REPORT

TRIAL RUN OF A MICROWAVE FURNACE: HEATING OF FRESH FRUIT BUNCHES

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Objective

The objective of the report is to record the trial run of a microwave furnace on the heating of fresh fruit bunches with a view to assess the potential of microwave energy for the sterilisation of fresh fruit bunches on a commercial basis. It is also aimed to confirm some of the observations of laboratory trials which have been carried out on spikelets of fruits using the domestic microwave oven.

Summary

The microwave system tested is capable of evenly heating a whole fresh fruit bunch. Within 10 minutes, the temperature of the fruits could reach an average of 70°C. However, not all the fruits were detachable or softened. Only some fruits from the outer layer of the bunch were detached. Water of condensation may be needed to effect fruits detachment. The fatty acid composition of the crude palm oil may be affected by microwave while the fatty acid composition of the kernel oil was not affected. The quality of the extracted crude palm oil and kernel oil was also not affected by microwave heating. Modification in the design of the furnace is necessary for further research and developmental work on sterilisation of fresh fruit bunches. The recommended specifications for such a furnace for research and developmental work is listed in Appendix I. Microwave in conjunction with other processes may be necessary to completely detach and soften the fruitlets of a whole bunch.

TRIAL RUN OF A MICROWAVE FURNACE : HEATING OF FRESH FRUIT BUNCHES

1. INTRODUCTION

An opportunity to assess the potential of microwave energy in heating the whole palm fruit bunches was taken when a microwave oven was made available by a manufacturer from Germany. This oven, a continuous microwave belt furnace (Fig. 1), is a mobile unit and can be transported to the place of an interested user quite readily.

In collaboration with the local agent the mobile microwave unit was set up at a palm oil mill where several tests on fresh fruit bunches were carried out.

1.1 THE MICROWAVE FURNACE

The system consists of a continuous microwave belt furnace with a heating zone diameter of 64 cm ,length 2000cm and a continuous belt width of 29 cm. It is fixed with 8 magnetrons capable of generating microwave at frequency 2450 kHz. The power of each magnetron is 800 watt but the power can be controlled between 15-100%.

There are openings at both ends of the microwave cavity where products to be microwaved are continuously fed in via the continuous belt .The opening was too small to introduce a bunch of palm fruits. Thus the cover was removed so that a bunch of palm fruits could be introduced into the center of the oven (Fig. 2).

1.2 TEST PROCEDURE

a. Test 1-5

Before microwave treatment, the fresh fruit bunch (ffb) was weighed and then thrown on to the floor at least 2 or 3 times to ensure that fruits which could be detached were removed. After the bunch had been put into the furnace the cover was screwed back.

Three bunches were microwaved separately for 10,20 and 50 minutes respectively (Test 1,2 and 3). Another bunch was immersed in water for 30 minutes prior to being microwaved for 20 min. (Test 4). Another bunch was crushed with a roller crusher before microwaved for 50 minutes (Test 5).

In every test after microwave treatment, the bunch was removed from the oven and the temperatures of the outer and inner layer of fruits immediately determined by inserting a thermocouple into the respective layers of fruits (Fig. 3a) The positions were identified as C_1 core, F_2 inner and F_3 outer layer fruits (Fig. 3b) .

Besides attempting to detach some of the fruits manually (Fig. 4), the bunch was again thrown on to the floor another two /three times to determine whether any more fruits could be detached.

The bunch was then axed longitudinally into two halves and the temperature of the core,C_A and innermost layer of fruits, F_A determined (Fig. 5).

b. Extraction of Crude Palm Oil and Kernel Oil

For every test, some of the detached fruits were collected and the mesocarp peeled and dried. The nuts were cracked and the kernel dried. The dried mesocarp and kernel were Soxhlet extracted separately to obtain the respective crude palm oil and kernel oil.

c. **Fatty Acid Composition**

The fatty acid composition of the oils were determined by gas chromatography according to PORIM's Method.

d. **Quality Analysis**

Some quality parameters of the crude palm oil were determined using PORIM's Method. They are Oxidative Stability by Rancimat, free fatty acid content, Degree of Bleachability Index (DOBI) and carotene content. For kernel oil only the free fatty acid content was determined.

1.3 RESULTS

a. *Test 1*

Weight of Bunch :7.5 kg

Power: 800w x 5 Magnetrons

Time of Microwave Heating : 10 mins.

Fruits Detachability: Only some fruits from outer layer were detached.

Visual Observation after Microwave: Fruits were fresh orange red similar to fresh bunch.

Fibrous core was fresh and pale beige in colour.

Table 1A: Temperature of Fresh Fruit Bunch after Microwave Heating.

Core, C_1 (^{O}C)	Inner Layer Fruits, F_1 (^{O}C)	Outer Layer Fruits, F_2 (^{O}C)
69	69	71

Table 1B: Temperature of Longitudinally Halved Bunch.

Core, C_A (^{O}C)	Inner Fruits, F_A (^{O}C)
37	35

b. ***Test 2***

Weight of Bunch : 8.0 kg

Power: 800w x 5 Magnetrons

Time of Microwave Heating:20 mins.

Fruits Detachability: Only some fruits from outer layer were detached.

Visual Observation after Microwave: The surface of the fruits were shiny indicating oil leaching from the mesocarp to the surface. Fruits were relatively softened compared to fresh fruits.

Table 2A: Temperature of Fresh Fruit Bunch after Microwave Heating.

Core,C_1 (^OC)	Inner Layer Fruits,F_1 (^OC)	Outer Layer Fruits,F_2 (^OC)
93	88	82

Table 2B: Temperature of Longitudinally Halved Bunch.

Core,C_A (^OC)	Inner Fruits,F_A (^OC)
50	71

c. *Test 3*

Weight of Bunch Before Microwave:11.0kg

Weight of Bunch After Microwave:8.5 kg. Computed at 23% wt. loss

Power: 800w x 5 Magnetrons

Time of Microwave Heating: 50 mins.

Fruits Detachability: Only some fruits from outer layer were detached. Some of the inner fruits were easily manually detached .

Visual Observation after Microwave Heating : Surface of fruits were dried and brittle but not scorched. The fruits were not softened. Kernels were browned . (Fig. 6). Core was fresh and wet.

Table 3A: Temperature of Fresh Fruit Bunch after Microwave Heating.

Core,C_1 (^{O}C)	Inner Layer Fruits,F_1 (^{O}C)	Outer Layer Fruits,F_2 (^{O}C)
95	92	87

Table 3B: Temperature of Longitudinally Halved Bunch.

Core,C_A (^{O}C)	Inner Fruits,F_A (^{O}C)
42	81

d. *Test 4*

Weight of Bunch: 7 kg

Power: 800w x 5 Magnetrons

Time of Microwave Heating :20 mins.

Bunch Treatment: Bunch immersed in water for half an hour before microwave heating (Fig. 7).

Fruits Detachability: Only some fruits from outer layer were detached.

Visual Observation after Microwave: Fruits looked fresh in colour but were not softened. Kernels were not burnt.

Table 4A: Temperature of Fresh Fruit Bunch after Microwave Heating.

Core,C_1 (^{O}C)	Inner Layer Fruits,F_1 (^{O}C)	Outer Layer Fruits,F_2 (^{O}C)
69	67	47

Table 4B :Temperature of Longitudinally Halved Bunch.

Core,C_A (^{O}C)	Inner Fruits,F_A (^{O}C)
65	37

e. *Test 5*

Weight of Bunch: 15 kg.

Power: 800w x 5 Magnetrons

Time of Microwave heating: 50 mins.

Bunch Treatment: Whole bunch was crushed with a roller crusher. Only a portion of the crushed bunch was put into the oven (Fig. 8).

Fruits Detachability: Fuitlets were not detachable.

Visual Observation after Microwave: The fibrous core was dried .The fruits visibly look fresh . Some kernels were browned.

Table 5: Temperature of Crushed Fruit Bunch after Microwave.

Fibrous Core (^{0}C)	Fruits (^{O}C)
36-38	38-60

f. ***Fatty Acid Composition of Extracted Oil.***

Table 6 : Fatty Acid Composition of Crude Palm Oil (%)

Source / Fatty Acid	Test 2	Test 3	Test 4	Test 5
C14:0	1.1	1.0	1.0	1.2
C16:0	41.5	48.2[1]	42.9	48.9[1]
C18:0	4.9	3.2	3.9	3.5
C18:1	42.9	36.4[2]	40.4	32.0[2]
C18:2	8.3	10.1	10.9	12.6
Others	1.3	1.1	0.9	1.8

[1]Composition out of normal range 41.1-47.0%
[2]Composition out of normal range 38.2-43.5%

Table 7: Fatty Acid Composition of Palm Kernel Oil (%)

Source / Fatty Acid	Test 2	Test 3	Test 4	Test 5
C8:0	3.7	4.0	3.8	4.1
C 10:0	3.2	3.8	3.6	3.5
C 12:0	49.5	52.5	52.1	51.5
C 14:0	16.9	16.2	16.1	16.6
C 16:0	8.0	7.5	7.5	7.9
C 18:0	1.7	1.8	1.6	1.7
C 18:1	14.2	11.8	12.8	12.0
C 18:2	2.4	2.0	2.1	2.2
Others	0.4	0.4	0.4	0.5

g. *Quality of Extracted Oil*

Table 8: Quality of Crude Palm Oil

Source / Parameter	Test 2	Test 3	Test 4	Test 5
Rancimat at 120°C (Hrs)	15.9	9.05	8.33	8.42
Free Fatty Acid (%)	0.59	1.65	1.71	2.35
Carotene (ppm)	766	643	475	716
DOBI	3.55	2.63	3.08	3.16

Table 9: Free Fatty Acid Content of Palm Kernel Oil

Source Parameter	Test 2	Test 3	Test 4	Test 5
Free Fatty Acid (%)	0.10	0.20	0.29	0.22

1.4 DISCUSSION

a. *Temperature*

Test 1 indicated that when a whole bunch was heated the outer ,inner fruits and the upper portion of the core could reach at least 69°C within a short period of 10 minutes (Table 1A).

There was no significant temperature difference between the temperature of the inner (69°C) and outer layer of fruits (71°C). The outer fruits were relatively evenly heated as the temperature ranged from 55-84°C when the thermocouple was randomly probed around the whole bunch . This indicated that there was no localised heating which was observed in one other previous trial; also carried out on a whole bunch of fruits.

The thermocouple was not able to penetrate right into the center of the bunch thus it was necessary to split the bunch to determine the temperature of the center of the bunch. In this respect the strippability of the inner fruits could also be determined. The temperature of the longitudinally halved bunch indicated a relatively lower temperature of 35°C and 37°C at the core, C_A and inner fruits, F_A respectively (Table 1B). This lower temperature was partially due to the time lapse when the bunch was thrown to the ground for the detachability test and once the bunch was split there was further drop in temperature. However, the higher temperature observed above the ambient temperature did indicate that the inner core could be heated within the 10 minutes.

In Tests 2 and 3 where the bunches were heated longer there was a further rise in the temperature of the core ,inner and outer layer fruits. After 30 minutes of heating the temperature of the core, inner and outer layer fruits were recorded at 93°C, 88°C and 82°C respectively (Table 2A) .When heating was extended to 60 minutes, the temperature was further raised to 95°C, 92°C and 87°C at the core, inner and outer layer fruits respectively (Table 3A).

In the split bunch, the inner core of the bunches showed a lower temperature of 50°C and 42°C compared to a higher temperature of 71°C and 80°C of the inner fruits when the bunches were heated for 30 and 60 minutes respectively (Table 2B and 3B).

For Test 4 a ffb was immersed in water before microwaved for 20 minutes . The temperature of the outer layer fruits could reach up to 47°C (Table 4). A bunch which was also heated for the same period of 20 minutes but not immersed in water before heating (Test 1) recorded a higher temperature of 71°C (Table 5). The lower temperature of the soaked bunch could be due to the energy being used in evaporating the water which were adhered on the surface of the palm fruits and interstices of the bunch instead of being used to heat the water in the fruits. Similarly, the higher temperature of the core was attributed to better absorbance of microwave energy of the core as it has a higher water content than the mesocarp. Polar molecules such as water are very susceptible to microware and as such are able to absorb microwave energy better than triglycerides resulting in the core getting heated up more rapidly.

In Test 5, where the bunch was crushed with an experimental crusher, only a portion of the crushed bunch was heated. After microwave heating, the fibrous core became very dried and a low temperature of 36-38°C were recorded (Fig.8). The fruits were not detachable. The temperature of the heated fruits were also relatively low, ranging from 38-60°C. This test confirmed the finding in Test 4 where the fibrous core was more sensitive to microwave energy. The core gets heated so rapidly that it is dried. The heating of the oil or fruit bunches is thus a consequence of the heating of the water inside the fruits. Subsequently, the palm fruits and triglycerides get heated too. As the water is energised and evaporated, some of the energy is transferred to the fruits.

It was noted that in the design of the furnace, there was an exhaust fan at one end of the furnace to draw the water vapor and thus the bunches that were heated were all dry with no droplets of condensed water on the bunch . Unlike that in the laboratory study, water condenses on the spikelet of fruits when a spikelet is microwaved. In the laboratory test good detachment and softening of fruits were observed. It may be some moisture ,water/steam at the point of detachment i.e. between the pedicel and the base of the subtending bracteoles and base of the fruits may enhance fruit detachment. In the conventional milling process where prolonged steam is used to heat the bunches, the fruits are easily detached.

b. ***Visual Observation and Fruits Detachability***

In Test 1 when the bunch was heated for 20 minutes, there was no obvious visual changes to the fruits . The fruits were brightly yellow orange red in colour. Only some fruits from the outer layer of the bunch were detached when the microwaved bunch was thrown to the ground. The fruits were slightly softened. The same visual observation was made from Test 4 where the bunch was immersed in water before microwaved for 20 minutes.

Under Test 2, when the bunch was heated for 30 minutes, the fresh orange to red colour was retained but the surface of the fruits became shiny indicating leaching of oil from the mesocarp although the kernels were not browned. Only some fruits from the outer layer of the bunch were detachable and the fruits were slightly softened.

In Test 3 as the heating was prolonged to 60 minutes, the kernels were browned (Fig. 6). The surface of the fruits were visibly dried but the amount of fruits detached were negligible although some of the inner fruits were detachable.

In Test 5 the fruits visibly looked fresh and not dried but some of the kernels were browned. The fibrous core was visibly dried.

c. *Fatty Acid Composition and Quality of Extracted Oil.*

The fatty acid composition of the crude palm oil from a soaked and unsoaked bunches that were heated for 20 minutes (Test 2) and (Test 5 respectively) had fatty acid composition that was within the range of that in commercial crude palm oil (Table 60). However ,the fatty acid composition of the palm oil extracted from the bunch that was microwaved for an hour and the crushed bunch that was microwaved for 50 minutes indicated a relatively high percentage of C16:0 and a low percentage of C18:1. However, the fatty acid composition of the kernel oils from Tests 2-5 were within the range of commercial kernel oils (Table 7A).

The quality of the palm oil and palm kernel oil was also within the range of these two types of oil (Table 8 and 9).

1.4 CONCLUSION

In general the trial indicates that a whole bunch of palm fruits can be heated rapidly using a microwave furnace. This rapid rise in temperature may possibly be utilised in conjunction with the conventional steam sterilisation in the mill to effect complete detachment and softening of the ffb.

The trial also indicates that there is a different rate of heating in the core and different layer of fruits of the whole bunch. This may be due to the different chemical and water composition which absorb different degree of microwave energy.

The trial also indicates that the use of this microwave furnace which is designed for heating and drying purpose, may not be appropriate for the processing of palm bunches and will not meet the conventional objectives of mill sterilisation i.e. fruit detachment, softening of the mesocarp ,kernel conditioning and enzymes deactivation. In this trial only some of the outer fruits from a whole were detached while the fruits were slightly softened and in extreme heating the kernels were browned. At such a high temperature of 60°C the enzymes were probably deactivated .The detachment of inner layer of fruits from the bunch was not achieved.

It is of the view that the design of this microwave system will need to be modified to facilitate further research and development studies . This should include continuous feeding of the ffb and monitoring of the temperature at various position of the ffb as it is microwaved. Water from the ffb which will be converted to steam in the process may need to be retained to improve the detachability of the fruits. A technical computation on the energy consumption required to heat per mass of ffb to the required temperature is necessary to specify the actual power output for the design of the microwave oven.

The physiology of natural ripening requires the synthesis of ethylene which initiates biochemical changes involving the cells at the base of the mesocarp and the pedicel which leads to fruit abscission. In the processing of fresh fruit bunches in the mill, the physiology and chemistry of forced fruit detachment /abscission is not well understood. Although it is an established technology that prolonged steaming can achieve fruit detachment; a better understanding of physico-chemico changes necessary to detach fruits from a harvested bunch may be necessary before any attempt is made to introduce the optimum conditions required to detach fruits from a cut bunch.

It is pertinent to stress that microwave is just another method of heating which polar molecules water, is very susceptible to. In the process of absorbing this particular wavelength the molecules are excited and in returning to the ground state much energy in the form of heat is dissipated leading to rapid heating. Thus the use of microwave can be extended to other processes in the mill such as drying of fibres, nuts and sludge too.

The chemical composition and quality of the mesocarp oil and palm kernel oil is not expected to be altered by microwave but in this trial the fatty acid composition show otherwise. This fact however needs to be reconfirmed as laboratory studies (not reported) did not indicate any fatty acid variations. In terms of the energy consideration, microwave radiation is of low energy, about1 joule per mole of photons. This when compared to bond energies (H-bonds=20 kJ/mole, C-H bond energy=350 kJ/mole), seems unlikely to preferentially rupture any chemical bonds. Any chemical compositional changes could be due to superheating at certain hot spots of the bunch.

The temperature of the fruits were shown to be all below 100°C. It is not possible for the temperature to reach beyond that of the boiling point of water i.e. 100°C as the most abundant polar constituents in ffb is water unless there is localised superheating at certain hot spots. .At such a temperature which is below that of the conventional sterilisation in the mill, at about 120°C under steam pressure, no deterioration of quality is expected as compared to the conventional processing of fruit bunches.

Fig.1 : The Continuous Belt Microwave Furnace. Note Small Opening.

Fig. 2: The Front Cover of Furnace Removed to Accommodate a Whole Fresh Fruit Bunch.

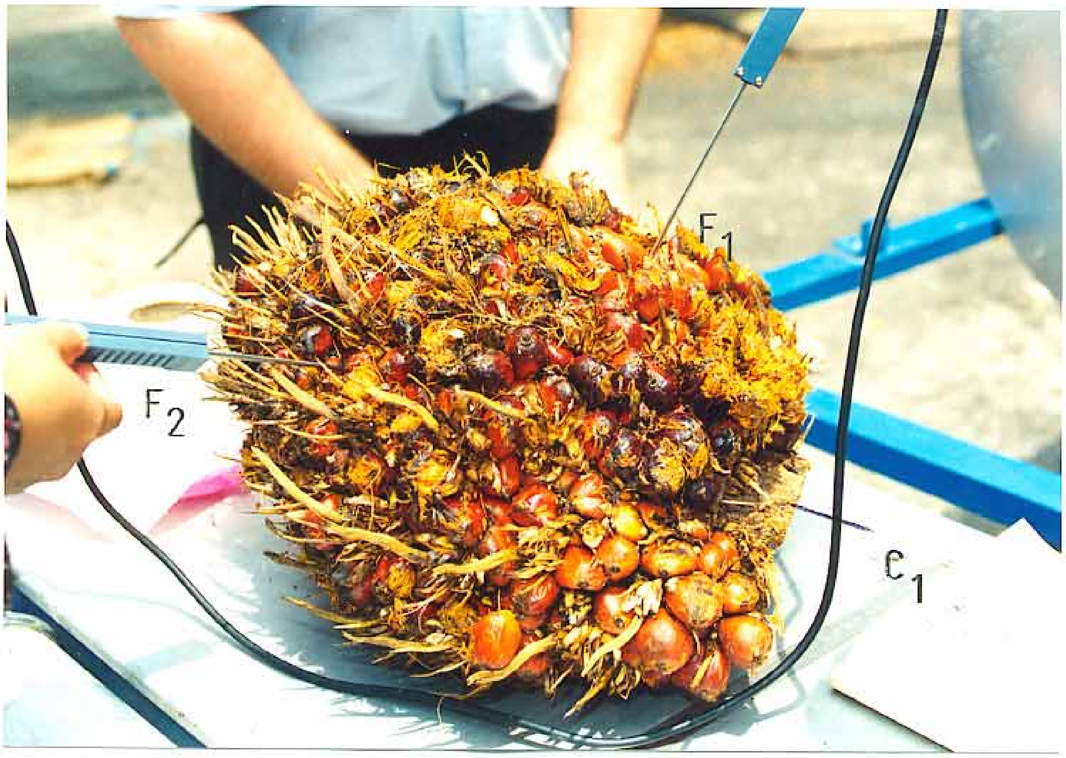

Fig. 3a: Themocouples Inserted into the Respective Position of the Whole Bunch.
F_1:Outer layer of fruits, F_2:Inner Layer of Fruits, C_1:Core of Bunch

Fig. 4: Detaching Fruits Manually.

Fig. 5: Longitudinally Axed Bunch indicating the Positions where the Temperatures were taken. C_A :Core, F_A: Innermost Fruits

Fig. 6: Browned Kernels due to Excessive Heating.

Fig. 7: Bunch Immersed in Water before Microwave.

Fig. 8: Portion of Crushed Bunch after Heating. Note Very Dried Fibrous Core.

Specifications for a Continuous Microware Oven for Research and Developmental Purpose in the Palm Oil Mill.

a. Adjustable Power, to be able to step up and down the power supply
b. Sufficient number of magnetrons installed along the cavity .The individual. magnetron can be selectively controlled during processing.
c. Continuous durable belt able to withstand vegetable oils and bulky bunch.
d. Exhaust facilities along the furnace.
e. Openings along the top of the cavity for incorporation of water/steam.
f. Big opening of at least 80 cm in diameter.
g. Capable of heating 25 kg fresh fruit bunch to at least 90^0C within 5 minutes; including the inner most layer of fruits.
h. International safety standards incorporated.

Accessories: Compatible temperature sensors to determine the temperature of fruits as they are microwaved.
: Detector for microwave leakage.