PROGRAMA DE AGROINDUSTRIA RURAL

PROYECTO
CARITAS - PRODAR

ASESORIA
CIAT

EVALUACION DE TRES FABRICAS PRODUCTORAS DE HARINA DE YUCA Y PLATANO

SEGUNDO INFORME
ANEXO 5:
OBRAS DE REFERENCIA

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ANEXO 5

OBRAS DE REFERENCIA

i) Evaluation of an Oil/Wood Furnace at the IIAP Flour Plant, Pucalpa (D.Jones).

ii) La Investigación en el secado artificial de yuca como apoyo al desarrollo agroindustrial de la Costa Atlántica de Colombia. (L.Alonso, M.A. Viera y R. Best).

EVALUATION OF AN OIL/WOOD FURNACE AT THE IIAP FLOUR PLANT (PUCALPA)

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ACRONYMS USED IN THE TEXT

CIAT	Centro Internacional de Agricultura Tropical
$D\eta$	Drying Efficiency
ICMSF	International Commission on Microbiological Specifications for Foods
IDRC	International Development Research Centre
IIAP	Instituto de Investigaciones de la Amazonia Peruana
INIA	Instituto Nacional de Investigacion Agraria
NGO	Non Government Organisation
NRI	Natural Resources Institute
$P\eta$	Pick-up Efficiency
$S\eta$	System Efficiency
$T\eta$	Thermal Efficiency
UNIVALLE	Universidad del Valle

TERMS OF REFERENCE

1. The Terms of Reference for the visit were:

(a) to participate in the first Training Workshop offered under the Agroindustrial Development Program of Cáritas del Perú, in collaboration with Cáritas staff;

(b) to carry out a technical evaluation of the IIAP Cassava flour pilot plant, in collaboration with plant staff, and recommend changes needed to increase plant throughput.

SUMMARY

2. This visit was carried out under Project Q0017 (Field testing and implementation of Improved Cassava Flour Production Process technologies), by the project engineer based in Colombia. The visit itinerary is given in Appendix 1. Under the auspices of the Cáritas Agroindustrial Development Program four rural communities are starting production of cassava and plantain flour, and another five are starting grain processing operations. Two representatives from each community and various Cáritas personnel attended this 5 day course, which aimed to prepare them for the management and practical operation of their plants. Two days of classroom sessions were held in Lima, during which a presentation on Quality Control was given to the whole group. The handout for this is given in Appendix 2. This was followed by three days of practical training, carried out at the IIAP Pilot plant in Pucallpa for those starting cassava flour production. During this period, quality control procedures for each unit operation were recommended and discussed with the participants. Demonstrations of the Specific Gravity method for determining fresh root dry matter content, and of water chlorination and chlorine determination were also given. For further details of this part of the visit, see Jones (1994:2).

3. During the second part of the visit a comprehensive technical evaluation of the IIAP cassava flour Pilot plant was carried out, with the main aim of identifying the factors limiting plant capacity. Inputs, outputs and processing conditions were monitored, with particular emphasis on drying parameters. Dry chip quality was evaluated, and furnace performance determined. The low air output from the fan was identified as the major limiting factor in the process. A series of recommendations are made, to increase plant throughput and also to improve product quality.

INTRODUCTION

BACKGROUND

4. Dr Rupert Best, the Leader of CIATs Cassava Program, has been supporting Dra Sonia Salas in the development of cassava flour in Peru since 1989. Dra Salas designed and constructed the IIAP cassava

flour Pilot plant, while working for IIAP under Dra Guzmán. The plant uses processing equipment designed under the CIAT/IDRC Cassava flour project, and fabricated in Colombia. The plant has operated successfully since 1991 despite losing Dra Salas to Cáritas del Perú.

CASSAVA IN PERU

5. Some 407 MT of cassava was produced in Peru in 1991, 20,000 t in the Ucayali district, making it the 4th largest producer in the country (Salas, Guzman & Aquino, 1995). Cassava area in Peru has increased slightly over the last 10 years, but production has dropped by some 15%. This reflects a drop in yields, although they remain among the highest in Latin America (CIAT, 1993). Cassava and Plantain are the two major crops in the region which, like much of Peru, has very poor soils, severely limiting crop options. Transport is slow and difficult in the region, and most producers do not have access to even the limited fresh root markets of urban centres. The long term guerrilla activity in the district has slowed its development considerably, and there is virtually no industry outside the urban centres.

IIAP PLANT

6. The IIAP Pilot Cassava/Plantain plant is sited at the IIAP field station, 13 km from Pucallpa. Pucallpa is a busy frontier town built on the timber industry, and the start of the road to Lima. Much of the timber logged in the Selva is channelled thorough the town, and through its ever increasing sawmills.

7. The plant can process about 1.5 t of prepared roots per day, to an absolute maximum of 2.0 t. These are provided by a group of about 100 farmers within a 35 km radius of the plant. It produces Cassava Flour for human consumption and for industrial uses, and also dried chips and bran for animal feed. IIAP also has an experimental animal feed compounder associated with the Pilot plant. There is significant local market demand for these products, due in large part to the efforts of Dra Salas, who designed the plant, and of Dra Guzmán, then head of the centre. Customers are generally satisfied with product quality, and the microbiological quality and residual cyanogen levels of the food grade flour are thought to be satisfactory. The plant now has greater local demand for the flour than it can meet, and capacity limitation has become a problem. This experiment has definite development potential, but IIAP lacks the funding to extend or replicate the technology.

CARITAS AGRO INDUSTRIAL PROGRAMME

8. Dra Salas left IIAP for Cáritas del Perú, a Catholic NGO dedicated to development of impoverished communities. Cáritas have an extensive network of 44 regional offices in Peru, from which they support the development of community projects, farms etc. Under their new Rural Agroindustry Programme, they are now supporting rural communities in starting agro processing enterprises. To date, four are starting to process cassava and plantain, and five with small

grain mills. Dra Salas is heavily involved with the programme, which is providing advice, soft loans, training and practical assistance to the villagers involved.

NEED FOR IIAP PLANT EVALUATION

9. This evaluation was arranged during a previous visit to Peru in January 1994, by two NRI engineers (Trim, 1994). Dras Salas and Guzmán were concerned about drying hygiene at the plant, and experiencing some problems with the milling system. They were also concerned about plant capacity, and how it might be increased.

10. The four Cáritas cassava/plantain plants are based on the IIAP plant, which uses an artesanal and very low cost furnace, designed by Dra Salas to use sawmill waste. The drying operation is known to be the bottleneck limiting throughput. A technical evaluation of the system should allow the specific problems to be identified and possible solutions suggested. Recommended modifications to increase plant capacity can then be applied to the new plants, which are currently under construction.

11. Comparison of the performance of this plant with the one in Colombia would also enable significant differences in either plant operation or environment to be identified.

IIAP PILOT PLANT

IIAP - UCAYALI CENTRE

12. IIAP has undergone significant changes since January 1994, with particularly severe effects on the Ucayali Regional office. The previous director of this station, Dra Yolanda Guzmán Guzmán, has been promoted to director of IIAP at the national level, as of April 1994. Consequently, the office and field station were without a leader between April and early July, while Dra Guzmán settled in. Responsibility was then passed to Ing Olga Z Rios del Aguila, who is also Minister of Agriculture for Ucayali. Sra Aquino, the previous plant manager has also left IIAP, and Ing Llamoka has taken on her duties.

RESEARCH DIRECTION

13. Under Ing Rios, the marketing strategy for the flour targets the human consumption market, rather than the industrial where the flour is mostly used in plywood adhesive. Research at the plant is currently directed towards developing new food products, and a bakers oven and pasta extruder are recent acquisitions. The plant is producing small bread rolls (30% substitution) for local sale, which appeared to be very popular at the regional Agricultural fair taking place in July. However, these were sold within hours of production, and do not last overnight. Production of pasta using cassava or rice flour is still at the research stage, and a new member of staff started on this project during the visit.

PLANT CURRENT STATUS

14. IIAP is severely limited by funding, and most of the projects at the Field Station are at least partly self-supporting. The Plant manager and plant engineer are IIAP staff, and plant revenues support the plant operators. A separate team of two are employed in the bakery. The plant had cash flow difficulties during the period when the office was without a leader, and is now short of working capital, having spent it on maintenance and repairs. Unfortunately, the current plant manager does not seem to be as good as the previous ones, and the levels of plant organisation and staff morale appeared to be significantly lower than in January.

15. Local market openings for the flour are all based on partial substitution of wheat flour, which is comparatively expensive due to transport costs. Local markets for the food grade flour include some of the 200 small bakers (<20% substitution), the National Government food aid programme and a small factory producing 'ships' biscuits (30% substitution). The main industrial use of the flour is in the adhesive used in plywood manufacture (<46% substitution).

TECHNICAL EVALUATION OF PILOT PLANT

PLANT LAYOUT

16. The layout of the IIAP plant is given in Figure 1. This is generally similar to the CIAT layout, but with less bin drying area at 12 m^2 (cf. 21 m^2), and including 42 m^2 of raised mesh tray sun drying area and 100 m^2 of concrete sun drying floor. The milling system is also considerably simpler than at the CIAT plant, consisting of the premilling unit and a single conical sifter for flour production, and a hammer mill for animal feed chips. The plant is constructed from a local hardwood, rather than concrete block and shows few visible signs of deterioration. Process water is pumped from a well to two elevated water storage tanks and then gravity fed to the plant. The plant has a diesel generator which also provides power to the rest of the field station.

OPERATING PROCEDURES

17. Plant operation is managed to maximise product output, even at the expense of production efficiency or product quality. Fresh roots are harvested, selected, graded and prepared in the field, and transported to the plant overnight. The following morning, the roots are inspected and the price agreed with the farmer. The plant has agreed a grading system with the producers, and pays a premium of about US$ 10/tonne for grade 1 roots. Three varieties dominate production in the region, Señorita Blanca (white), Señorita Amarilla (yellow) and Huangana (red). Roots are harvested at about 10 months, and are large with high Dry Matter contents of 34 - 40%. The roots are then rechecked by plant operators, before washing and chipping. The well water is thought to be of good quality, and is not treated.

However, a new problem has arisen with the chipping disk. This has discoloured to a dull grey colour which is passed on to the chips.

18. The two drying chambers are always filled first, starting with Bin 1, the more effective of the two bins. The fresh chips are transferred from the chip trolley to basins and weighed into the bins to 250 kg/bin (42 kg m^{-2}). The drying air is channelled through the first bin while the second is being filled, then split between the two. The sun drying trays are filled next, with 15-20 kg/tray (10 kg m^{-2}) to about 480 kg. The next 500 kg of chips are dried on the concrete floor at 5 kg m^{-2}, on black plastic sheeting if intended for flour, or direct for animal feed. This takes throughput to a nominal 1.5 t of roots. When the first bin has been drying for two hours, the partially dried chips from the second bin are added to the drier chips in the first, and the chips from the trays loaded into the second bin. Any remaining roots are then chipped and loaded onto the trays. The chips on the floor are usually left there. All the chips are turned every hour during drying. When it rains, the trays are moved under cover, and the floor drying chips wrapped or covered in the plastic sheet.

19. It takes about eight hours to dry all the chips (500 kg fresh weight) in the first bin, usually ending about 1600. These chips are allowed to cool for a while, then unloaded from the bin, and the floor dried chips loaded in. Depending on the quantity of chips in the second batch of sun drying on trays, these are either added to the first bin with the floor dried chips, or added to the dryer chips in the second bin, or transferred to the second bin when its contents are dry. At maximum throughput of 2.0 t fresh roots, drying continues well into the early hours of the morning.

20. The plant is manned by four operators in the morning, and by two different ones in the afternoon. At the start of the day, two operators check the incoming fresh roots and one starts the furnace, while the plant engineer prepares the basins, balances, generator etc. The furnace is lit about an hour before drying begins. Once processing starts, one operator mans the washer, two load the chips into the dryers, and the other maintains the furnace. The chips are all loaded during the morning shift, and the machinery cleaned. In the afternoon, one operator mans the furnace and turns the chips, and the other operates the milling system. The dry chips are passed through the sifter only once due to the low processing capacity, with an average flour extraction rate of 76.5%. The plant operates 5½ days per week, processing on weekdays, and carrying out plant maintenance on Saturdays, which are normally half days for IIAP staff. Maintenance includes raising the perforated plates in the drying bins to collect the accumulated dust from the plenum chambers (used for animal feed), washing of the sun drying bandejas and scouring of the tarnished chipping disk.

FURNACE CONSTRUCTION AND OPERATION

21. A wood-fired combined furnace and heat exchanger is in use at the plant. The furnace has a cylindrical combustion chamber 700 mm

in diameter, made of two oil drums and fuelled by assorted plank offcuts. Air flow into the chamber can be controlled with a door, and it exits by natural convection through a rectangular chimney about 3 m high at the other end of the 2100 mm chamber. Neither the door or the original grate are currently in use. A schematic plan of the unit is given in Figure 2, and photographs in Figures 3.1 and 3.2. The drying air is channelled spirally around the combustion chamber through the 250 mm heat exchanger duct surrounding it. A centrifugal fan at the end of the unit sucks the air through the heat exchanger and blows it into the drying bins. The outer insulating wall of the unit is made of hollow adobe bricks and covered with a layer of mud.

22. The furnace is fuelled by plank offcuts, discarded by local sawmills. These are provided free of charge by the mills, as they are usually burned and the plant pays only transport costs. The offcuts, of varying sizes and different wood types are used as they come, sometimes stretching the length of the combustion chamber.

WORK PROGRAMME

23. Five production trials were monitored. Given the minimum staffing levels at the plant and the operating procedure employed, it was not possible to weigh all the chips at change over points and maintain normal operation. Therefore, two trials were dedicated to furnace evaluation (1 & 3), two to the mixed drying system (2 & 4), and one to normal operation, as a control (5). The milling system was not functional due to a ruptured sieve screen, and could not be evaluated. The replacement mesh needed for the screen is not available in Peru, which does not bode well for replication of the plant.

24. All relevant factors were monitored during the trials. Samples of the fresh roots used in each trial were conserved as soon as they arrived at the plant, using the treatment developed by CIAT and NRI (Wheatley, 1987). Samples were also taken of the bin dried chips, and of the sun and bin (mixed) dried chips. Both fresh and dry samples were returned to CIAT for determination of Dry Matter Content by air drying, and of cyanogen (CN) levels by the quantitative enzymic assay method of O'Brien et al (1991). Analyses were carried out by the Cassava Utilisation Section. The microbiological quality of the dry chip samples was also evaluated by the Laboratorio de Microbiologia de Alimentos in Cali, using ICMSF approved methods (ICMSF, 1978). Composite samples ($\approx$ 1.0 kg) of the wood fuel used in each trial were gathered by collecting a sliver from each plank fed to the furnace. These were then sub sampled by taking a sliver from each sliver collected. The sub samples were milled and their dry matter contents determined the following day at INIA. The Gross Calorific Values of the composite samples were determined in the Engineering Department of the UNIVALLE, Cali.

RESULTS

25. Flow sheets of all the trials are given as Figures 4.1-4.5. Mass balances are summarised in Table 1, and the Conversion Factors compared to those of the CIAT Pilot plant in Table 2. The Energy balances for trials 1-4 are given in Tables 3.1-3.4, and drying data are summarised for both plants in Table 4. Furnace performance is summarised in Table 5, and compared to the CIAT Pilot plant in Table 6. Cyanogen concentrations in the fresh roots and dry chips are summarised in Table 7, and cyanogen levels for product samples taken in January 1994 are given in Table 8. Fresh and dry chip cyanogen levels measured at the CIAT plant are given in Table 9 for comparison. Table 10 gives the microbiological quality of the dried chips, and Table 11 the microbiological data for product samples taken in January 1994.

FLOW SHEETS

26. The flow sheets for the trials, Figures 4.1-4.5 show the general production process that has evolved to maximise plant output. The mixing of different lots of partly dried chips in the bins cannot be recommended, as it leads to less efficient drying and cross contamination of the chips.

MASS BALANCES

27. The dry matter losses during processing were noticeably lower when the chips were bin dried than when sun drying was also used (Table 1). This was probably largely due to the additional handling of unloading the chips from the trays or floor and loading them into the bin, but there are also losses through the trays and off the floor during turning and collection. About 10% of the dry matter losses can be accounted for in the dust accumulated in the drying bins, which is recovered and used in animal feed formulation. Monitoring trials might lead to greater losses than normal operation, due to the extra handling of weighing the chips at intermediate points in the process. However, higher losses were seen in all the mixed drying trials, including trial 5 where the chips were only weighed at the beginning and end of processing, under normal operating practices. This indicates that the bulk of the losses occur during collection and transfer of the sun drying chips, whether or not they are weighed during the transfer. These losses could probably be reduced by tightening up operating practices.

28. The fresh chip to dry chip (FC:DC) conversion factor averaged 2.64:1 over the trials (Table 1). This factor is primarily dependant on the fresh root dry matter content. The overall fresh root to flour (FR:F) conversion factor, in turn depends primarily on the FC:DC factor, and the flour extraction rate from the dry chips (DC:F). The FR:F factor is used to determine the economic viability of the process under local market conditions.

29. Comparative conversion factors for both plants are given in Table 2. Salas, Guzman and Aquino (1995) cite FR:F factors of 3.2-

3.9:1 for the IIAP plant, depending on the variety processed. These are roughly equivalent to FC:DC factors of 2.33-2.84:1, in good agreement with the range of 2.44-2.80:1 measured during these trials. The Plant norms given for the CIAT plant are the limits under which the plant can operate economically, and can be achieved if the dry matter content is at least 30%. The FC:DC factor is pushed above these limits by use of roots with a lower dry matter content. An average fresh root dry matter content of 40% was measured during this evaluation, compared to 35% during evaluation of the CIAT plant.

30. The CIAT plant has been unable to agree a quality based pricing structure with local cassava suppliers, who have tried this before with a Starch plant using a similar pricing structure. They feel that they got a very poor deal, and are reluctant to try again. It is common practice to harvest at about 7 months, when the root dry matter content is very low, at 25-30%, and many of the roots are very small. The area suffers from bacteriosis, which also diminishes the root dry matter content. The high level of rejection of these roots by the plant has led the producers to choose not to select in the field, and the plant must purchase all or nothing. In contrast, the IIAP plant has a working quality based pricing structure, which appears to satisfy both parties. The Colombian farmers are in a 'sellers market' and know that they can sell their roots elsewhere if the plant does not purchase. The Peruvian farmers have much more limited market options, and are generally keener to supply their plant. The farmers select and prepare the roots in the field, usually dividing them into 1st and 2nd grade at this point. However a further 10% of the field selected roots are then rejected during reinspection at the plant. Further training of the producers could probably reduce this figure. Dry matter contents were 40% (+/- 2%) during these trials, and 34% is about the minimum level (Salas, Guzman and Aquino, 1995), probably due to root harvests between 10 and 12 months. Individual roots can be huge (≤12 kg), and are cut into 2-3 segments before washing.

SUN DRYING PERFORMANCE

31. During the two mixed drying trials (Tables 3.2 & 3.4), only some 9% of the energy required was provided by sun drying. However, the sun drying operation is more important than this figure implies. The fresh roots are highly perishable, and must be processed rapidly after harvest. If only bin drying was used, only 500 kg of chips could be processed at the start of the day, and a large quantity of roots would have to be stored until there was room in the bins for them to be processed. The roots would deteriorate over this 2-8 h period. Use of sun drying allows up to 1500 kg of chips to be processed as early as possible, and while the drying rates are slow, the chips do not deteriorate as unprocessed roots would.

DRYING RATES

32. An average drying rate of 0.18 (+/- 7%) g of moisture loss per second per m^2 tray area was recorded with sun drying on the raised bandejas. This is much higher than the rate of 0.02 (+/- 56%) g s^{-1}

m^{-2} achieved with sun drying on the concrete floor, and can be expected to produce dry chips of better microbiological quality (Jones, 1993:2). However, neither compare to the rate of 1.52 (+/- 18%) g s^{-1} m^{-2} achieved in the bins. The bin drying rate is not vastly lower than the 1.79 (+/- 20%) g s^{-1} m^{-2} measured at the CIAT plant (Table 4), but the total drying rate of 13.38 (+/- 6%) kg s^{-1} is only one third of the rate of 37.59 (+/- 20%) kg s^{-1} achieved at the CIAT plant. This is due largely to the air flow at the IIAP plant being only about a third of the air flow at the CIAT plant. With nearly 3 times the drying air flow rate of the IIAP system, the CIAT system has nearly 3 times the drying capacity.

33. Both the Pick-up Efficiency (Pη) and the Drying Efficiency (Dη) are very similar in both plants (Table 4), indicating that the drying processes are very similar. This is coincidental, as a relatively greater amount of moisture evaporates into the lower velocity airstream in the IIAP plant, but a relatively smaller amount evaporates from a thinner layer of fresh chips. However, the total System efficiency (Sη) of the CIAT plant is some 2.5 times greater than of the IIAP plant, indicating that the transfer of heat to the drying air is much less effective at the IIAP plant as the transfer of heat from the drying air to the chips is similar in both plants.

FURNACE PERFORMANCE

34. The Thermal efficiency, Tη of the furnace (Table 5) describes how effectively the energy in the fuel is transferred to the drying air. The dynamic Tη is some 6% greater than the total Tη, as it does not take account of start up of the furnace. While the drying air exited at a satisfactory temperature of 63°C, only 25% of the potential energy of the fuel was used. The Gross Calorific Values of the wood fuel varied only +/- 7% from the mean. This is surprisingly constant, given the wide range of types used.

35. Comparison of Tη with the CIAT plant (Table 6), shows that the furnace is only about half as effective in heating the air. The heat supplied is similar in both plants, so they should be able to achieve similar throughputs. Again, the low air flow rate is a significant factor, affecting the heat transfer.

PRODUCT QUALITY - CYANOGEN LEVELS

36. The residual cyanogen concentrations in the dry chips were generally acceptable when compared with those achieved at the CIAT plant (Tables 7 & 9). The residual cyanogen concentrations and the degree of elimination were very similar for both bin and mixed drying, implying similar periods of enzyme activity, and similar initial drying rates. The degree of cyanogen elimination achieved was slightly lower than that achieved at the CIAT plant. This is partly due to the higher fresh root dry matter content, and also to the lower loading densities used. There may also be varietal differences in Linamarase concentration and activity. The fresh root

cyanogen concentrations were generally lower than at the CIAT plant, and more variable, at +/- 40% of the mean as compared to +/- 15%. Use of greater loading densities, as would be possible with increased air flow, can be expected to increase the degree of cyanogen elimination. The cyanogen levels measured in January 1994, and given in Table 8, are all considerably lower than those measured during these trials. For comparison, the flour produced from these chips would be expected to have a total cyanogen concentration of about 55 mg kg^{-1} (db). This may be partly a seasonal effect. Milling and storage have also been shown to affect cyanogen levels in chips and flour (Jones, 1994:1), though these effects are not yet understood.

PRODUCT QUALITY - MICROBIOLOGICAL

37. The microbiological quality of the dried chips (Table 10) was surprisingly good given operating practices. The Aerobic Plate Counts at 10^5 - 10^6 cfu g^{-1} were slightly higher than those at 10^5 cfu g^{-1} achieved at CIAT plant, but can be expected to drop by a factor of 10 with storage. The drying regime used generally had no significant effect on microbiological quality. Use of normal operating practices in Trial 5 produced chips of worse microbiological quality than the other trials. While no conclusions can be drawn from this amount of data, this is still an ominous result. The presence of Coliforms in 21 samples out of 24 is also not encouraging. This does not necessarily mean that Faecal Coliforms are also present, but that they are possible.

38. It is worth noting that at the CIAT plant Total Coliforms have been reduced from ≥1100 cfu g^{-1} in all samples in November 1991 (Trim and Wareing, 1991) to none being detected in 98 samples in March 1993 (Jones, 1993:1). Several factors have contributed to this improvement:

(a) Quality control of the fresh roots has been improved;
(b) The delay between harvest and drying has been reduced from 36 hours to 20 hours;
(c) The drying bin has been walled in from the furnace area and the wet processing area;
(d) The delay between chipping and the start of drying has been reduced from 3 hours to 1 hour;
(e) The chip drying time has been reduced from 22 to 8-13 hours.

The level of hygiene and cleanliness at the plant is generally high, and good operating practices are in use.

39. High Yeast and Mould counts were also found in some samples. These also continue to be a problem at the CIAT plant, and their elimination requires further research.

RECOMMENDATIONS

THROUGHPUT OF THE DRYING BINS

40. This could be increased by:

(a) Use of a more powerful fan to increase the drying air available. **This is the main modification required to increase bin drying capacity.** Increasing the air flow rate through the beds would allow the chip loading density to be increased in order to maintain the Drying rate and Pick-up efficiency (and hence cost of drying). It would also increase the air velocity through the heat exchange duct, and hence the heat transfer efficiency.

(b) Addition of a grate to the furnace combustion chamber and repair of the door to the furnace. This would improve the efficiency of combustion within the furnace.

(c) Chopping up the fuel wood to similar size pieces, compatible with the capacity of combustion chamber. This would stabilise the rate of heat supply and also improve the efficiency of combustion. It might be possible to pay the sawmills a small fee to chop the offcuts before they are collected.

(d) Addition of more heat transfer area to the conical Heat exchanger surrounding the combustion chamber, by moving the spiral fins closer together. This would increase the air velocity, and hence also the heat transfer efficiency, but would also increase the pressure drop through the system. This would have to be taken into account when sizing the new fan.

THROUGHPUT OF THE MILLING SYSTEM

41. This could be increased by purchase of another milling/sieving unit. These could be run in sequence, increasing both throughput and flour extraction.

BIN DRYING PROCESS

42. This could be improved by:

(a) Drying the chips in more homogenous batches. The mixing of nearly dry and wet chips reduces the microbiological quality of the whole batch to the lowest level.

(b) Construction of access doors in the brick plenum chambers of the two bins. This would eliminate the need to lift the perforated plates regularly to clean the chambers, thus increasing their useful lifetime, and allowing the plates to be securely fixed to the frames, minimising air leakage and chip losses at the edges of the bins.

(c) Renovation of the air flow control dampers in the drying air ducting from the fan to the plenum chambers. The drying air flow cannot be satisfactorily controlled with the dampers in their present state. When the bins are empty or contain similar loads, the outside one receives a greater proportion of the drying air, leading to its preferred use. Renovation or replacement of the dampers would allow the split of the drying air between the bins to be controlled, and the air apportioned relative to the bin loads. Also, when only one bin is in use, the leakage of drying air to the other bin would be considerably reduced..

43. Note: The air flow with the current fan is so low that controlling it is not worth increasing the system pressure drop, and hence reducing it still further. However, with a more powerful fan the difference in both air flow and drying rate between the bins will be more marked, and control will become more important.

SUN DRYING PROCESS

44. This could be improved by:

(a) Tighter control over the tray loading densities, (which varied considerably from the design value of 15-20 kg m^{-2}) to allow more even drying on the trays.

(b) Mixing (turning) of the chips on the trays during drying. While this would increase the losses of particulates through the mesh, it would increase the drying rate and conformity considerably. Losses due to mixing can be quantified by collecting the particulates generated on a plastic sheet under the trays.

(c) Laying of the 3 concrete floor plastic sheets parallel to the length of the plant (E-W), rather than at right angles to it (N-S). Plant operators could then walk from the plant through the lanes between the plastic sheets to retrieve the trays, rather than having to choose between going right round the floor or taking the most direct route through the floor drying chips. This should not affect the effectiveness of drains in the floor which run N-S but are relatively narrow (≈100mm). When it rains the plastic sheets are wrapped around the chips, and the resulting bundles are too rigid to sag into the narrow drainage channels.

(d) Purchase of enough plastic sheeting to cover the trays when rain starts (the plant currently only has enough sheeting to cover the drying floor). This would protect the trays immediately, and keep the chips much dryer than the current practice of carrying the trays under cover.

GENERAL POINTS:

45. (a) It is highly likely that the discoloration of the chipping disk, and consequent discoloration of the chips is due to plantain peel being processed through the chipper (A University student is investigating possible uses of the peel). Manual peeling of Plantains generates a very sticky black exudate from the peel which is extremely difficult to remove from the skin, even when fresh.

This problem does not occur in the CIAT plant where only Cassava roots are processed. If the disk was initially galvanised, only a small portion remains, due to the vigorous cleaning with a wire brush required to remove the discoloration.

(b) Hygiene at the plant is generally poor. Provision of bathroom facilities for the plant operators, and of a centrally located hand basin in the plant are strongly recommended. Plant operators will also have to be trained and motivated to use them.

(c) The brick wall of the drying bins, at 1.25 m, extends at this height to the equipment storeroom, separating the furnace area from the chip drying and storage area. The ash from the furnace is dumped a short distance the other side of the furnace (Figure 3.2). Elevation of this wall to the roof would considerably reduce the potential for contaminating the drying chips in the bins with smoke, ash, dust etc from the "dirty" furnace area. Similarly, use of a pit with a cover for ash disposal would reduce the possibility of contaminating the chips on the E-W row of bandejas, which are also close to the furnace area.

(d) There appears to be no provision for cleaning of the milling equipment. Contamination builds up in mills generally over time, and the equipment must be cleaned regularly. However, a satisfactory low cost method is not, to my knowledge available.

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Table 1.

SUMMARY OF MASS BALANCES

Trial	Fresh Chips Input kg	Fresh Chips DMC %	Fresh Chips DM kg	Dry Chips - Bin Output kg	Dry Chips - Bin DMC %	Dry Chips - Bin DM kg	Dry Chips - Mixed Output kg	Dry Chips - Mixed DMC %	Dry Chips - Mixed DM kg	Total Dry Chips Output kg	Total Dry Chips DMC %	Total Dry Chips DM kg	Mevap M kg	Losses DM kg	Losses % of FC DM	Losses % of FC input	Conv. factor FC:DC
1	500.0	42.30	211.5	205.0	95.31	195.4				205.0	95.31	195.4	278.9	16.1	7.6	3.2	2.4
2	959.0	38.92	373.2	185.0	94.44	174.7	171.6	93.59	160.6	356.6	94.03	335.3	564.5	37.9	10.2	4.0	2.7
3	500.0	38.85	194.3	191.1	97.01	185.4				191.1	97.01	185.4	300.0	8.9	4.6	1.8	2.6
4	1078.0	40.26	434.0	171.0	95.77	163.8	214.4	95.52	204.8	385.4	95.63	368.6	627.2	65.4	15.0	6.1	2.8
5	1340.0	41.86	560.9				491.0	95.16	467.2	491.0	95.16	467.2	755.3	93.7	16.7	7.0	2.7

Notes:

1. DMC - Dry matter content expressed in % wet basis.
2. DM - Dry matter.
3. M - Moisture.
4. Mevap - Moisture removed during drying.
5. FC - Fresh chips.
6. DC - Dry chips.

Table 2.

COMPARISON OF IIAP AND CIAT PLANT CONVERSION FACTORS

Pilot Plant	Fresh: Fresh Roots: Chips FR[5]: 1FC	Fresh: Dry Chips: Chips FC: 1DC	Dry: Chips: Flour DC: 1F	Flour: Dry Yield: Chips F/DC(%)	Fresh: Roots: Flour FR: F	Variety Processed
IIAP (1) 1991-1993	*1.05*[3]	2.33[4]	**1.31**[2]	**76.5**	**3.20**	Señorita
IIAP (1) 1991-1993	*1.05*	2.84	*1.31*	*76.5*	3.90	Nusharuna
IIAP July 1994 trials	*1.05*	**2.64**	*1.31*	*76.5*	3.62	Señorita Huangana
CIAT (2) March 1993 trials	**1.01**	**2.53**	**1.22**	**82.0**	**3.11**	Llanera Pedoce (P12)
CIAT (2) March 1993 trials	**1.01**	**2.41**	**1.22**	**82.0**	**2.96**	Llanera
CIAT (2) March 1993 trials	**1.01**	**2.61**	**1.22**	**82.0**	**3.21**	Pedoce
CIAT (2) June 92-March 93	*1.05*	**2.96**	*1.22*	*82.0*	3.79	Llanera Pedoce
CIAT (3) Jan 94-March 94	*1.05*	2.84	**1.35**	**74.3**	**4.01**	Llanera Pedoce
CIAT (3),(4) Plant norms	*1.05*	2.73	**1.22**	**82.0**	**3.50**	60 mesh 251μm
	1.05	*2.64*	1.29	75.0	**3.70**	100 mesh 152μm

Notes:
1. All conversion factors are expressed in kilogrammes of input required for 1 kilogramme of output (kg $1kg^{-1}$), except Flour Yield from Dry chips which is expressed in %.
2. Bold type idicates values measured, or cited in other publications.
3. Itallic type indicates assumed values, based on measured values.
4. Normal type indicates calculated values.
5. FR indicates selected and prepared roots.

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Table 3.1

TRIAL 1 - ENERGY BALANCE

Energy inputs/outputs		Bin 1	Bin 2	Furnace Total	Trays	Sun Total
Energy requirements:						
Mevap	kg	50.4	46.2		10.0	
Mevap	kg	198.4	96.3		51.0	
Total Mevap @ 2638 KJ/kg M	kg	248.8	142.5	391.3	61.0	61.0
Energy required:	KJ	656,334	375,915	1,032,249	160,918	160,918
Energy inputs:						
Insolation						
1130-1230: I = 235 W/m2	KJ				35,024	
1330-1900: I = 188 W/m2	KJ				154,107	189,131
Solid Fuel						
605 kg wood @ 15,886 KJ/kg	KJ			9,611,266		
Energy outputs to Drying air:						
Energy used Tamb-Tda	KJ	882,893	630,891			
Energy input req. 25 C-Tda	KJ	1,021,311	745,903			
Drying Air Evap. Potl.	kg	350.5	263.2			
Pick up Efficiency	%	71.0	54.1			
Drying Efficiency	%	64.3	50.4			
Furnace Efficiency	%			15.8		
System Efficiency	%			10.7		85.1

Notes:

1. Mevap - Moisture evaporated during drying, in kg.
2. I - Average Insolation level over Drying period, in Watts per square metre of Drying area.
3. Tamb - Ambient Air temperature, in deg C.
4. Tda - Temperature of Drying air, in deg C.
5. Evap. Potl. - Potential evaporative capacity of the Drying air, in kg Moisture.
6. Latent Heat of evaporation: HL = 2638 KJ/kg Moisture.
7. Gross Calorific Value of Wood fuel: GCV = 15,886 KJ/kg (wet basis).
8. Total Drying area of Trays = 41.4 m2.
9. Pick up Efficiency = Mass of water evaporated into Drying air / Potential evaporative capacity of the Drying air
10. Drying Efficiency = Energy required to evaporate water / Energy required to raise Drying air temperature (25 C-Tda)
11. Furnace Efficiency = Energy removed by drying air / Energy input to furnace
12. System Efficiency = Energy required to evaporate water / Total energy input

Table 3.2

TRIAL 2 - ENERGY BALANCE

Energy inputs/outputs		Bin 1	Bin 2	Furnace Total	Trays	Floor	Sun Total
Energy requirements:							
Mevap	kg	96.2	68.2		39.4	17.0	
Mevap		150.6	231.0				
Total Mevap @ 2638 KJ/kg M	kg	246.8	299.2	546.0	39.4	17.0	56.4
Energy required:	KJ	651,058	789,290	1,440,348	103,937	44,846	148,783
Energy inputs:							
Insolation							
0945-1000: I = 620 W/m2	KJ				23,101		
1000-1110: I = 644 W/m2	KJ				111,979	121,716	
1110-1230: I = 488 W/m2	KJ					105,408	
1300-1330: I = 675 W/m2	KJ					54,675	416,879
Solid Fuel							
600 kg wood @ 14,877 KJ/kg	KJ			8,926,200			
Energy outputs to Drying air:							
Energy used Tamb-Tda	KJ	1,045,468	991,980				
Energy input req. 25 C-Tda	KJ	1,299,572	1,213,549				
Drying Air Evap. Potl.	kg	462.1	431.1				
Pick up Efficiency	%	53.4	69.4				
Drying Efficiency	%	50.1	65.0				
Furnace Efficiency	%			22.8			
System Efficiency	%			16.1	76.9	15.9	35.7

Notes:

1. Mevap - Moisture evaporated during drying, in kg.
2. I - Average Insolation level over Drying period, in Watts per square metre of Drying area.
3. Tamb - Ambient Air temperature, in deg C.
4. Tda - Temperature of Drying air, in deg C.
5. Evap. Potl. - Potential evaporative capacity of the Drying air, in kg Moisture.
6. Latent Heat of evaporation: HL = 2638 KJ/kg Moisture.
7. Gross Calorific Value of Wood fuel: GCV = 14,877 KJ/kg (wet basis).
8. Total Drying area of Trays = 41.4 m2.
9. Drying area of Concrete floor = 45.0 m2.
10. $\text{Pick up Efficiency} = \dfrac{\text{Mass of water evaporated into Drying air}}{\text{Potential evaporative capacity of the Drying air}}$
11. $\text{Drying Efficiency} = \dfrac{\text{Energy required to evaporate water}}{\text{Energy required to raise Drying air temperature (25 C-Tda)}}$
12. $\text{Furnace Efficiency} = \dfrac{\text{Energy removed by drying air}}{\text{Energy input to furnace}}$
13. $\text{System Efficiency} = \dfrac{\text{Energy required to evaporate water}}{\text{Total energy input}}$

Table 3.3

TRIAL 3 - ENERGY BALANCE

Energy inputs/outputs				Furnace		Sun
		Bin 1	Bin 2	Total	Trays	Total
Energy requirements:						
Mevap	kg	69.0	62.0		62.0	
Mevap	kg	177.9				
Total Mevap @ 2638 KJ/kg M	kg	246.9	62.0	308.9	62.0	62.0
Energy required:	KJ	651,322	163,556	814,878	163,556	163,556
Energy inputs:						
Insolation						
0940-1700: I = 462 W/m2	KJ				504,948	504,948
Solid Fuel						
400 kg wood @ 15,567 KJ/kg	KJ			6,226,944		
Energy outputs to Drying air:						
Heat used Tamb-Tda	KJ	1,412,129	161,422			
Heat input req. 25 C-Tda	KJ	1,752,364	207,933			
Drying Air Evap. Potl.	kg	612.4	75.0			
Pick up Efficiency	%	40.3	82.7			
Drying Efficiency	%	37.2	78.7			
Furnace Efficiency	%			25.3		
System Efficiency	%			13.1	32.4	32.4

Notes:

1. Mevap - Moisture evaporated during drying, in kg.
2. I - Average Insolation level over Drying period, in Watts per square metre of Drying area.
3. Tamb - Ambient Air temperature, in deg C.
4. Tda - Temperature of Drying air, in deg C.
5. Evap. Potl. - Potential evaporative capacity of the Drying air, in kg Moisture.
6. Latent Heat of evaporation: HL = 2638 KJ/kg Moisture.
7. Gross Calorific Value of Wood fuel: GCV = 15,567 KJ/kg (wet basis).
8. Total Drying area of Trays = 41.4 m2.
9. $\text{Pick up Efficiency} = \dfrac{\text{Mass of water evaporated into Drying air}}{\text{Potential evaporative capacity of the Drying air}}$
10. $\text{Drying Efficiency} = \dfrac{\text{Energy required to evaporate water}}{\text{Energy required to raise Drying air temperature (25 C-Tda)}}$
11. $\text{Furnace Efficiency} = \dfrac{\text{Energy removed by drying air}}{\text{Energy input to furnace}}$
12. $\text{System Efficiency} = \dfrac{\text{Energy required to evaporate water}}{\text{Total energy input}}$

Table 3.4

TRIAL 4 - ENERGY BALANCE

Energy inputs/outputs		Bin 1	Bin 2	Furnace Total	Trays	Floor	Sun Total
Energy requirements:							
Mevap	kg	85.1	67.1		48.2	12.4	
Mevap	kg	176.8	28.3				
Mevap	kg	166.1	108.6				
Total Mevap @ 2638 KJ/kg	kg	428.0	204.0	632.0	48.2	12.4	60.6
Energy required:	KJ	1,129,064	538,152	1,667,216	127,152	32,711	159,863
Energy inputs:							
Insolation							
0930-1300: I = 712 W/m2	KJ				212,236		
1000-1400: I = 680 W/m2	KJ					881,189	1,093,425
Solid Fuel							
690 kg wood @ 17,836 KJ/kg	KJ			12,306,681			
Energy outputs to Drying air:							
Energy used Tamb-Tda	KJ	1,812,673	762,327				
Energy input req. 25 C-Tda	KJ	2,048,326	977,519				
Drying Air Evap. Potl.	kg	736.9	350.3				
Pick up Efficiency	%	58.1	58.2				
Drying Efficiency	%	55.1	55.1				
Furnace Efficiency	%			*20.9*			
System Efficiency	%			13.5	59.9	3.7	14.6

Notes:

1. Mevap - Moisture evaporated during drying, in kg.
2. I - Average Insolation level over Drying period, in Watts per square metre of Drying area.
3. Tamb - Ambient Air temperature, in deg C.
4. Tda - Temperature of Drying air, in deg C.
5. Evap. Potl. - Potential evaporative capacity of the Drying air, in kg Moisture.
6. Latent Heat of evaporation: HL = 2638 KJ/kg Moisture.
7. Gross Calorific Value of Wood fuel: GCV = 17,836 KJ/kg (wet basis).
8. Total Drying area of Trays = 41.4 m2.
9. Drying area of Concrete floor = 90.0 m2.
10. Pick up Efficiency = Mass of water evaporated into Drying air / Potential evaporative capacity of the Drying air
11. Drying Efficiency = Energy required to evaporate water / Energy required to raise Drying air temperature (25 C-Tda)
12. Furnace Efficiency = Energy removed by drying air / Energy input to furnace
13. System Efficiency = Energy required to evaporate water / Total energy input

Table 4.

DRYING DATA FOR IIAP AND CIAT PILOT PLANTS

Pilot Plant	Air Flow	Air Flow Rate	Moisture Evaporation Rates			Pick-up Efficiency	Drying Efficiency	System Efficiency
	kg s^{-1}	kg s^{-1} m^{-2}	g s^{-1}	g $s^{-1}m^{-2}$	g(kg Air)$^{-1}$	%	%	%
IIAP								
LD≈42 kg m^{-2}	1.99	0.17	13.38	1.52	6.72	60.9	57.0	13.4
CIAT								
LD=52 kg m^{-2}	5.50	0.26	29.54	1.41	5.37	45.9	37.3	22.0
LD=75 kg m^{-2}	5.85	0.28	31.92	1.52	5.46	49.5	47.4	29.9
LD=95 kg m^{-2}	5.82	0.28	37.33	1.78	6.41	55.4	51.7	36.4
LD=140 kg m^{-2}	5.51	0.27	37.59	1.79	6.81	62.6	57.1	32.7

Notes:

1. LD - Fresh chip Loading Density in drying bin, expressed in kg fresh chips per square metre of bin area (kg m^{-2})
2. IIAP mean LD ≈ 42 kg m^{-2}, with a range of 25 - 82 kg m^{-2}.
3. Pick-up Efficiency = $\frac{\text{Mass of water evaporated into the drying air}}{\text{Potential evaporative capacity of the drying air}}$
4. Drying Efficiency = $\frac{\text{Energy required to evaporate water}}{\text{Energy required to raise drying air temperature from 25°C to drying temperature}}$
5. System Efficiency = $\frac{\text{Energy required to evaporate water}}{\text{Total energy input}}$

Table 5.

THERMAL PERFORMANCE OF FURNACE

Total System Performance

Trial	Burn time h	Fan time h	Ambient T deg C	Drying air flow rate kg/s	Wood fuel Total input kg	Fuel GCV KJ/kg	Energy supplied MJ	Energy utilised MJ	Furnace efficiency %
1	10.5	8.2	29.8	1.80	605	15,886	9,611	1,712	17.8
2	11.5	10.7	31.1	2.02	600	14,877	8,926	2,458	27.5
3	8.0	7.2	32.4	2.01	400	15,567	6,227	1,830	29.4
4	13.0	12.4	29.9	2.06	690	17,836	12,307	2,929	23.8
Mean	**10.8**	**9.6**	**30.8**	**1.97**	**574**	**16.042**	**9,268**	**2,232**	**24.6**

Dynamic System Performance

Trial	Wood fuel feed rate kg/h	Drying air flow rate kg/s	Ambient T deg C	Furnace exit T deg C	Drying air T increase deg C	Energy supply rate KW	Energy use rate KW	Furnace efficiency %
1	58	1.80	29.8	61.8	32.0	255.9	58.0	22.7
2	52	2.02	31.1	62.5	31.4	214.9	63.8	29.7
3	50	2.01	32.4	67.3	34.9	216.2	70.6	32.7
4	53	2.06	29.9	61.5	31.6	262.6	65.5	24.9
Mean	**53**	**1.97**	**30.8**	**63.3**	**32.5**	**237.4**	**64.5**	**27.5**

Notes:

1. Burn time - Total Furnace operation time.
2. Fan time - Total Fan running time.
3. GCV - Gross Calorific Value of Wood fuel, expressed in KJ/kg wet basis.
4. $\text{Furnace Efficiency} = \dfrac{\text{Energy utilised by the Drying air}}{\text{Energy input to Furnace}}$

Table 6.

COMPARISON OF THERMAL PERFORMANCE OF FURNACES AT CIAT AND IIAP PILOT PLANTS

Total System Performance

Pilot Plant	Burn time h	Fan time h	Ambient T deg C	Drying air flow rate kg/s	Total Fuel input kg	Fuel GCV KJ/kg	Energy supplied MJ	Energy utilised MJ	Furnace efficiency %
IIAP(wood) July 1994	10.8	9.6	30.8	1.97	574	16,042	9,268	2.232	24.6
CIAT(coke) March 1993	11.7	9.6	30.8	5.82	363	27,394	9,944	4,632	46.6
CIAT(coke) May 1993	7.3	5.8	31.3	5.17	235	30,612	7,194	3,131	43.5
CIAT(coal) May 1993	6.1	5.2	29.3	5.48	250	32,614	8,154	3,361	44.9

Dynamic System Performance

Pilot Plant	Fuel feed rate kg/h	Drying air flow rate kg/s	Ambient T deg C	Furnace exit T deg C	Drying air T increase deg C	Energy supply rate KW	Energy use rate KW	Furnace efficiency %
IIAP(wood) July 1994	53	1.97	30.8	63.3	32.5	237.4	64.5	27.5
CIAT(coke) March 1993	34	5.86	30.8	54.8	29.8	258.1	139.8	54.2
CIAT(coke) May 1993	40	5.17	31.3	60.2	28.9	340.2	149.2	43.9
CIAT(coal) May 1993	40	5.48	29.3	64.7	35.4	362.4	195.4	53.9

Notes:

1. Burn time - Total Furnace operation time.
2. Fan time - Total Fan running time.
3. GCV - Gross Calorific Value of Wood fuel, expressed in KJ/kg wet basis.
4. Furnace Efficiency = Energy utilised by the Drying air / Energy input to Furnace

Table 7.

SUMMARY OF FRESH ROOT AND DRY CHIP CYANOGEN CONCENTRATIONS

Trial		Fresh roots T	Fresh roots G	Fresh roots NG	Fresh roots DMC	Bin Dried Chips T	Bin Dried Chips G	Bin Dried Chips NG	Bin Dried Chips DMC	Sun/Bin(Mix) Dried Chips T	Sun/Bin(Mix) Dried Chips G	Sun/Bin(Mix) Dried Chips NG	Sun/Bin(Mix) Dried Chips DMC	Bin Λ T	Mix Λ T
1					42.30	118	94	23	95.31						
Pa:Pe	Pa	*74*	*61*	*13*	*41.12*										
3.83:1	Pe	*1781*	*1288*	*493*	*26.75*										
2	WR	428	315	112	38.93	177	143	34	94.44	181	149	32	93.59	58.6	57.7
Pa:Pe	Pa	*156*	*138*	*18*	*40.84*										
5.24:1	Pe	*1577*	*942*	*635*	*28.43*										
3	WR	384	267	117	38.85	172	156	17	97.01					55.2	
Pa:Pe	Pa	*60*	*44*	*16*	*41.82*										
5.28:1	Pe	*953*	*561*	*392*	*32.01*										
4	WR	203	126	76	40.26	127	93	34	95.77	107	75	32	95.52	37.4	47.3
Pa:Pe	Pa	*77*	*58*	*19*	*44.61*										
4.79:1	Pe	*1490*	*976*	*514*	*28.72*										
5	WR	321	217	105	41.87					166	140	26	95.20		48.3
										141	115	26	95.12		56.1
Average	WR	334	231	103	40.44	149	122	27	95.63	149	120	29	94.86	50.4	52.3

Notes:

1. All Cyanogen concentrations are expressed in mg CN equiv./kg Dry Matter.
2. T - Total Cyanogen content.
3. NG - Non-Glucosidic Cyanogen content.
4. G - Glucosidic Cyanogen content (by difference).
5. DMC - Sample Dry Matter content, expressed in % (wet basis).
6. WR (whole root) Cyanogen contents are weighted averages based on Pa (Parenchyma) and Pe (Peel) Cyanogen contents. Fresh root Cyanide data is not available for Trial 1.
7. Λ T is the reduction in Total Cyanogen content with drying, expressed as a percentage.
8. All samples were analysed by the Cassava Quality/Utilisation Section, CIAT, and the figures presented are average values for 5 samples.
9. Cyanogen contents were determined using the quantitative enzymic assay method: O'Brien G, Taylor A and Poulter N (1991). *Improved Enzymic Assay for Cyanogens in Fresh and Processed Cassava*. Journal of the Science of Food and Agriculture, 56, 277-289.

Table 8.

CYANOGEN CONCENTRATIONS IN PILOT PLANT PRODUCTS SAMPLES TAKEN JANUARY 1994

Sample	Storage Time weeks	T	G	CH	F	DMC
Cassava Flour Human consumption	8	42	32	4	6	94.35
Cassava Chips Human consumption	7	47	31	10	6	96.06
Cassava Flour Industrial use	14-18	9	3	2	4	90.61
Cassava Chips Industrial use	14-18	12	5	2	5	90.64
Bran (Milling byproduct)		108	77	24	6	92.02
Water Biscuits (30% substitution)		9	5	0	4	94.41

Notes:

1. All Cyanogen concentrations are expressed in mg CN equiv./kg Dry Matter.
2. T - Total Cyanogen content.
3. G - Glucosidic Cyanogen content.
4. CH - Cyanohydrin content.
5. F - Free Cyanide content (HCN).
6. DMC - Sample Dry Matter content, expressed in % (wet basis).
7. All samples were analysed by the Cassava Quality/Utilisation Section, CIAT, and the figures presented are average values for 3 samples.
8. Cyanogen contents were determined using the quantitative enzymic assay method: O'Brien G, Taylor A and Poulter N (1991). *Improved Enzymic Assay for Cyanogens in Fresh and Processed Cassava*. Journal of the Science of Food and Agriculture, 56, 277-289.

Table 9. SUMMARY OF FRESH AND DRY CHIP CYANOGEN CONCENTRATIONS MEASURED AT THE CIAT PILOT PLANT, MARCH 1993

Trial		Fresh Chips T	G	NG	DMC	Bin Dried Chips T	G	NG	DMC	Bin Λ T
Pa:Pe	Pa	*160*	*128*	*32*						
6.2:1	Pe	*2606*	*2167*	*439*						
11	FC	500	411	88	37.3	242	164	78	90.3	51.6
Pa:Pe	Pa	*195*	*171*	*25*						
7.4:1	Pe	*1894*	*1550*	*344*						
9	FC	398	335	63	32.8	211	161	50	90.3	47.0
Pa:Pe	Pa	*160*	*23*	*137*						
6.1:1	Pe	*2102*	*385*	*1717*						
10	FC	431	357	74	30.7	190	140	50	90.0	55.9
Pa:Pe	Pa	*170*	*128*	*42*						
5.2:1	Pe	*1698*	*1313*	*385*						
12	FC	417	319	97	35.5	217	125	92	89.4	48.0
Pa:Pe	Pa	*96*	*62*	*34*						
6.4:1	Pe	*2177*	*1600*	*578*						
13	FC	403	287	116	37.1	137	89	48	89.5	66.0
Pa:Pe	Pa	*83*	*53*	*30*						
6.6:1	Pe	*2441*	*1966*	*475*						
14	FC	393	305	89	37.5	185	105	80	89.5	52.9
Pa:Pe	Pa	*131*	*95*	*36*						
6.6:1	Pe	*2494*	*2016*	*478*						
15	FC	442	348	94	36.5	133	123	10	88.5	69.9
Pa:Pe	Pa	*128*	*82*	*46*						
6.2:1	Pe	*2642*	*2552*	*91*						
16	FC	477	425	52	34.7	145	138	7	93.1	69.6
Average	FC	433	348	84	35.3	183	131	52	90.1	57.6

Notes:

1. All Cyanogen concentrations are expressed in mg CN equiv./kg Dry Matter.
2. T - Total Cyanogen content.
3. NG - Non-Glucosidic Cyanogen content.
4. G - Glucosidic Cyanogen content (by difference).
5. DMC - Sample Dry Matter content.
6. FC (Fresh Chip) Cyanogen contents are weighted averages based on Pa (Parenchyma) and Pe (Peel) Cyanogen contents.
7. Λ T is the reduction in Total Cyanogen content with drying, expressed as a percentage.
8. All samples were analysed by the Cassava Quality/Utilisation Section, CIAT, and the figures presented are average values for 3 samples (Pa & Pe), or for 6 samples (Dry Chips).
9. Cyanogen contents were determined using the quantitative enzymic assay method: O'Brien G, Taylor A and Poulter N (1991). *Improved Enzymic Assay for Cyanogens in Fresh and Processed Cassava*. Journal of the Science of Food and Agriculture, 56, 277-289.

Table 10.

SUMMARY OF MICROBIOLOGICAL QUALITY OF DRY CHIPS

Dry Sample	Bin Drying only				Mixed Drying			
	APC	Sps	MPN Cs	Y&M	APC	Sps	MPN Cs	Y&M
T1	9.99×10^{6}	5.25×10^{4}	2.50×10^{4}	5.15×10^{3}				
T2	2.12×10^{5}	3.50×10^{4}	30	1.00×10^{4}	9.90×10^{5}	5.77×10^{4}	180	0
T3	1.62×10^{6}	0	80	100				
T4	8.12×10^{5}	3.87×10^{4}	64	0	2.15×10^{5}	1.15×10^{4}	21	67
T5A					5.44×10^{6}	1.55×10^{5}	83	6.00×10^{3}
T5B					2.54×10^{7}	4.00×10^{5}	157	100
T5 A&B					1.54×10^{7}	2.78×10^{5}	120	3.05×10^{3}

Notes:

1. All counts expressed as colony forming units per gramme of sample (cfu g^{-1}), wet basis.
2. APC - Aerobic Plate Count at 35°C.
3. Sps - Vegetative Spore Count at 35°C.
4. MPN Cs - Most Probable Number of Coliforms.
5. Y&M - Yeast and Mould Count.
6. All samples were analysed by Laboratorio: Microbiologia de Allimentos, Cali, and the figures presented are average values for 3 samples.
7. Counts were determined using ICMSF recommended methods: ICMSF (1978). *Micro-organisms in foods 1. Their significance and methods of enumeration.* 2nd Edition. International Commission on Microbiological Specifications for Foods (ICMSF). Toronto: University of Toroto Press.

Table 11.

MICROBIOLOGICAL QUALITY OF PILOT PLANT PRODUCTS
SAMPLES TAKEN JANUARY 1994

Sample	Storage Time weeks	APC	Sps	MPN Cs	Y&M	Yeasts & Moulds
Cassava Flour Human consumption	8	6.30×10^{5} 2.50×10^{6}	4.45×10^{4} 7.63×10^{4}	120 210	0 0	
Cassava Chips Human consumption	7	1.50×10^{4} 1.00×10^{4}	6.00×10^{2} 6.36×10^{3}	280 80	0 0	
Cassava Flour Industrial use	14-18	8.01×10^{7} 8.59×10^{7}	7.63×10^{4} 9.54×10^{4}	3500 3800	450 800	Aspergillus niger Aspergillus fumigatus
Cassava Chips Industrial use	14-18	1.72×10^{7} 2.29×10^{7}	1.02×10^{5} 1.08×10^{5}	3800 4100	0 200	Aspergillus niger
Bran (Milling byproduct)		1.14×10^{8} 2.00×10^{5}	6.36×10^{4} 3.18×10^{4}	8000 450	80 0	Aspergillus niger
Water Biscuits (30% substitution)		6.00×10^{3} 1.90×10^{4}	6.30×10^{2} 1.27×10^{4}	<3 60	0 0	
Plantain Flour Human consumption		5.00×10^{5} 3.18×10^{6}	6.36×10^{4} 7.63×10^{4}	350 1200	250 400	Aspergillus niger Aspergillus fumigatus

Notes:
1. All counts expressed as colony forming units per gramme of sample (cfu g^{-1}), wet basis.
2. APC - Aerobic Plate Count at 35°C.
3. Sps - Vegetative Spore Count at 35°C.
4. MPN Cs - Most Probable Number of Coliforms.
5. Y&M - Yeast and Mould Count.
6. Aflatoxins and Salmonella were absent in all samples.
7. All samples were analysed by Laboratorio: Microbiologia de Allimentos, Cali, and the figures presented are average values for 3 samples.
8. Counts were determined using ICMSF recommended methods: ICMSF (1978). *Micro-organisms in foods 1. Their significance and methods of enumeration*. 2nd Edition. International Commission on Microbiological Specifications for Foods (ICMSF). Toronto: University of Toroto Press.

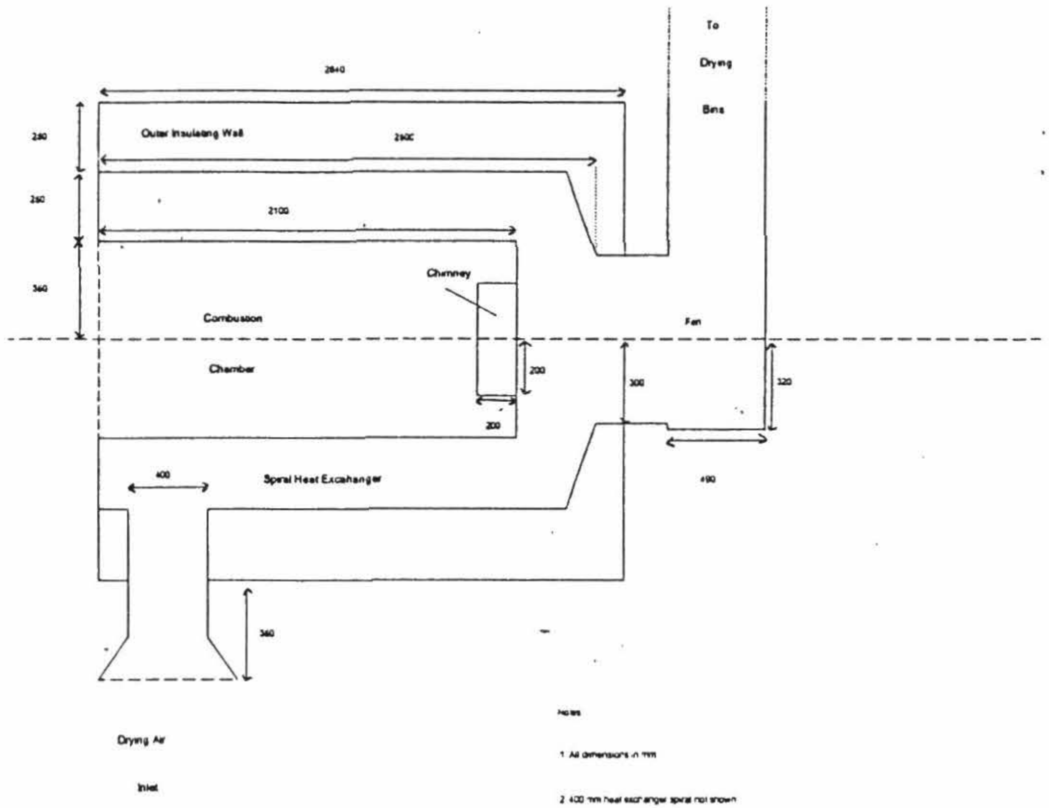

Figure 2.

SCHEMATIC OF FURNACE AT IIAP PILOT PLANT

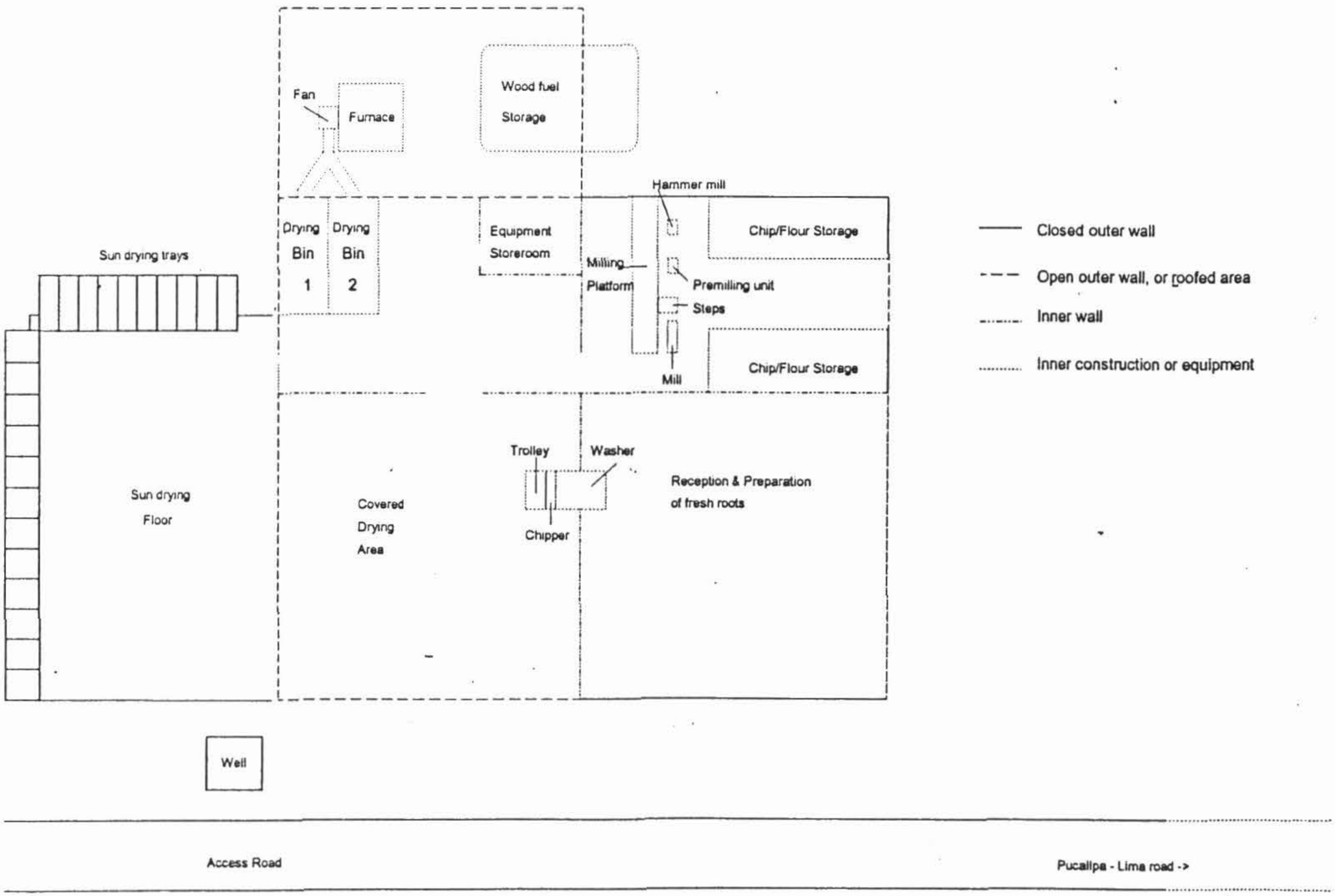

Figure 1.

LAYOUT OF IIAP PIIOT PLANT, PUCALLPA.

Figure 3.1

COMBUSTION CHAMBER OF IIAP FURNACE

Figure 3.2

SIDE VIEW OF IIAP FURNACE

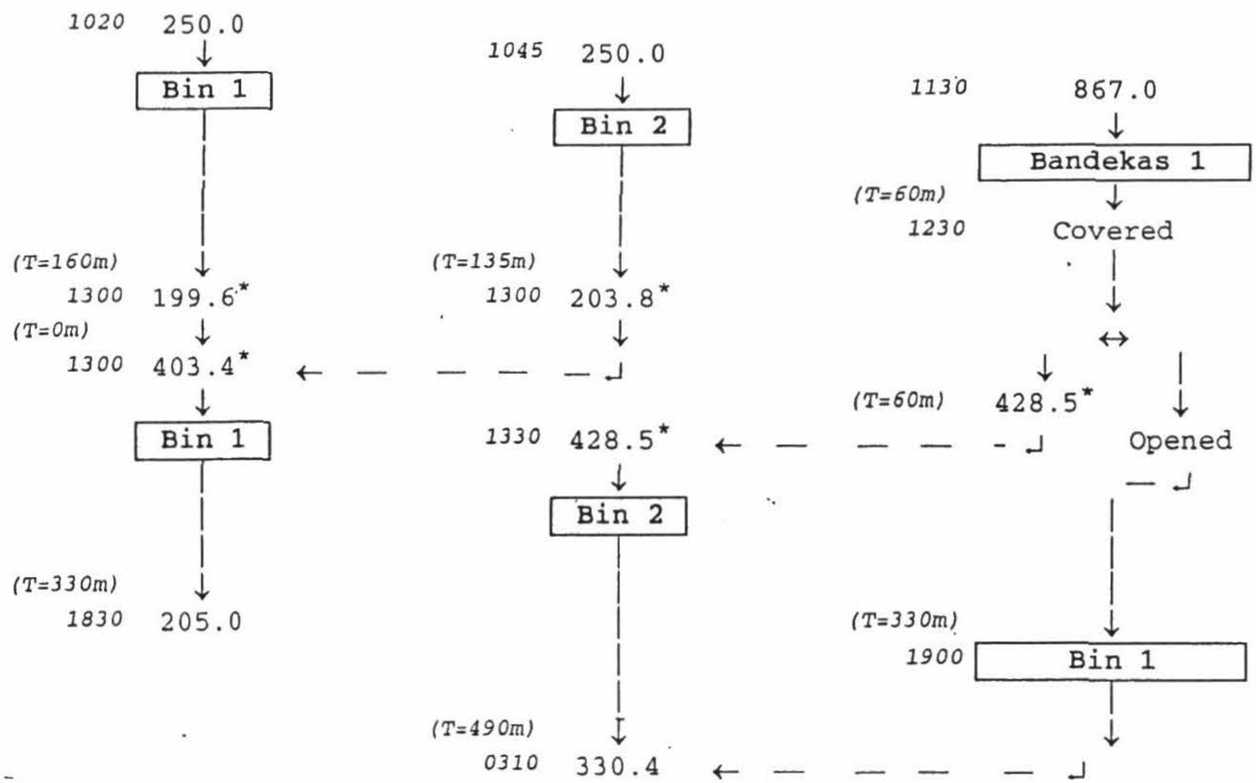

Figure 4.1

TRIAL 1 - FLOWSHEET

Notes:

1. All chip weights are expressed in kgs.
2. * indicates an estimated rather than measured chip weight.
3. Itallic type indicates Clock (real) time.
4. Drying times are given in brackets (), expressed in minutes.

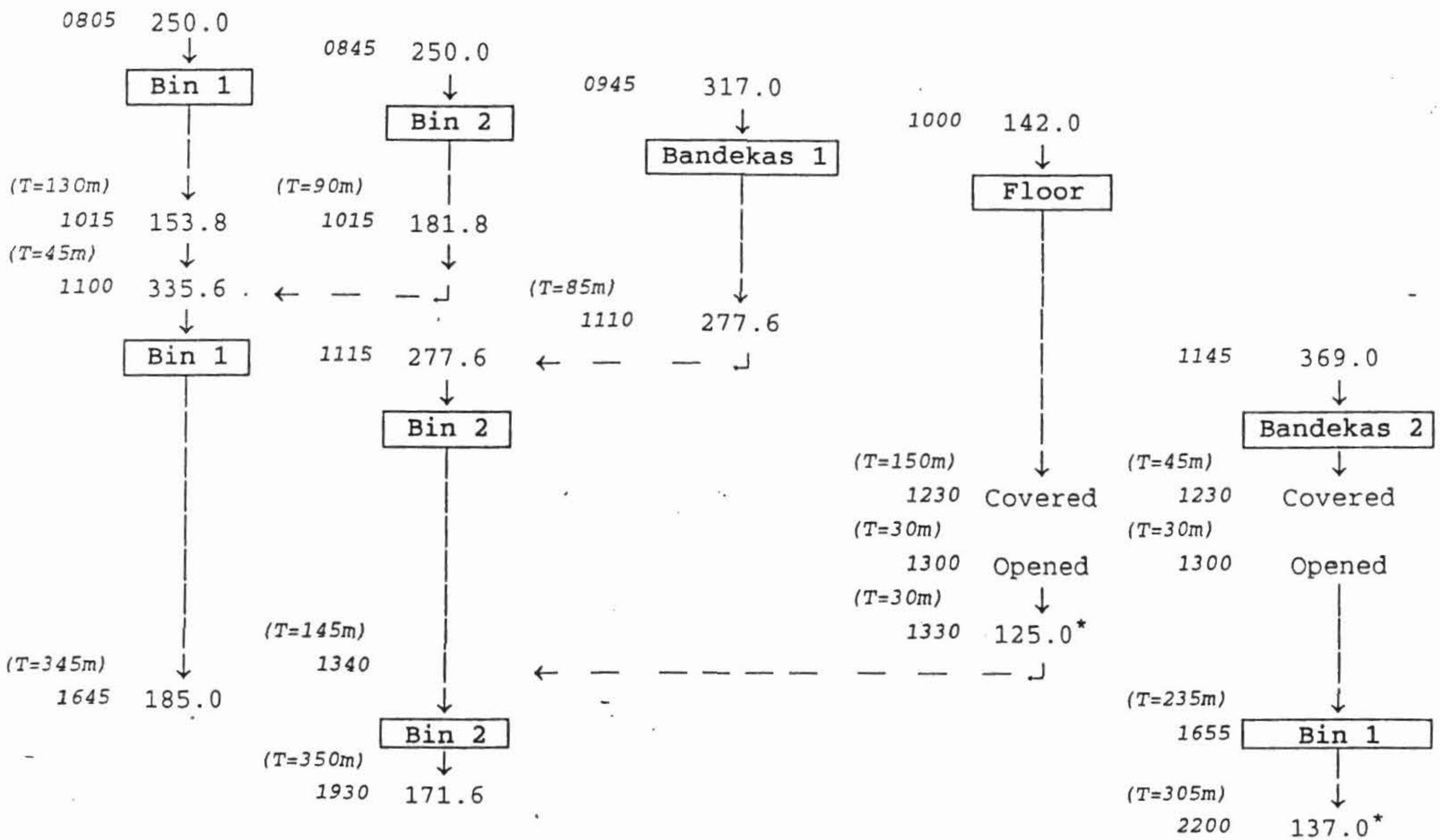

Figure 4.2

TRIAL 2 - FLOWSHEET

Notes:
1. All chip weights are expressed in kgs.
2. * indicates an estimated rather than measured chip weight.
3. Itallic type indicates Clock (real) time.
4. Drying times are given in brackets (), expressed in minutes.

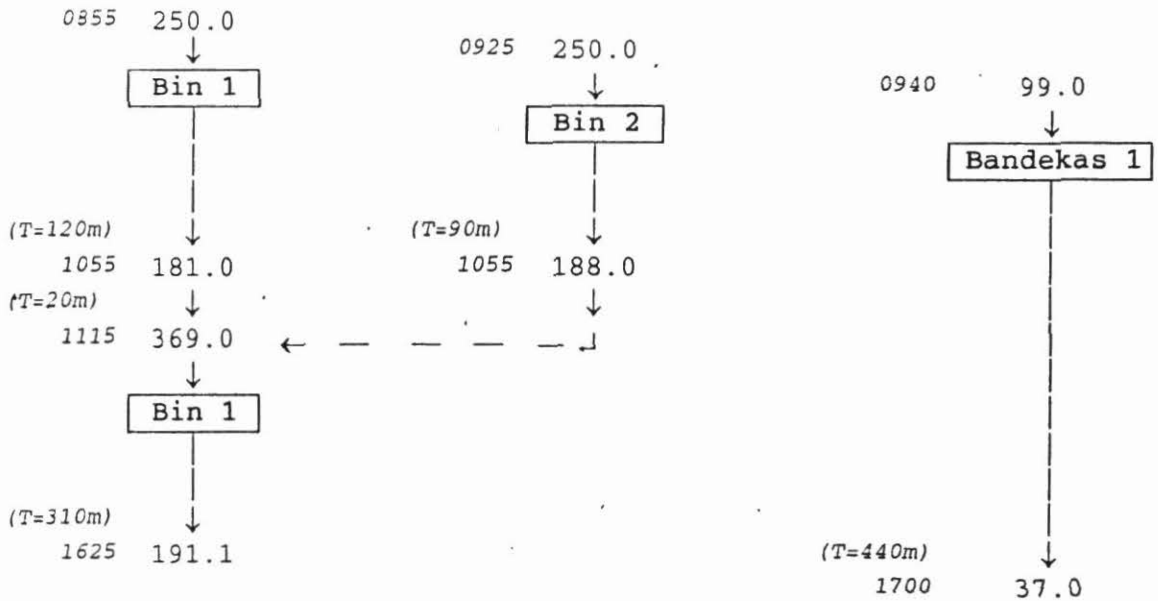

Figure 4.3

TRIAL 3 - FLOWSHEET

Notes:
1. All chip weights are expressed in kgs.
2. Itallic type indicates Clock (real) time.
3. Drying times are given in brackets (), expressed in minutes.

T4FS.DOC

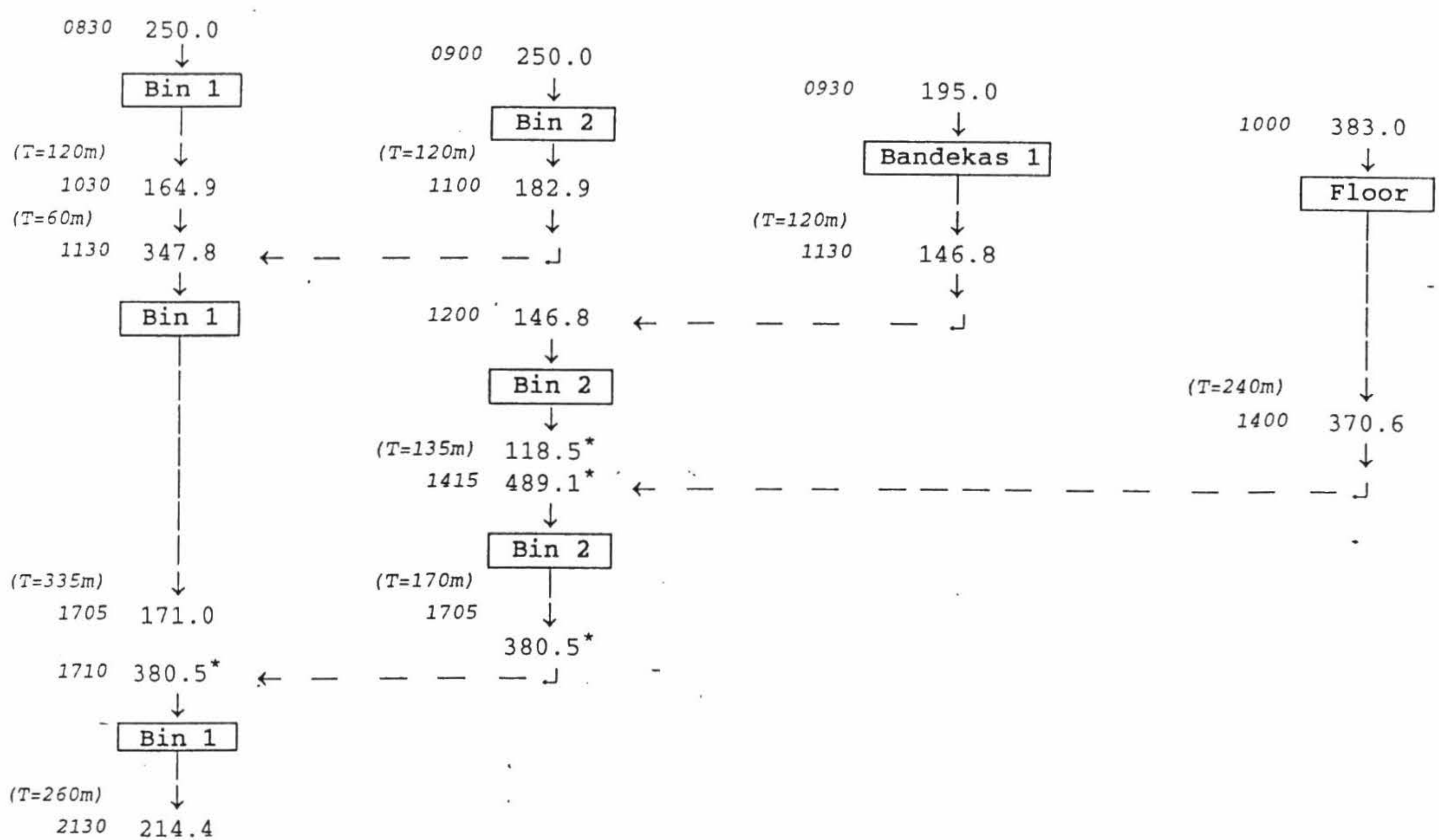

Figure 4.4

TRIAL 4 - FLOWSHEET

Notes:
1. All chip weights are expressed in kgs.
2. * indicates an estimated rather than measured chip weight.
3. Itallic type indicates Clock (real) time.
4. Drying times are given in brackets (), expressed in minutes.

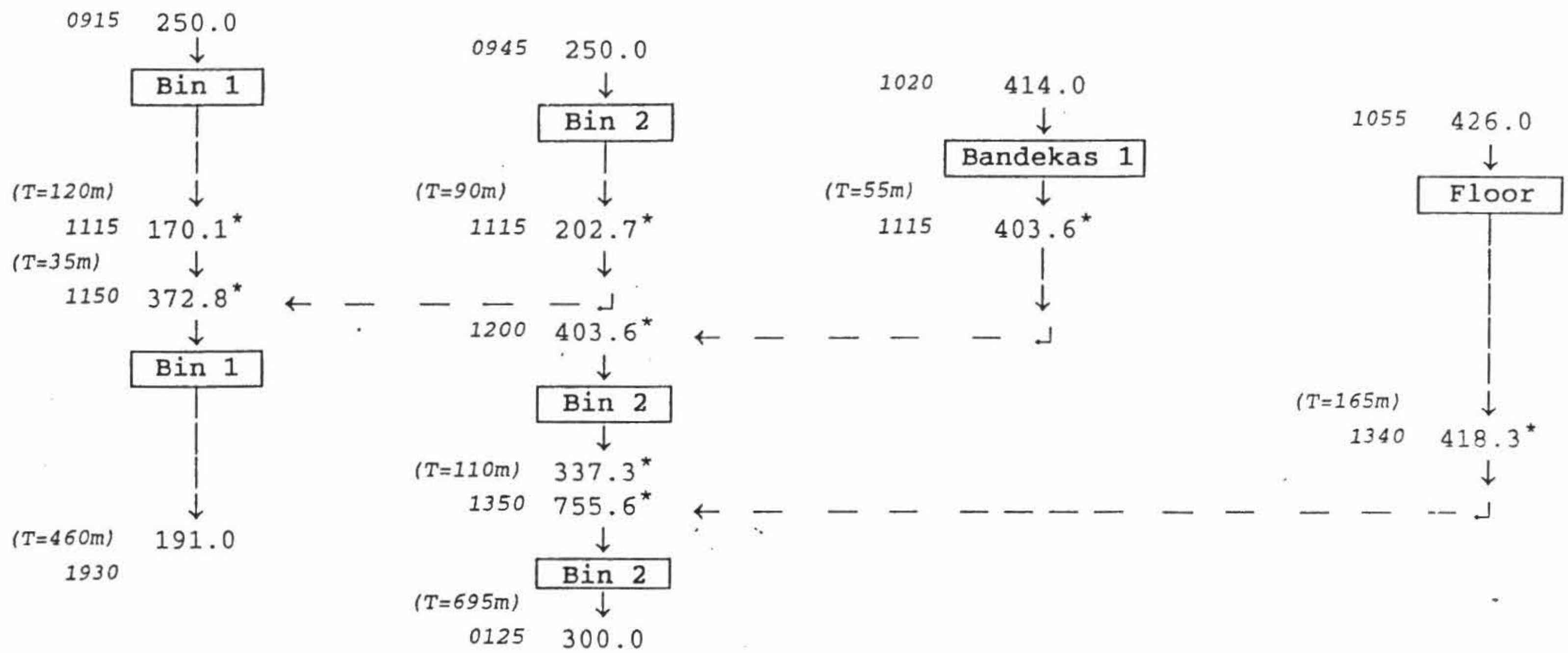

Figure 4.5

TRIAL 5 - FLOWSHEET

Notes:
1. All chip weights are expressed in kgs.
2. * indicates an estimated rather than measured chip weight.
3. Itallic type indicates Clock (real) time.
4. Drying times are given in brackets (), expressed in minutes.

APPENDIX 1

VISIT ITINERARY:

S 17 Jul	Cali - Lima
M 18 Jul	Caritas training course, Classroom sessions
T 19 Jul	Continue course, Quality Control presentation
W 20 Jul	Lima-Pucallpa with course participants Introduction to IIAP and tour of station
T 21 Jul	Caritas training course, practical
F 22 Jul	Caritas training course, practical
S 23 Jul	Caritas training course, practical Meeting with Dra Salas, Ing Rios, Sra Llamoka and Sr Santillan
S 24 Jul	Course participants depart Pucallpa. Attended official town parade with Ing Rios, and visited Agrofer'94
M 25 Jul	Preparation for plant evaluation, visit to INIA
T 26 Jul- F 29 Jul	Plant evaluation trials
S 30 Jul	'Day of rest', visit to INIA
S 31 Jul- M 01 Aug	Plant evaluation trials
T 02 Aug	Preparation of equipment and samples for travel, final meeting with Ing Rios Pucallpa - Lima
W 03 Aug	Lima - Cali

La investigación en el secado artificial de yuca como apoyo al desarrollo agroindustrial de la Costa Atlántica de Colombia

Lisímaco Alonso
Miguel Angel Viera
Rupert Best (1)

RESUMEN

Se investigó el secado artificial de trozos de yuca con aire caliente en un secador de capa fija utilizando cuatro fuentes de energía solar captada mediante un colector plano, carbón mineral, gas propano y combustible diesel, y se comparó con el secado natural en pisos de concreto.

La evaluación del secado con el colector solar se hizo en la Costa Atlántica de Colombia durante la época seca del año. El colector de 30 m^2 de área absorbente, calentó un caudal de aire de 106 m^3/min hasta una temperatura promedia de 36°C, pudiéndose aplicar caudales entre 78 a 141 m^3/min por tonelada de trozos frescos de yuca para obtener tiempos de secado entre 3 y 2 días. Este sistema no resultó factible para secado de yuca.

El empleo de los tres combustibles para calentar el aire en unidades conformadas por quemadores e intercambiadores de calor, permitieron operar con caudales aplicados de 130 y 190 m^3/min por tonelada de trozos frescos y temperaturas de 50 y 60°C para obtener tiempos de secado entre 5.5 a 10 h. De los combustibles utilizados, el secado con carbón mineral resultó con menores costos tanto de inversión en equipos como de operación, seguido por el gas propano y el diesel.

Se hizo un análisis económico para un proyecto de producción de 538 toneladas de yuca por año dentro de las condiciones de producción y comercialización de la yuca que existieron en la Costa Atlántica durante 1985. En este estudio se compararon el secado natural en pisos de concreto y el secado en capa fija con carbón mineral dentro de 4 alternativas de inversión. La primera opera 20 semanas de época seca al año con un secado natural. La segunda lo hace durante 35 semanas con el mismo sistema. La tercera opera 20 semanas con un secado natural y 30 semanas con un secado artificial. La cuarta opera 50 semanas con un secado artificial. Las rentabilidades calculadas mediante computador para las 4 alternativas fueron 26.4, 37.0, 12.6 y 12.4%, respectivamente. El empleo de un secador artificial y carbón mineral como fuente energética resultaron rentables para la producción de yuca seca durante todo el año.

INTRODUCCION

Existe un gran potencial en los países tropicales de América Latina para la utilización de la yuca seca en la alimentación animal y buenas perspectivas para su inclusión en la alimentación humana como fuente de calorías en productos elaborados con otras materias primas, tales como harinas compuestas para sopas y coladas, pan y pastas. Esto ha creado la necesidad de desarrollar métodos de secado eficientes y confiables con respecto a la calidad del producto, que sean técnica y económicamente factibles dentro de las condiciones socioeconómicas de estos países en vías de desarrollo.

Entre los diferentes sistemas de secado, existen dos que, por requerir relativamente bajo inversión y presentar simplicidad de manejo, despertaron interés y fueron considerados en los programas de investigación del Centro Internacional de Agricultura Tropical, CIAT. Estos son el secado natural y el secado artificial en capa fija.

En los años 70 se adaptó en el CIAT una tecnología para el secado natural de la yuca, que se está aplicando en la Costa Atlántica de Colombia a nivel comercial en un proyecto cooperativo con el Fondo de Desarrollo Rural Integrado, DRI, orientado hacia el establecimiento de pequeñas empresas campesinas que produzcan yuca seca para la alimentación animal. Actualmente existen 36 plantas con una capacidad de más de 6.000 toneladas de yuca seca por año.

El secado natural es un método que depende completamente de las condiciones climáticas, lo que restringe su uso en las épocas lluviosas del año. Por lo tanto, con el objeto de prolongar el período de secado y posibilitar el suministro contínuo de yuca seca se seleccionó un secador de capa fija con circulación artificial de aire caliente. Este sistema se evaluó utilizando diversas fuentes de calor tales como el diesel, gas propano, carbón mineral y un colector solar.

En este trabajo se presentan los resultados de esta evaluación y se discute el empleo del secado artificial con respecto a las condiciones actuales de producción y comerciaización de la yuca en la Costa Atlántica y como alternativa para la producción de yuca seca destinada al consumo humano.

REVISION DE LITERATURA

El sistema de secado más económico y utilizado por el hombre desde tiempos remotos es el secado natural. Este sistema fue investigado para el secado de la yuca, tanto en pi-

(1) Sección utilización del Programa de Yuca - Centro Internacional de Agricultura Tropical - Cali, Colombia.

sos de concreto como en bandejas verticales o inclinadas, durante la década de los 70 por difernetes autores, entre los que se destacan Roa (1974), Best (1978) y Thanh y otros (1979). Estos estudios permitieron entender mejor el efecto de los factores que más inciden en el proceso, tales como el estado de subdivisión de los trozos de yuca (tamaño y forma geométrica), la densidad de carga y las condiciones ambientales.

A pesar de las mejoras en las técnicas de secado natural y las ventajas que ofrece sobre el secado artificial en términos de costos de inversión y operación, es un método que no se puede utilizar en regiones donde las condiciones ambientales son desfavorables. En estos casos, el uso de secadores por tandas con aire ambiente o aire caliente o una combinación de ambos, en circulación directa a través de una capa o lecho fijo, es una alternativa económicamente más favorable para América Latina que el empleo de secadores artificiales continuos y de gran capacidad (Crown, 1981 y Freivalds, 1982).

Paralelamente a las investigaciones del secado natural, se han llevado a cabo estudios del secado en capa fija con miras a determinar los mejores parámetros de operación, altura de la capa, temperatura y velocidad del aire, para secar trozos de yuca. Chirife y Cachero (1970) hallaron que con capas de hasta 12 cm de altura no se reduce apreciablemente el tiempo de secado con flujos de aire por encima de 5.000 kg/h.m^2, y la temperatura a la que los trozos se tuestan a bajos contenidos de humedad (menores del 35°/o) ocurre por encima de 84°C. Estos autores también encontraron que no se presenta un período de velocidad constante y que el movimiento interno del agua contenida en los trozos es el mecanismo que controla el proceso desde el comienzo, resultado confirmado posteriormente por Webb y Gill (1974) y Akhtar (1978).

A una escala mayor, Rossi y Roa (1980) y Ospina (1980) experimentaron con un secador de 15 m^2 de área, acoplado a un colector solar de 100 m^2 de área absorbente, y usaron modelos matemáticos para determinar el mínimo caudal de aire que se debe aplicar cuando la temperatura y la humedad relativa son cambiantes. Reportaron que para capas de 30 cm de altura, el cuadal aplicado varió entre 47.5 y 102.5 m^3/min por tonelada de trozos de yuca alimentados al secador, cuando la temperatura del aire fluctuó entre 40° y 20°C y la humedad relativa entre 25 y 55°/o.

Toh (1973) investigó el secado de pulpa rallada de yuca a varios niveles de temperatura, caudal de aire y densidad de carga, en un secador contínuo de túnel. La pulpa previamente había sido secada hasta humedades de 50°/o (b.H.) e una filtropensa. Para calentar el aire utilizó un quemador de kerosene. El consumo de combustible varió exponencialmente con la densidad de carga y aumentó con menor pendiente cuando se incrementó el caudal. Encontró que no es apropiado, para las condiciones del experimento, calentar aire a temperaturas mayores de 70°C por los altos consumos de combustible.

Con este mismo material, pulpa rallada prensada, Seng (1976) evaluó el empleo de un secador rotatorio y continuo. El combustible utilizado participó con el 55°/o en el costo total de operación; aún así, el empleo de este sistema podría competir en términos de costo con el secado tradicional al sol para las condiciones de Malasia, donde se desarrolló el estudio.

Un estudio de factibilidad económica para el establecimiento de una planta de secado artificial de trozos de yuca seca fue hecho por el Centro de Investigaciones en Tecnología de Alimentos CITA (1974) en Costa Rica; encontraron que el proyecto es factible, con rentabilidades del 11°/o sobre la inversión total y 16°/o sobre la inversión fija, operando con una capacidad mínima de 10 t/ha. durante 20 horas por día y 200 días por año. Con base en este estudio se montó la planta, la cual fracasó debido a su mala ubicación y a la incapacidad de la zona para suministrar la materia prima necesaria.

La información que se obtiene de los estudios mencionados es que los parámetros de control en el proceso para minimizar los costos de operación y obtener yuca seca de buena calidad, son el estado de subdivisión del material, la temperatura y el caudal aplicado de aire. Además, para que el proceso sea factible, se debe garantizar un suministro continuo y adecuado de la materia prima.

MATERIALES Y METODOS

El estudio experimental se llevó a cabo en dos fases. En la primera fase se evaluó un secador de 6 m^2 acoplado a un colector plano de 30 m^2 de superficie absorbente de radiación solar. El secador y el colector se construyeron en el municipio de San Juan de Betulia, Departamento de Sucre (Costa Atlántica de Colombia).

La segunda fase se realizó en el CIAT, con dos secadores, uno de 2m^2 y otro de 6 m^2 de áreas de secado, acoplados el primero a un quemador de carbón y el segundo, independientemente, a quemadores de gas propano y diesel.

Para la evaluación de los secadores con las fuentes de calor mencionadas, se varió la cantidad de trozos alimentados para lograr diferentes caudales aplicados por toneladas de trozos de yuca fresca. La temperatura del aire se rebajó a los valores obtenidos còn el colector y se fijó en 50 y 60°C para los combustibles utilizados.

MATERIALES

Las raíces de yuca, especie *Manihot esculenta* Crantz, fueron cosechadas entre los 8-10 meses de edad de cultivos experimentales. En la primera fase se empleó la variedad local Venezolana sembrada en la Costa Atlántica y en la segunda fase se usó la variedad Manihoica P12 cultivada en el CIAT.

Las raíces de yuca fueron trozadas en el prototipo de máquina denominada Tailandia, que consistía de una estructura metálica con una tolva de alimentación y un disco vertical giratorio. El disco tenía 6 filas de agujeros de aproximadamente 25 mm de diámetro, que cortaban la yuca en forma de tajadas. En la Figura 1 se presenta la máquina picadora.

Los trozos típicos producidos por esta máquina midieron 60-80 mm de longitud, 25-30 mm de ancho y 7-10 mm de espesor. Junto con el trozo típico se producen también trozos más pequeños y partículas finas o ripio. Los porcentajes obtenidos de toda la muestra se distribuyen en 42°/o para el trozo típico, 34°/o para trozos más pequeños y 24°/o para el ripio.

Descripción de los sistemas de secado

Para los ensayos de la primera fase, se utilizó el sistema presentado en la Figura 2, que consta de un secador de 6 m^2, un ventilador centrífugo y un colector solar plano de 30 m^2.

El secador era una cámara construida con materiales disponibles en la región, de 3 m de largo por 2 m de ancho. El área de secado era un piso falso conformado por láminas de acero galvanizado perforadas el 3°/o del área total con agujeros de 3 mm de diámetro. Las láminas, de 1 m x 2 m, se soportaron con vigas de madera a 60 cm del suelo.

El ventilador (marca Dayton, referencia 3C073) que hizo circular el aire por el sistema fue de aletas curvadas hacia atrás, accionado por un motor eléctrico de 1 hp.

El colector solar de 30 m^2 de superficie absorbente, se construyó sobre un piso de concreto de 6 cm de espesor, con paredes de bloques de concreto. Como medio absorbente de la radiación se emplearon láminas acanaladas de zinc pintadas de negro mate, colocadas dentro del colector entre el piso y una cubierta de marcos calibre 6, la que se soportó sobre una estructura de madera y malla de alambre tipo gallinero, como se muestra en la Figura 2.

Para la segunda fase del experimento, realizada en el CIAT, se utilizaron los dos secadores. El de 2 m^2 se acopló a través de un ventilador centrífugo (marca Dayton, referencia 3CO73) con un conjunto quemador de carbón-intercambiador de calor. El quemador de carbón era de tiro natural, constaba básicamente de una cámara de combustión u hogar con parrilla estacionaria. El intercambiador de calor era de doble tubos concéntricos, con aletas longitudinales en ambos lados del tubo interior, por el cual fluían los gases de combustión. El aire de secado circulaba por el anillo formado por los dos tubos. Este sistema se muestra en la Fig. 3.

El secador de 6 m^2 se acopló independientemente con dos unidades de calentamiento, una de gas propano y otra de combustible diesel (1) (ACPM). La unidad diesel estaba conformada por un motor (marca Lister, modelo LT1) de 7.5 hp, acoplado directamente a un ventilador axial (marca Lister) y, mediante transmisión por correa, impulsaba un generador (marca Markon) de corriente eléctrica de 1.5 KVA, el cual proporcionaba la corriente necesaria para el funcionamiento del quemador de ACPM (marca Nu-Way Benson). La unidad de gas propano (marca Farm Fans, modelo 116SH) consistía de un ventilador axial y un quemador de gas. En las figuras 4 y 5 se presentan las unidades de calentamiento, a base de ACPM y gas, que se acoplaron al secador.

Los quemadores de carbón y ACPM calentaban el aire indirectamente, es decir, no se mezclaba el aire con los gases de combustión.

Los quemadores se conectaron con los secadores por medio de ductos de medición de cuadal, instalados según las normas de AMCA (ASHRAE, 1977).

El caudal del aire se determinó con un anemómetro de aletas, un tubo de pitot y un manómetro inclinado de escala 0-2,4 pulg. de agua y precisión ± 0.02. En la cámara pleno de los secadores se midió la temperatura del aire con un termómetro de mercurio de 0-120°C y precisión de ± 1°C.

RESULTADOS Y DISCUSION

Evaluación del secado artificial con colector solar

El período en el que se hizo el estudio con el colector solar comprendió entre febrero a marzo de 1984. Los resultados se clasificaron en dos grupos. El primer grupo contiene la evaluación del comportamiento del colector solar y el segundo, la capacidad del secador cuando se utilizó el colector como elemento de calentamiento del aire.

Los resultados de la evaluación del colector se presentan en la Tabla 1. El período de operación del colector cada día fue desde las 7:00 hasta las 19:00 horas, y calentó un caudal de 106 m^3/min hasta una temperatura promedio de 36°C. La temperatura inicial del aire ambiente fue en promedio de 31°C.

(1) El aceite combustible diesel (fue oil No. 2) es llamado en Colombia ACPM, abreviatura de Aceite Combustible de Peso Medio.

TABLA 1. Comportamiento de un colector solar plano de 30 m^2 de superficie absorbente (a)

Aire ambiente: Temperatura °C	Aire ambiente: Humedad relativa °/o	Radiación solar cal/cm^2.min	Caudal de aire m^3/min	Incremento de temperatura °C	Eficiencia del colector °/o
31	62	0.62	106	5	63

Valores promedios de 43 días de observaciones entre las 7:00 a las 19:00 horas.

(a) Superficie absorbente conformada por láminas acanaldas de zinc pintadas de negro mate, por debajo de una cubierta de polietileno

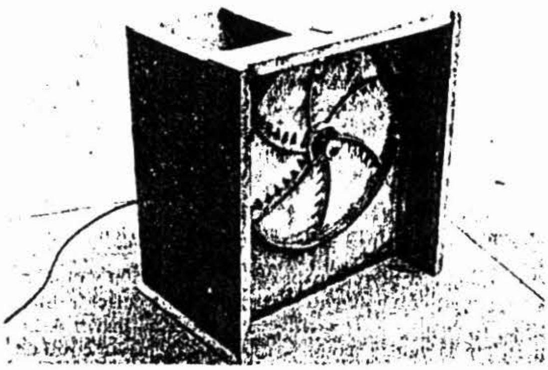

FIGURA 1. Máquina trozadora tipo Tailandia

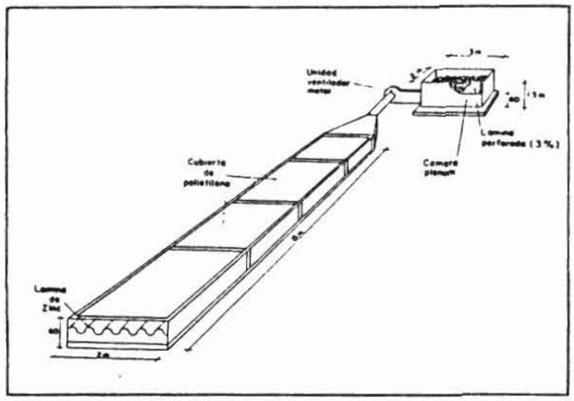

FIGURA 2. Secador de trozos de yuca que emplea un colector solar para calentar el aire.

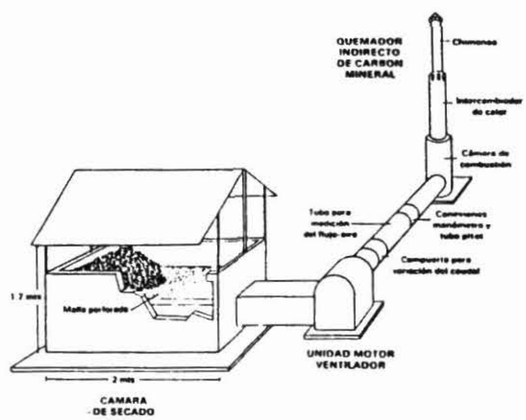

FIGURA 3.

Secador artificial de capa fija con quemador de carbón para calentar el aire.

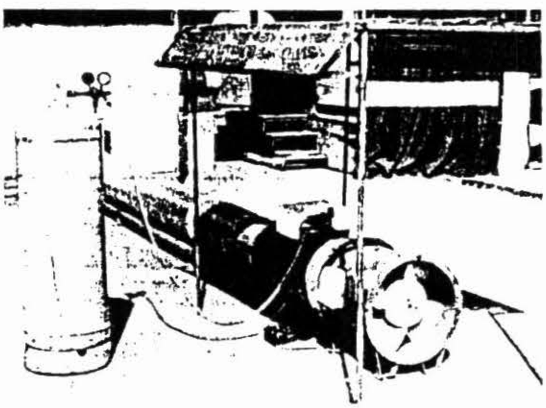

FIGURA 4. Sistema de calentamiento diesel acoplado a un de capa fija.

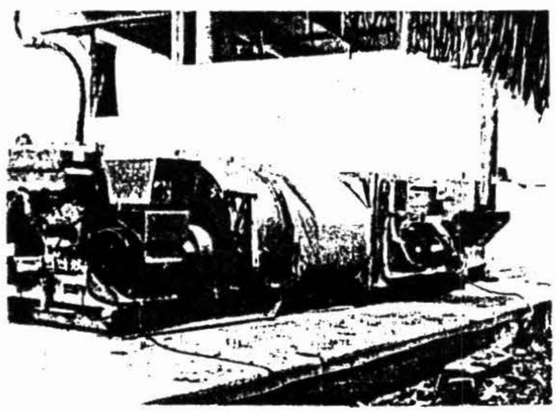

FIGURA 5. Sistema de calentamiento a base de gas propano acoplado a un secado de capa fija.

La humedad relativa del aire tuvo un descenso desde 62º/o hasta 46º/o. La eficiencia del colector, definida como la razón entre las cantidades promedios de energía ganada por el aire y la energía de radiación solar incidente, resultó de 63º/o, valor normal, según Rossi y Roa (1980), para este tipo de colectores.

En la tabla 2, se presentan los resultados obtenidos cuando se acopló el secador al colector solar. Al aplicar diversos caudales, se obtuvieron diferentes tiempos de secado, los que se expresan en horas netas durante períodos entre las 7:00 a las 20:00 horas, y en días, incluyendo las horas de la noche en las que se suspendió el proceso. El número de tandas por semana que se pueden secar, de acuerdo con el tiempo de secado, se determinaron sobre la base de que no se procesan nuevas tandas cuando la anterior termina después del medio día. Esto porque no se garantiza la calidad final del producto por problemas de deterioración o porque los trozos, cuando se secan con interrupciones y no se reduce el contenido de humedad a niveles por debajo del 35º/o b.h. en el primer día, presentan al final un color amarillento indicativo general de un mal procesamiento y del mal aspecto. Lo mismo sucede cuando al tiempo de secado se prolonga a más de 2 días.

Aunque es posible operar después de las 20:00 horas, no se consideró porque la reducción de contenido de humedad a las bajas temperaturas que se obtuvieron con el colector no justificó el gasto de energía eléctrica.

De acuerdo con laTabla 2, se obtuvo la mayor capacidad por semana cuando se aplicó un caudal de 118 m^3/min.t.

En la Tabla 3 se presentan los costos de inversión y producción de un sistema natural y uno artificial con colector solar. Como se puede ver, el sistema artificial es de mayor costo inicial por la unidad motor ventilador y de mayor costo de producción por la reposición del plástico y consumo de energía eléctrica; por lo tanto, no compite con el sistema natural y, además, no es un sistema independiente de las condiciones ambientales.

TABLA 2. Efecto del caudal aplicado sobre el tiempo de secado y la capacidad de un sistema artificial de capa fija acoplado a un colector solar plano.

Caudal Aplicado m^3/min. t.	Tiempo de secado		Capacidad por semana	
	Neto (a) h	Real (b) días	Tandas	Yuca seca kg
78	41	3.2	1.5	810
88	42	3.3	1.5	720
001	29	2.2	2	840
118	26	1.6	3	1.077
141	20	1.3	3	480

Valores promedios de 3 repeticiones por nivel de caudal aplicado

Condiciones generales del ensayo:

- Humedad de los trozos de yuca (º/o b.h.)
  Inicial: 64.5 ± 2ºC
  Final: 12.3º/o (interpolado)
- Condiciones del aire:
  Temperatura: 36 ± 2ºC
  Humedad relativa: 43.5 ± 6.5º/o
  Caudal: 106 m^3/, min
- Radiación solar (cal/cm^2): 0.60 ± 10º/o

(a)Período de secado por día: 7:00 - 20:00

(b)Incluye las horas nocturnas durante las cuales se suspendió el secado.

TABLA 3. Costos de inversión y producción de los sistemas de secado con capacidad de 2.4 toneladas de trozos secos de yuca por tandas (1985)

SISTEMA	COSTOS	
	INVERSION Col. $	PRODUCCION Col $/t
1. Natural sobre pisos concreto (500 m^2)	330.500	21.360
2. Artificial capa fija y colector solar (a)	1.020.000	22.730
Diferencia	689.500	1.370(b)

(a) Costos de los elementos del sistema: Cámara (30 m^2): $ 200.000; colector solar: $ 220.000; motor ventilador: $ 600.000.

(b) La diferencia se deeb a la reposición del plástico y consumo de energía eléctrica en el secado artificial.

El empleo de un colector solar para secar artificialmente yuca, un producto de humedades iniciales altas (60-65°/o b.h.) a las temperaturas relativamente bajas que se obtienen (34-38°C), requiere caudales altos; lo que incide en los tamaños del colector y ventilador, limitando la capacidad del sistema *a no más de 2.5* a *3 t* de producto seco por tanda.

Evaluación del secado artificial con tres combustibles

En la Tabla 4 se presentan los resultados que se obtuvieron cuando se realizó el secado artificial con tres combustibles disponibles, carbón mineral, gas propano y diesel, la eficiencia global del proceso para las diferentes condiciones de operación y los costos de operación debido al empleo de combustible. Con los caudales aplicados y los niveles de temperatura dados se pueden secar trozos de yuca hasta un contenido de humedad de 12.3°/o (b.H.) entre 5.5 a 10 horas, dentro de una jornada normal de trabajo. El consumo de combustible, fue mayor para carbón y menor para gas propano, en orden creciente a las eficiencias térmicas de los quemadores. Se observa también que cuando se aumenta la temperatura o el caudal aplicado se reduce el tiempo de secado a expensas de un mayor consumo de combustible y, por ende, a un costo más alto.

La mayor eficiencia se alcanza con el gas propano, seguido por el diesel y el carbón, entre los que no hay diferencia apreciable. La mayor eficiencia con el propano se debe a que el calentamiento del aire fue directo, mezcla de aire con gases de la combustión.

A pesar de que el secado con carbón presentó menor eficiencia y mayor consumo, resulta el menor costo de operación debido a su relativamente bajo precio por kg. Se observa que a *caudales y temperaturas mayores*, se obtienen los más altos costos de operación y la diferencia entre el carbón y el gas propano es mínima, por lo que la elección entre ellos se debe basar en la disponibilidad del combustible y en el costo de los equipos de combustión y calentamiento. En la tabla 5 se presentan estos costos, en los que se incluyen los quemadores, intercambiadores, ventiladores y controles que conforman cada unidad. El resultado final continúa favoreciendo la opción de carbón mineral, que presenta menores costos tanto de inversión como de operación.

Análisis económico

En vista de que los quemadores de carbón como equipos de transferencia de calor en los secadores artificiales presentan ventajas sobre el gas propano o diesel, se hace un estudio económico de 4 alternativas de inversión que nacen de acuerdo con las condiciones actuales de producción y comercialización de la yuca seca en la Costa Atlántica, donde se está afianzando la tecnología de la yuca seca. Los datos de costos se expresan en pesos colombianos para 1985.

TABLA 4. Efecto de la temperatura y el caudal aplicado sobre el tiempo y el consumo de combustible en el secado artificial de yuca con tres diferentes fuentes de calor.

Temperatura del aire (a) °C	Caudal aplicado m³/min.t (b)	Tiempo neto secado h	Consumo de combustible (c)			Eficiencia global			Costos, $ Col/tc		
			Carbón mineral kg/t	Gas Propano kg/t	Diesel gal/t	Carbón °/o	Gas Propano °/o	Diesel °/o	Carbón	Propano	Diesel
50	130	10.0	250	105	65	38	70	36	1.625	3.150	7.150
	190	7.5	390	110	70	32	72	36	2.535	3.300	7.750
60	130	7.5	300	100		35	65		1.950	3.000	
	190	5.5	350	130		25	54		3.575	3.900	

Promedios de 3 valores por tratamiento.
- Temperatura promedio de aire ambiente: 26°C
- Humedad de los trozos de yuca (°/o, b.h.): Inicial: 61 ± 2; Final: 12.3 (interpolado)
- Poder calorífico de los combustibles (kcal/kg): carbón: 6.700; gas propano: 14.000; diesel: 41.000
- Eficiencias de los quemadores (°/o): Carbón: 60 ± 5; gas propano: 95 ± 2; Diesel: 76 ± 2
- Precios de los combustibles para 1985: Carbón: $ 6.5 por kg; gas propano: 30.0 por kg; Diesel: $ 110.00 por galón

(a) El sistema de calentamiento diesel solo proporcionó temperaturas de 50°C
(b) Se refiere a toneladas de trozos de yuca fresca
(c) Se refiere a toneladas de trozos de yuca seca

TABLA 5. Costos de equipos para combustión de ACPM, propano y carbón con una capacidad de 70.000 Kcal. por hora. 1985.

SISTEMA	COSTO DE INVERSION Col. $
Carbón	470.000
Diesel	1.225.000
Propano	645.000

Los principales supuestos para este análisis se presentan a continuación:

1) Capacidad de producción: se determinan de acuerdo con la capacidad de una planta modelo de la Costa Atlántica, que se estima en 538 t de yuca seca por año.

2) Precio de la materia prima: $ 8.000 por tonelada de yuca fresca, valor reportado por las plantas de secado durante la operación del año 1985.

3) Factor de conversión de yuca fresca a yuca seca de 2.5; es decir, se requiere 2.5 toneladas de yuca fresca para producir 1 tonelada de yuca seca.

4) Precio de venta por tonelada de yuca seca al 12.3o/o bh: $ 27.200 (85o/o del precio de sorgo en 1985).

5) Consumo de carbón de 450 kg/ t de yuca seca y precio de compra a $ 6.5 por kilo.

6) Días laborables por semana: 6

7) Métodos de secado:
- Secado natural en pisos de concreto
- Secado artificial en capa fija y aire calentado a 60°C con carbón mineral.

Los precios para la yuca fresca y seca varían durante la vida útil del proyecto, pero para el análisis se asumen en moneda constante, es decir, son deflectados por el mismo índice.

En la tabla 6 se describen las 4 alternativas de inversión que se consideraron. La primera de ellas corresponde a una planta modelo de la Costa Atlántica, que opera durante el verano entre los meses de Diciembre a Abril, un total de 20 semanas por temporada al año.

La alternativa 2, es igual a la alternativa 1 pero opera 15 semanas más, durante los períodos de transición de invierno a verano y verano a invierno, o en regiones donde el verano se prolonga un poco más, como sucede en los departamentos del noreste de la Costa Atlántica, - se presenta un veranillo.

La alternativa 3 opera durante 50 semanas por año, 20 semanas con un sistema de secado natural en piso de concreto y 30 semanas de época lluviosa con un secado artificial en capa fija. Por último, la alternativa 4 también opera durante 50 semanas por año pero empleando un secado artificial.

TABLA 6. Descripción de las alternativas de inversión

Alternativa	1	2	3	4
Método de secado	Natural	Natural	Natural/Artificial	Artificial
Período de operación anual (semanas)	20	35	20/30	50
Espedificación del sistema de secado	Secado en piso de concreto de 2.000 m^2	Secado en pisos de concreto de 1.300 m^2	Secado en piso de concreto de 1.000 m^2/ secador de capa fija de 20 m^2	Secado en capa fija de 20 m^2
Capacidad máxima de procesamiento de yuca fresca por tanda (t)	24	13	12/4	4

La inversión en equipos (máquinas picadoras, secadoras y motores) y herramientas del proceso, y capital de trabajo se presentan en la tabla 7. El capital de trabajo se estimó como el *dinero necesario* para captar materia prima durante un mes de operación y varía para cada planta debido a que los períodos de operación por año son diferentes y la capacidad de producción es igual, por lo que unas manejan mayores volúmenes de yuca fresca que otras por mes.

TABLA 7. Costos de inversión y capital de trabajo para 4 alternativas de inversión en 1985.

Alternativas	1	2	3	4
Inversión inicial, Col.$	3.097.900	2.283.600	3.503.100	2.537.600
Capital de trabajo, Col.$	2.152.00	1.232.000	860.800	860.800

En la tabla 8 se presentan los costos de producción expresado por tonelada de yuca seca producida. El costo de procesamiento comprende la mano de obra, mantenimiento, consumos de energía eléctrica y carbón.

TABLA 8. Costos de producción por tonelada de yuca seca para 1985 Col. $/t.

Alternativas	1	2	3	4
Materia prima (yuca fresca)	20.000	20.000	20.000	20.000
Procesamiento	3.580	3.580	5.320	6.500
TOTAL	23.580	23.580	25.320	26.500

Componente	Humedad	Proteína	Grasa	Fibra	Carbohidratos
o/o	13,7	3,5	0,5	1,0	78,6

Con respecto a la inversión, presenta menor valor la alternativa 4 pero implica los más altos costos de operación.

Con los datos tabulados se hizo el cálculo de la rentabilidad o tasa de interés, igualando el valor presente de los ingresos al valor presente de los egresos. El cálculo se realizó utilizando un computador personal.

Las cuatro alternativas resultaron económicamente factibles, con rentabilidades de 26.4, 37.0, 12.6 y 12.4o/o para las alternativas 1, 2, 3 y 4, respectivamente. La alternativa 2 es la más rentable porque logra utilizar las instalaciones durante un período más amplio a bajos costos de operación e inversión.

Los datos económicos del análisis son válidos para la temporada de verano, en la que se produce y hay oferta de yuca seca. En épocas de invierno la producción de yuca seca es nula debido al actual empleo de un secado natural, por lo que el precio sube y puede llegar hasta $ 37.00 por tonelada, o aún más, siempre que se mantengan restringidas las importaciones de sorgo y hay escases de éste en el mercado. Es razonable esperar que, cuando haya oferta de yuca seca todo el año, el precio tienda a estabilizarse hasta un punto de equilibrio entre la oferta y la demanda, o se hagan acuerdos para estabilizarlo, motivo por el que se consideró el mismo precio para todas las alternativas, a pesar de que operan en diferentes temporadas del año.

Por otro lado, el precio de captación de la yuca fresca va a sufrir variaciones de la época seca a la lluviosa, por dificultades de cosecha, recolección y transporte, o por escasez. A pesar de que la materia prima es el renglón que más incide en los costos de producción, también se consideró el mismo precio en el análisis de las 4 alternativas porque no se tiene información para predecir un precio confiable durante la época de lluvias. Sin embargo, se sugiere que para hacer rentable un proyecto de producción o expansión de capacidad a todo el año, la planta de secado, además de estar ubicada en la región de producción de yuca fresca, debe fomentar o desarrollar infraestructura y poseer cultivos propios para garantizar el suministro de materia prima a un precio estable.

CONCLUSIONES Y RECOMENDACIONES

La oportunidad de evaluar la tecnología de producción de yuca seca mediante la creación de una agroindustria en la Costa Atlántica, ha permitido introducir mejoras al proceso que no se hubiesen podido lograr si el trabajo se queda tan solo a nivel experimental. Estas mejoras se han manifestado en la disminución de los costos de producción con el consecuente aumento en las utilidades del proyecto.

La existencia de producción de yuca seca y su utilización como fuente de calorías para sustituir ciertos cereales, especialmente sorgo, en la alimentación animal, ha generado una demanda creciente en el mercado. Satisfacer esta demanda implica desarrollos tanto en la producción como en el procesamiento de la yuca. En el área de producción, es necesario aumentar los rendimientos por hectárea y la tierra cultivada. Esto permitirá producir yuca para el mercado fresco, que paga mejores precios, y para la industria de la yuca seca.

En el campo del procesamiento, el empleo de un sistema de secado natural obliga a trabajar durante la época seca del año o a procesar volúmenes grandes en este período para distribuir el producto durante el resto del año, con el aumento en los costos de inversión a que esto conlleve, debido al aumento de capacidad y al almacenamiento. En cambio, el uso de un secador artificial de capa fija y carbón mineral como fuente de energía, resulta la mejor alternativa para posibilitar la oferta de yuca seca todo el año; además, permite mejorar la calidad del producto, lo que puede ser una ventaja si se pagan incentivos por la calidad o se comercializa este producto para la alimentación humana, donde se puede lograr mejores precios de venta.

Dentro de las condiciones del estudio hecho, los dos sistemas, natural o artificial, son opciones rentables. El método natural ofrece mayores utilidades que el artificial porque presenta los menores costos de inversión y operación, sin embargo, son dos alternativas de operación que se pueden complementar para lograr aumentos en la capacidad productiva.

El empleo de un colector solar en el secado artificial de yuca no es factible debido a la demanda de energía para evaporar la gran cantidad de agua que contiene la yuca fresca, lo que no se puede suministrar con las temperaturas que se obtienen con este sistema.

Se recomienda hacer un estudio de sensibilidad para establecer el efecto del precio de la materia prima, el precio de venta, el factor de conversión de yuca fresca a yuca seca y el consumo y precio del carbón sobre la rentabilidad de un proyecto de producción de yuca seca cuando se emplea alternativamente un secado natural y artificial.

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