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On farm Evaluation of Jimma Model Engine Operated Double Disc Coffee Pulpier

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ABSTRACT

Coffee processing is the process of converting the coffee cherry into green coffee bean after the fruit or pulp has been removed. Farmers in West Guji zones lost out because of the lack of value-adding technologies, which resulted in low quality and profit. The on-farm evaluation of Jimma model engine operated double disc coffee pulpier was undertaken at Adola Redde Woreda, Guji Zone to evaluate its performance under different operational parameters. A 3x3 factorial experiment in Completely Randomized Design (CRD) was used to determine the effects of disc speed (100, 200, 300 rpm) and feeding rate (6, 9, 12 kg/min) on pulping capacity, efficiency and mechanical damage. The results showed that both factors have a significant effect on machine performance. The pulping capacity was increased with increase in disc speed and feeding rate and attained maximum of 531.38 kg/hr at 300 rpm and 12 kg/min. However, the highest pulping efficiency (96.24 %) and the least mechanical damage were obtained at 200 rpm and 6 kg/min feeding rate. The study concluded that the Jimma model double-disc pulpier performs best at a disc speed of 200 rpm and a feeding rate of 6-9 kg/min and can be a good alternative for smallholder farmers to improve the quality and efficiency of wet coffee processing and hence improve market competitiveness and income.

Keywords: Adola Redde; Coffee; Coffee Processing; Double-Disc Pulpier; Guji; Jimma Model; Mechanical Damage; On-Farm Evaluation; Pulping Capacity; Pulping Efficiency.

1.0. Introduction

Agriculture is the leading sector in the Ethiopian economy. The predominant role of coffee Arabica in Ethiopian economic, social and cultural dimensions update to back to several centuries as the country is the primary centre of origin and genetic diversity of the plant[1]. Presently coffee stands first among the three major agricultural export commodities followed by oilseeds and pulses. Coffee is very important in the Ethiopian economy and contributes from 30-35% of the coffee export earnings of the country, 4.7 million[6 and 2]. The coffee production and export data obtained from indicate that out of the coffee produced in Ethiopia in 2010, 34% was consumed domestically and 66% of the total production was exported to the world market.

According to the East African Fine Coffee Association (EAFCA), about a third of Ethiopia's coffee exports last year were washed[5]. Because washed coffees traditionally fetch better prices and score higher on quality, expanding this processing method has been a long-standing goal for the country's coffee sector. The heart of this industry lies with small-scale farmers; managing just one to two hectares of land each, these families actually drive 90% to 95% of Ethiopia's total coffee production.

In the Guji Zone of the Oromia National Regional State, coffee serves as the economic backbone, providing the primary income for 83% of local farmers. Alongside coffee, families cultivate maize and enset to secure their food supply and bring in extra income. The scale of this production is substantial: in 2015, the Kercha District Agriculture Development Office reported a yield of 20,240 tons of coffee accounting for 11.7% of Oromia's regional output and 7.4% of Ethiopia's total production[4]. Given coffee's vital socioeconomic role both locally and nationally, building a more efficient marketing system is crucial. Optimizing processing, storage, and transportation can significantly cut post-harvest losses and boost marketable surplus for these communities.

Coffee processing transforms the harvested cherry into green coffee beans by removing the surrounding fruit and pulp. This can be achieved through either dry or wet processing methods[7]. Pulping represents the critical first phase of post-harvest handling. While dry processing is an option, wet pulping which must be performed immediately after harvest has gained widespread popularity. The wet method is generally preferred by consumers because it preserves the bean's intrinsic qualities, such as aroma, and yields higher-quality green beans that command premium market prices[8 and 12]. Today, wet processing techniques vary primarily by their degree of fermentation[11]. Ultimately, regardless of the initial processing method chosen which depends on local traditions, coffee varieties, and weather conditions the final step is hulling, which remove the dried parchment or hull to release the two green beans within.

In the global coffee trade, quality is paramount, playing an irreplaceable role in an increasingly competitive international market. For smallholder farmers, however, the inability to access proper handling and post-harvest processing technologies remains a major barrier to improving their livelihoods. Empowering these farmers to adopt and actively utilize modern post-harvest machinery is therefore one of the sector's most pressing development challenges. In the West Guji Zone, a lack of value-adding technologies has historically resulted in sub-optimal coffee quality and a subsequent drop in earnings, severely impacting local farming families. Given that this area is one of the region's premier coffee-producing hubs, this study addresses this critical technological gap by introducing and evaluating an efficient, double-disc wet coffee pulper.

Jimma Agricultural Engineering Research Center (JAERC) has adapted and popularized double disc pulpier. The machine performance was assessed by pulping capacity, percentage of mechanical damage, pulping efficiency and un-pulping loss. The results showed that the maximum pulping capacity, maximum percentage of mechanical damage, pulping efficiency and minimum un pulping loss were found 983.33 kg/ hr at 7 kg/min feed rate and 208 rpm, 1.28% at 7 kg/min and 92 rpm, 97.10% at 9 kg/min and 208 rpm and 1.87% at 9 kg/min and 208 rpm respectively. In order to address the issue of coffee pulping at the household level, this study was conducted by taking into account the aforementioned facts and evaluating and demonstrating the Jimma model wet coffee pulpier on the farm level for the farmers in the chosen districts from Guji zone.

░ 2.0. Materials and Methods

2.1. Description of Experimental Site

The fabrication of the wet coffee pulping machine prototype was performed at Asella Agricultural Engineering Research Center, located at 6° 59' to 8° 49' N latitudes and 38° 41' to 40° 44' E longitudes, having an elevation of 2430 meters above sea level. The on farm performance evaluation was performed at a selected farmer’s field at Adola Redde Woreda which is one of the potential coffee growing districts of Guji zone.

2.2. Equipment and apparatus used during wet pulping

- Stopwatch
- Tachometer
- Weight balance

➢ Moisture meter

➢ Graduate cylinder

2.3. Constructional and experimental materials

Mild steel materials, sheet metal, angle Iron, flat Iron, discs, v-belt, pulleys, petrol engine, nuts, and bolts were the materials used during the construction, and wet coffee is the experimental material used to evaluate the performance of the machine.

2.4. Description of the machine and it's working principle

The pulpier has a power source (5 hp petro engine) and power transmission assembly that is vertically aligned with the shaft of the pulping disc and mounted on the frame. The wet coffee cherries are manually fed into the feeding hopper and the machine was calibrated for the speed of the disc and feeding rate. The double disc wet coffee pulpier removes the outer skin of ripe coffee cherries using two counter-rotating abrasive discs. The primary mechanism is compression and shear force, not cutting. The cherries are squeezed between the two discs, which are spaced just right to tear the skin and pulp away from the hard, inedible bean (the seed inside the parchment hull) without crushing it.

Figure 1. Double disc coffee pulpier during on farm evaluation.

2.5. Performance evaluation of the machine

2.5.1. Pulping capacity

Weight of coffee cherry fed into the pulpier per unit of time, expressed in kilogram per hour[9].

Pulping capacity (kg/hr), $PC = \frac{W_{tp}}{T_p}$ …(1)

where:- PC = pulping capacity, kg/hr

W_{tp}=Total weight of pulped coffee, kg

T_p= pulping time, hr

2.5.2. Pulping efficiency

Ratio of total weight of parchment coffee collected at all outlets to the total coffee cherry to the machine, expressed in percentage[9].

Pulping efficiency, $P_e = \frac{W_p}{W} x\,100$ …(2)

2.5.3. Mechanically damaged parchment coffee

Ratio of the total weight of damaged parchment coffee to the total weight of sample, expressed in percentage[13].

$$Md\,(\%) = \frac{weight\ of\ damaged\ coffee}{total\ weight\ of\ sample} * 100 \qquad \ldots(3)$$

2.6. Experimental design

The experimental design for the performance test of the pulping machine was done for three speeds of the disc (100, 200, and 300 rpm) and three feeding rates(6, 9, and 12 kg/min) of coffee berries. The experimental design of completely randomized design in full factorial design with two factors was used. The design had the form of 3 × 3 equal to 9 treatment combinations with three replications which result in a total test run of 27.

2.7. Statistical analysis of data

The collected data was analyzed by Analysis of Variance (ANOVA) using statistical R-software (version 3.4.3, 2017). Where the effects of the treatment were found significant, the Least Significance Difference (LSD) test was performed to assess the difference among the treatments at a 5% level of significance.

3.0. Results and Discussions

The pulping capacity, pulping efficiency, and mechanical damage percentage were estimated and examined as a function of the disc speed and feed rate (FR). The results of performance evaluation obtained from the experiments conducted in the research investigation are reported and discussed in this chapter. During the experiment, the average value of wet coffee moisture content was 37.2%.

3.1. Main effect of disc speed and feeding rate on wet coffee pulping machine performance

The performance evaluation of the double disc wet coffee pulping machine revealed that both disc speed and feeding rate had significant effects on key performance indicators, including pulping capacity, pulping efficiency, and mechanical damage. As shown in Table 1, an increase in disc speed from 100 rpm to 300 rpm enhanced pulping capacity from 330.4 kg/hr to 504.29 kg/hr. This is expected, as higher disc speeds increase the throughput capacity of the pulping mechanism. Similar trends were reported by[14], who observed that higher machine speeds improved coffee pulping rates due to increased shear forces and contact frequency between cherries and pulping surfaces. However, pulping efficiency was highest at 200 rpm (94.21%) and declined slightly at 300 rpm (89.59%). This indicates that excessively high speeds, although improving capacity, reduce the completeness of pulping by causing more cherries to pass through unpulped or partially pulped.

The feeding rate also influenced performance outcomes. At 12 kg/min, the machine recorded the highest pulping capacity (450.26 kg/hr), but efficiency decreased to 91.73% compared with 92.92% at 6 kg/min. This suggests that while higher feeding rates increase throughput, they also raise the probability of unpulped cherries and mechanical stress. These results align with findings of[3], who reported that excessive feed rates overload the machine, causing cherries to bypass pulping surfaces, whereas too low rates underutilize machine capacity.

Mechanical damage followed a similar pattern, increasing with both disc speed and feeding rate. At 100 rpm, damage was lowest (1.07%), but rose to 1.65% at 300 rpm, while at higher feeding rates (12 kg/min), damage also increased (1.52%). This can be attributed to the increased impact forces at higher speeds and feeding densities, which cause beans to crack or break. Previous studies by[9] confirmed that mechanical damage is a common drawback of high-speed pulping operations, necessitating optimization to preserve bean quality. Overall, the results suggest that operating the double disc pulpier at around 200 rpm and a moderate feeding rate of 9 kg/min provides an optimal balance between capacity, efficiency, and bean quality.

Table 1. Main effect of disc speed and feeding rate on wet coffee pulping machine.

Disc Speed (rpm)	**Pulping Capacity(kg/hr)**	**Pulping Efficiency (%)**	**Mechanical damage (%)**
100	330.4^{c}	93.22^{a}	1.07^{c}
200	427.55^{b}	94.21^{a}	1.55^{b}
300	504.29^{a}	89.59^{b}	1.65^{a}
Feeding Rate(kg/min)			
6	334.66^{c}	92.92^{a}	1.28^{b}
9	423.31^{b}	92.38^{ab}	1.46^{a}
12	450.26^{a}	91.73^{b}	1.52^{a}
CV	2.21	1.12	6.62
LSD (5%)	9.2	1.025	0.093
SEM	4.38	0.35	0.031

Where, CV = coefficient of variation; LSD = least significance difference, SEM= Standard error of the mean, Values are means. Mean values comparison arranged according to descending order followed by the same letter in a column are not significantly different at 5% level of significance.

Results of the analysis of variance (ANOVA) revealed that disc speed had a significant effect ($p < 0.05$) on all performance indicators (pulping capacity, pulping efficiency, and mechanical damage). Also, feeding rate had a significant effect ($p < 0.05$) on all performance indicators (pulping capacity, un-pulped loss, and mechanical damage) except pulping efficiency.

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3.2. Interaction effect of disc speed and feeding rate on wet coffee pulping machine performance parameters

The experimental results presented in Table 2 demonstrate the interaction effects of disc speed and feeding rate on the performance of the double disc wet coffee pulping machine. The data clearly show that both machine parameters interact significantly to influence pulping capacity, pulping efficiency, and mechanical damage.

Pulping capacity increased consistently with both disc speed and feeding rate. At 100 rpm and 6 kg/min, the capacity was 297.60 kg/hr, which increased to 356.40 kg/hr at 12 kg/min. Similarly, at 300 rpm and 12 kg/min, capacity reached 531.38 kg/hr, the highest observed during the trials. This demonstrates that simultaneous increases in speed and feed rate substantially boost throughput. Comparable findings were reported by[9], who highlighted that higher mechanical input increases cherry handling capacity but requires careful control to avoid negative quality impacts.

Pulping efficiency, however, did not follow the same increasing trend. The highest efficiency (96.24%) was recorded at 200 rpm and 6 kg/min, while the lowest efficiency (88.65%) occurred at 300 rpm and 12 kg/min. This indicates that higher feed rates at elevated disc speeds compromise efficiency, likely because cherries pass through the pulping surfaces too rapidly, resulting in incomplete pulping. [3]similarly observed that excessively high speeds and feed rates can reduce effective contact time between cherries and pulping surfaces, thereby lowering efficiency.

Table 2. Interaction effect of disc speed and feeding rate on wet coffee pulping machine performance parameters.

Disc Speed (rpm)	Feeding Rate(kg/min)	Pulping Capacity(kg/hr)	Pulping Efficiency (%)	Mechanical damage (%)
	6	297.60^{h}	91.89^{cd}	1.0^{d}
100	**9**	337.20^{g}	93.76^{b}	1.07^{d}
	12	356.40^{f}	94.01 ^{b}	1.10 ^{d}
	6	398.67^{e}	96.24^{a}	1.37^{c}
200	**9**	420.97^{d}	93.87 ^{b}	1.62^{b}
	12	463.01^{c}	92.52^{bc}	1.67^{ab}
	6	469.71^{c}	90.63^{de}	1.45^{c}
300	**9**	511.77^{b}	89.50^{ef}	1.71^{ab}
	12	531.38^{a}	88.65^{f}	1.79^{a}
CV		**2.21**	**1.12**	**6.62**
LSD (5%)		**15.94**	**1.78**	**0.16**
SEM		**7.59**	**0.6**	**0.054**

Where, CV = coefficient of variation; LSD = least significance difference, SEM= Standard error of the mean, Values are means. Mean values comparison arranged according to descending order followed by the same letter in a column are not significantly different at 5% level of significance.

Mechanical damage was also influenced by the interaction of parameters. Mechanical damage was lowest (1.0%) at 100 rpm and 6 kg/min, whereas the highest damage (1.79%) was recorded at 300 rpm and 12 kg/min. As the recorded maximum percentage of mechanical damage (1.79%) is less than range of tolerable mechanical damage(<%2) of coffee beans during pulping operation reported by International Coffee Organization (ICO) and Food and Agricultural Organization (FAO) guidelines. This suggests that optimal machine operation requires balancing throughput and quality, since aggressive machine settings increase the risk of both un-pulped cherries and bean breakage. [13]similarly found that elevated machine speeds intensify bean cracking and loss of quality.

Results of the analysis of variance (ANOVA) confirmed that the interaction of disc speed and feeding rate, had a significant effect ($p < 0.05$) on pulping efficiency and had no significant effect ($p > 0.05$) on pulping capacity and mechanical damage. Overall, the results suggest that the optimal performance of the double disc pulpier can be achieved at a disc speed of around 200 rpm and feeding rate of 6–9 kg/min, where high capacity, efficiency, and minimal bean damage are balanced.

3.3. Farmers' feedback on the introduced technology

When we did this study, our main objective was to evaluate this technology on the farm level and introduce this wet coffee pulping technology to the local community. Accordingly, we took the feedback of both male and female farmers during and after the successful trial of our machine.

According to the farmers, there is a large wet coffee pulping machine in the area, but the machine is not affordable for small and medium scale farmers, but the machine we have provided is a good solution for small and medium-scale farmers. We asked them for feedback regarding the performance and operation of the machine and they said that the machine has good pulping capacity and efficiency, but they pointed out the suggestions that they would be happier with if the percentage of mechanical damage of the machine could be avoided as much as possible.

Overall, they indicated that this technology and its operation is suitable for both men and women, as it allows them to process their coffee cherry as needed and take to market at the right time. Most of them concluded their feedback by asking us how they could access such a machine, and we considered their ideas to be valuable.

3.4. Conclusion and Recommendation

3.4.1. Conclusion

The on-farm evaluation successfully established the performance of the Jimma model double-disc wet coffee pulpier. The study conclusively showed that the disc speed and feeding rate are critical operational parameters that significantly affect the pulping capacity, pulping efficiency, percentage of un-pulped loss, and mechanical damage. While the maximum pulping capacity was recorded at the highest disc speed and feeding rate (300 rpm and 12 kg/min), this setting resulted in reduced pulping efficiency (88.65%), higher un-pulped loss, and increased mechanical damage to the beans. The optimal performance, which balanced high throughput with high quality, was achieved at a disc speed of 200 rpm and a moderate feeding rate of 6-9 kg/min. At this setting, the machine maintained high pulping efficiency above 93%, minimized bean damage, and kept un-pulped losses low. Therefore, the Jimma model pulpier is a technically suitable technology for small-scale farmers, provided it is operated within its recommended parameters to ensure both efficiency and the production of high-quality parchment coffee.

3.4.2. Recommendations

Demonstration and pre-scaling up of this pulping technology should be undertaken for small scale farmers in Guji Zone and other coffee-growing areas.

Declarations

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Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors made an equal contribution in the Conception and design of the work, Data collection, Drafting the article, and Critical revision of the article.

Availability of data and materials

Authors are willing to share data and material on request.

Ethical Approval

Not applicable for this study.

Institutional Review Board Statement

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Informed Consent

Not applicable for this study.

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