Tropical Agricultural Research Vol. 13: 100-111 (2001)

Quality Improvement in Cottage Level Cashew Processing Through Modification of Dryers

V. Hidellage and U. Samarajeewa[1]

Postgraduate Institute of Agriculture
University of Peradeniya
Peradeniya, Sri Lanka

ABSTRACT. Quality of processed cashew kernels deteriorates at each processing step from shelling to final stages of export in conventional method of processing. Therefore, an attempt was made to increase the quality of processed cashew kernels by introducing appropriate technology; equipment, processing methods and practices. This study was focussed on developing and testing a dryer at cottage level. A semi continuous tray dryer was modified to reduce its size, capacity and tray moving operation. The modifications were carried out after deriving theoretical values of airflow; temperature and size of trays and heat exchanger to suit the dryer for cottage level processing. It was further modified based on field experiments with processors. The dryer performance was evaluated by monitoring the heat distribution and the airflow within the drying chamber against the theoretical values. The quality of processed kernels was compared with the standards required by the buyers. The fabrication costs and operation difficulties of the dryer were reduced to suit requirements of users. Four successive model dryers were fabricated rectifying problems of each model. Model IV recommended for cashew processing has a drying temperature between 50-70°C, airflow of 0.1-0.7 m/s and cost Rs. 26,000/-. Changes introduced in the sequence of unit operations in cashew processing helped to improve the quality of processed cashew. The major change brought about in the sequence was peeling kernels after drying. Whole kernels were graded by size and packed soon after peeling. Modified dryer and the processing methods introduced, helped to increase income of cashew processors by reducing average defect of dried kernels from 13-4% and increasing percentage of whole kernels from 55-67.

INTRODUCTION

Cashew is an important export crop that brings about Rs. 142 million foreign exchange annually (Central Bank, 1999) and creates employment for about 30000 people, mostly poor, in the rural informal sector (Ariyabandu and Hidellage, 1994). Cashew processing in Sri Lanka can be identified in two phases. Each of these phases is different from the other by the nature of persons engaged/employed and location of processing. An initial phase of home/cottage based processing is followed by the second phase that is continued at collecting centres. Inadequate technology and practices, insufficient knowledge and skill level of processors and subsistence nature of cottage level operation contributed to accumulation of quality defects in cashew kernels as processing proceeded from initial cottage level to exporters through collecting centres (Hidellage and Samarajeewa, 1999). The study discusses the improvements in operation and product

---

1 Department of Food Science and Technology, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

quality that resulted from the modification of cashew drying technology and testing it with processors.

MATERIALS AND METHODS

The experiments on drying behaviour of kernels were conducted at Cathy Rich Memorial Food Processing Centre, Embilipitiya, Sri Lanka. The dryer was fabricated in Asoka Industries; a small workshop in Matara and the trials with modified dryers were conducted in Vanathavilluwa in a hut (3×3×4 m), with the participation of 16-25 processors. Cashew kernels having a moisture content of 8-10% (dry basis) within 24 h of shelling, obtained randomly from the processors were used for the experiments.

Drying pattern of kernels

Kernels with testa (200 g ×10) were dried (electrical dryer 1000 W, 60×60 cm, 4 trays, 8" fan, 30-110°C with a thermostat) at 55±2°C and weighed hourly, for 20 h. The rate of drying with time and moisture content on dry matter basis was determined, assuming that the flow of air and the RH of air remained constant during the experiment.

Modification of selected dryer

The selected tray dryer (Table 1) was tested with processors and feedback was obtained. Criteria for redesigning the dryer was decided based on the feedback.

Airflow requirements

The modified dryer carried 13 trays as in the original, and a reduced capacity to dry 60 kg/8 h, to suit processing capacities at cottage level. Amount of hot air (70°C), required to dry kernels from 10-5% moisture (to maintain 55°C average drying temperature), was calculated, using the psychometric chart.

Holding capacity of a tray was determined based on the assumption that drying time is 20 min/tray, after an initial pre-heating period of 3 h, as in the tray dryer. The size of a tray was derived experimentally by measuring the area needed for 2 kg of kernels in a single layer. The expected airflow inside the modified dryer was calculated based on tray area and air requirement.

Size of heat exchanger

Heat required for drying, was derived using the heat balance equation between heat in the incoming and outgoing air (Chupakhin and Dormenko, 1976). The area of heat transfer was estimated considering the heat exchange between flue gases and air ignoring radiation (Salisbury, 1950).

Table 1. Description of selected tray dryer and modified dryers Models I-IV.

Tray dryer	Model I	Model II	Model III	Model IV
Size/Appearance				
• Size: 1.8×1.6.×4.5 cm • Wooden cabinet with 13 mesh based trays with 0.4 m gap on a side • Trays (12 kg) stacked alternately • Cost: Rs. 75,000/-	• Size: 1×1×2.8 m • Plywood, cabinet with 13 full mesh based trays • Trays (6 kg) stacked on top of each tray • Cost: Rs. 45,000/-	• Size: Same as Model I • Plywood cabinet interior lined with GI sheeting • Trays same as Model I • Cost: Rs. 40,000/-	• Size: Same as Model I • Plywood cabinet with 6 trays. Tray heights doubled compared to Model II • Trays (9.5 kg) stacked as in Model II • Cost: Rs. 36,000/-	• Size: 0.9×0.8×2.4 m • Plywood cabinet exterior lined with GI sheets provided an observation window • 6 trays (4.5 kg); 0.3 m gap on a side stacked alternatively • Cost: Rs. 26,000/-
Tray Moving Mechanism				
• A lever lifts all trays except the bottom, which is removed and upper trays lowered creating space on top for loading a tray through a door	• Wheel at the base of the cabinet replaced the lever to operate trays • Same tray operation and movement	• Tray operation same as Model I • Tray guide placed on the horizontal bar to operate with the wheel guided tray movement.	• Operation same as Model II • A wedge system replaced the guide for balanced tray movement	• Operation was same as in Model III • A hydraulic jack placed below the trays connected to operating wheel facilitated tray movement.
Heat Supply System				
• Kerosene oil burner	• Two stoves (RPRDC[1] design) placed under the cabinet, connected to rectangular mild steel tube heat exchanger (0.9×5 m) placed below trays and above stoves • Perforated mild steel sheet 0.9×0.9 m placed above heat exchanger	• Single traditional stove placed 1 m away from drying chamber, replaced RPRDC stoves • Heat exchanger placed perpendicular to the drying chamber, had less bolts and smooth bends compared to Model I	• Same as Model II • Chimney was shifted 0.3 m away from the back wall of cabinet	• Same as Model III • Perforated mild steel sheet 0.8×0.7 m placed above heat exchanger
Airflow				
• Natural convection • Perforated bottom for air inlet • Air outlet (0.2 m) on the cabinet roof	• Natural convection • Air inlet: perforated bottom and vents on the side of heat exchanger • Air outlet same as in tray dryer	• Natural convection • Air inlet: perforated bottom and vents on the side of heat exchanger • Air outlet: Two top vents and outlet on the roof that sloped with roof towards chimney	• Natural convection • Air inlet: bottomless cabinet • Single adjustable vents on the roof. Air outlet connected to a tube that is placed inside the chimney	• Natural convection • Air inlet: bottomless cabinet • Vents removed. Alternatively stacked trays to get zigzag air flow as in the original dryer • Base of the chimney sloped diameter reduced to 0.8 m. Height increased to 5 m

[1] - Paddy husk/saw dust stove developed by the Rice Processing and Research and Development Centre (RPRDC), Anuradhapura.

Experiments with modified dryer

The dryer (Model I) was modified using above estimates. Model I was field tested with processors to monitor drying conditions. Distribution of temperature and air within the drying cabinet, quality of dried kernels and acceptability (cost and the operation) of users were monitored.

Heat and airflow in drying

Temperatures at the heat exchanger inlet and difference between heat exchanger and flue gas outlet were measured. Fuel and labour consumption in stove operation was monitored to assess their performance. Temperature and airflow measurements were taken at each tray level. Temperature measurements were also taken at the front and back of the top, middle and bottom trays. Temperature and airflow were measured 2 h after start of operation and every hour thereafter. Time spent to dry each tray load was recorded.

Quality of kernels

Quality was derived by estimating percentage of broken kernels and kernels with defects and comparing with dried kernels obtained through current methods. Kernels (100 kg) graded to wholes, splits and pieces. Each grade was weighed, dried and the weight of each grade recorded. Dried kernels (100 g) collected randomly from every other tray were peeled separately and packed in 200 gauge polypropylene bags. Kernels in randomly selected 10 packages were examined after 10 days to identify quality defects in relation to colour, black spots, appearance of the surface, case hardening and taste. The colour was evaluated using a hedonic scale of 1-10 with a range of light grey as 1 to ivory to light yellow as 10. Kernels with more than 1/10 of surface covered with brown patches or 25% scratched/scraped losing its characteristic shape were also identified as defective.

Kernels (100 g) stored for 2 weeks in airtight container, were checked for case hardening by probing centres using a needlepoint to identify texture difference due to trapped moisture. "Cooked" taste was examined by 10 randomly selected untrained panellists consisting of 5 men and 5 women between 23-56 years from Puttalam. Affordability and the problems associated with operation of the dryer were monitored through observation and feed back of processors.

Modification process

The Model I was further modified based on the results of the experiments, and the same seven experiments were repeated with the Model II. Modification was carried out sequentially in 3 steps to develop 4 models of dryers (Table 1). At each step, the dryer was improved based on the performance of the previous model. All drying experiments were repeated 10 times to obtain average data.

RESULTS AND DISCUSSION

Drying pattern of cashew kernels

Drying curves of kernels were not smooth, but indicated patterns similar to typical solid drying curves (Fig. 1 and 2).

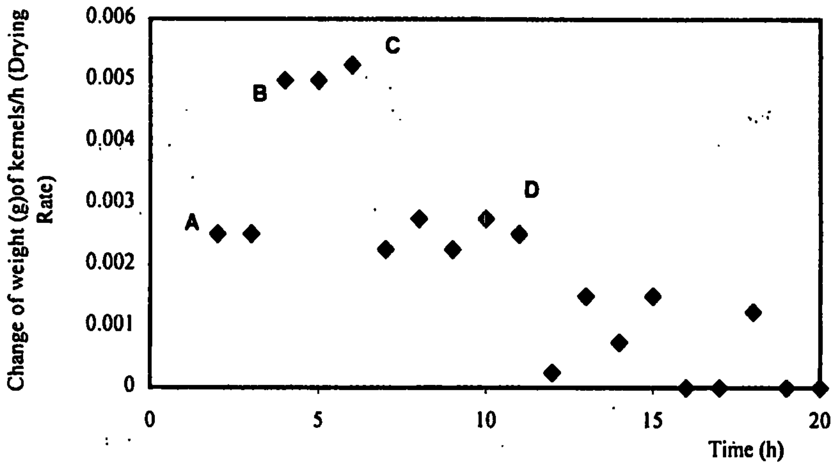

Fig. 1. Change of rate of drying of kernels with time at 55°C under laboratory conditions.

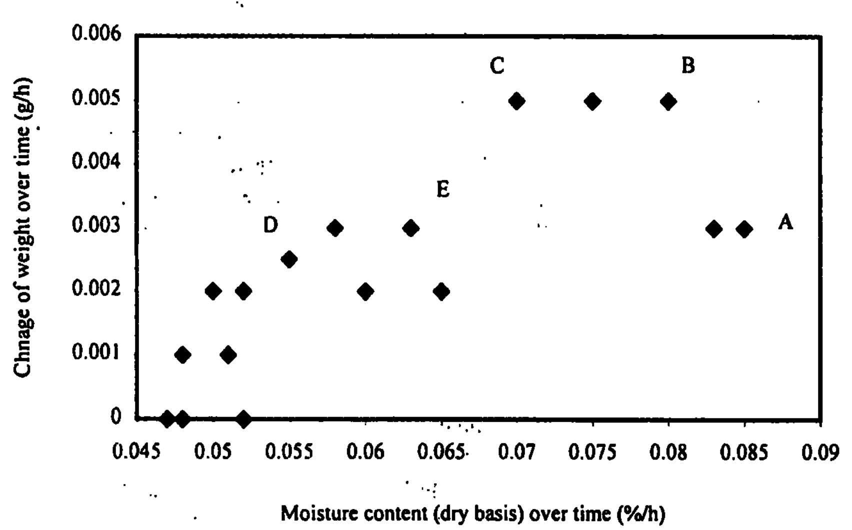

Fig. 2. Change of rate of drying of kernels with moisture content at 55°C under laboratory conditions.

According to the drying curves (Fig. 1 and 2) warming up (A-B) took 2 h followed by constant rate of drying (B-C) that lasted for about 2 h. The critical moisture content (dry basis) of 7% (C) was reached after 6 h of drying. Initial stage of falling rate period [evaporation from unsaturated surface (C-E)] was 2 h. Drying continued to a 3 h phase where the evaporation is governed by internal moisture movement (E-D). Kernels reached the recommended moisture level of 5.5% (Bureau of Ceylon Standards, 1976) after 11 h at 55°C. This necessitated reducing drying time to improve commercial applicability.

At constant rate period, temperature has an exponential effect on drying rate due to the increased evaporation from saturated surface (Henderson and Perry, 1979). Increasing temperature during this period is not recommended as it could lead to case hardening. A continuous airflow around drying kernels must be maintained to accelerate drying soon after moisture content falls below the critical. The moisture diffusion from the drying surface is the determining factor in drying in this zone. When the drying enters second zone of falling rate period (E-D), relatively high temperature around 70°C, would accelerate drying by facilitating better internal moisture movements in kernels (Henderson and Perry, 1979). Maintaining 55°C at the top of the drying cabinet and 70°C at the bottom recommended. Air velocity inside the cabinet should be within specified 0.5-1.5 m/s (Axtell and Bush, 1991). The flow should be higher at the end of drying cycle.

Determination of key criteria for modification of the selected dryer

Airflow requirement

Air entering the heat exchanger, at RH 70% and 30°C had moisture content of 0.02 kg/kg air and wet bulb temperature of 25.2°C. The maximum amount of moisture that air at 70°C, could absorb was 0.022 kg/kg air. Air entering the dryer would pick up moisture up to 0.002 kg/kg air. The amount of moisture that air would practically pick would be 0.001 kg/kg air, when the capacity of air to pick up moisture is calculated as 0.5.

Moisture in 60 kg of kernels at average 10% moisture content was 6 kg. Weight of bone dry kernels was 54 kg. If the kernels were dried to final moisture of 5.5%, the dried kernels would contain 2.82 kg moisture. This means that 3.2 kg moisture should be removed from kernels. Air required to pick 3.2 kg moisture was calculated as 3200 kg (at the rate of 0.001 kg/kg).

The area required to spread 2 kg kernels in a single layer was 1500 cm^2. The design of dryer necessitated that each tray holds 4 kg and this required an area of 3000 cm^2. The tray dimensions, which are also equal to those of a cross section of drying cabinet, should be convenient for operation. On this basis, 70×40 cm (3000 cm^2) was recommended as dimensions for fabricating trays.

The volume of 3200 kg air is 2286 m^3, at the assumed average temperature of 55°C inside the drying cabinet (specific volume of air at 55°C is 1.4 m^3/kg). This amount of air should flow through the tray area of 3000 cm^2, during a period of 8 h to dry 60 kg kernels. It should therefore travel 7619 m with a velocity of 0.3 m/s.

Heat requirement in drying

Heat balance was determined by considering the incoming and out going heat with the air.

Q, Q_l	Incoming heat and loss	kj/h
L	Amount of dry air passing through the plant	kg/h
I_o I_l I_2	Specific heat of air entering and leaving heat exchanger and leaving dryer	kj/kg
θ_1 θ_2	Temperature of kernels entering and leaving the dryer	°C
τ_1 τ_2	Initial and final temperature of handling devices	°C
C_t, C_k	Specific heat of trays and kernels	kj/kg. deg
G_t, G_k	Weight of trays and cashew kernels	kg
W	Moisture in drying kernels	kg

As the gains and losses will be equal:

$$L I_o + W\theta_1 + G_k C_k \theta_1 + G_t C_t \tau_1 + Q = L I_2 G_k C_k \theta_2 + G_t C_t \tau_2 + Q_1$$

According to literature, specific heat of nuts was 0.29 (Henderson and Perry, 1976), wood and mesh were 0.65 and 0.12 respectively (Perry *et al.*, 1997). The weight of the trays was assumed to be 6 kg (frame 5.5 kg + mesh 0.5 kg) equal to half the weight of a tray of the original dryer. Heat loss (Q_1) was taken as 5% of total heat.

Substituting values for the above equation:

$$[3200\times(85*4.2)] + (6\times30) + (54\times1.2\times30) + [(71.5\times2.7\times30) + (7\times0.54\times30)] + Q$$
$$= [3200\times(125*4.4)] + (54\times1.2\times70) + (71.5\times2.7\times70) + (7\times0.54\times70) + 0.05Q$$

Total heat required to dry 60 kg kernels:

Q = 576841 kj = 546770 Btu/8h = 68346 Btu/h

Area of the heat exchange:

Rate of heat transfer q = $UA\Theta_m$ (Btu/h)

A = area of heat exchange (f^2) U = overall coefficient of heat transfer (Btu/h f^2)
Θ_m = mean temperature difference of cross flow heat exchange
Θ_m can be derived by:

$$\Theta_m = F(T_1 - t_2) - (T_2 - t_1) / [\ln (T_1 - t_2) / (T_2 - t_1)]$$

T_1 and T_2 are the inlet and outlet temperatures of air (°F) and t_1, t_2 were inlet and outlet temperature of the flue gases (°F). The correlation factor F was derived through the graphs of Bowman Muller and Nagale (Henderson and Perry, 1976), after calculating the values of X and Z. The X and Z are derived through:

$$X = (t_2 - t_1) / (T_1 - t_2) \qquad Z = (T_1 - T_2) / (t_2 - t_1)$$

$X = 0.14$ and $Z = 5.0$ By substituting the above with the following values:
$T_1 = 350°C$ (662°F) $T_2 = 150°C$ (302°F); (Assumed based on known patterns);
$t_1 = 30°C$ (86°F) $t_2 = 70°C$ (158°F); (Based on the given values above)
Based on Z and X the F = 1. Substituting F, and temperature values $\Theta_m = 51$ Btu
If U = 50 (Henderson and Perry, 1976), substituting the values of Θ_m and q to the equation
$q = UA\ \Theta_m = 50 \times A \times 51$ $A = 28.4\ f^2 = 26.8 \times (9.3 \times 10^{-2}) = 2.6\ m^2$
Calculated value for area of the heat exchanger was 2.6 m^2 (Πdh). If radius of the mild steel tubes used for heat exchanger was 12 cm, length of tubes = 7 m

Experiments with the dryers

Heat distribution

The Model I had inadequate drying temperature at the top (47°C) of cabinet (Fig. 3). The output of dried kernels has decreased (1.9 kg/h) on continuous operation (Fig. 4), while unabsorbed heat in flue gases increased gradually. Accumulated deposits of burning residues were found inside heat tubing acting as barriers to heat exchange. Stoves had operational problems increasing labour consumption (3.5 person h/day) and waste of fuel, paddy husk (26%).

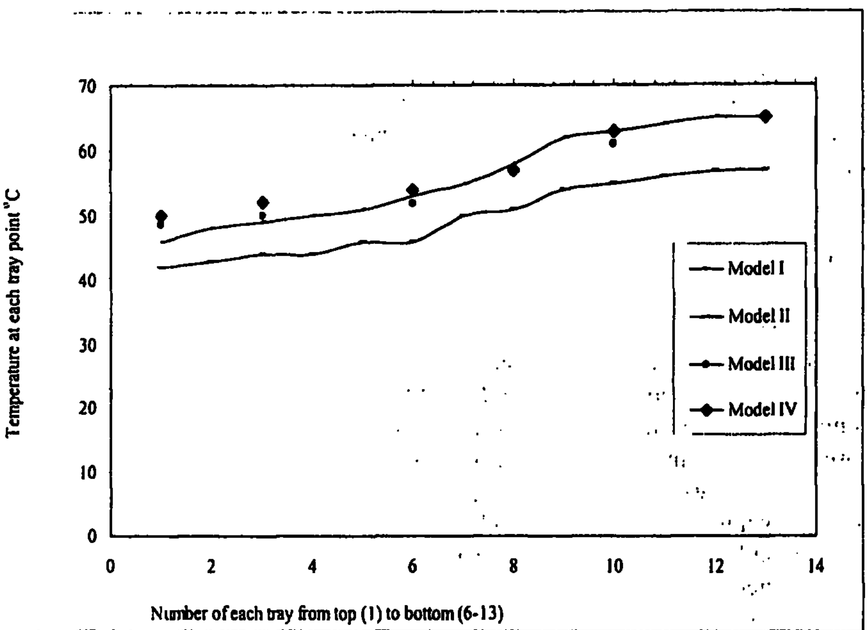

Fig. 3. Distribution of temperature inside drying cabinet in the Models I-IV.

Model II with modified tubing and stove design, facilitated continuous heat supply reducing labour and fuel wastage to 1.75 labour h/day and 4% respectively. Smooth curvatures of tube bends reduced build up of deposits inside tubing. There was provision for easy maintenance in the Model II.

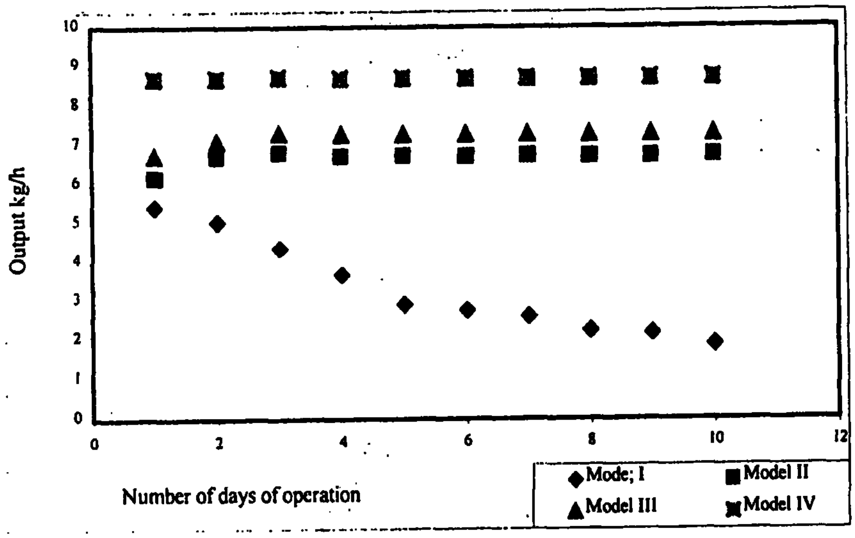

Fig. 4. Output of dried kernels using dryer Models I-IV on operation for 10 days.

The slightly tilted position of heat exchanger placed under the drying cabinet resulted in temperature difference of 1-4°C across in the Model I. Reduced temperature gradient (1-2°C) resulted after levelling the heat exchanger in Model II. Moving the chimney away from the cabinet wall in the Model III, minimised the temperature gradient.

Airflow pattern

The temperature inside the drying cabinet decreased from bottom to top (57-42°C), as the hot air flowed from the bottom. The Model I. even at the empty status did not show any airflow at the top (Fig. 5). The Model II designed with the roof sloping towards the chimney guided the air out (Table I). Moist air was expected to be removed easily as it got closer to the hot chimney. Improved airflow was inadequate in Model II too. The vents in Model's I and II were removed in designing the Model III, to a single adjustable vent on the roof. Flow improved when tray heights were doubled and air outlet was placed inside the chimney outlet on top of the drying chamber in the Model III (Fig. 5). Model IV brought about further improvements of airflow from 0.1-0.6 m/s. Air was channelled in a zigzag manner through the cabinet and increased venturi effect resulted due to improved design of conical shape chimney in the Model IV. Gradual improvements in airflow resulted in uniform distribution of temperature.

Output of dryer

Modifications to heat supply and distribution in the Model II stabilised the output that fluctuated between 5.4-1.9 kg/h in the Model I (Fig. 4). Improvements in temperature and airflow during modification process gradually increased output of dried cashew in Model IV to 70 kg/h, exceeding targeted 60 kg/day (8h).

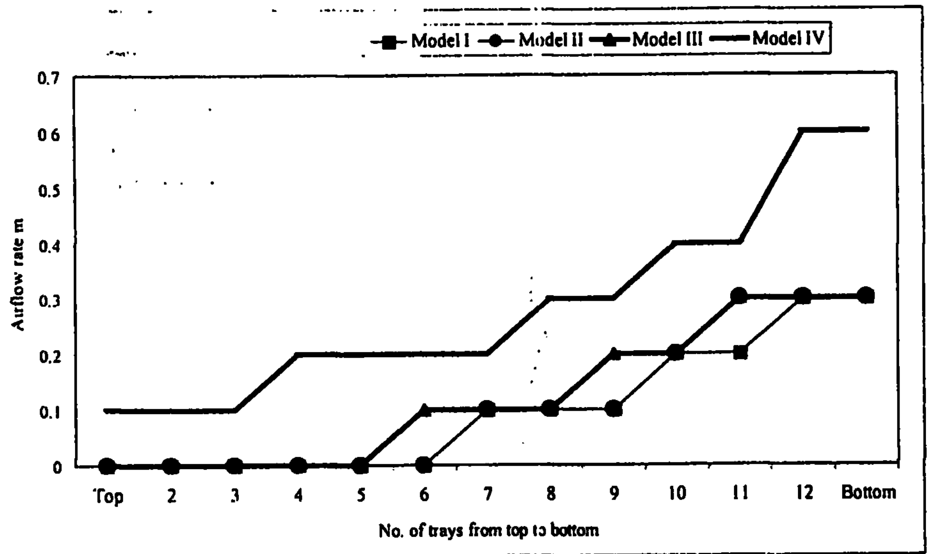

Fig. 5. **Airflow patterns inside the drying cabinets of dryer Models I-IV.**

Quality of kernels

Breakage of kernels

Breakage due to manual handling in current practices was minimised in modified dryers that avoided handling during drying. High kernel breakage of 14% associated with the Model I was due to jerks and falls of kernels during tray movement. Improvements to tray moving mechanism reduced breakage of kernels in Model I to 5% as given in Fig. 6.

Colour of kernels

In the current processing practice shelled kernels are stored for 7-10 days and the kernels are peeled before drying. Prolonged storage before drying and damage to kernel in peeling allow enzymatic discolouration. Reduced storage time and drying at 70°C before peeling minimised enzymatic discolouration giving an improved colour score of 2 as assessed through the hedonic scale.

Scraped kernels

Kernels are peeled after pre-heating few seconds on a hot surface in the current method. Peeling partially dried testa with scraping tool and removal of burnt parts disfigured the kernels. Dehydrated/brittle and breakable nature of testa after drying and cooling to room temperature made peeling easy. Smooth peeling minimised disfiguration of kernel to 3% with scarping reduced to the removal of natural black spots. Avoiding temperatures above optimum (70°C) eliminated scorching.

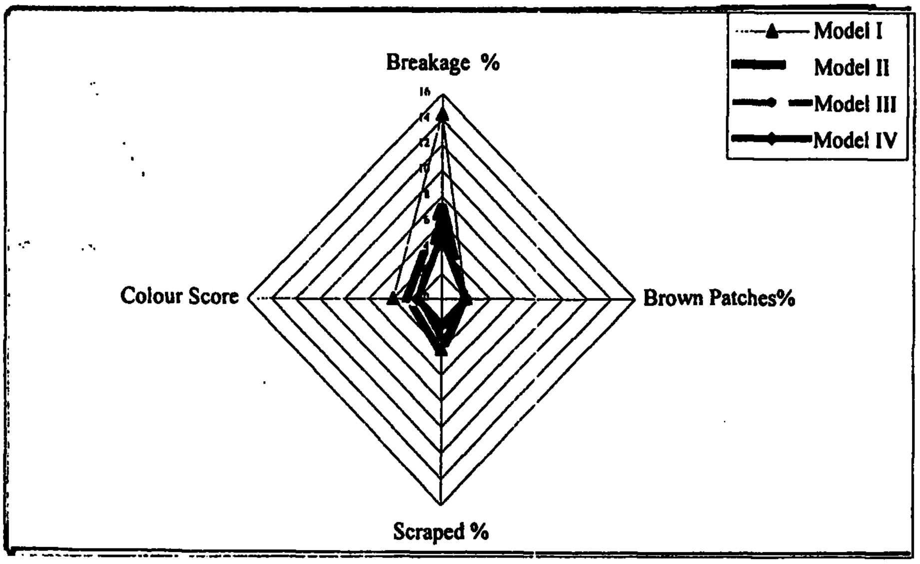

Fig. 6. Quality defects of the kernels dried using dryer Models I-IV.

Case hardening

Pre-heating and drying which starts with high temperatures in conventional methods can result case hardening. Drying cycle in modified dryers began with low temperatures, gradually increased as drying proceeded. No case hardening was found in kernels dried using modified dryers.

Cooked taste

Cooked taste was not found in kernels that dried using modified dryers. The taste of the kernels therefore was acceptable.

Acceptability of dryer

Cost of the dryer reduced from Rs. 42,000/- (Model I 1995) to Rs. 26,000/- (Model IV 1999) (Table 1). The height and weight of the dryer of Model I were reduced from 1870-1450 mm and from 6-4.5 kg respectively in Model IV for the convenient operation by women processors.

CONCLUSIONS

The Model IV designed as a result of modification process contained following features. Average drying temperatures inside cabinet were 50-70°C and airflow was 0.1-0.6 m/s. Modification reduced breakage to 5 from 15% and defects to 4 from 13%. The dryer cost only Rs. 26,000/- and was affordable and convenient for independent use of women. The modified dryer Model IV is presently used by more than 15 cottage level cashew processing co-operatives.

ACKNOWLEDGEMENTS

ITDG South Asia is gratefully acknowledged for the assistance provided during the study.

REFERENCES

Ariyabandu, M.L.M. and Hidellage, V. (1994). Impact of structural adjustment policies on small scale producers in South Asia. pp. 73-75. *In*: Twigg, J. and Bush, A. (Eds). Intermediate Technology Development Group, Sri Lanka.

Axtell, B. and Bush, A. (1991). Try Drying It! Case Studies in the Dissemination of Tray Drying Technology, Intermediate Technology Publications, U.K.

Bureau of Ceylon Standards. (1976). Sri Lanka Standards 405, Bureau of Ceylon Standards, Sri Lanka.

Central Bank. (1999). Annual Report, Central Bank of Sri Lanka, pp. 598-599.

Chupakhin, V. and Dormenko, V. (1976). Fish Processing Equipment, MIR Publishers, Moscow, USSR.

Henderson, S.M. and Perry, R.L. (1979). Agricultural Engineering, AVI Publishing Company, U.K.

Hidellage, V. and Samarajeewa, U. (1999). Quality Defects in Manually Processed Cashew: Incidents Origins and Recommendations. Trop. Agric. Res. 11: 61-73.

Perry, R.H., Green, D.W. and Maloney, J.O. (1997). Perry's Chemical Engineers' Hand Book, 7th Int. Edition, The McGrew-Hill Companies Inc., U.K.

Salisbury, K.J. (1950). Mechanical Engineers' Handbook, Power Volume, 12th Edition, John Wiley and Sons, U.K.