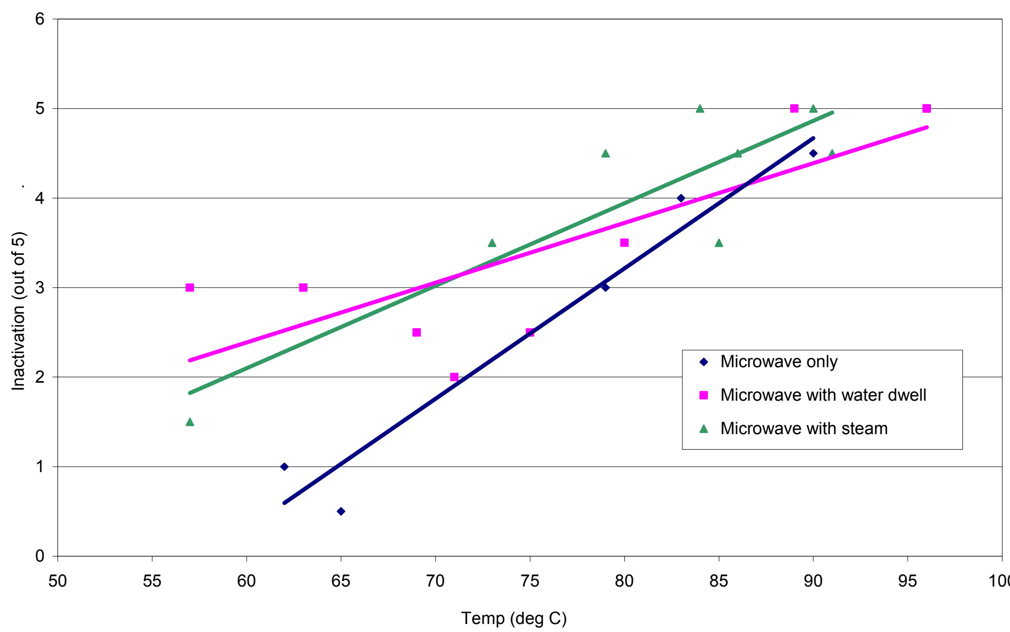


Figure 3.2 Carrot centre inactivation trends

The above figure shows the expected trend of increased inactivation with increased temperature. Initial inspection of the data suggests that inactivation is aided by holding the temperature after microwave processing, but as the temperature reached by microwave heating increased, the benefits obtained by the additional water or steam treatment reduced. This was due to the fact that at lower temperature microwave runs, the water/steam hold period would continue to raise the carrot temperature. The level of inactivation at around the 90° C mark are approximately even, suggesting that, in fact, the hold period may only help because it allows for the low temperature regions of the product to equilibrate with the higher temperature regions, improving the inactivation.

The results from the broccoli and corn displayed similar results, however the data from these vegetables was more scattered, and hence displayed the trends less clearly. During these trials the vegetable temperature was measured at the end of the microwave treatment and after the dwell period. The large scatter in the results highlights the inherent inaccuracies with this technique. Thus for the subsequent trials, continuous temperature measurement was employed. Despite this scatter in the results, this initial phase successfully provided the processing parameters and setup from which the next two phases were based.

3.2 Phase 2 - Intermediate trials

The Neoptix™ temperature measurement equipment allowed for continuous monitoring of the sample temperature during microwave processing. This information feedback meant that the entire heating process (temperature ramp and dwell time) could be performed using microwave energy, replacing the conventional dwell methods used in phase 1, and meant the exact temperature profile within the centre of the sample could be recorded.

Through an iterative experimentation process, appropriate vegetable sizing, location within the cavity and probe location were determined for corn, carrot and broccoli. The Neoptix™ equipment logged the temperature within the product over the heating and cooling period. This data allows for more detailed analysis of heating profile and the effect this has on inactivation of enzymes. This analysis was performed in the third phase of trials. Two sample curves on corn from this phase of trials are shown below. Next to the curve is the correlating image of the sample after application of the enzyme testing solutions. The brown areas in the image indicate where the peroxidase enzyme was not inactivated completely.

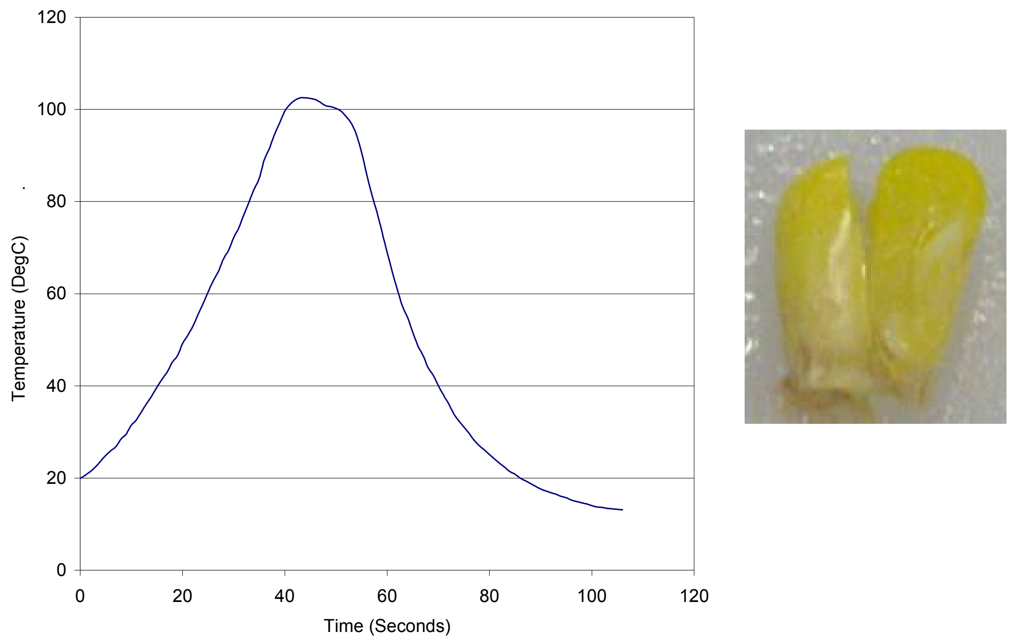


Figure 3.3: Temperature contour and peroxidase image, corn trial # 8

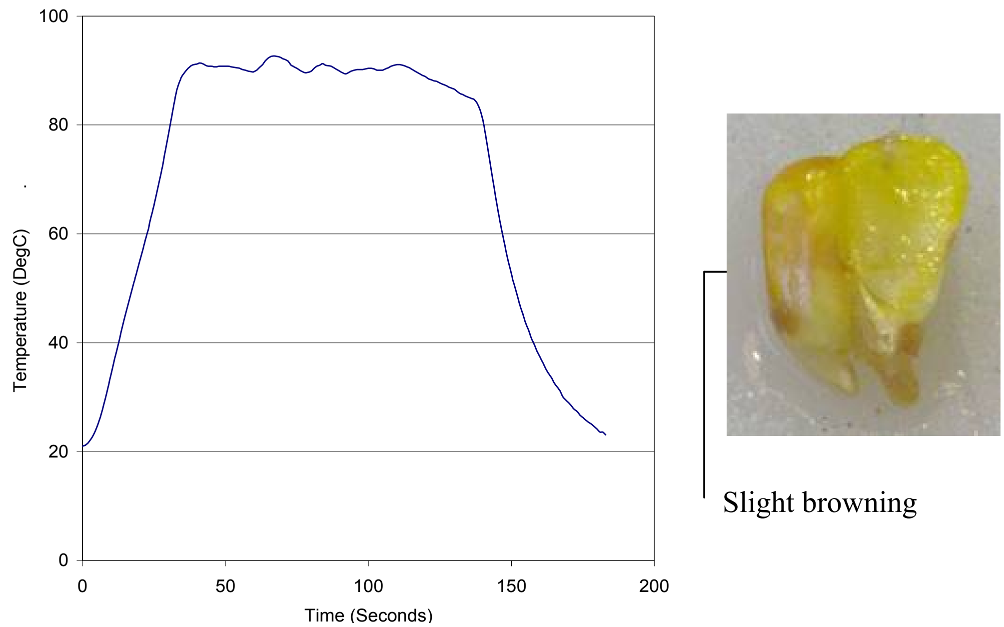


Figure 3.4: Temperature contour and peroxidase image, corn trial # 16

Figure 3.3 is from a test run to 100° C with no dwell. The image of the corn shows no visible brown, indicating that close to 100% peroxidase inactivation was achieved. Figure 3.4 shows the profile of a test run to around 90° C with a 90 second hold period in the microwave cavity. The temperature holding during these tests was achieved by pulsing the microwaves at the required rate to maintain temperature. The image above shows that this run produced only slight browning on one part of the shell of the corn kernel. The inside of the kernel (the half on the right of the image) indicates no peroxidase activity.

The phase 2 trials successfully allowed the refinement of the testing procedure and parameters for each vegetable. The use of the Neoptix™ probe returned consistent results and allowed for accurate measurement of the temperature at a specific location within the vegetable sample.

3.3 Phase 3 – Detailed trials

The third phase of trials provided useful information on the effects of ramp time and dwell time on the textural quality of the vegetable. It was found that no dwell period was required to successfully inactivate enzymes within the vegetables. The trials indicated that reducing time at elevated temperatures increased textural quality while not necessarily reducing the level of inactivation achieved. In order to take both processing time and temperature into a single analysis of the results, the area under the temperature profile for each microwave run was calculated. The figure below shows the relationship between the area under the time temperature curve and the textural quality for the carrots.

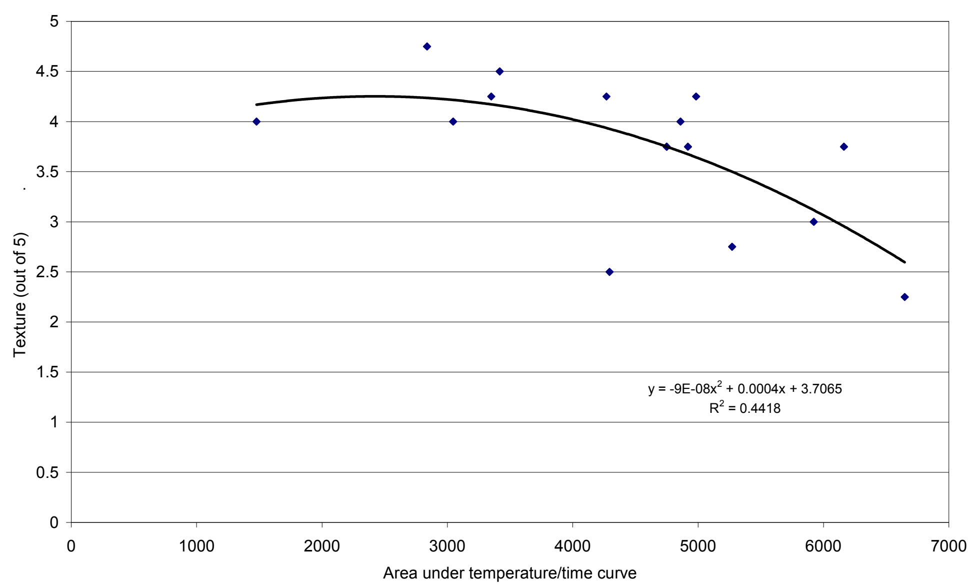


Figure 3.5: Sensory test versus curve area (Carrots)

The curve indicates that as the area under the time/temp curve increases the texture decreases. The coefficient of determination (R^2) for the curve of best fit was 0.44. The broccoli curve of best fit had a similar coefficient of 0.46 but the corn data a near perfect correlation of 0.99. The curves showed a closer correlation than when only maximum temperature or ramp times were compared with texture. This indicated that both these variables affect texture and that combining them by calculating the area under the curve, provides a single useful analysis. Each of these curves indicated that minimising ramp time and temperature improved the texture.

The key results from this stage of work were:

- no dwell time is required to inactivate, when microwave heating is employed, and
- minimising area under the time/temp curve improves textural quality, achieved by:
    - reducing ramp time, and
    - processing to minimum temperature required for each vegetable.

Based on the curves obtained from the trials, the following table provides estimates for optimum temperature and ramp times for each vegetable.

Table 3.1: Estimated optimum parameters

	Carrots	**Corn**	**Broccoli**
Optimum temperature	77° C	77° C	72° C
Optimum ramp time	15 sec	32 sec	< 30 sec

While these results provided the information necessary to begin work on the next stage applicator, another series of trials was performed to achieve higher volumes of vegetable and more even product, from which more detailed texture and sensory analysis work could be performed. This was achieved in the fourth phase of trials

3.4 Phase 4 – Trials for product evaluation

This phase of trials successfully produced evenly heated vegetables with high levels of peroxidase inactivation and reasonable textural quality. Batch sizes ranged from 100 to

400 grams. The glass bowl containing the vegetables was rotated, providing a randomised mixing action creating evenly heated batches. Steam was used in some trials during this phase of testing in order to raise the level of surface inactivation.

The textural rating given to each sample from these trials returned the most consistent results from any of the trials to date. These results gave good insight into the behaviour of the vegetable quality with respect to the amount of microwave energy and steam used. The amount of microwave time and steam time were graphed against the textural rating given to the sample.

The gradients of the curves give indication of the sensitivity of the vegetables to the textural degradation via microwaves or steam. The net energy of the steam used in these trials was not known and hence the microwave gradient cannot be compared directly to the steam gradient. The results do, however, allow comparison of degradation rates between vegetables. The table below summarises these results:

Table 3.2: Texture gradient analysis

	Carrots	Corn	Broccoli	Sensitivity
Microwave time vs. texture gradient	-0.07	-0.02	-0.09	Broccoli: High Carrots: Medium Corn: Low
Steam time vs. texture Gradient	-0.05	-0.04	-0.06	Broccoli: Medium Carrots: Medium Corn: Medium - Low

Note: The sensitivity ratings can only be compared between vegetables, not between microwave and steam, as the energy applied by each is not equivalent.

The heating due to the steam was minimal compared with that due to microwaves, so if equivalent energy was used with steam, much higher textural degradation would have been observed (discussed in 3.4.1). Table 3.2 indicates that microwave heating degrades the textural quality of broccoli the greatest, followed by carrots, but that the corn textural quality was not affected greatly by the microwave heating. Broccoli also showed the highest sensitivity to steam treatment but carrot and corn texture loss were of similar values. This analysis highlights the sensitivity of broccoli to heat treatment and shows the need to find the optimum temperature level in the next stage of development that will, for each vegetable, provide an adequate compromise between enzyme inactivation and textural quality.

3.4.1 Trials for product evaluation

Trials were performed during this phase to obtain larger samples of blanched vegetables, so that textural evaluations could be performed. Two sample types for each vegetable were evaluated:

- a sample with peroxidase inactivation similar to that achieved in the Devonport factory (equivalent inactivation), and
- a sample with peroxidase inactivation approaching 100% (high inactivation).

Test runs were performed with each vegetable to determine what process time would produce the appropriate inactivation level. The process powers and times are shown in the table below.

Table 3.3: Process settings for samples

	Batch size (g)	Microwave Power (kW)	Microwave Time (secs)	Steam Time (secs)
Carrot (equivalent inactivation)	200	0.9	20	20
Carrot (high inactivation)	200	0.9	30	30
Broccoli (equivalent inactivation)	300	1.8	20	20
Broccoli (equivalent inactivation)	300	1.8	27	27
Corn (equivalent inactivation)	200	0.9	20	20
Corn (high inactivation)	200	0.9	25	25

During the early parts of these trials the machine which was supplying steam to the system experienced failure, necessitating the acquisition of another steam source. This process shortened the time in which the trials had to be performed. The second machine that was sourced also provided higher levels of steam. After analysis of the trial results, it became evident that this increase in steam volume substantially reduced the textural quality of the blanched vegetables. This is indicated in the following figures for carrots.

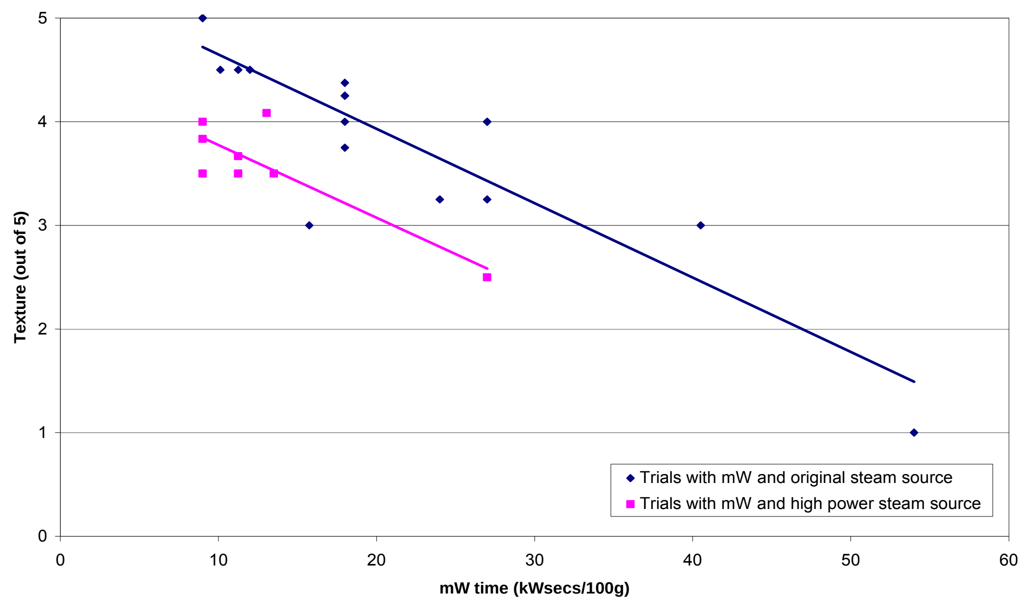


Figure 3.6: Microwave time versus texture (Carrots, steam comparison)

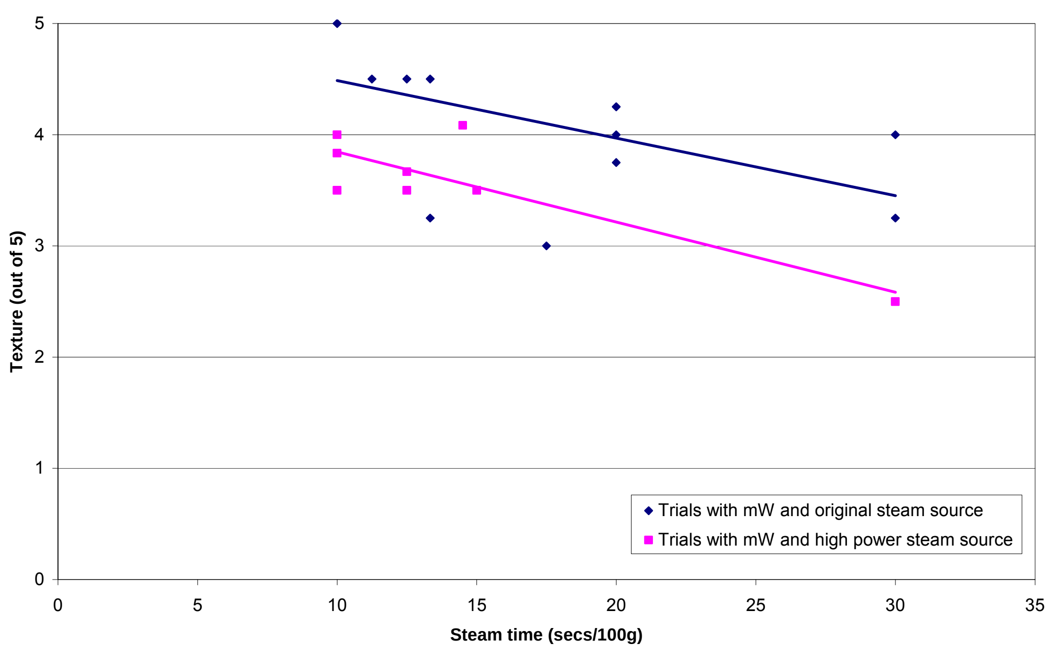


Figure 3.7: Steam time versus texture (Carrots, steam comparison)

The figures above illustrate that with the higher steam power the textural quality of the previous trials was not maintained. These high powered steam trials did not dramatically increase the inactivation rate of the peroxidase. While this result was not the ideal scenario product textural quality, it does indicate again the ability of microwave processing to achieve superior texture than steam blanching. Optimisation of the balance between steam and microwave power would largely occur during the second stage of work once the prototype, continuous system was built.

3.4.2 Product evaluation results and discussion

Results from textural and sound tests on the samples from this phase of trials are outlined in the figures below. The use of the Lloyd texture analyser to quantify the force and sound generated when samples are penetrated by the blade fork allows for an unbiased measurement of their toughness and crunchiness.

In summary, five carrot sticks (or five broccoli pieces or 100g of corn kernels) were positioned immediately below the five blades fork. Sound/frequency (Hz) and force (KN) were recorded as soon as the blades contacted the sample's surface until penetration was complete.

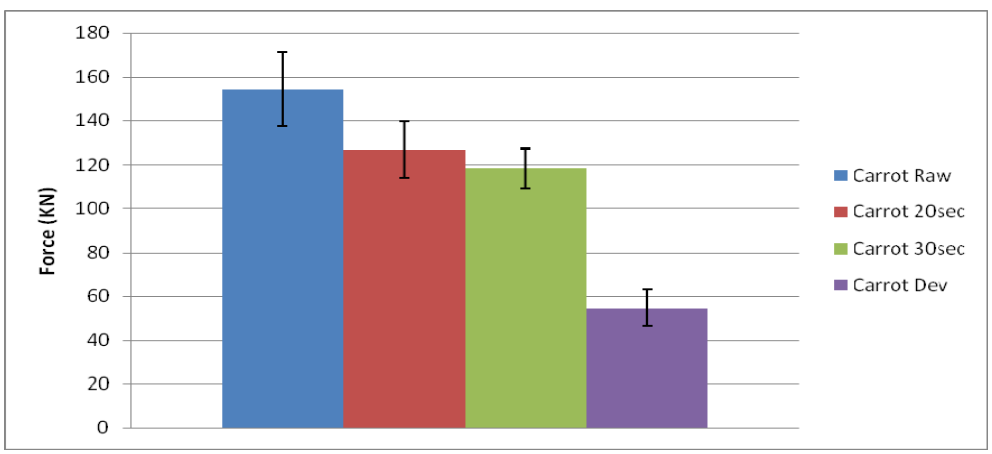


Figure 3.8: Julienne carrots: force test

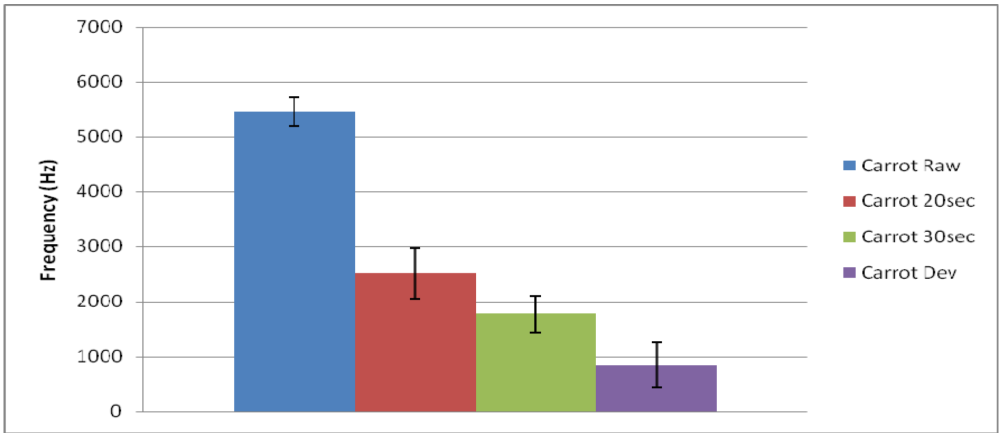


Figure 3.9: Julienne carrots: sound test

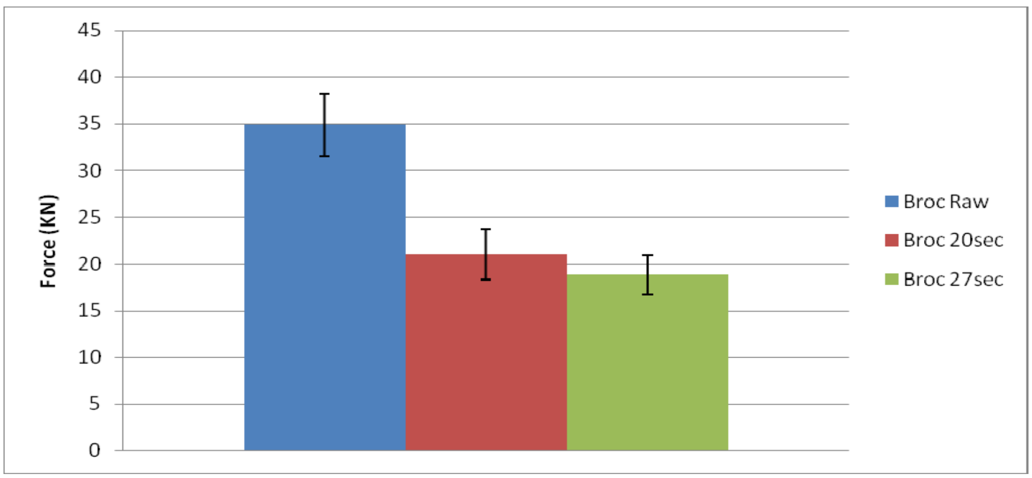


Figure 3.10: Broccoli: force test

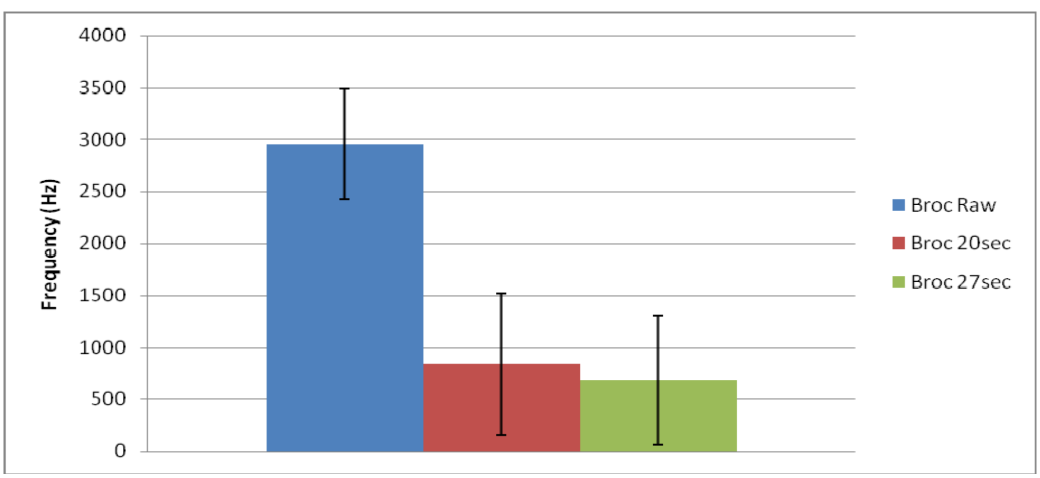


Figure 3.11: Broccoli: sound test

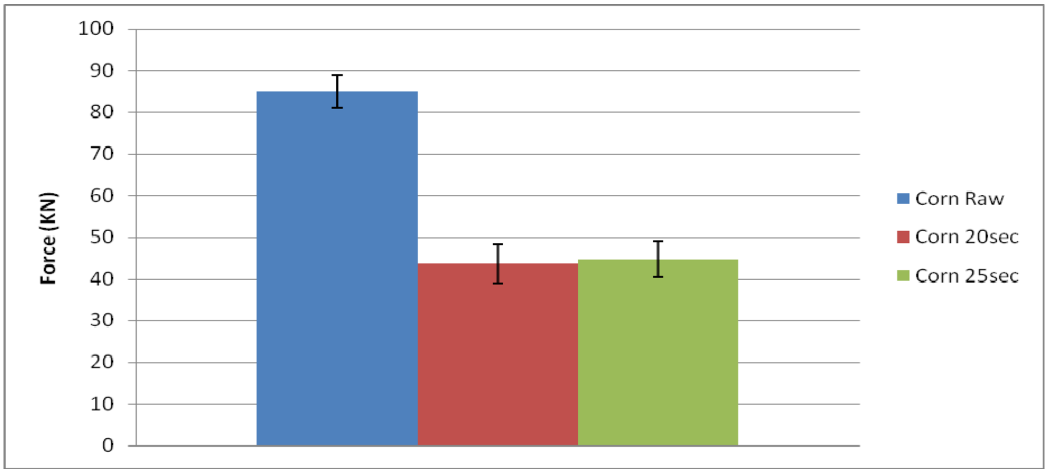


Figure 3.12: Corn: force test

The figures above illustrate the reduction in quality occurring due to the heating process. All of the vegetables show reduction in force and sound tests after processing. Unfortunately, only the carrots from Devonport were available for comparison of the two processes. Figures 3.8 and 3.9 show that the microwave blanched samples maintained at least double the textural quality of the steam blanched samples. This result is particularly positive considering that higher quality tests than the samples sent to Melbourne are easily achievable (see Figures 3.6 and 3.7). The broccoli and corn both also showed reduction in quality compared with the unprocessed product. Corn sound results were very low and unreliable and for these reasons are not presented here.

The sensory evaluation also returned positive results. The group overall preferred the processed corn and broccoli flavour, appearance, and quality over the unprocessed samples. The overall quality and flavour of the carrots had divided opinion in the group. With all three of the vegetables, the crispness and crunchiness of the processed vegetables were evaluated as lower than the control samples. This result correlates with the Figures 3.8 – 3.12. The group could not identify significant quality difference between the low and highly processed vegetables indicating that higher inactivation could possibly be achieved with little further loss of textural quality.

Inactivation tests performed in Devonport returned results different from those conducted in Wollongong during the trials. This was thought to be due to possible reactivation of the peroxidase during the 5 days between processing and testing. It is possible that the current Devonport processed vegetables also experience some enzyme reactivation.

During the next stage reactivation could be reduced by increasing process time and decreasing temperature (Thongsook & Barrett, 2005). The similarity of the results between the low and highly processed samples, as mentioned above, indicates that changes to the process to reduce inactivation, may not reduce textural quality substantially.

4 DISCUSSION / CONCLUSION

The literature reviewed clearly indicates that microwave blanching of vegetables has many advantages, particularly the ability to achieve superior textural quality and increased nutrient retention.

Dielectric modelling was undertaken. The dielectric properties of the vegetables were found at both 2.45GHz and 922MHz. From this data it was shown that the penetration depths of microwave energy into the vegetables at 922MHz is adequate over the entire temperature range for all three analysed vegetables. At 2.45GHz the majority of the incident energy would be dissipated in the first 4–8 mm of the vegetables, whereas at 922MHz the majority of incident energy is absorbed in 12–20mm. This higher penetration depth at 922MHz will lead to an inherently more uniformly heated product, and hence 922MHz is the recommended frequency for future stages of work.

Extensive microwave blanching trials were undertaken. These trials confirmed, by sensory and textural analysis, that microwave blanching returned superior quality vegetables than conventional techniques. The trials demonstrated that complete enzyme inactivation was possible using microwave energy in times between 10 and 30 seconds, and established that no dwell time was required to achieve this. Inactivation was achieved at temperatures around 80° C. It was found during trial work that a “hybrid” system which utilised microwave energy with some additional steam achieved the best quality vegetables with the most uniform heat distribution. The fourth phase of trials provided a framework from which bulk vegetables could be consistently processed and this framework will be adapted to achieve successful processing of larger throughputs in the second stage of work.

A conceptual design has been produced based on the stage I results. The design will allow for control of processing time, microwave/steam energy balance, mixing rate, feed rate and ultimately process temperature in order to optimise vegetable quality and enzyme inactivation. This level of control was not available during the successful 2.45GHz trials of stage I, where microwave power was only controllable via 25 % intervals and the steam output was fixed. Due to the high level of control in the stage 2 system, the vegetable texture, flavour and overall quality will be further improved from that achieved during stage 1.

The initial trials were largely very successful, and from them the following conclusions have been drawn regarding the microwave blanching of vegetables. Microwave blanching can provide superior textural characteristics to conventional blanched vegetables. Achieving evenly heated product is aided through displacement during processing and the use of a multimode applicator.

The addition of small amounts of steam during processing aids the process by raising surface temperatures without greatly reducing quality. However, if too much steam is used, textural degradation is increased dramatically. Heating to approximately 80° C, for each vegetable returned good textural results and significant enzyme inactivation. Temperature holding periods were not required to achieve full enzyme inactivation.
Minimising ramp times improved texture.

Development of a new blanching technology for vegetables

Stage II - Prototype development and validation

5 MATERIALS & METHODS

5.1 Materials handling testing

Thorough trials were performed with a range of equipment (conveyor and rotary), materials, loads and conditions to determine what types of conveyor, lining material and mixing types would likely succeed in microwave trials. The following points briefly outline the tests undertaken.

- Tests were performed on a range of potential lining materials. The tests recorded the angle required for the three vegetables to slide down the walls of a rotary style applicator. Two materials showed consistent low angles of slip.
- Vegetable dwell time (time product is in the device under test) tests were performed on the following equipment.
    - Vibratory feeder open converging channel,
    - Vibratory feeder closed parallel channel,
    - Unlined rotary drum at
        - A range of heights and
        - A range of rotation speeds, and
    - Rotary drum with internal helical vane at
        - A range of heights and
        - A range of rotation speeds.

The dwell time tests measured not only the overall dwell time of the vegetables through the equipment, but more importantly the consistency and range of dwell times experienced by the vegetables. Conveying methods mentioned above showed significant levels of variation and inconsistency in the dwell times. Examples of the dwell times for the vibratory feeder and drum trials are shown in the figures below.

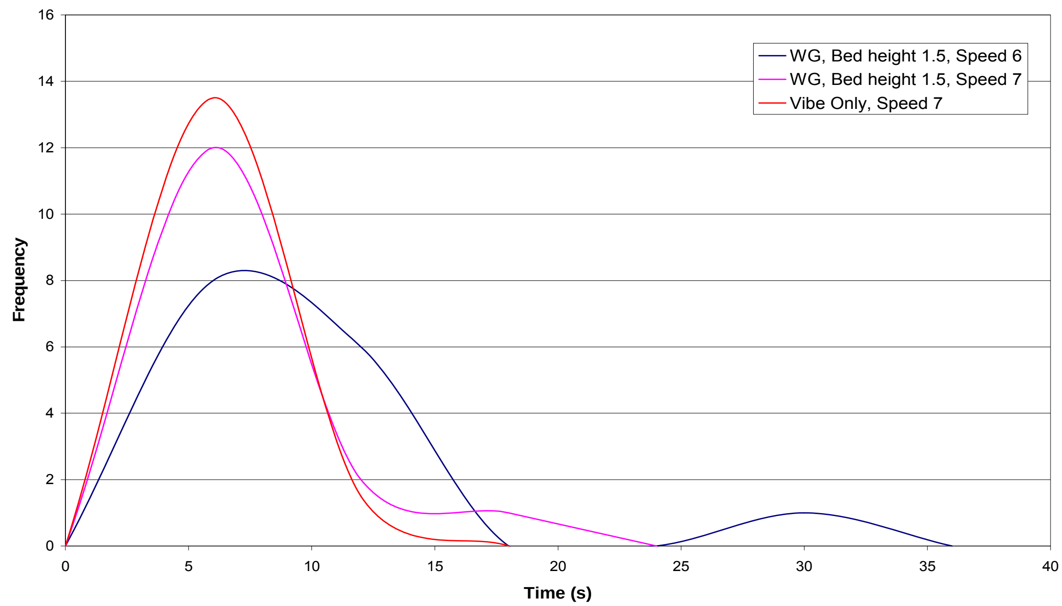


Figure 5.1: Bunching levels of carrot in vibrating applicator

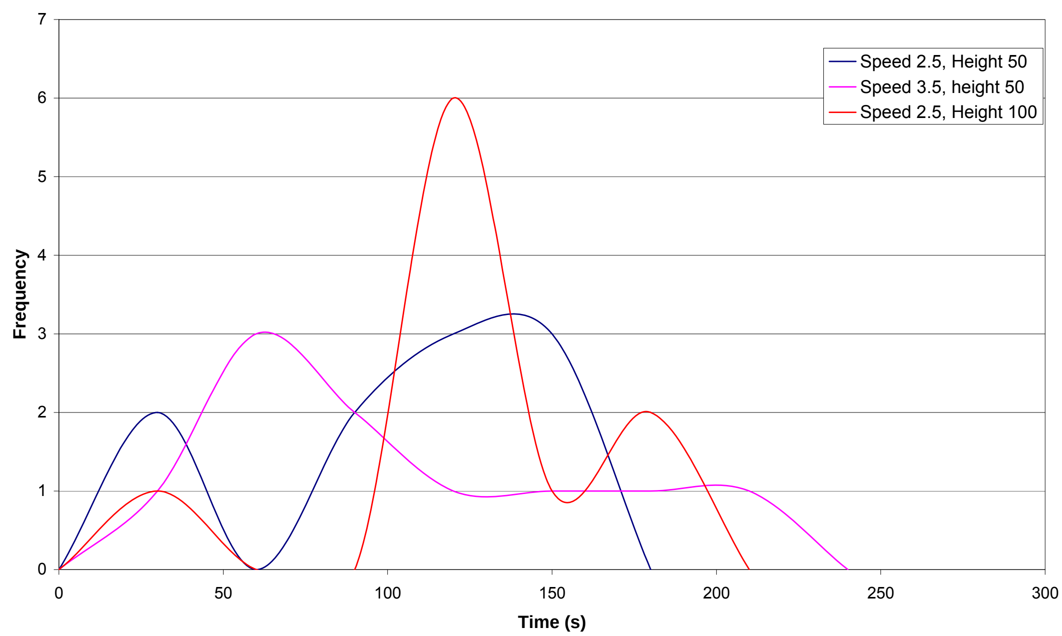


Figure 5.2: Bunching levels of broccoli in rotary drum

These graphs illustrate the high level of variation in dwell times for these styles of applicators. This means that varying amounts of microwave energy would be received by each vegetable during microwave processing thus heating the vegetables to different temperatures. Dwell test were also performed on corn in each of the pieces of test equipment and returned similar results to the graphs above. From these trials it was evident that alternate material transport would be required.

Conveyor belt transport would overcome these challenges, guaranteeing 100% consistent dwell times in the microwave chamber, but reducing the relative movement of the vegetable pieces. The following section describes microwave trials undertaken to evaluate conveyor belt system processing.

5.2 Conveyor trials

These trials were conducted to establish the capabilities of a conveyor belt microwave cavity in achieving uniform heating. The conveyor system is a very effective technique in material transport and offers many benefits. One advantage of the conveyor system is that the dwell time for each vegetable piece are 100% consistent eliminating some of the concerns described in the previous section. Conveyor belt systems also offer simplicity in equipment design, fabrication, maintenance and cleaning and are a well established form of continuous processing.

A conveyor system moves product one dimensionally through the microwave field. This theoretically leads to an evening out or 'banding' of the heating along the direction of movement. The trials described in this section sought to determine whether this movement would allow for adequate uniformity in heating, and thus be a viable option for the final blanching apparatus. This section describes the microwave blanching trials performed and explains the reasons why heating uniformity was greatly reduced using this processing method.

5.2.1 Objective

The objective of this test was to assess the ability of a conveyor running through a microwave to uniformly heat a sample of vegetables.

5.2.2 Apparatus

Figure 5.3 below shows the apparatus used to perform the microwave trials.

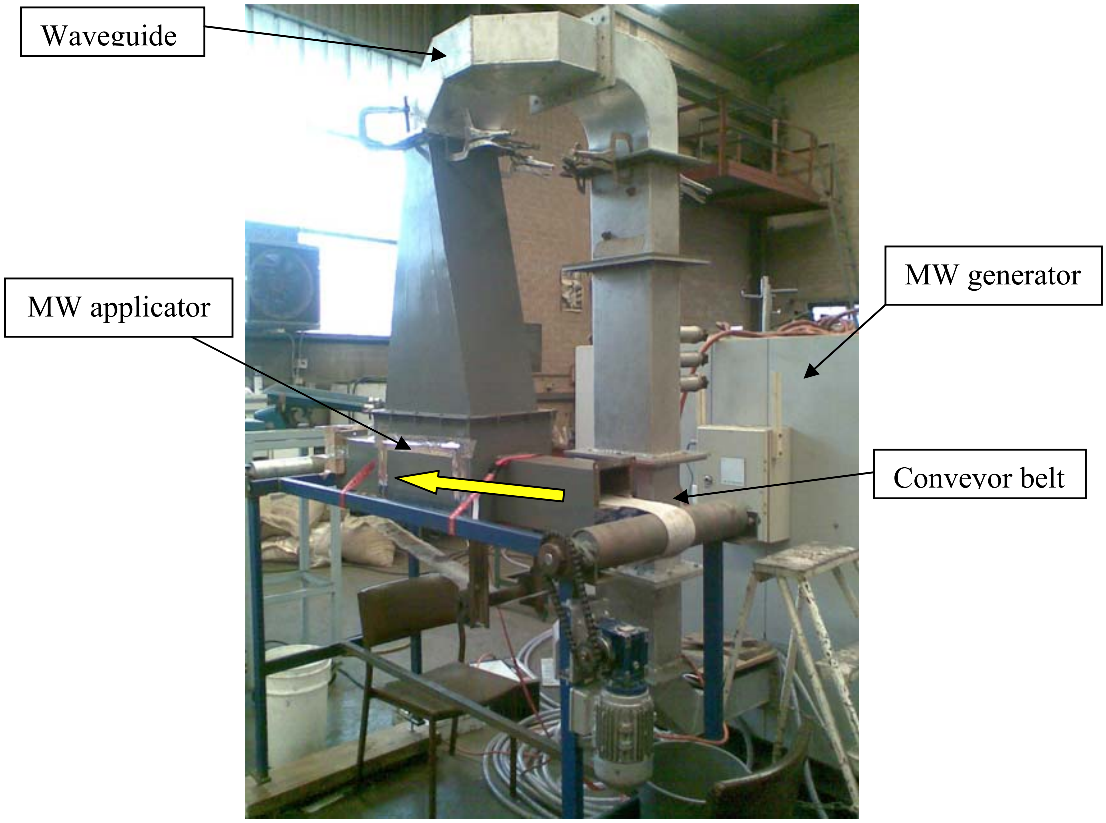


Figure 5.3 - Microwave Conveyor System

The conveyor travelled through a heating chamber approximately 500mm in length. The microwave feed into the chamber utilised a 5 way split waveguide horn. This effectively spreads the microwave field along the direction of conveyor travel whilst maintaining maximum electric field strength at the centre of the conveyor. 400mm choke sections on either side of the chamber reduced exterior radiation levels to well below Australian standards. The conveyor was driven by a motor attached to a variable speed drive (VSD) which allowed control of the conveyor speed.

5.2.3 Method

The following method was used for the microwave trials:

1. Situate a vibratory feeder above the conveyor filled with the test vegetable (with carrots and broccoli, samples were manually placed on the belt).
2. Feed sample vegetables through the cavity.
3. Quench in cold water after exiting cavity.
4. Peroxidase activity testing as described in 2.3.2 (v).

5.3 Barrel design development

To successfully heat vegetables uniformly in a microwave oven, two critical factors are:

- Thorough randomised mixing, and;
- Accurate, repeatable microwave exposure times.

The trials performed in continuous conveyor and rotary systems described in the previous sections displayed the inability of these transport styles to perform well in both these areas. This is likely the reason that large scale microwave blanching or sterilizing has never been successfully commercialised.

With this information in hand, discussions were held between University of Wollongong and Simplot personnel and it was decided that semi-continuous processing holds the greatest ability to adequately mix whilst inherently controlling microwave exposure time. This was demonstrated by the successful batch trials performed in the latter parts of Stage I work. Semi-continuous processing, when used with high quality materials handling and automation, also possesses the majority of the advantages offered by continuous processing; that is, consistent output rates, high efficiencies and minimum downtime.

Stage 2 development was aimed at achieving a prototype that can process low-medium quantities of vegetables (~20kg/hr), but in a system that can be scaled-up to through-puts matching the process requirements of the product range (~1000kg/hr per applicator). A barrel style mixing cavity which can take loads of 2 to 5kg of vegetables in a batch was adapted, redesigned and fabricated. The barrel features internal mixing arms and rotates during processing. Quick release latches can be undone immediately after processing to allow the barrel to be tipped to unload. The system is shown in the Figure 5.4.

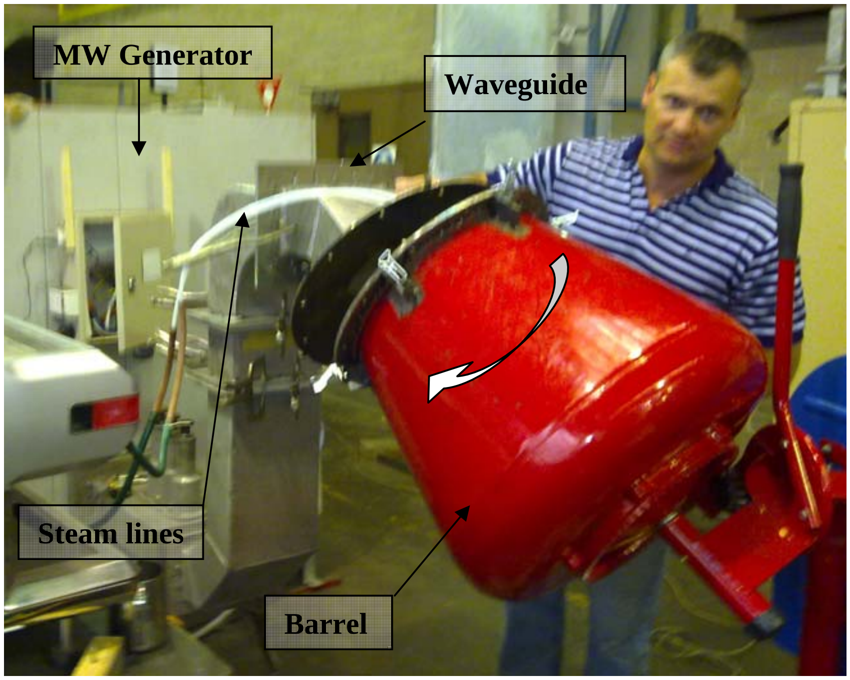


Figure 5.4: Barrel mixer applicator

A rotary sealing choke section for this applicator was designed specifically to fit this purpose. This is shown in Figure 5.5.

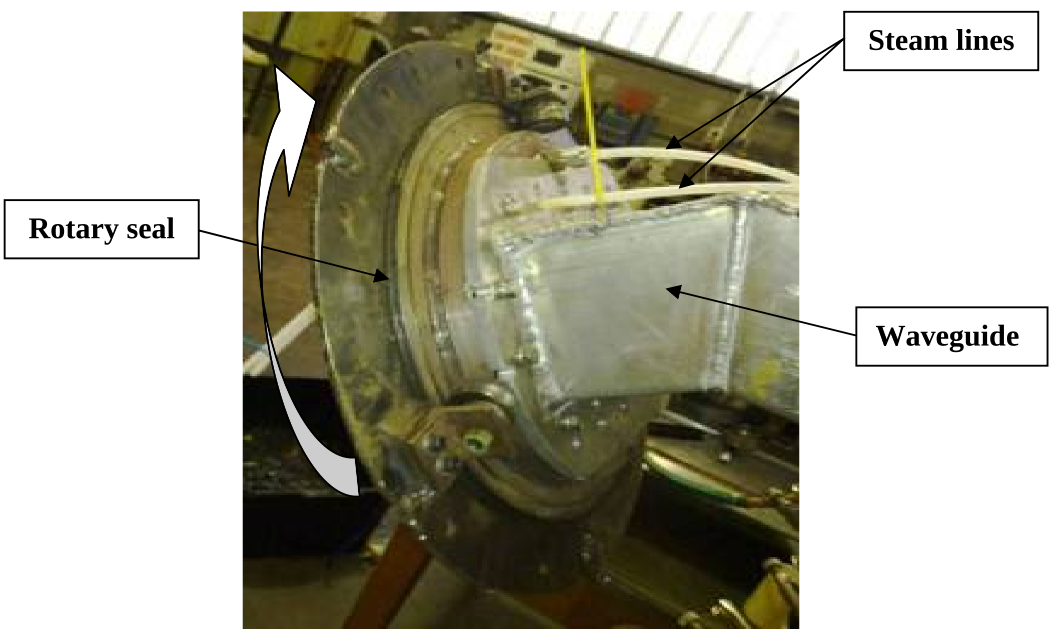


Figure 5.5: Rotary seal section

The rotary seal section allows the waveguide to attach to the rotating drum, provides a microwave seal to prevent leakage through the rotating joint and allows space to insert steam lines into the cavity.

The barrel demonstrated good mixing ability with thorough movement observed by all vegetable pieces.

Figure 5.6: Barrel internals and mixing motion

5.4 Initial barrel trials

Trials were performed to test the capabilities of the barrel. It was found that with steam insertion and up to 8 kW of microwave power, that batches of 1.5 – 2.5 kg of vegetables could be blanched in 1 to 2 minutes. Higher volumes of vegetables could be used if necessary but this would increase the blanch time and reduce textural quality. Trials were performed with broccoli, corn and carrots and results appeared similar to those observed with the glass bowl used in Stage 1 trials. From this point it was determined that a series of trials would be performed to evaluate what was needed for final official tests.

5.5 Test trials Round 1

5.5.1 Method

Trials were performed using the following steps:

1. Place 2 kg of vegetable in applicator,
2. Close applicator rotary seal,

3. Start rotation,
4. Start microwaves steam,
5. Switch off microwaves and steam at set times,
6. Release clamps,
7. Unload into iced water,
8. Rinse and,
9. Perform peroxidase analysis as per 2.3.2 (v).

5.6 Modifications

In order to improve the blanching uniformity and quality the following modifications were made to the equipment:

A second steam source was acquired to add the required steam power to efficiently blanch the outer surface of the vegetables (particularly corn).
Three of the six mixing arms were removed to improve microwave coupling into the cavity. These three arms were higher and served little purpose when processing loads under approximately 4 kg.

The inside of the cavity was lined with a non stick liner to improve mixing by reducing vegetables sticking to the walls of the cavity during processing. The liner achieved this by reducing the contact surface area between the vegetable pieces and the wall, thus reducing suction and surface tension adhering effects. A polyurethane board was added to one of the remaining mixing arms to aid the tumbling of carrots during processing. The modified drum is shown in the Figure 5.7:

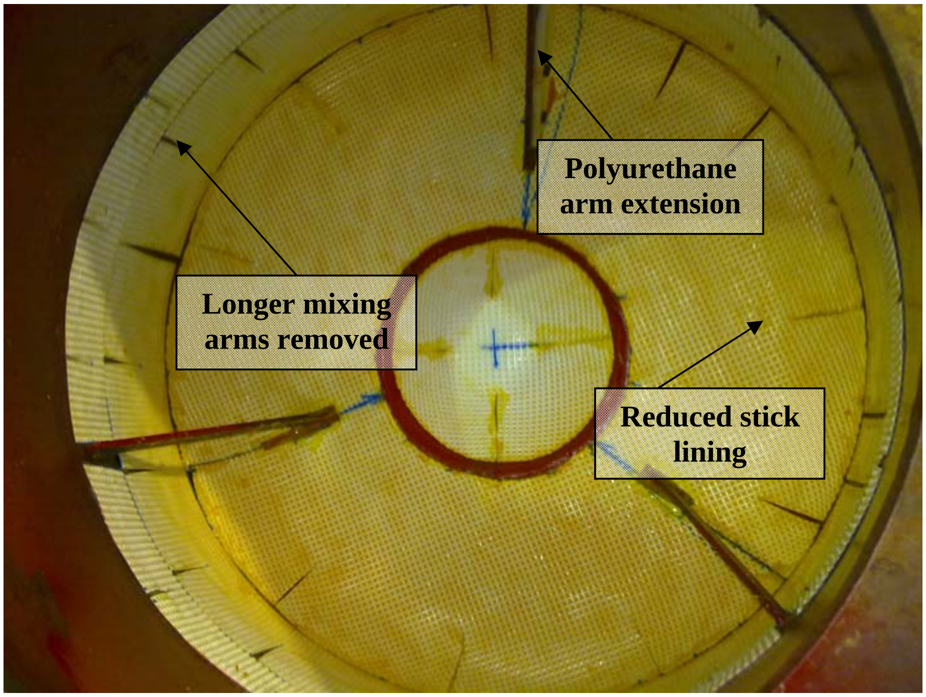


Figure 5.7: Drum modifications

The modifications to the drum improved mixing by reducing sliding and increasing microwave coupling into the cavity. The ridged lining greatly reduced "sticking" during processing. Due to this success it is recommended that subsequent equipment is fabricated using ridgidised stainless steel. Tests using the modified drum confirmed that improvements had been made in mixing uniformity. To gain further insight into the level of uniformity of heating achievable with the modified drum, inactivation tests were performed on up to 15 samples after each run. The results of these tests were encouraging, with highly consistent inactivation between samples.

5.7 Final microwave trials

A final round of trials was performed in conjunction with packaging experts (Cryovac) to evaluate the shelf life limits of the microwave blanched vegetables. Several days of trials were performed at the University of Wollongong, with approximately 45kg each of broccoli, corn and carrots being blanched and sealed in 300g containers.

In conjunction with experts from Air Liquide three modified gas mixtures to trial were determined in an attempt to extend shelf life of processed vegetables. These mixtures were packaged by Cryovac. The gas mixtures were:

- 30% CO_2, 5% O_2, 65% N_2, with pressure at or slightly above atmosphere,
- 45% CO_2, 5% O_2, 50% N_2, pressure at or slightly above atmosphere,
- ~5% O_2, vacuum packed.

Figure 5.8 shows the Cryovac machine:

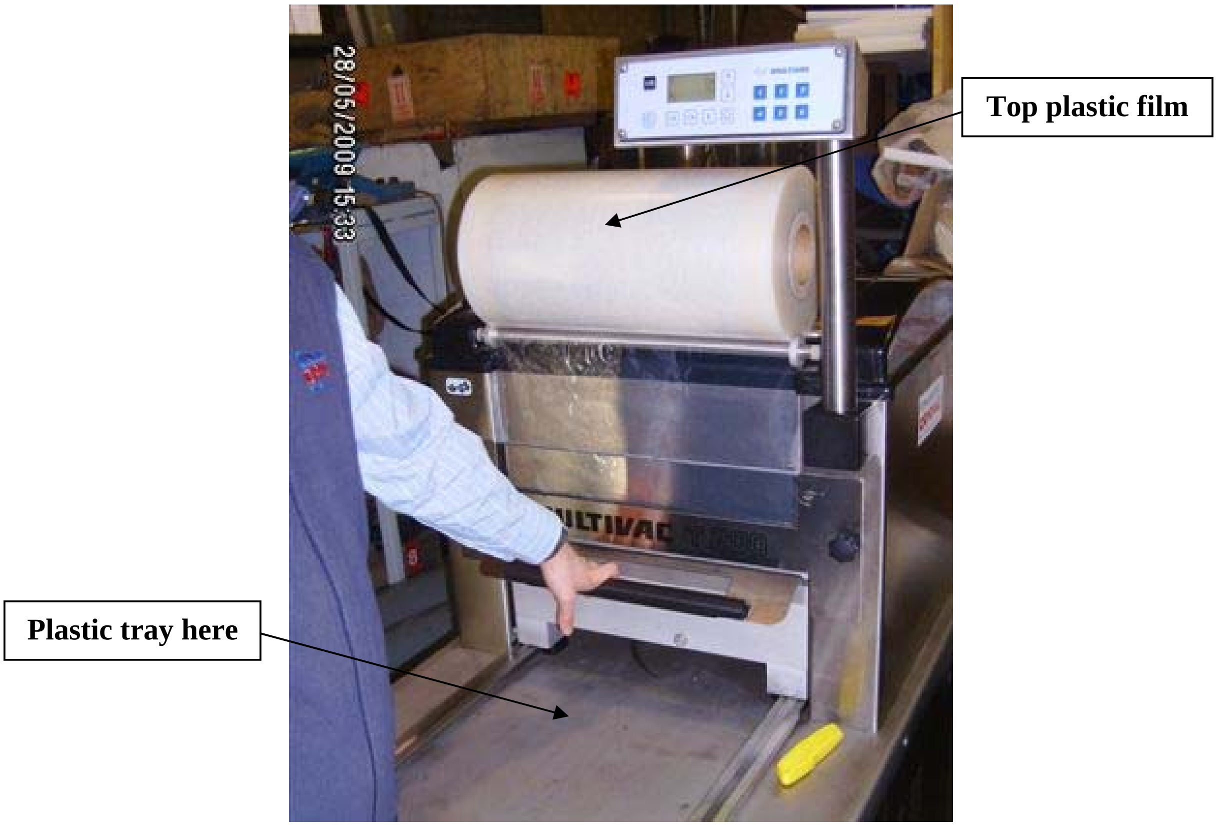


Figure 5.8: Cryovac packaging machine

Beluga water cooling equipment was used to provide clean water at near 0° C to quickly drop the temperature of the vegetables once unloaded from the blanching unit. iButton data loggers were placed in the blanching cavity with the vegetables to log the temperatures in the cavity during processing and cooling.

The trial procedure was as follows:

1. Load 2.4kg of selected vegetable and two iButtons into the cavity,
2. Process with microwaves and steam input to set times,
3. Unload batch (immediately after heating stops) into cold water bath, leave for 2-3 minutes to cool,
4. Dry on racks,
5. Perform peroxidase activity test as per 2.3.2 (v),
6. Weigh 300g samples,
7. Package to specified gas conditions,
8. Refrigerate.

Figure 5.9 shows the production line:

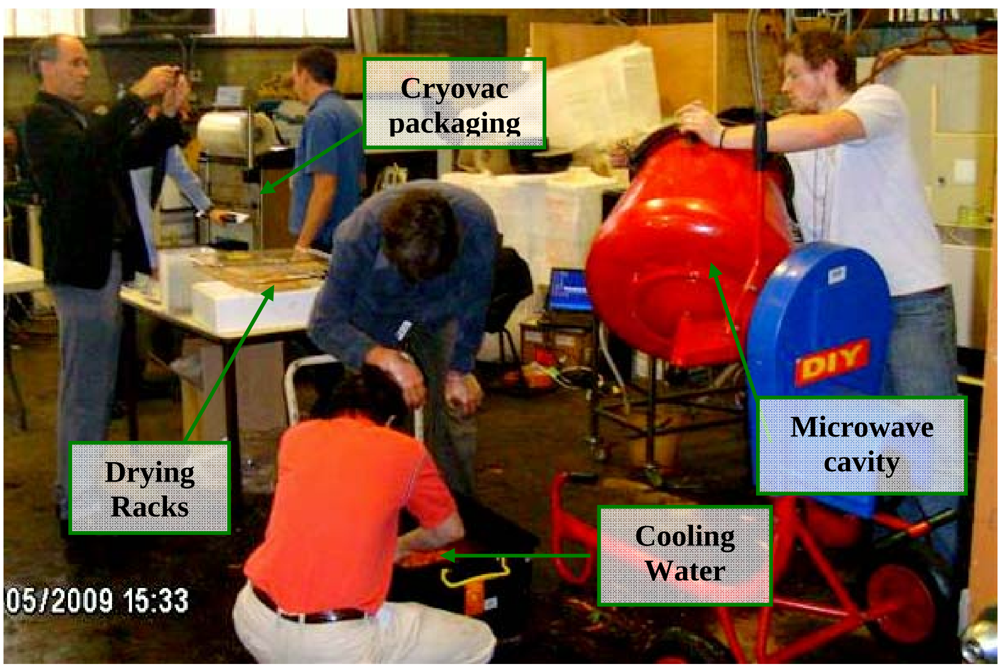


Figure 5.9: Final trials production

Temperatures were logged using the ibutton data loggers. The figure below (5.10) shows four of the broccoli batches.

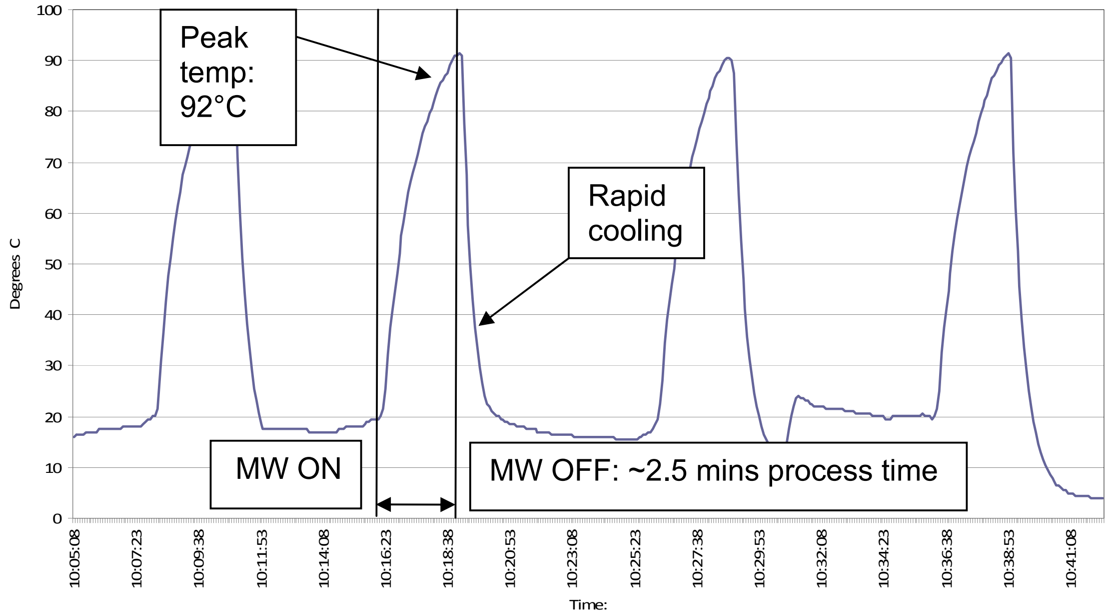


Figure 5.10: Broccoli heating profiles

The temperature profile highlights the rapid temperature rise to 92°C and the quenching effect of the ice water bath post process. These curves also reveal the high levels of repeatability achievable with microwave blanching.

These trials went as planned and close to 100% inactivation results were observed during the peroxidase activity tests. Textures of each vegetable appeared quite reasonable given the high level of inactivation achieved. Some samples were taken and snap frozen at a liquid nitrogen freezing plant in Wollongong. Initial taste tests with these vegetables returned encouraging results with texture similar to frozen un-blanched vegetables.

6 RESULTS AND DISCUSSION

6.1 Initial trials

The results obtained during this test highlighted the inability of the conveyor to produce the required conditions for uniform heating and inactivation of enzymes. In all trials, the samples showed two major downfalls of the applicator. The main limitation was the significant difference in heating between samples, as can be seen in Figure 6.1 below.

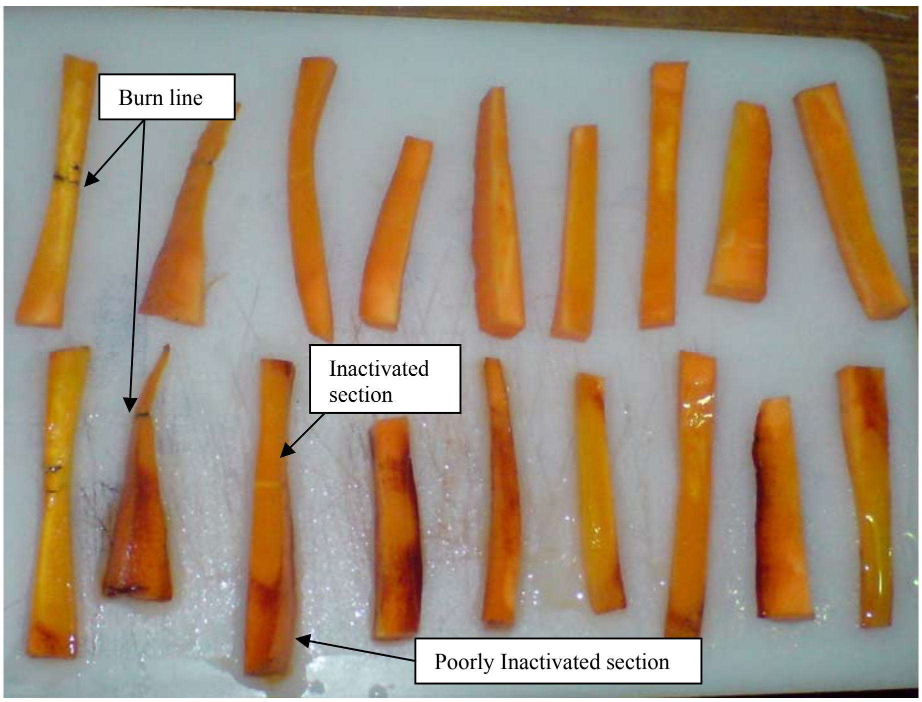


Figure 6.1 – Conveyor test carrot peroxidase results

Figure 6.1 shows the peroxidase test results from a single test run. It is shown here not to illustrate overall level of inactivation but to illustrate the difference in inactivation between pieces. The aim of these tests was not to achieve total inactivation, but to gain an understanding of the capabilities of this style applicator. Figure 6.1 clearly shows the variety of heating received by each carrot piece. A number of the samples achieved almost total inactivation, whilst others seem to have none at all. The second major issue illustrated in these tests was the lack of uniform heating within each individual sample. This is most evident in the thin burn lines across a number of the samples caused by focussing of the microwave energy leading to thermal runaway.

A number of other methods of loading were used, but none that displayed any improvements. Samples shown in Figure 6.1 were placed lengthways along the belt. When samples were placed transversely, there was insufficient microwave coupling, thus insufficient heating of the product.

The results for corn in the conveyor were almost identical to that of the carrots. A number of different conditions were tested including different levels of loading on the conveyor as well as speeds and power input. Again however, heating was varied across samples in each case, with many of the samples being burnt around the exterior. Figure 6.2 shows the results of the peroxidase test of corn samples.

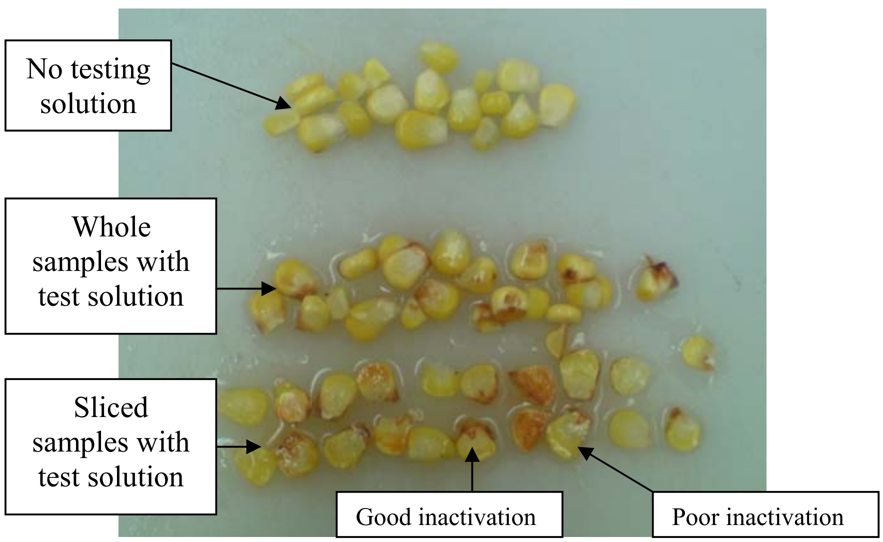


Figure 6.2 – Conveyor test corn peroxidase results

Just as was observed in the carrot samples, the levels of inactivation vary significantly between individual samples. The samples shown were put through the applicator at the same time, yet the results vary from completely inactivated, through to full colour development.

The test results for broccoli in the conveyor were slightly better than that for carrot and corn. The thin burn strips that occurred in the previous trials were not as prevalent and the heating uniformity was improved marginally. The improvements, however, were only minor, as can be seen from the non-uniform inactivation shown in Figure 6.3.

Figure 6.3 – Conveyor test Broccoli peroxidase results

Again there is a large variation in heating between samples, and even within some individual samples, the heating is not uniform. A second test was carried out with broccoli, lowering the microwave power input and running the samples through the cavity twice at a different position to try and achieve better homogenisation. The results were very similar to those from the original tests.

6.2 Applicator trials and development

The trials revealed both challenges and successes. The vegetable were able to be blanched to a level equivalent to current Devonport inactivation levels (labelled: 70%), and blanched to 100% inactivation (Note: "100% inactivation" in this report refers to: no colour development during the peroxidase testing period). At both these levels, textural and sensorial quality was of a high standard. Texture testing showed the microwave blanched samples to have far higher quality than the Devonport samples for broccoli and corn. However, the carrot sample cut sizes were irregular and affected the test equipment accuracy.

Tests performed revealed that in all 3 vegetable types there was little difference in quality between the Devonport 70% and the close to 100% inactivated samples. This information indicates that microwave blanching can be performed to a high degree of inactivation without substantial loss of vegetable quality, and suggests that perhaps a higher degree of blanching than is currently used will be acceptable, leading to longer shelf life of products. Microbial tests also revealed a 100 fold bacterial activity reduction in the blanched samples. Table 6.1 shows the process parameters for each test run performed during these trials.

Table 6.1 Drum trials 1 parameters and results

Veggie	Weight	mW Time	Microwave power (KW)				Steam time	Comments
						Efficiency		
	(kg)	(sec)	For	Ref	Net	(kWhrs/tonne)	(sec)	
Carrots	2	60	10	2	**8.2**	**68**	45	Underblanched: 2 out of 5 ok
Carrots	2	75	10	2	**8.2**	**85**	60	Closer to dev. Equiv, 3 out of 5 ok
Carrots	2	90	10	2	**8.2**	**102**	75	100% inact
Carrots	2	70	10	2	**8.2**	**79.3**	80	3 @ 100%, 1 Equiv, 1 between equiv-100%
Carrots	1.9	60	10	2	**8.2**	**71.6**	80	Equiv inact, 1 underdone
Carrots	2	70	8	3.3	**4.8**	**46.3**	90	Underblanched (low power)
Carrots	2	60	10	2	**8.2**	**68**	80	Underblanched
Carrots	2	75	10	2	**8.2**	**85**	80	Equivalent. (a little over equiv)
Carrots	2	85	10	2	**8.2**	**96.3**	85	100%
Brocolli	2	60	10	4	**6.1**	**51**	60	Crisp, underblanched
Brocolli	2	75	10	2.7	**7.5**	**77.9**	75	Soft in middle, slightly underblacnhed
Brocolli	2	65	10	2.7	**7.5**	**67.5**	90	Underblanched in stems
Brocolli	2	75	10	2.7	**7.5**	**77.9**	85	Equivalent, (1 underdone)
Brocolli	2	75	10	2.7	**7.5**	**77.9**	85	Equivalent (slightly over equiv)
Brocolli	2	75	10	2.7	**7.5**	**77.9**	85	Slightly overblanched 90% inact
Brocolli	2	70	10	2.7	**7.5**	**72.7**	80	Equivalent
Corn	2	60	10	2	**8.2**	**68**	80	Close to equiv (shells underblanched)
Corn	2	50	10	2	**8.2**	**56.7**	100	Equivalent (shells underblanched)
Corn	2	60	10	2	**8.2**	**68**	120	Need higher steam power
Corn	2	75	10	2	**8.2**	**85**	120	100% inside

There were, however, some inconsistencies with the results. In some peroxidase tests, one out of the five samples would show a different level of inactivation to the others. This could be caused by two main factors:

1: Some samples receiving more microwave and/or steam energy to others. It was thought that this could be due to some samples sticking to the cavity walls. This result seems to be confirmed by the fact that the broccoli was highly consistent but the carrots (which adhere to smooth surfaces) were more unevenly blanched.

2: Natural variation of the enzyme level between samples; especially in Julienne carrots, where different pieces are cut from different areas of the carrot.

The corn was able to be blanched to a Devonport equivalent level. The outer surface showed resilience to inactivation and it is deemed that more steam power is required to be able to achieve a close to 100% inactivation result for corn. Based on these results it was deemed that some modifications to the equipment would reduce the effect of Point 1.

Samples of Devonport "equivalent" and close to "100%" inactivated vegetables were tested for sensory and texture analysis.
These tests returned results consistent with the previous set of trials. That is, the equivalent and close to 100% inactivated samples were similar in quality and far superior to the Devonport steam blanched samples. The results of the force test for fresh and the microwave blanched samples are shown in Figure 6.4 below.

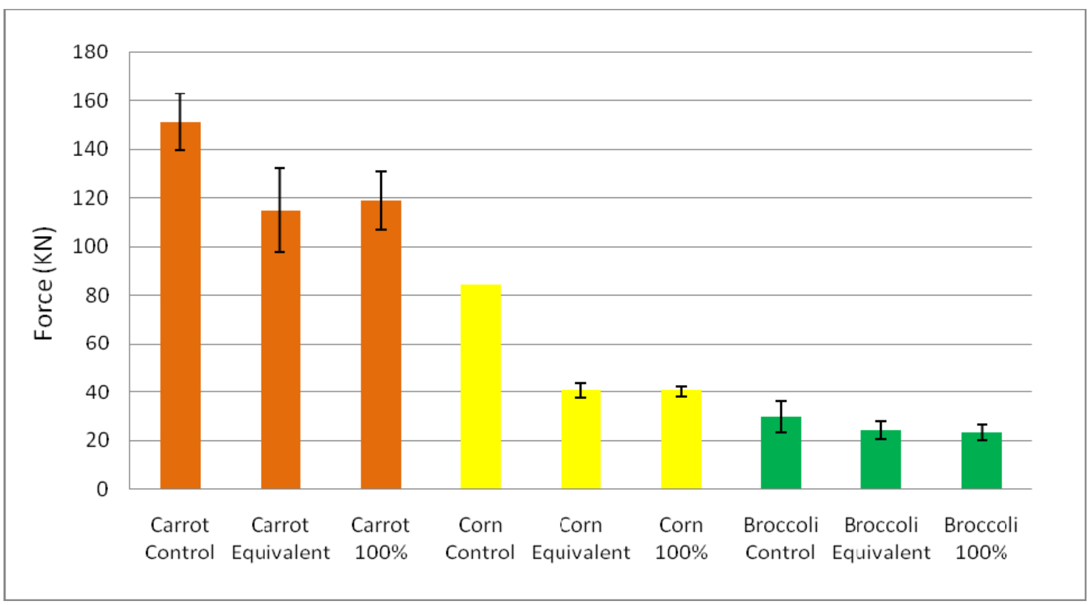


Figure 6.4: Force tests, Modified drum trials

From these trials, machine cut carrots were used and the irregularities found with the texture analysis of the previous trials were removed. As can be seen in Figure 4.5, the broccoli and carrot samples show little degradation between the fresh and blanched samples. Carrot force tests had previously been performed on Devonport blanched carrots. The microwave blanched samples achieved twice the force level as the Devonport samples, indicating far superior textural quality. Sound tests were also performed on the vegetable samples as shown below.

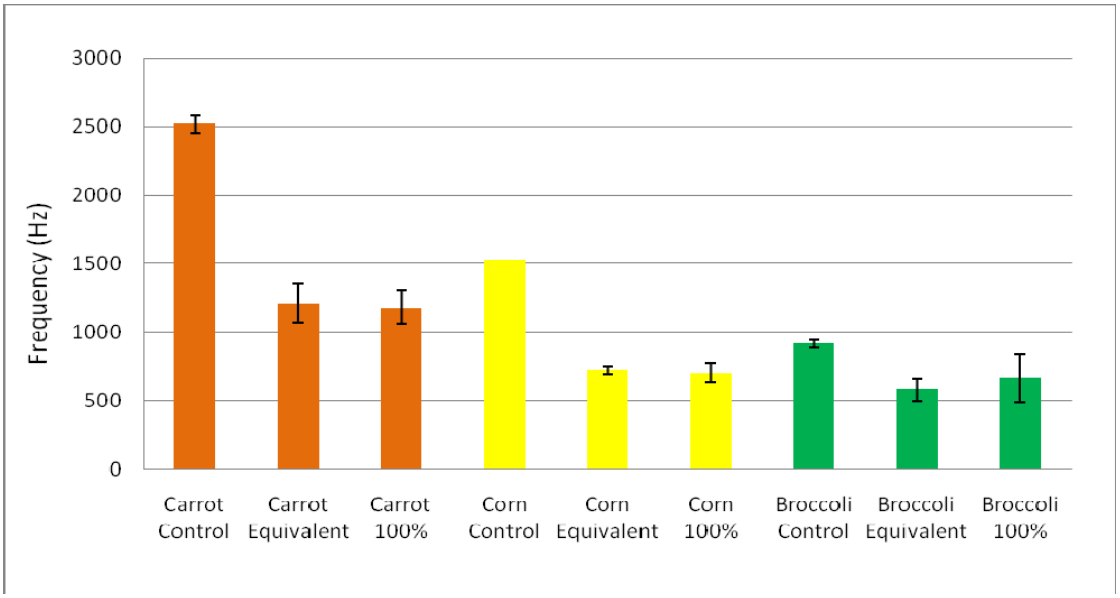


Figure 6.5: Sound tests, modified drum trials

The sound results above show that the equivalent and close to 100% blanched samples displayed similar sound quality. The equivalent and close to 100% blanched samples displaying similar force and sound results, indicates that a very high level of enzyme inactivation could be achieved with little additional vegetable quality loss, extending the potential shelf life of the vegetables whilst maintaining high sensorial quality.

6.3 Product shelf-life trials

Thorough shelf-life testing on the trial samples was performed at 7 day intervals. At each test period, samples were evaluated in the following areas:

- Sensorial qualities;
- Textural quality (sound and force tests), and;

- Microbial count and gas composition.

The results of these tests give an indication of the shelf life and overall quality achievable for these products. Unfortunately overall shelf life is highly dependent on many factors including: microbial activity, texture, smell, and taste. The gas composition and dynamics in the packaging affect the microbial activity, flavour and smell. Enzyme inactivation largely determines the texture degradation; the relationship is directly related to the level of inactivation. All microwave blanched samples used during these trials returned peroxidase test results close to 100% inactivation. As such it was expected to see no textural loss during storage. Little further gain in shelf life would be attainable by changing the blanching process parameters, but rather the storage and packaging conditions are the factors requiring improvement to increase the longevity of the vegetable quality.

The aim of the microwave blanching process was to achieve close to 100% enzyme inactivation during the time the peroxidase assay was carried out with as little vegetable quality loss as possible. As such, the analysis and comments in this section will largely be restricted to the sensorial tests and the texture force tests as they give indication of the quality achieved via microwave blanching and the trends seen with storage time.

6.3.1 Force test results

The texture tests from 5 days to 19 days post blanching show no significant decrease in force measurements for all three vegetables. Thus in evaluating the textural quality of the samples only one set of trials need be closely analysed. The test results at 5 days after the blanching give a good overall picture of the quality of the blanched vegetables because control samples and Devonport blanched samples were also tested for comparison. The results for each vegetable will be discussed. The results for the day 5 carrot tests are shown in Figure 6.6 below.

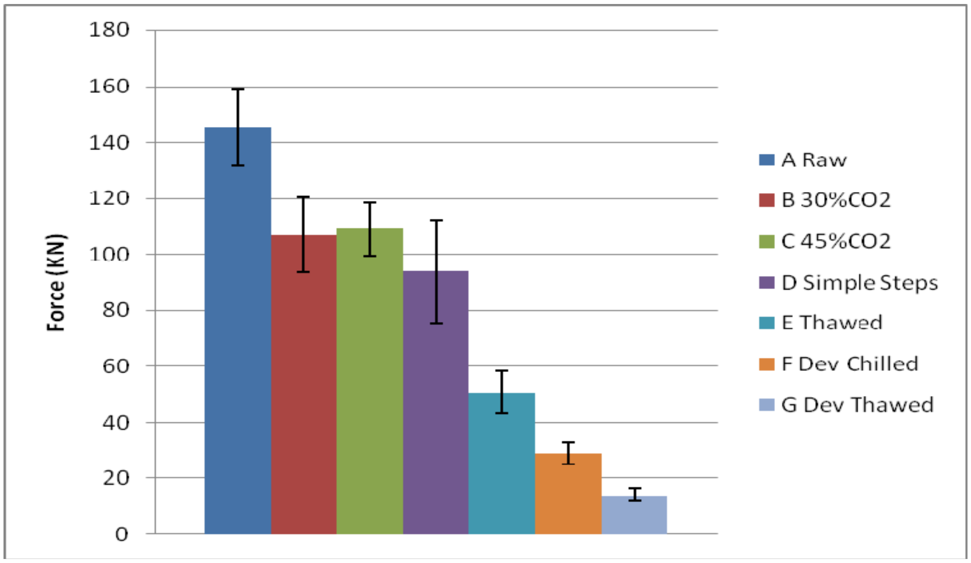


Figure 6.6: Day 5 carrot force tests

Figure 6.6 shows the force tests for the raw control sample, close to 100% inactivation samples using the three packaging methods, close to 100% inactivated samples frozen and thawed as well as samples from Devonport inactivated less than 100% and either chilled or frozen then thawed for comparison. The results show that with microwave blanching close to 100% inactivation approximately 25% force reduction occurs and a further 50% reduction occurs during the freezing/thawing processes. While the freezing/thawing accounts for the majority of the textural loss, the figure demonstrates that by using microwave technology the losses associated with blanching are drastically reduced and thus even frozen samples exhibit high textural quality. This increased texture retention is seen even though the microwave blanched samples were inactivated to a higher level than the Devonport samples.

The results cannot be directly compared with the Devonport samples in this figure because the sample cross sections were different and thus give different results. This was remedied for the tests at day 12 and the results are shown in Figure 6.7 below.

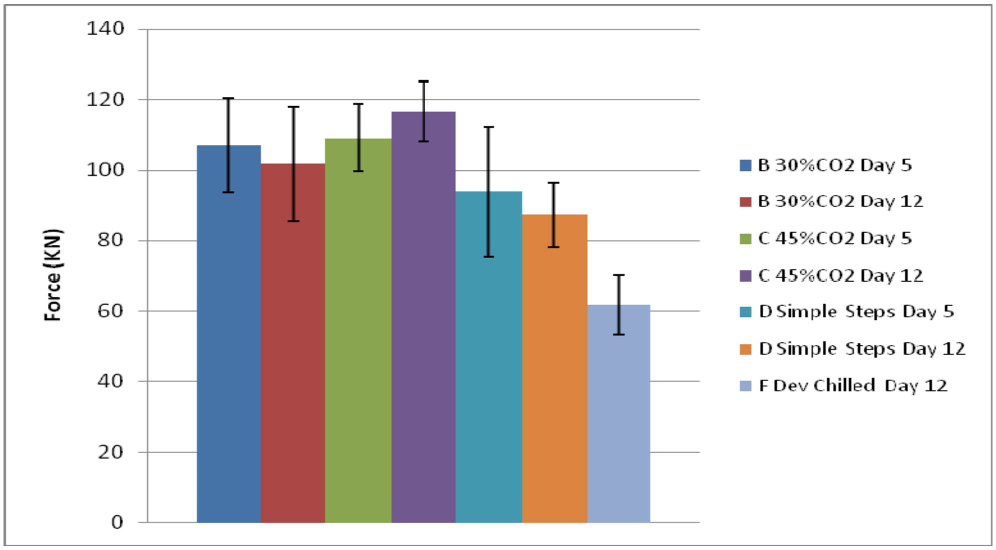


Figure 6.7: Day 12 carrot force tests

Figure 6.7 shows that little degradation was seen between days 5 and 12 for the microwave blanched samples (B, C, and D). The modified packaging microwave samples (B and C) returned average force values close to double that of the Devonport chilled samples (F) demonstrating that far superior quality is achievable using microwave blanching technology. The subsequent force trials at days 15 and 19 showed that there was no loss of texture over the storage period.

The force tests for broccoli and corn provided less useful information as direct comparison between microwave and Devonport samples was not applicable. The day 5 broccoli and corn test results are shown below.

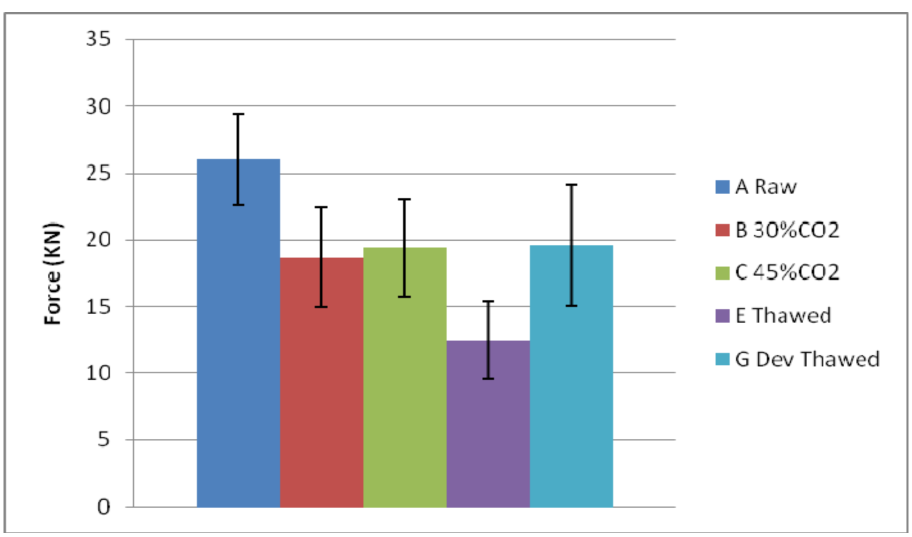


Figure 6.8: Day 5 broccoli force tests

Figure 6.8 above shows that broccoli lost a similar amount of texture during blanching (27%) to carrots. This is a positive result. The Devonport sample shown here does not provide an accurate comparison between samples and does not correlate with the sensorial tests performed.

Corn quality retention was lower than broccoli and carrots, as shown in Figure 6.9.

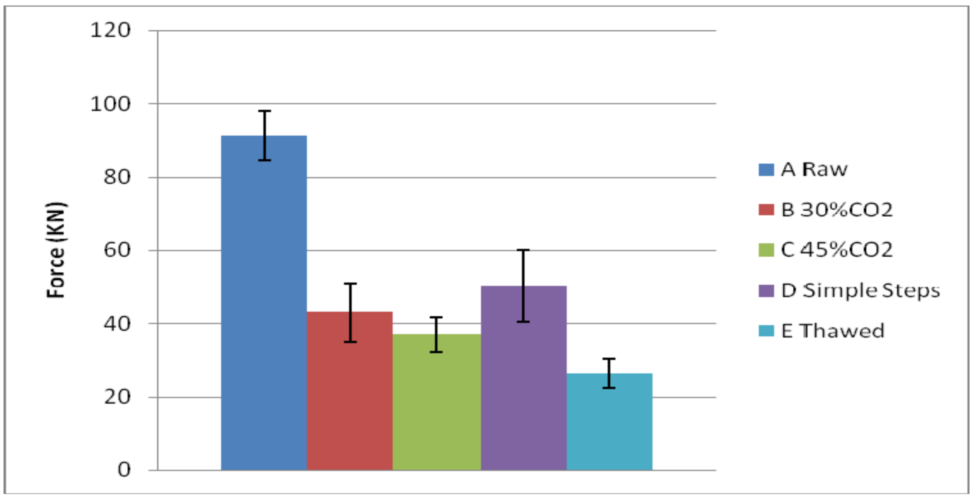


Figure 6.9: Day 5 corn force tests

The lower quality retention for corn (44%) was due to the much higher levels of steam used during blanching. This should be able to be improved with process refinement during the subsequent stages.

The force tests during storage for all three vegetables showed no significant reduction (no more than 5%). This result indicates that the inactivation of the enzymes during blanching was successful in maintaining texture for all three vegetables over an extended period. If improvements in the modified atmosphere composition can be made, microbial count results should decrease and overall storage life further improve.

6.3.2 Sensory test results

Sensory tests 15 and 19 days ($45\%CO_2/5\%O_2/50\%N_2$) and 17 and 21 days ($70\%CO_2/5\%O_2/25\%N_2$) after blanching indicated overall that a high textural quality was maintained during chilled storage. For all three vegetables the $45\%CO_2/5\%O_2/50\%N_2$ and

$70\%CO_2/5\%O_2/25\%N_2$ gas mixtures slowed odour and slimy development on the surface of the vegetable (Table 6.1 and 6.2). The microwave blanched frozen/thawed samples of carrots and broccoli had lower textural quality than the chilled samples but maintained good colour and better texture than the Devonport blanched samples.

Table 6.1 Organoleptic attributes – Veggies packed under 45% CO_2

Veggies	Day 15	Day 19	Day 25
Corn	√	√ (slight discoloration)	X
Carrots	√	√	X (slimy)
Broccoli	X (grey colour from day 2)	X (grey colour from day 2)	X

√ = acceptable; X = non-acceptable

Table 6.2 Organoleptic attributes – Veggies packed under 70% CO_2

Veggies	Day 10	Day 17	Day 21
Corn	√	√	√ (slight discoloration)
Carrots	√	√	X (slimy)
Broccoli	√ **(**colour start to deteriorate)	√ X	X

√ = acceptable; X = non-acceptable

6.3.3 Microbiological results

Microbiological samples from MAP chilled corn, broccoli and carrots were taken and TPC (total plate count) analysed on day 5, 12, 15 and 19 ($45\%CO_2/5\%O_2/50\%N_2$) and on day 3, 10, 17 and 21 ($70\%CO_2/5\%O_2/25\%N_2$) after packing.

In summary, the microbial shelf-life achieved was between 14-17 days. This estimate is based on the targeted maximum number of 1×10^5 – 5×10^5 CFU/g at the end of the shelf-life.

6.4 Prototype power and efficiency

The theoretical energy input required for the blanching of carrots, corn and broccoli is presented in Table 6.3 assuming heating begins at 5°C and ends at 92°C.

Table 6.3: Energy breakdown: Vegetables

Physical Process	Calculation *Mass x C_p x ΔT*	Energy	Notes
Carrots $\Delta T=87^oC$	1 x 3.81 x 87	**331 kJ/kg (92 kWhr/tonne)**	C_p = 3.81 kJ/kg/°C
Corn $\Delta T=87^oC$	1 x 2.03 x 87	**177 kJ/kg (49 kWhr/tonne)**	C_p = 2.03 kJ/kg/°C
Broccoli $\Delta T=87^oC$	1 x 3.85 x 87	**335 kJ/kg (93 kWhr/tonne)**	C_p = 3.85 kJ/kg/°C

Note: these values are for the **ideal** case only. In any real world system other losses will occur from heat transfer, cavity inefficiencies, uneven heating and possible temperature holding period.

Table 6.4 below displays the energy densities used during the final trials in Stage 2:

Table 6.4: Energy Usage (Stage 2)

	Microwave energy (kWhr/tonne)	Steam energy (kWhr/tonne)	Overall Energy (kWhr/tonne)
Carrots	84	71	155
Broccoli	79	85	164
Corn	48	156	204

The values in Table 6.4 are higher than the "ideal" energy values shown in Table 6.3. In reality all systems operate with heat/energy losses. The power usage of the prototype system does not reflect the efficiencies that will be achievable in the latter stages of the project. Large amounts of energy were lost due to the following factors:

- Heating of the processing cavity;
- Low loading factor of the cavity, causing less direct heat transfer into workload;
- Long downtime periods between process batches leading to cooling of the cavity;
- No insulation of cavity utilised;

- Inefficient steam lines causing condensation of steam prior to entry to the cavity, and;
- Lack of steam jets at the end of lines leading to some water droplets rather than steam, causing less efficient heat transfer to the workload.

All of these factors can be reduced or eliminated in the subsequent stages. Through engineering design an improved, energy efficient system will be produced. Both steam and microwave efficiencies should be improved. Substantial improvements will be seen in the steam energy in particular, by correcting the factors mentioned above.

Approximate heat loss calculations were performed based on the size and temperature of the Stage 2 system. These figures are shown in Table 6.5 below.

Table 6.5: Heat loss figures

Energy used to heat cavity	Density of steel	7400	kg/m^3
	Thickness	2	mm
	Weight	15.2	kg
	Specific heat	0.5	kJ/kg°C
	Temp 1	20	°C
	Temp 2	60	°C
	ΔT	40	°C
	Energy Req'd	304.6	kJ
	heating time	90	secs
	Power lost to heat cavity:	**3.4**	kW
Convective heat loss	H_{air}	50	W/m^2°C
	Heat loss	**2.1**	kW
Total heat loss	**Heat loss + drum temp**	**5.5**	kW

Table 6.5 demonstrates that significant heat is lost via the cavity drum. This power loss estimate of 5.5 kW correlates up to 50% of the process power used (including microwaves and steam). Significant savings should be made in later stages of the project by reducing the time between batches and by insulating the cavity.

In order to predict the power and system size requirements for Stages 3 and 4, estimates were made for improved heating efficiencies when insulation and reduced down times are utilized. The following efficiencies are achievable if the heat loss shown in Table 6.4 is reduced by 80%.

Table 6.6: Heating Efficiency with reduced heat loss

	Microwave Energy (kWhr/tonne)	**Steam Energy (kWhr/tonne)**	**Overall Energy (kWhr/tonne)**
Carrots	57	48	**105**
Broccoli	50	53	**103**
Corn	35	113	**148**

The values in Table 6.6 reflect more closely the sort of efficiencies that would be expected in later stages. Both broccoli and corn predicted energy usage are within 12% of the 'ideal' values. Further gains should be made by refining the process parameters, especially that of corn, where excessive amounts of steam were used.

7 CONCLUSION

Throughout the trial and test work undertaken during the first two stages of this project, many unique advantages of microwave blanching have become evident. Microwave blanching allows instantaneous control over the energy incident into the vegetable and thus allows for a very high level of control over the temperature profile during heating. In the later stages of the project (Stages III & IV – outside of HAL project) this will allow for blanching process refinement unavailable to other processing technologies. Part of this control is the ability to vary processing times; blanching could be completed in as little as 10 secs if desired with the correct combination of workload and microwave power.

Conventional heating relies on heat transfer from a hotter medium (usually steam in blanching) into the workload. This transfer is inherently uneven, with the outer parts of the product being hotter than the inner parts. The only partial remedy is the addition of time which adds cost and size to the equipment and reduces vegetable quality. Microwave heating is volumetric; penetrating into the workload and (given well designed cavity conditions) provides much more uniform heating throughout the cross section of the workload. This virtually eliminates the need for a dwell period and means that a much larger range of cross section dimensions are available for successful blanching.
Microwave energy couples directly into the workload, reducing the need for heat transfer and thus reducing potential heat loss via heat transfer into the equipment and atmosphere. This means that microwave processing systems are usually more energy efficient and smaller than conventional heating equipment.

Microwave blanching combines all the advantages above producing a product with superior flavour, texture, colour and nutrient retention when compared to conventionally blanched vegetables.

A range of potential applicators (vibratory feeders, rotary drums, helical vaned drum and conveyor belt) were thoroughly tested for materials handling suitability for microwave applications. They were not found to provide adequate consistency, control or mixing. It was determined that a semi-batch processing style would be the most effective method to ensure thorough mixing and 100% consistent microwave exposure time.

A drum mixing system was utilised and refined to perform hybrid (microwave and steam) blanching. Several rounds of trials were undertaken using the new prototype.

The final series of trials were highly successful. Very high levels of enzyme inactivation were achieved. This increased inactivation meant that no textural loss was observed during the storage testing period. The vegetables also retained a high quality level due.

The work performed throughout Stage 2 has confirmed what the literature has claimed about microwave blanching: most importantly, the vegetables show substantially improved quality over commercially steam blanched samples. Many other benefits have been observed: The heating profile of the vegetables is controllable. The combination of microwave and steam heating creates more uniform heating than was observed in any single blanching method. This uniform heating gives more flexibility in the shapes and sizes of vegetables to be processed (for example thicker cut carrots). The hybrid heating also allows for blanching in reduced time (no temperature hold period required). The space required for a microwave blanching unit should also be smaller than conventional systems.

A conceptual design has been thought about for Stage 3 development, features including: 40kW microwave power mechanised unloading, cleaning and processing movements, and throughputs exceeding 600kg/hr.

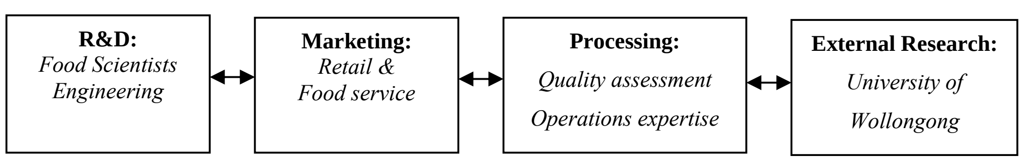
Predicted energy values for the Stage 3 and 4 systems should be close to the theoretical energy required and the larger cavity should provide more uniform field distribution, leading to improved heating uniformity. Stages 3 and 4 should see further gains made in processing techniques, blanching parameters as well as equipment quality and setup, leading to a process that consistently and efficiently delivers crisp superior quality blanched vegetables with high nutrient and flavour retention and the potential for extended shelf life.

8 TECHNOLOGY TRANSFER

Simplot is very keen for the successful development of this technology and as a privately owned commercial business we have a vested interest in ensuring that all our R&D efforts result in commercialization. This project is strongly aligned with four key company corporate strategies:

1. Product Leadership encompassing product and process innovation and technology;
2. Achievement of new product and process outcomes;
3. Defend core business through improving product quality offerings.
4. Build a strong presence in the chilled food market.

Throughout the life of the project to date (stages I and II – HAL project) every effort has been made to ensure that all activities resulted in information, design and processes that is commercially practical and sound. This included identifying, understanding and quantifying the potential variables and technical and commercial risks up-front with the right people and tools and to develop mitigation strategies to reduce risks to ensure maximising every chance of commercial success. Simplot Australia provided a significant R&D and supply chain development system, which featured collaboration between:



The team utilised resources to obtain the necessary support with respect to microwave technology, vegetable physicochemical and microbiological properties, commercial processing criteria and specifications, processing knowledge, execution of product performance trials and commercial manufacturing environment requirements to ensure trials were performed with a commercial feasibility requirements in mind. This involved considerable consultation with engineering and operations personnel in our vegetable processing plants and with our research provider University of Wollongong. During this primary phase of the overall development, some emphasis has been placed on compiling and developing some preliminary data and an understanding of the chilled vegetable market. More in-depth market investigation and development work is planned immediately after the completion of this HAL project and is discussed below.

As this project is of a confidential nature there has at this stage been no media coverage or communication to rural industry of the project.

With the laboratory and pilot development now complete (Stages I & II – HAL Project), the initial strategy for adoption is the development and subsequent presentation of a robust business case for the Simplot Board of Management to evaluate and provide approval for the team to proceed to the next phase; which involves commercial technical development and validation of the technology and process. Business case development will commence at the completion of this project (September, 2009). Significant information on the technical requirements to take the technology from a pilot scale to validation on a larger scale has been attained from this project to date as outlined in the sections above. This will be used to understand and estimate the commercial investment required from a technical development and capital requirement perspective. This will be coupled with further and more extensive market investigation and product concept refinement work, the development of a business model and benchmarking against target business metrics. This business case development work should take approximately 3-4 months to complete (by end of 2009). The business case shall provide a project proposal, a preliminary market launch plan, a financial and risk analysis review and a preliminary product life cycle outlook. It will also present a detailed preliminary production and supply chain plan including capital requirements, manufacturing strategies and developing procurement contracts for a range of vegetables from mainland growers.

Based upon the results of the trials from this project's Stage II, Stage III will involve demonstrating that the technology can successfully process at commercial power levels and commercially viable throughput rates. A commercial scale prototype system will be designed and fabricated to allow processing of 600 – 1200kg vegetables/hr (this piece of equipment will be equal in size to one processing module that would form part of the overall production line). This stage will be used to optimise the final design of the microwave applicator to accept the specified vegetable products and firm up the process parameters for full scale production throughputs at high power. The outputs from this stage will be:

1. Validation of 600kg/hr microwave blanching of vegetables,
2. High uniformity of heating due to mixing and larger applicator size,
3. Consistent high quality vegetables,
4. Streamlined loading, unloading and cleaning processes.

Specifically this work will involve:

- Design of large microwave applicator:
    - pre-design testing and research and materials handling and flow tests,
    - detailed design work including electromagnetic modelling,
- Fabrication of the commercial applicator prototype,
- Low power trials to validate that both the materials handling and microwave cavity designs are compatible and consistent with the overall process requirements of the project,
- High power trials to validate that both the materials handling system and microwave cavity designs at the higher power density are compatible and consistent with overall process requirements,
- Finalisation of design for integration into a processing plant including finalisation of specifications for ancillary equipment.

Significant work will also be focused on packaging development and shelf-life validation work and ultimately the development of product specifications. Results from the trial work will also determine any design changes needed to optimise the quality of the process and products being blanched. This will involve a review of equipment and design of any required equipment modifications and features modified to improve processing and product targets.

After Stage III, technical, market, product and business targets will be re-evaluated and the business case will be updated to reflect any changes and re-presented to the Simplot Board of management. Approval to proceed will result in activities focusing on implementation of a full scale system into our processing plant (Stage IV: Plant likely to be in Bathurst) and ultimately production and commercialisation of targeted products. The anticipated likely investment for Simplot to purchase necessary equipment and to align the system with existing line set-up is in the order of $5.5M. SAPL in the last 3 years has invested approximately $75M for new capital, and if the financial benefits and return pay-back are favourable there will be no hesitation by the company to make this investment. This capital will consist of the following major requirements plus other smaller needs: microwave blanching equipment, a cooling system and a packaging system.

As described above Stage IV will involve the full design, construction and commissioning of an automated production system at our Simplot manufacturing site (likely at this stage to be in Bathurst). This stage involves building a high power 922MHz switched mode microwave generator system for commercial throughputs. The microwave system will be designed and built to allow a minimum commercial throughput rate of 1 tonnes/hr of finished product. The system will also include a materials handling system ready to receive packaged product in a manner that is compatible with existing equipment. The system will provide safe protection and machine management using a SCADA (or equivalent) control system that will be configured to allow easy interface with our existing production lines. The microwave applicator will comprise of having vapour extraction and a simple easy to clean applicator compatible with the food industry standards. The microwave system will be designed such that it can be modular. This will enable Simplot to relocate equipment between current vegetable processing plants and other yet to be determined processing sites if necessary.

The technology is proposed to be commercialised at the completion of Stage IV. In the launch stage, production will be increased to full-scale and products will be launched via the execution of business case implementation plans. It is envisaged that we will launch a range of chilled vegetable products in the retail and foodservice sector (in different configurations and variants yet to be determined). All launches will be supported by over and above advertising and promotional activity.

9 RECOMMENDATIONS – SCIENTIFIC AND INDUSTRY

From a scientific point of view the steam aided microwave blanching technology evaluated in this project has proven it is capable of delivering superior blanched vegetables with respect to texture and appearance than current steam methods. Industry wise it potentially offers cost reduction in terms of energy and water usage as well as a more controlled process.

The results to date have been validated on a small scale. To commercialise this technology, it is recommended that further work be undertaken to develop and validate a commercial scale-up system that delivers the required process and product quality. This forms the basis of work described above in Section 8 (Stage III & IV).

10 ACKNOWLEDGMENTS

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11 REFERENCES

Bergmeyer, H. U., 1974. 'Methods of Enzymatic Analysis 1', Academic Press, New York, 2nd Edition, page 495.

Bradshaw, S, Delport, S and van Wyk, E, 1997. 'Qualitative measurement of heating uniformity in a multimode microwave cavity', *Journal of Microwave Power and Electromagnetic Energy,* 32(2), 87-95.

Brinley, T. A., Truong, V. D., Coronel, P., Simunovic, J. and Sandeep, K. P., 2008. 'Dielectric Properties of Sweet Potato Purees at 915 MHz as Affected by Temperature and Chemical Composition', *International Journal of Food Properties*, 11:1, 158 — 172.

Canet W., Hill M. A., 1987. 'Comparison of several blanching methods on the texture and ascorbic acid content of frozen potatoes' *International Journal of Food Science & Technology* 22 (3) , 273–277.

Chen S. C., Collins J. L, McCarty I. E., Johnston M. R., 1971. 'Blanching of white potatoes by microwave energy followed by boiling water', *Journal of Food Science*, 36 (5) , 742–743.

Collins, JL, and McCarthy, IE, 1969. 'Comparison of microwave energy with boiling water for blanching whole potatoes', *Food Tech,* 23, 337-340.

Datta, AK, and Anantheswaran, RC, 2001. *Handbook of microwave technology for food applications, Marcel* Dekker Inc., New York.

De Ancos, B, Cano, MP, Hernandez, A, and Monreal, M, 1999. ' Effects of microwave heating on pigment composition and colour of fruit purees', *Journal of Science and Food Agriculture,* 19, 663-670.

Dietrich, WC, Huxsoll, CC, Wagner JR, and Guadagni, DC, 1970. 'Comparison of microwave with steam or water blanching of corn-on-the-cob. Peroxidase inactivation and flavour retention', *Food Technology,* 24(3), 293-296.

Dorantes-Alvarez L, Barbosa-Canovas G, and Gutierrez-Lopez G, 2000. ‘Blanching of fruit and vegetables using microwaves’, in Barbosa-Canovas G and Gould G, *Innovations of Food Processing,* Technomic Publishing, Lancaster, PA, 149-162.

Drake, SR, Spayd, SE, and Thompson, JB, 1981. ‘The influence of blanch and freeze methods on the quality of selected vegetables’, *Journal of Food Quality,* 4, 271-276.

Fu, W and Metaxas, A, 1994. ‘Numerical prediction of three-dimensional power density distributions in a multimode cavity, *Journal of Microwave Power and Electromagnetic Energy,* 29(2), 67-75.

Goldhahn SL, & Stratford NJ. *Continuous food sterilisation system with hydrostatic sealed treatment chamber,* US Patent 4537383.

Gunes, B and Bayindirli, A, 1993. ‘Peroxidase and lip oxygenase inactivation during blanching of green beans, green peas, and carrots’, *Food Science and Technology,* 26(5), 406-410.

Guthier EH, 1944. *Continuous type steam blancher,* US Patent 2355798.

IEC 60519: 2002 – Safety in electroheat installations – Part 6: Specifications for safety in industrial microwave heating equipment, International Electrotechnical Commission.

Ihl, M, Monsalves, M, and Bifani, V, 1998. “Chlorophyllase inactivation as a measure of blanching efficiency and colour retention of artichokes’, *Food Science and Technology,* 31(1), 50-56.

Jackson, HW and Barmatz, M, 1991. ‘Microwave absorption by a lossy dielectric sphere in a rectangular cavity, *Journal of Applied Physics,* 70(15), 5193-5204.

Jwala Engineering Company website, Accessed Oct 2008. *Blancher,* http://jwala.tradeindia.com/Exporters_Suppliers/Exporter2593.33106/Blancher.html

Jwala Engineering Company website, Accessed Oct 2008. *Pasteurizer,* http://jwala.tradeindia.com/Exporters_Suppliers/Exporter2593.33097/Pasteurizer.html

Kadlec, P, Rubecova, A, Hinkova, A, Kaasova, J, Bubnik, Z and Pour, V, 2001. 'Processing of yellow pea by germination, microwave treatment and drying', *Innovative Food Science and Emerging Technologies*, 2, 133-137.

Kermasha, S, Bisakowski, B, Ramaswamy, HS, and Van de Voort, FR, 1993a. 'Comparison of microwave, conventional and combination treatments inactivation on wheat germ lipase activity', *Int. J. Food Sci. Technol.,* 28, 617-623.

Kermasha, S, Bisakowski, B, Ramaswamy, HS, and Van de Voort, FR, 1993b. 'Thermal and microwave inactivation of soybean lip oxygenase'. *Leberism Wiss. U. Tchnol.,* 26, 215-219.

Kidmose, U, and Martins, HJ, 1999. 'Changes in texture, microstructure and nutritional quality of carrot slices during blanching and freezing', *J Sci Food Agric,* 79, 1747-1753.

Koch K, 1990. *Method and apparatus for evenly heating of products by means of microwaves,* US Patent 4956532.

Kumar, Prabhat, Coronel, Pablo, Simunovic, Josip and Sandeep, K. P., 2008. 'Thermophysical and Dielectric Properties of Salsa Con Queso and its Vegetable Ingredients at Sterilization Temperatures', *International Journal of Food Properties*, 11:1, 112 — 126.

Ledet BA, & Johnson DA, 1993. *Apparatus and method for high volume steam cooking,* US patent 5410951.

Metaxas, R, & Meredith, R, 1988. *Industrial Microwave Heating,* Institute of Electrical Engineers, London.

Meredith, R J, 1998. Engineer's Handbook of Industrial Microwave Heating – Power and Energy Series.

Mudgett, RE, 1989. ‘Microwave food processing: scientific status summary’, *Food Technology,* 42(1), 117-126.

Mufugil, N, 1986. ‘Effect of different types of blanching on the colour and the ascorbic acid and the chlorophyll contents of green beans’, *J Food Processing and Preservation,* 10, 69-76.

Perch, C and Schubert, H, 1995. ‘Characterisation of household microwave ovens by their efficiency and quality parameters’, *The 5th International Conference on microwave and high frequency heating,* Cambridge University, UK.

Premakumar, K and Khurdiya, DS, 2002. ‘Effect of microwave blanching on the nutritional qualities of banana puree’, *Journal of Food Science and Technology,* 39(3), 258-260.

Quenzer, N M, and Burns, E E, 1981. ‘Effects of microwave, steam, and water blanching on freeze dried spinach’, *J Food Sci,* 46(2)*,* 410-413.

Ramesh, M N, Wolf, W, Tevini, D, and Bognar, A, 2002. ‘MB of vegetables’, *Journal of Food Science,* 67(1), 390-398.

Ramaswamy, H S, and Abbatemarco, C, 1996. ‘Thermal processing of fruits’, in Somogyi Ramaswamy, H S, and Hui Y H, *Biology, Principles and Applications, Processing Fruits Science and Technology,* Technomic Publishing, Lancaster, PA, 1, 31-33.

Ringle, CH, and Donaldosn, DB, 1975. ‘Measuring electric field distribution in a microwave oven’, *Food Technology,* 29(12), 46-54.

Risman, PO and Ohlsson, T, 1992. ‘Metal in the microwave’, *Microwave World,* 13(1), 28-33.

Ryynänen S, 1995. 'The electromagnetic properties of food materials: a review of the basic principles', *Journal of Food Engineering*, 29, 409-429.

Schubert S and Regier M, 2005. *The microwave processing of foods,* Woodhead Pub. Ltd, Abington.

Sun T. Tang J, and Powers JR, 2007. 'Antioxidant activity and quality of asparagus affected by microwave-circulated water combination and conventional sterilization', *Food Chemistry*, 100(2), 813-819.

Tajchakavit, S and Ramaswamy, HS, 1995. 'Continuous-flow microwave heating of orange juice: Evidence of non-thermal effects', *Journal of Microwave Power and Electromagnetic Energy,* 30(3), 141-148.

Tajchakavit, S, 1997. *Continuous-flow microwave heating of orange juice: Evidence of non-thermal effects*, McGill University, Ph.D. thesis.

Tajchakavit, S, and Ramaswamy, H S, 1997. 'Continuous flow microwave inactivation kinetics of pectin methyl esterase in orange juice', *J Food Processing and Preservation, 21*, 365-378.

TI: AS/NZ 60335.2.25 (AS/NZ 3350.2.25) - Australian and New Zealand Standard 2004 SO: Standards Australia / Standards New Zealand, IEC.

Tong Engineering website, Accessed Oct 2008. *Pintle lining to barrel washer,* http://www.tongpeal.co.uk/washingequipment/1/subproducts/1/index.phtml

Viña S.Z., Olivera D.F., Marani C.M., Ferreyra R.M., Mugridge A, Chaves A.R. and Mascheroni R.H., 2007. 'Quality of Brussels sprouts (*Brassica oleracea* L. *gemmifera* DC) as affected by blanching method', *J Food Engineering*, 80(1), 218-225.

Wrolstad, R E, Lee, DD, and Poel, MS, 1980. 'Effect of MB on the colour and composition of strawberry concentrate', *Journal of Food Science,* 45(6), 1573-1577.

Willert-Porada, M, 2006. Advances in Microwave and Radio Frequency Processing : Report from the 8th International Conference on Microwave and High-Frequency Heating held in Bayreuth, Germany, September 3-7.

Zhang, H and Datta, AK, 2000. 'Microwave power absorption in multi compartment foods', Submitted to Inst. of Chemical Engineers.

Zhang, H and Datta, AK, 1999. 'Heating concentrations of microwaves in spherical and cylindrical foods. Part Two: In a cavity', Submitted to *Journal of Microwave Power* and Electromagnetic Energy.

Zhang, H and Datta, AK, 2000. 'Heating concentrations of microwaves in spherical foods. Part One: In plane waves', Submitted to *Journal of Microwave Power* and Electromagnetic Energy