

Vacuum fried gold kiwifruit: Effects of frying process and pre-treatment on the physico-chemical and nutritional qualities

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Abstract: A study was conducted to determine the effects of frying process and pre-treatment on the physico-chemical and nutritional qualities of vacuum fried gold kiwifruit. The kiwifruit samples were peeled and cut into slices 5 mm thick. Half of the kiwifruit samples were soaked for one hour in a 33% maltodextrin solution, then placed into plastic bags and frozen and the other half (unsoaked) were simply frozen. The two set of samples were subjected to three frying processes and all at 2.3 kPa vacuum, after which the kiwifruit was removed from the fryer and centrifuged in cheese cloth for four minutes to remove excess surface oil. Generally, the vacuum fried gold kiwifruit samples from the 80°C for 50 minutes process gave higher moisture content and lower oil content followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process. The vacuum fried samples from the 100°C for 25 minutes process gave consistently higher total colour change and browning index, followed by the 90°C for 35 minutes process and then the 80°C for 50 minutes process. The unsoaked sample from the 80°C for 50 minutes process gave significantly lower breaking force than the sample from the 100°C for 25 minutes process. There was no significant difference in the breaking force of all vacuum fried soaked samples. Generally the samples from the 80°C for 50 minutes process gave higher ascorbic acid contents followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process.

Keywords: Ascorbic acid, frying process, gold kiwifruit, pre-treatment, maltodextrin solution, physico-chemical qualities, vacuum fried

Introduction

Kiwifruit are well-known to contain high levels of fibre, minerals, vitamins, antioxidants, phenolic compounds and other bioactive substances that have the effect of improving digestive health, increasing and maintaining immunity, protecting the body against oxidative stress that could lead to health problems and disease, and contributing to overall well-being (Farr *et al.*, 2008; Shu Molan *et al.*, 2008; Skinner *et al.*, 2008). Their abundance and economic importance in New Zealand leads to kiwifruit products being both cost-effective and high-earning, making them a good candidate for the development of new health food products, including functional foods (Zespri Group Ltd., 2009). There are two well known cultivars, the green kiwifruit (Hayward) and the gold kiwifruit (Hort16A) (Martin, 2003). Green kiwifruit has a green fleshed pulp, with a small white core and black seeds. Gold kiwifruit has a smooth

hairless skin that is bronze in colour, a golden fleshed interior and a white core with black seeds (Zespri Group Ltd., 2009).

Vacuum frying is the technique of deep-fat frying foods under pressures well below atmospheric levels, preferably below 6.65 kPa, which serves to reduce oil content, discolouration and losses of vitamins and other compounds normally associated with oxidation and high temperature processing (Garayo and Moreira, 2002). One of its first applications was to reduce acrylamide formation in potato crisps, as this tends to occur during high-temperature processing of high carbohydrate foods (Granda *et al.*, 2004). It has also shown some success in producing vacuum fried products with other foods, including pineapple, apples, carrots, blue potato, sweet potato, beans, mangoes and jackfruit (Da Silva and Moreira, 2008; Diamante, 2009; Mariscal and Bouchon, 2008; Perez-Tinoco *et al.*, 2008; Fan *et al.*, 2005). The main factors influencing fried products are the time and temperature combinations of the cooking process;

the correct combination is mandatory in producing a food product with acceptable physical attributes (such as colour, appearance, texture and flavour) as well as preserving nutritional, but unstable, compounds such as vitamin C. In contrast, Diamante *et al.* (2010) reported that hot air drying of green and gold kiwifruits at increasing temperatures (60 to 100°C) leads to increased browning and ascorbic acid loss.

Maltodextrin is a common food additive that is made by the hydrolysis of starch and that comes in the form of a white powder with a sweet taste. It is commonly used as a bulking agent for artificial sweeteners and as a drying aid (Wang and Wang, 2000). Osmotic dehydration through the use of salt, sugar and starch solutions is used to concentrate solids in foods. The driving force for water removal is the concentration gradient between the osmotic solution and intercellular fluid, while the cells act as a semi-permeable membrane (Shukla and Singh, 2007). Thus, during this process the texture of the product is not disturbed and the product gains solids through concentration (Shukla, 2004; Gupta and Shukla, 1999). The dried products obtained after convective drying utilising osmotic dehydration as a pre-treatment (osmo-convective drying) are of higher quality than products dried conventionally. This is because uncontrolled drying results in uneven drying and, often, exposure to high temperatures for long periods of time (Shukla and Singh, 2007). Osmotic dehydration can shorten the drying process through partial removal of food moisture. Indeed, Fan *et al.* (2005) reported the use of a 30% maltodextrin solution for pre-treatment of carrot chips before vacuum frying.

Preliminary vacuum frying studies on the green and gold kiwifruit have shown that the gold kiwifruit give a product with an attractive gold colour while the green kiwifruit gave a product with a brownish green colour. It was also observed that the vacuum fried products were very crunchy but brittle. Hence, the objectives of this study were to study the effect of different frying processes (frying temperature and time combinations) and pre-treatments (soaking in maltodextrin solution or no soaking) on the physico-chemical and nutritional qualities of only the vacuum fried gold kiwifruit.

Materials and Methods

Raw material

Gold kiwifruit (*Actinidia deliciosa* Planch) were purchased from a local supermarket in Christchurch, New Zealand and stored under refrigeration (4°C)

until ready for use. The kiwifruit were firm and ripe with a juice soluble solids content of ranging from 16 to 18°Brix.

Sample preparation

The kiwifruit were peeled and sliced 5 mm thick using a mechanical slicer (Bizerba GmbH & Co.Kg, Balingen, Germany). Three bags of three-kilogram samples designated as receiving no pre-treatment and were frozen immediately. A further nine kilograms of fresh kiwifruit slices were soaked for one hour in a 33% maltodextrin solution (Oino International Group Ltd., Xiamen, China). The slices were then divided into three plastic bags (three kilograms in each bag) and frozen at -18°C until ready for frying.

Vacuum frying

Figure 1 shows the schematic diagram of the vacuum frying system used in the experiments. The canola oil (Seafrost, Kuala Lumpur, Malaysia) used was fresh at the commencement of the frying, using 460 litres. The vacuum vessel was set to the target temperature (80, 90 and 100°C) and allowed to preheat for 30 minutes before commencing each frying experiment.

The process consisted of loading the products into the fryer basket (3 kg per batch) suspended above the oil, closing the lid and then depressurizing the vessel. When the pressure in the vessel achieved a 2.3 kPa vacuum, the basket was submerged into the hot oil. The basket was moved in and out of the oil every 30 seconds for the first 10 minutes to separate the kiwifruit slices; they were not frozen individually in the form of a frozen kiwifruit slab. The samples were vacuum fried using the following frying processes: a) 80°C for 50 minutes; b) 90°C for 35 minutes; and c) 100°C for 25 minutes. The frying processes had been determined previously to give vacuum fried kiwifruit with a moisture content of about 3% dry basis (d.b.). Once the products were fried, the basket was raised above the oil. The top of the basket was then knocked 30 times with a metal rod while still inside the frying chamber to shake off as much of the surface oil as possible. The fried products were held inside the fryer for about four minutes. The vessel was pressurised back to atmospheric pressure, the samples blotted dry with paper towels to remove surface oil, then centrifuged inside cheese cloth for four minutes in a spinner using 750 rpm (to further remove oil). Once cooled, the vacuum fried kiwifruit samples were stored in sealed polyethylene terephthalate bags.

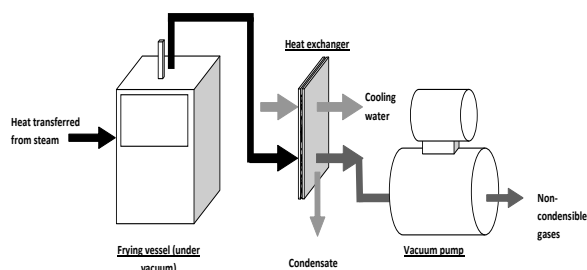


Figure 1. Schematic diagram of the vacuum frying system.

Moisture content measurement

The moisture content was determined by drying the samples in an air oven at 105°C (Watson Victor Ltd., Auckland, New Zealand) until a constant weight was reached, as described in Diamante *et al.* (2010). The moisture content of the samples was calculated on a percent dry basis and the average value of the triplicate measurements were used.

Oil content determination

The oil content of the ground vacuum fried samples was determined gravimetrically by solvent extraction using the Soxhlet technique (AOAC, 1995), as described in Bouchon *et al.* (2003). The oil content of the samples was calculated on a percent dry basis and the average value of the duplicate measurements were used.

Colour properties determination

The colour was measured using a Minolta Reflectance Chroma Meter CR 210 (Minolta Corp., Osaka, Japan). This involved taking three readings of ground samples of the vacuum fried kiwifruit in order to obtain average L* (lightness-darkness), a* (redness-greenness) and b* (yellowness-blueness) values. Calibration against a standard white tile occurred immediately prior to each set of three readings. In addition, the total colour change and browning index were calculated from the L*, a* and b* values, as described in Diamante *et al.* (2010).

Texture measurement

A Tenderometer (MIRINZ, Hamilton, New Zealand) was used to measure the force required to break the vacuum fried kiwifruit, which was then correlated to the texture of the product. A metal tooth 1 cm wide was lowered on to single kiwifruit slices by the action of compressed air supplied at 500 kPa (gauge). The force required to break through the kiwifruit slice was measured in kPa, which was then converted to KgF through use of the formula:

$$KgF = (kPa \times 0.2) - 1$$

Each treatment combination was measured for breaking force five times using five different slices of fried kiwifruit, which were then averaged to obtain the average force required to break the kiwifruit.

Ascorbic acid determination

The ascorbic acid content of the vacuum fried kiwifruit was measured by titration using 2, 6-dichloroindophenol following a standard method (Method 967.21) (AOAC, 2002). The measurements were automated using a modified Metrohm titrimetric method (Application bulletin No. 98/2e), as described in Diamante *et al.* (2010).

Statistical analyses

A two-way analysis of variance (ANOVA) using Minitab 15 (Minitab Inc., State College, Pennsylvania, USA) was carried out on the moisture content, oil content, colour values and properties, breaking force and ascorbic acid content in order to determine the significance of the results. Duncan's Multiple Range Test was used to locate the difference between the means and the Bartlett's test was used to test for homogeneity of the variances (Walpole *et al.*, 1998).

Results and Discussion

Moisture and oil contents of vacuum fried gold kiwifruit

Table 1 shows the mean values of the moisture content of different vacuum fried gold kiwifruit samples. The samples fried at the 80°C for 50 minutes process gave higher moisture contents followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process. The pre-treatment method (soaked or unsoaked) did not affect the moisture content of the samples from the 80°C for 50 minutes process and the 90°C for 35 minutes process. However, the moisture content of the soaked sample was significantly lower than the moisture content of the unsoaked sample fried at the 100°C for 25 minutes process. The results show that the 80°C for 50 minutes process was not long enough to reduce the moisture content of the samples to below 3% d.b.. In contrast, Diamante (2009) reported that vacuum frying of frozen half-ripe jackfruit at 90°C for 120 minutes with 6.77 kPa vacuum resulted in a moisture content of 2.5% d.b.. Additionally, vacuum frying of unfrozen pineapple slices at 112°C for 7 minutes with 24 kPa vacuum resulted in a moisture content of 2.9 to 3.8% w.b. (3.0 to 4.0% d.b.) (Perez-Tinoco *et al.*, 2008). Furthermore, Da Silva and Moreira (2008) found that vacuum frying unfrozen mango slices at

121°C for 3 minutes with less than 1.33 kPa vacuum resulted in a moisture content of 1.48% w.b. (1.50% d.b.).

The mean values of the oil content of the different vacuum fried gold kiwifruit samples are also presented in Table 1. The samples fried at the 80°C for 50 minutes process and 90°C for 35 minutes process gave lower oil contents than the samples from the 100°C for 25 minutes process. The pre-treatment method (soaked or unsoaked) did not affect the oil contents of the samples from the 90°C for 35 minutes process and the 100°C for 25 minutes process. However, the oil content of the soaked samples were significantly lower than the oil content of the unsoaked samples fried using the 80°C for 50 minutes process. The results show that all processes gave samples with oil content of 31 to 37% d.b.. Frying samples at temperatures of 100°C or less usually results to higher oil content compared with samples fried at temperatures above 100°C. This is probably due to the absence of a dried surface layer which lower the oil absorption of the samples. This concurs with Diamante (2009) who reported that vacuum frying of frozen half-ripe jackfruit at 90°C for 120 minutes with a 6.77 kPa vacuum resulted in an oil content of 34% d.b.. Conversely, vacuum frying unfrozen pineapple slices at 112°C for 7 minutes with a 24 kPa vacuum resulted in an oil content of 18.6 to 19.2% d.b. (Perez-Tinoco *et al.*, 2008).

Colour values and properties of vacuum fried gold kiwifruit

Table 2 shows the mean colour values (L^* , a^* and b^*) of the fresh gold kiwifruit and the different vacuum fried gold kiwifruit samples. The L^* values of all the vacuum fried samples decreased in comparison with the fresh sample. The soaked sample gave a significantly lower L^* value than the unsoaked sample from the 80°C for 50 minutes process. The samples from the 100°C for 25 minutes process gave the lowest L^* values followed by the 90°C for 35 minutes process. However, the pre-treatment method (soaked or unsoaked) did not affect the L^* values of the samples from these two processes. Frying the kiwifruit samples at higher temperature would result to more darkened fried products hence resulting to lower L^* values. Diamante *et al.* (2010) found that hot air drying gold kiwifruit slices at 80 to 100°C also decreased L^* values to about 52- 58. The a^* values of all the vacuum fried samples increased in comparison with the fresh sample. The unsoaked samples from all processes gave significantly higher a^* values than the soaked samples. The a^* values of the samples fried using the 100°C for 25 minutes process were

significantly higher than the fresh gold kiwifruit, followed by the 90°C for 35 minutes process and then the 80°C for 50 minutes process. Frying the kiwifruit samples at higher temperature would yield reddish fried samples hence increasing the a^* values. But soaking the kiwifruit samples in 33% maltodextrin solution and frying decreased the a^* values of fried samples due to the coating on the surface of the products. Hot air drying of gold kiwifruit slices at 80 to 100°C also increased the a^* values to 7.5-10.7 (Diamante *et al.*, 2010). The b^* values of the vacuum fried samples from the 100°C for 25 minutes process decreased in comparison with the fresh sample. The soaked sample gave a significantly lower b^* value than the unsoaked sample from the 80°C for 50 minutes process. The samples fried using the 100°C for 25 minutes process gave the lowest b^* values, followed by the 90°C for 35 minutes process. However, the pre-treatment method (soaked or unsoaked) did not affect the b^* values of the samples from these two processes. Frying the kiwifruit samples at higher temperature gave more darkened fried products hence decreasing the b^* values. Diamante *et al.* (2010) found that hot air drying gold kiwifruit slices at 80 to 100°C also decreased b^* values to 37.8-40.7.

Table 1. Mean values of moisture and oil contents of vacuum fried gold kiwifruit processed with 2.3 kPa vacuum using different frying process and pre-treatment

Frying Process	Moisture Content (% d.b.) [#]	Oil Content (% d.b.) [#]
Fresh (no frying and pre-treatment) ^{##}	488.24	0.2
80°C and 50 minutes		
Unsoaked	3.72a	34.6c
Soaked ^{###}	3.80a	31.4a
90°C and 35 minutes		
Unsoaked	2.75b	32.9bc
Soaked ^{###}	2.67b	32.0b
100°C and 25 minutes		
Unsoaked	2.56c	36.6d
Soaked ^{###}	2.11d	35.2d

where: d.b. – dry basis

- mean values with the same letters are not significantly different from each other for that column at $p < 0.05$

- from Lesperance (2009)

- soaked in 33% maltodextrin solution for one hour

Table 2. Mean values of L^* , a^* and b^* colour values and properties of fresh and vacuum fried gold kiwifruit processed with 2.3 kPa vacuum using different frying process and pre-treatment

Frying Process	Colour Values [*]			Colour Properties [#]	
	L^*	a^*	b^*	Total Colour Change	Browning Index
Fresh (no frying and pre-treatment)	69.7a	-4.6a	47.3b	0.00a	0.00a
80°C and 50 minutes					
Unsoaked	62.1b	3.0c	50.4a	11.3b	143.1c
Soaked ^{##}	55.4c	2.6b	44.5c	16.4c	140.8b
90°C and 35 minutes					
Unsoaked	56.5c	5.7e	47.3b	16.9c	155.3e
Soaked ^{##}	55.5c	4.9d	45.9b	17.3c	151.1d
100°C and 25 minutes					
Unsoaked	49.8d	11.0g	43.1c	25.8d	173.4g
Soaked ^{##}	52.2d	7.9f	44.6c	21.8d	164.7f

where: # - mean values with the same letters are not significantly different from each other for that column at $p < 0.05$

- soaked in 33% maltodextrin solution for one hour

The mean values of total colour change of the different vacuum fried gold kiwifruit samples are also presented in Table 2. The samples fried using the 100°C for 25 minutes process gave significantly higher total colour change, followed by the 90°C for 35 minutes process and then the 80°C for 50 minutes process. The total colour change of the soaked and unsoaked samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process were not significantly different from each other. However, the soaked sample had a significantly higher total colour change than the unsoaked sample fried using the 80°C for 50 minutes process. Frying the kiwifruit samples at higher temperature gave more darkened and reddish fried products hence increasing the total colour change. Diamante *et al.* (2010) found that hot air drying of gold kiwifruit slices at 80 and 100°C gave products with total colour changes of 18.3 and 25.6, respectively. Vacuum frying of unfrozen apple slices at 95 and 105°C for 15 minutes with 15 kPa vacuum resulted in products with total colour changes of 23 and 22, respectively which is almost constant but still above 20 units (Mariscal and Bouchon, 2008).

Table 2 also shows the mean values of the browning index of the different vacuum fried gold kiwifruit samples. The browning index values of the different samples were not significantly different for all frying processes or pre-treatment method. The samples from the 80°C for 50 minutes process gave the lowest browning index followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process. The browning indices of the soaked samples were significantly lower than the unsoaked samples from all processes. Frying the kiwifruit samples at higher temperature gave more darker and reddish fried products hence increasing the browning index. But soaking the kiwifruit samples in 33% maltodextrin solution and frying decreased the browning index of fried samples due to the coating on the surface of the products. Hot air drying gold kiwifruit slices at 80 and 100°C resulted in products with browning indices of 119.7 and 131.3, respectively (Diamante *et al.*, 2010).

Breaking force of vacuum fried gold kiwifruit

The mean values of the breaking force of the different vacuum fried gold kiwifruit samples are presented in Table 3. The unsoaked sample from the 80°C for 50 minutes process gave significantly lower breaking force than the sample from the 100°C for 25 minutes process. There were no significant differences in the breaking force of all soaked samples. This means that the texture of all samples were about the

same. The soaked samples gave significantly higher breaking forces than the unsoaked samples for the 80°C for 50 minutes process and the 90°C for 35 minutes process. In contrast, the soaked and unsoaked samples from the 100°C for 25 minutes process did not show this effect. Generally soaking the kiwifruit samples in 33% maltodextrin solution and frying resulted in a harder product texture due to the coating on the surface of the product. This is a desirable property since vacuum fried gold kiwifruit easily breaks up during handling. Perez-Tinoco *et al.* (2008) also found that there was a no trend in the breaking force when vacuum frying unfrozen pineapple slices with no pre-treatment at 108°C (2.3N), 112°C (1.9 N) and 116°C (2.5N) using approximately 7 minutes of frying time at a constant vacuum of 24 kPa.

Table 3. Mean values of breaking force and ascorbic acid content of vacuum fried gold kiwifruit processed with 2.3 kPa vacuum using different frying process and pre-treatment

Frying Process	Breaking Force (kg) [†]	Ascorbic Acid Content (mg/100g dry solids) [‡]
Fresh (no frying and pre-treatment) ^{###}	-----	583.0 ^{###}
80°C and 50 minutes		
Unsoaked	3.74a	281.8a (51.7%) ^{###}
Soaked ^{####}	4.24d	265.5ab (54.5%)
90°C and 35 minutes		
Unsoaked	3.96ab	238.1bc (59.2%)
Soaked ^{####}	4.36d	265.4ab (54.5%)
100°C and 25 minutes		
Unsoaked	4.00bc	187.6d (67.8%)
Soaked ^{####}	4.10cd	225.1c (61.4%)

where: # - mean values with the same letters are not significantly different from each other for that column at p<0.05
 ## - from Diamante *et al.* (2010)
 ### - value inside the parentheses is the % decrease based on the initial ascorbic acid content
 #### - soaked in 33% maltodextrin solution for one hour

Ascorbic acid content of vacuum fried gold kiwifruit

Table 3 also shows the mean values of ascorbic acid content of different vacuum fried gold kiwifruit samples. The initial ascorbic acid content of fresh gold kiwifruit was 528 to 641 mg/100g dry solids (Diamante *et al.*, 2010). Generally the samples from the 80°C for 50 minutes process gave higher ascorbic acid contents followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process. The percent decrease from the average initial ascorbic acid content of 583 mg/100g dry solids ranged from 51.7 to 67.8%, which was quite considerable. Frying the kiwifruit samples at higher temperature decreased the ascorbic acid content of the fried products due to the heat sensitivity of this vitamin. Diamante *et al.* (2010) found that there was no significant loss of ascorbic acid during hot air drying gold kiwifruit slices at 80°C down to a final moisture content of about 17% (w.b.) but there was about a 19% loss of ascorbic acid at 100°C. The soaked and unsoaked samples from the 80°C for 50 minutes process and the 90°C for 35 minutes process were

not significantly different from each other. However, the unsoaked sample had significantly lower ascorbic acid content than the soaked sample for the 100°C for 25 minutes process, inferring that pre-treatment with a 33% maltodextrin solution has a protective effect for ascorbic acid.

Optimum vacuum frying process for gold kiwifruit

Based on the results of the experiment, the gold kiwifruit slices soaked in 33% maltodextrin solution and vacuum fried at 80°C for 50 minutes and 90°C for 35 minutes with a 2.3 kPa vacuum gave products with optimum qualities based on the moisture content, oil content, colour values and properties, texture and ascorbic acid content. The results further suggest that a lower frying temperature and time will lead to a higher moisture content but lower oil content, total colour change, browning index and ascorbic acid content of vacuum fried gold kiwifruit. However, the effect of higher final moisture content of the vacuum fried product on its storage stability needs to be assessed.

Conclusions

Generally, the vacuum fried gold kiwifruit samples from the 80°C for 50 minutes process gave higher moisture content and lower oil content followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process. The pre-treatment (soaked or unsoaked) did not affect the moisture content or oil content of the samples fried using the 90°C for 35 minutes process.

The vacuum fried samples from the 100°C for 25 minutes process gave consistently higher total colour change and browning index, followed by the 90°C for 35 minutes process and then the 80°C for 50 minutes process, showing temperature to be an important determinant of the final colour. The total colour change and browning index of the soaked and unsoaked samples from the 90°C for 35 minutes process and the 100°C for 25 minutes process were not significantly different from each other.

The unsoaked sample from the 80°C for 50 minutes process gave significantly lower breaking force than the sample from the 100°C for 25 minutes process. There was no significant difference in the breaking force of all vacuum fried soaked samples. The soaked samples gave significantly higher breaking force than the unsoaked samples for the 80°C for 50 minutes process and the 90°C for 35 minutes process.

Generally the samples from the 80°C for 50 minutes process gave higher ascorbic acid contents

followed by the samples from the 90°C for 35 minutes process and then the 100°C for 25 minutes process. The percent decrease of ascorbic acid content ranged from 51.7 to 67.8% for vacuum fried samples, which was quite considerable. The ascorbic acid contents of soaked and unsoaked samples from the 80°C for 50 minutes process and the 90°C for 35 minutes process were not significantly different from each other. However, the unsoaked sample had significantly lower ascorbic acid content than the soaked sample for the 100°C for 25 minutes process.

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