Approaches to Successful Development of Low-Cost Fruit Juice Extraction Technologies: A Case Study to Improved Rural Livelihood in Malawi

Hendrex Wyckliffe Kazembe-Phiri1

Chitedze Agricultural Research Station, Department of Agricultural Research Services, Po Box 158, Lilongwe, 265 Malawi; E-mail: e-mail: fmw@sdnp.org.mw

Keywords: Equipment, extraction, fruits, juice, Malawi, packaging, processing

1.0 Abstract

Fruits, in Malawi, are locally available and widely grown ranging from Mangoes, Mangifera indica (Kalisere and Boloma), watermelon, guava, pineapples, paw paws, oranges, tomatoes, tangerines, malambe (baobab fruit), Masau, Tamarind (Bwemba) and many other indigenous fruits. National production is estimated at over 200,000 metric tones per year. Unfortunately, most of this undergoes post-harvest losses accounting to over 70% due to fruit perishability, poor marketing and lack of improved post harvest processing techniques strategic to product development for value-addition to fruits. Two simple hand-operated fruit juice extractors; Horizontal Extractor “Mfinyazipato Owerama” and Vertical Extractor “Mfinyazipato Oyimilira” were developed to increase fruit utilization and minimize post harvest losses in Malawi. Performance evaluations on both on-station and on-farm were conducted on pulp extraction capacity, efficiency, fruit-seed breakage, power requirement, rest period and economic analysis (cost-benefit) in terms of gross margin analysis, pay back period, internal rate of return and sensitivity analysis were conducted respectively. A split-plot design with two treatments replicated three times was used for on-station evaluation. The two treatments were machine type-horizontal versus vertical (T1) and fruit type (T2) in which 12 kg fruit sample was used in turns. Data were recorded and analyzed statistically using GenStat software. In these tests it was shown that in combination both machines resulted with 5 to 38 l/h and grand mean of 24 l/h, 59 to 86% and grand mean of 72%, 6 to 60 W and 23 W as grand mean and then 240 to 1912 min/h and 1010 grand mean in terms of capacity, efficiency, power requirement and rest period respectively. However, comparative performance between the two machines showed that horizontal scored 7 to 35 l/h at 61 to 82% and vertical ranged 10 to 36 l/h at 63 to 85%, extraction capacity and efficiency respectively. In both cases, the performance of the two machines was not significantly different (P< 0.01) and thus performed the same. On the other hand, significant differences were recorded between fruit types (P<0. 01). In terms of power requirement and rest periods between machine types (T1) horizontal extractor versus vertical extractor, the former was significantly inferior to the latter (P< 0.01) achieving 9 to 57 W at 1900 to 251 min/h compared to 8 to 48 W at 1908 to 319 min/h respectively. The same trend was also observed between fruit types. These results therefore showed that the horizontal extractor required more energy to operate than the vertical one. For seed breakage, both machines recorded zero and thus acceptable performance with seeded fruits. On-farm evaluation showed that 1256 farmers practiced both machines using a total fruit quantity handled of 121 metric tones (50% of which was handled by each machine) up on which a mean volumetric throughput 180 kg /h was obtained. These results indicated
sufficient durability of the machine operation. As it is naturally difficult to store fresh and ripe fruits under rural conditions for more than 2-3 days, the technology has proven that fruit juice and other developed fruit products offered increased utilization, availability (fruit concentrate formulation) and benefits in terms of nutrition (most juices and products contained almost all the needed nutrients as protein, vitamins, iron, zinc, calcium, magnesium and phosphorus. In terms of preservation, a shelf life of 90 – 120 days and 270 days was achieved at 16 to 40 °C room temperature, 55 to 80% relative humidity for fruit juices, by-products and formulated fruit concentrate. Economically the technology was viable achieving 69% & 69.7% internal rate of return, 8.3 months & 8.4 months pay back periods and was negatively sensitive to 20% drop to juice and increase to cost of fruits respectively. Comments from farmers viewed the technology to be a good candidate for offering improved rural livelihoods through income generation. The business entrepreneurs as well as local juice companies also saw the technology to be a window for investment in fruit industry. As for organoleptic for the fruit juices and other products the public, the local juice companies, Malawi Bureau of Standards, farmers as well as the Agricultural Development Divisions (ADD) staff were all impressed. The rural communities are so far adopting the technology in Malawi.

2.0 Introduction and Justification of the Study

Fruits are crops of high value grown for both cash and snack. They are fortified with valuable sources of vitamins and mineral salts essential for body protection against diseases. Ripe fruit products (juices) provide carbohydrates for energy too (Prinsley, 1987). In Malawi, fruits are widely grown in warm to hot areas with altitudes ranging from 0 to 750m above sea level. The varieties grown include, both local and improved grafted ones; mangoes, watermelon, guava, pineapples, paw paws, oranges, tomatoes, tangerines, malambe (baobab fruit), masau (Malawi Government, 1994).

Naturally, these fruits happen to be ripening one season after another such that there are fruits all year around. Fruits utilization in Malawi is mainly in form of ripe ones as snack or sold to middlemen for resale to consumers in major cities or reselling them by the roadside when in season. The juice production capacity is still too low to meet the national consumption and thus some commercial juice supplements as well as other fruit products (jams, purees, sauces) are imported from Zimbabwe and South Africa (Malawi Government, 1996). In terms of small-scale, juice production in Malawi, very little if any has been put up so far. An interview with the farming community as well as survey studies show that lack of low cost and efficient means or adequate processing techniques to quickly process the fruits, poor marketing and transport systems as well as fruit perishability, contribute to more post-harvest losses which at present account for over 60% of the fruit production (Malawi Government, 1996). Nanjundaswamy (1986) confirmed that lack of local and simple mechanical means for fruit processing into juice and other intermediate products, results in limitations on fruit utilization and thus more post-harvest losses due to rotting. This inefficiency in turn presents limitations to the rural income by small-scale farmers. Fortunately, in Malawi, most of these farmers run out of food (Maize- Zea mays) reserves when most fruits are in season. This means therefore that improved fruit juice agro-processing would assist to minimize the problem among the fruit-growing farmers. Hrapsky et al (1985) stated that a promotion of efficient fruit juice processing techniques raises the produce market value. Such an industry has an Internal Rate of Return (IRR) greater than 50%. Post-harvest losses would also be minimized. In an effort to address the above problem the design, trial making and performance testing of two simple hand-operated fruit juice extractors was carried out to benefit the smallholder farming community in rural areas, small business and thus improved rural livelihood in Malawi. The following were the objectives.
3.0 Objectives
The main goal was to introduce low-cost fruit juice/ concentrate processing technology that would adequately improve and ease the farmers and small businessmen capability in performing efficient fruit Agro-processing thereby optimizing fruit utilization and improving food self sufficiency (nutritional status) and rural incomes.

(a) To design and trial-make a low cost fruit juice extracting technology for small-scale juice making.
(b) To carry out performance evaluation on-station and on-farm.
(c) To draw a relationship of fruit quantity against juice
(d) To develop various fruit juice processing recipes for commercialization
(e) To train and demonstrate the technology to farmers, business entrepreneurs, juice companies and other stakeholders.
(f) To carry out economic and sensitivity analyses
(g) Transfer the technology upon success.

4.0 Materials and Methods

4.1 General Engineering Design considerations for the fruit juice extractors
At this stage, the following factors were considered: Plastic body so that it does not react with juice concentrate to maintain juice quality and Horizontal and Vertical Screw press principles for easy hand operation while standing or seated.

4.2 Design Layouts and Trial making of the Prototypes
This was carried out using Farm Machinery Engineering Workshop and then later by a local manufacturer (PROMAT LTD) Workshops.

5.0 On-Station and On-Farm Evaluation

5.1 On-Station Performance Evaluation
Experimental Design: Split-plot design with two treatments replicated three times: Machine types- horizontal & vertical (T1), Fruit type (T2)

5.2 Set-up of On-station Performance Evaluation
Both machines were set up side by side. A fruit sample of 12 kg (fill machine capacity) was used in each turn. The results were recorded using electronic balancing scale, stopwatches and calculators. The data were analyzed statistically using GenStat software.

Calculation of variables
\[
\text{Extraction Capacity (l/h)} = \frac{\text{Vol. of extracted pulp}}{\text{Pulp extraction time}}
\]
\[
\text{Extraction efficiency (\%)} = \frac{\text{Quantity of extracted pulp} \times 100\%}{\% \text{Pulp content} \times \text{sample quantity}}
\]
\[
\text{Power requirement (W)} = \frac{\text{Fruit quantity} \times \text{handle Circumferential distance} \times 9.81 \text{m/s}}{\text{Pulp extraction time}}
\]
\[
\text{Rest Period (min/h)} = 60 \left(1 - \frac{300}{W}\right) \text{ (absolute values only).}
\]

5.3 Determination of relationship of fruit quantity to fruit concentrate /pulp and Juice yield
From each of the set up an amount of fruit (quantity), pulp and processed juices were recorded upon which the relationship below was established.
5.4 Development of procedures for processing fruit juice concentrate into ready-to-drink fruit juice

In collaboration with Malawi Industrial Research and Technology Development Center and Malawi Bureau of Standards, procedures for processing the fruit juice into ready-to-drink juice were carried out. This included health aspects for fruit juice making, design of the processing shed, and consistency and hygiene of food handling. Organoleptic tastes with farmers, Malawi Bureau of Standards, local juice Companies and the public were also carried out until proven fruit recipes as below were fully developed or established. Further more, a sample of each fruit juice recipe was sent to Malawi Bureau of Standards for Certification. Also included in this work was proximate analysis of 25g plate count of fruit crude juice/pulp and juice and some microbiological study for the presence of some harmful microbes (E. Coli and Salmonella spp) on 25g juice plate count. The data was recorded as below.

5.5 Determination of shelf life for the developed fruit juice and Fruit formulated Fruit Concentrate.

1. Fruit Juice Shelf life Assessment
A sample of 500ml-bottle of each fruit juice replicated ten times was kept at room temperature, at Chitedze Library as a display as well as an observation to determine shelf life. Spot checks were done weekly and by different observers. Sampling for microbial count was done monthly until the last before date. A period of 2-4 months was targeted for juice. Finally, the sample was carefully analyzed and organoleptically tasted for comments.

2. Fruit Concentrate Formulation
From each the extracted fruit pulp, a one-liter sample was drawn to formulate fruit juice concentrate. There were four treatments; replicated ten times the set up was as follows T1- Control (1 liter pulp only), T2- 1 liter pulp plus 3x 90g white sugar only, T3- 1 liter pulp plus 3g sodium benzoate (preservative) only and T4- 1 liter pulp plus 3g sodium benzoate (preservative) plus 3 x 90 g white sugar. Data sampling: one line of 4 treatments kept intact. Each of the nine treatments sampled at one treatment per month

Data: Pulp color, microbial count, best before date, RH, ambient temperature

5.6 Economic and Sensitivity Analyses
To ascertain that the technology has a sustainable financial establishment, gross margin analysis or cost-benefit analysis in terms of pay back period, Internal Rate of Return (IRR) and sensitivity analysis was carried out as follows. Assumptions made in the analyses included: -17.5% Surtax Value, 10 years straight line depreciation, repairs and maintenance at 10% of investment cost, Five operators for 230 days per year watch men, 1000kg was the equal sample quantity of fruit types, the Fruit juice processing plant would operate throughout the year using different fruit types in season.

Calculations

- **Gross Margin Analysis**
  
  Pay back Period = \( \frac{\text{Total Capital Costs}}{\text{Total Annual Profit Sales}} \)
  
  Annual Profit = Total annual sales - total capital costs
  
  Monthly Profit = \( \frac{\text{Annual Profit}}{12} \)
  
  Internal Rate of Return (IRR) = \( \frac{\text{Total Capital Costs} \times 100}{\text{Total Annual Profit Sales}} \)

- **Sensitivity Analysis**
  This was carried out by introducing such change factors for cost of production as no change in prices and costs, fruit juice selling price up or down by 20%, cost of fruits up or down by 20%.
The respective responsiveness on gross margin in terms of Pay back period and internal rate of return (IRR) were recorded.

5.7 On-Farm Evaluation

Planning of On-farm Evaluation

Six Agricultural Development Divisions (ADDs) such as Lilongwe, Salima, Shire Valley, Mzuzu, Machinga and Karonga were selected as potential sites for evaluation. Each site was distributed with a set of horizontal and vertical extractors making twelve extractors for all sites. The planning was such that around trip to distribute and demonstrate the technology was made. Each site was trained for one week in juice making and packaging using the fruits in season and locally built processing shed in that location. Thereafter the machines were left for trials until to date. Data at periodic intervals of monthly and quarterly was taken. Such data as name of site, types of fruit of handled, quantity of fruits, time of juice extraction for each fruit, comments from operators and the other public and number of farmers in attendance. In turn volumetric throughput was calculated. Then the data was analyzed by means of averages and tabulated as below.

In addition, the technology was demonstrated to a number of agricultural shows / field days and even to the local juice companies such as Dairibord Malawi Ltd, New Capital Dairy and Suncrest Creameries Malawi, in Malawi.

6.0 Results and Discussions

Two Developed Fruit Juice Extractors

6.1 On-Station Performance.

6.1.1 Relationship of fruit quantity to fruit juice yield

It was shown that there was generally a linear relationship between fruit quantity to fruit juice concentrate and processed juice.
Table 2: On-Station Performance Evaluation of Vertical and Horizontal Fruit Juice Extractors for 2002/2003 seasons

<table>
<thead>
<tr>
<th>Technology for Juice Extraction</th>
<th>Fruit Type</th>
<th>Capacity (l/h)</th>
<th>Efficiency (%)</th>
<th>Power requirement (W)</th>
<th>Rest Period (min/h)</th>
<th>Seed Breakage (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Extractor</td>
<td>Mango Kalisere</td>
<td>13</td>
<td>78</td>
<td>57</td>
<td>251</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Mango Boloma</td>
<td>18</td>
<td>82</td>
<td>53</td>
<td>284</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Masau</td>
<td>34</td>
<td>69</td>
<td>31</td>
<td>567</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Tangerines</td>
<td>18</td>
<td>72</td>
<td>14</td>
<td>1241</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Oranges</td>
<td>16</td>
<td>69</td>
<td>16</td>
<td>1064</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Malambe</td>
<td>35</td>
<td>69</td>
<td>31</td>
<td>624</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Guava</td>
<td>33</td>
<td>70</td>
<td>30</td>
<td>570</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Tomato</td>
<td>35</td>
<td>81</td>
<td>9</td>
<td>1900</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Lemons</td>
<td>16</td>
<td>69</td>
<td>15</td>
<td>1062</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Watermelon</td>
<td>24</td>
<td>66</td>
<td>15</td>
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<tr>
<td></td>
<td>Pineapples</td>
<td>7</td>
<td>61</td>
<td>11</td>
<td>1555</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Paw paw</td>
<td>34</td>
<td>70</td>
<td>10</td>
<td>1711</td>
<td>0</td>
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<tr>
<td>Vertical Extractor</td>
<td>Mango Kalisere</td>
<td>16</td>
<td>81</td>
<td>48</td>
<td>319</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Mango Boloma</td>
<td>19</td>
<td>85</td>
<td>43</td>
<td>364</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Masau</td>
<td>34</td>
<td>70</td>
<td>29</td>
<td>580</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Tangerines</td>
<td>19</td>
<td>73</td>
<td>13</td>
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<tr>
<td></td>
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<td>67</td>
<td>15</td>
<td>1080</td>
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<tr>
<td></td>
<td>Malambe</td>
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<td>70</td>
<td>30</td>
<td>647</td>
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<td>Guava</td>
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<td>71</td>
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<td>8</td>
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<td>Lemons</td>
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<td>67</td>
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<tr>
<td></td>
<td>Pineapples</td>
<td>10</td>
<td>63</td>
<td>10</td>
<td>1555</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Paw paw</td>
<td>36</td>
<td>71</td>
<td>9</td>
<td>1708</td>
<td>0</td>
</tr>
</tbody>
</table>

**Capacity**
- Min.= 5
- Max = 38
- G.mean=24
- SE =0.325 Machines
- SE=1.451 Machines*
- CV% =1.4 Machines
- CV% =6.1 Machines*

**Efficiency**
- Min.= 59
- Max = 86
- G.mean=72
- SE =0.266 Machines
- SE=0.941 Machines*
- CV% =0.4 Machines
- CV% =1.3 Machines*

**Power Requirement**
- Min.= 6
- Max = 60
- G.mean=23
- SE =0.36 Machines
- SE=0.959 Machines*
- CV% = 1.6 Machines
- CV% = 4.2 Machines*

**Rest Period**
- Min.= 240
- Max =1912
- G.mean=1010
- SE =4.51 Machines
- SE=12.47 Machines*
- CV% = 0.4 Machines
- CV% = 1.2 Machines*
Table 2 above showed that in combination both machines resulted with 5 to 38 l/h and grand mean of 24 l/h, 59 to 86% and grand mean of 72%, 6 to 60 W and 23 W as grand mean and then 240 to 1912 min/h and 1010 grand mean in terms of capacity, efficiency, power requirement and rest period respectively. However, comparative performance between machine types showed that horizontal scored 7 to 35 l/h at 61 to 82% and vertical ranged 10 to 36 l/h at 63 to 85%, extraction capacity and efficiency respectively. In both cases, the performance of both horizontal and vertical extractors was not significantly different (P< 0.01) and thus performed the same. In that case, rate of work was the same such that both machines would be chosen. However, it was felt that with increased experience by operators, vertical extractor showed greater potential for higher capacity and extraction efficiencies. On the other hand, significant differences were recorded between fruit types (P<0. 01). As such, each fruit depending on types made the machine perform different from the other. Usually it was observed that large seeded fruit fruits such as mangoes were harder to operate than small seeded ones. Seedless fruits were even the softest. However, the seeds in the fruits assist in achieving better extraction efficiencies. In terms of power requirement and rest periods between machine types (T1) horizontal extractor versus vertical extractor, the former was significantly inferior to the latter (P< 0.01) achieving 9 to 57 W at 1900 to 251 min/h compared to 8 to 48 W at 1908 to 319 min/h respectively. The same trend was also observed between fruit types. These results therefore showed that the horizontal extractor required more energy to operate than the vertical one. For seed breakage, both machines recorded zero and thus acceptable performance with seeded fruits.

6.1.2 Developed range of fruit juice and other products
The following were the resultant range of fruit products such as those developed and packed which rural farmers sell for income and nutrition: Mango Juice and spread, Masau juice and jam, Guava juice and jam, paw paw juice and jam, Malambe juice and spread, Pineapple juice, Lemon juice, Tamarind (Bwemba) juice, Tangerine juice, Tomato juice, sauce, puree and jam.

6.1.3 Critical Microbial load in mango fruit juice.
Microbial tests showed presence of E.Coli and Salmonella spp of bacteria at a 25g plate count and thus safe for human consumption.

6.1.4 Determination of shelf life for the developed pure fruit juice, by-products and Fruit Concentrate Formulation Trial

**Fruit Juice, Concentrate and other fruit by-products Shelf life Assessment**

A shelf life of 2-4 months and 9 to 12 months for fruit juices and fruit concentrate plus by products was achieved at 16 to 40 °C room temperature and 55 to 80% relative humidity respectively.

6.1.5 Economic and Sensitivity Analyses

Gross margin analysis calculations the above information showed that the technology viable as follows. Economically the technology was viable achieving 69% & 69.7% internal rate of return, 8.3months & 8.4 months pay back periods and was negatively sensitive to 20% drop to juice and increase to cost of fruits respectively.

**Gross margin analysis**

In this case, it was therefore shown that both (Horizontal and Vertical) machines are viable each with annual profit of US $17,000 and a monthly profit of US $1,400 per month and US $ 19,950 with Mk 1,398 per month respectively. In terms of pay back periods, each machine showed 8.3 months and 8.4 months respectively. However, vertical extractor was superior to the horizontal one, as less power was required to operate it than the other one. Even though it like this the Vertical Extractor is still superior due to this is achieved at less effort than the Horizontal Design.
6.2 ON-FARM EVALUATION

On-farm evaluation showed that 1256 farmers practiced both machines using a total fruit quantity handled of 121 metric tones (50% of which was handled by each machine) up on which a mean volumetric throughput 180 kg /h was obtained. These results indicated sufficient durability of the machine operation. In addition, farming community, juice companies and the public commented as follows. Comments from farmers viewed the technology to be a good candidate for offering improved rural livelihoods through income generation. The business entrepreneurs as well as local juice companies also saw the technology to be a window for investment in local fruit juice industry. As for organoleptic for the fruit juices and other products the public, the local juice companies, Malawi Bureau of Standards, farmers as well as the Agricultural Development Divisions (ADD) staff were all impressed.

7.0 Conclusions.

The results above concluded that with the fruit extraction technology, it is possible and very sustainable to extract fruit juice for small-scale fruit juice production under both urban and rural conditions, using both local and improved fruits of Malawi. This is achievable at sustainable power requirement (<70 W) and rest periods. The availability of the fruits, the calculated gross margin analysis demonstrated that the technology has a lot of potential for improved rural livelihood in Malawi.

8.0 Recommendations

The above success and impressive performance of the technology has been recommended to The Agricultural Technology Clearing Committee to releasing the two newly developed machines for adoption by farmers, business community and local juice companies in Malawi.

9.0 References


