Performance evaluation of the *Enset* decorticator machine and comparison of the end product with manual decortication method

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Abstract: *Enset* is used as human food, fiber, animal forage, construction materials, and medicines. Decortication of this crop was mostly by traditional methods. This traditional method is inefficient, unhygienic, gender based, less productive and time consuming. To alleviate this problem, the way aimed for developing engine driven *Enset* decorticator. Therefore, the objective of this study was to determine the performance of the constructed *Enset* decorticated machine in Wolkite University. The machine was tested in the laboratory and field. The result revealed that the maximum decorticating capacity, 97.88 kg hr^{-1} was obtained at drum speed of 850 rpm, when the concave clearance was 1 mm and the feeding rate was 0.077 kg s^{-1}. The highest decorticating efficiency of the machine was 98.98% at drum speed of 850 rpm, with concave clearance of 1 mm and feed rate of 0.077 kg s^{-1} while the lowest decorticating efficiency of 75.63% occurred at drum speed of 950 rpm, concave clearance of 4 mm and feed rate of 0.40 kg s^{-1}. The mean decorticating efficiency of the machine at feeding rates of 0.040, 0.048 and 0.077 kg s^{-1} were 87.65%, 88.66% and 89.57%, respectively. The maximum un-decorticated pulp was 16.32% occurred at drum speed 1050 rpm, concave clearance 4 mm and feed rate 0.040 kg s^{-1}; while the lowest loss of 1.03% was recorded at drum speed 850 rpm, concave clearance 1 mm and feed rate 0.077 kg s^{-1}. The highest fuel consumption of 15.91 mL kg^{-1} was observed at drum speed 950 rpm, feeding 0.077 kg s^{-1} and concave clearance 1 mm.

Keywords: decortication, *Enset*, performance, speed

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1 Introduction

Enset (*Enset ventricosum*) belongs to the family Musaceae, and the genus *ensete*. *Enset* looks like a large, thick, single stemmed banana plant. Both *Enset* and banana have underground corm, a bundle of leaf sheaths that form the pseudo stem, and large leaves (Brandt et al., 1997). It can grow to a height of 10 meters with a pseudo stem up to one meter in diameter. The stem has three parts; the upper-most portion is the pseudo stem, which is made of a system of tightly clasping leaf bases or leaf sheaths, the underground corm an enlarged lower portion of the stem and a short section of stem near the soil surface. Between the pseudo stem and corm, is the true botanical stem (Brandt et al., 1997). It is usually multiplied by vegetative means and grown as clones

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(Tsegaye, 2002). All plant parts are valuable as a source of food, feed, fiber soil fertility protection and even moderating micro-climate of the area. Besides, its production is firmly related with culture, social expression and economic status of the community. The crop has existed several hundred years ago in south and southwestern part mainly in Sidama, Dawro, Kefa, Sheka, Yem, Gedio, and Gurage and in the rest of the zones; and contributed to food and nutritional security (Addis et al., 2008).

The processing of *Enset* for fermentation of kocho is labor and time intensive which manually they can decorticate 3 *Enset* /day for two locally experienced person and mainly done by women (Negash and Niehof, 2004). This processing is carried out dominantly by rural women using traditional tools such as bamboo scrapers, serrated wooden tools and metal knives. The process is, in general laborious, tiresome and unhygienic. During harvesting, old and young leaf sheaths are removed from the plants manually. The internal leaf sheaths (usually up to two meters of length) are separated from the pseudo stem down to the true stem, which is about 20 cm between corm and pseudo stem.

Women secure the leaf sheaths against wooden planks inclined from the vertical at half way of its length with their heels from seated position to prevent the leaf sheath from slipping down during scraping. The scraping process of the soft material results in the production of fibers as a byproduct. The upper half of the leaf sheath was then turned upside down, for further scraping (Hunduma and Ashenafi, 2011). Scraping from seated position is very common in the country. What so ever, the case may be, the traditional way of *Enset t* processing results in a lot of physical drudgery and strain among rural women involved in the processing *Enset*? To come-up this problem *Enset* decorticator prototype was constructed and tested in Wolkite University, College of engineering and in lab class of food engineering. This study was therefore aimed to determine and tests the performance of *Enset* decorticator machine which was driven by 6.5 HP diesel motor.

2 Materials and methods

2.1 Experimental area

The manufacturing of the machine was done at Wolkite University Mechanical shop/lab class and Wolkite town art engineering PLC which is located in Gurage Zone. It lies between latitude and longitude of 8 17' N 37 47' E and respectively and an elevation of 1910 and 1935 mean above sea level.

2.2 Device and tools for measurement

To measure different parameters the following tools and device were used:

A stopwatch with accuracy of 0.02 second;

A digital vernier caliper measuring capacity of 300 mm with accuracy of 0.01 mm;

A digital balance with capacity of 5.00 kg and accuracy of 1.00 g to estimate the mass of pulp and fiber;

A diesel engine with 6.5 HP;

Rulers and measuring tape to determine dimensions of the prototype machine parts and leaf sheaths;

Friction measuring apparatus to estimate coefficient of static friction of the leaf sheath.

2.3 Performance evaluation of the machine

The machine decorticating capacity, decorticating efficiency, fiber cleaning efficiency and fuel consumption was determined during performance evaluation. *Enset*, beam balance, cutter, stop watch, 6.5 HP diesel engines motor, diesel fuel, pH meter and bucket were used. For traditional methods two locally experienced women were selected and comparison was taken. The machine was operated by one person; he inserts the root part of *Enset* to hopper firstly and then start decorticates the sheath. The machine was tested in two ways. Laboratory test and field test. In laboratory test the decorticator machine was kept on the firm level and horizontal surface of the laboratory floor and various dimensions were measured and; also the machine was inspected thoroughly paying attention towards the power transmission components and other moving parts, tightness of nuts and bolts, etc. In the field test the actual working condition of the machine was conducted and some records and measurements were taken as per the parameter of the machine testing. Before going to decorticate, the *Enset* sheath was washed, piled with minimum depth, cut and separated accordingly and finally weight of the sheath was measured. Then the ready sheath was inserted by the gate of the machine for decortication. In the case of manual decortication activity the women's must wash their hand, leg and the tools needed for operation before starting the work. Then other activities like machine were taken like washing of the sheath, measuring the weight and cutting at appropriate size was conducted.

The test was carried out at three levels drum speed 850, 950 and 1050 rpm by using Testo-470 instruments. Those drum speeds are at ideal operating machine. The time taken for each treatment was accurately checked and recorded. *Enset* sheaves were fed manually between the raspador and breastplate and the fiber was produced by the scrapping action of beater blades. The sheaves were fed in the machine from the tip ends first and reversed the decorticated part by feeding the butt ends for complete decortication. The following parameters were taken to determine the performance of the machine and manual decorticating methods.

2.3.1 Decorticating capacity

Decorticating capacity, D_c, (kg hr^{-1}) of the machine is expressed as ratio of the total weight of the input *Enset* sheave to the total time consumed (Cantalino et al., 2015). The decorticating capacity of the machine was determined by using Equation 1.

$$D_c = \frac{W}{T} \quad (1)$$

Where,

W = total weight of the *Enset* sheave fed to machine, kg;

T = total time, hr.

2.3.2 Decorticating efficiency

Decorticating efficiency is the capability of the decorticator to separate the pulp from fibers with minimum loss. It was determined by taking samples of decorticated pulp and un-decorticated pulp. The weight of each decorticated and un-decorticated samples was determined. Un-decorticated samples were decorticated and reweighed separately. The decorticating efficiency of the machine was determined by using Equation 2 (Maduako et al., 2006).

$$\eta = \left(\frac{W_d}{W_d + W_u}\right) \times 100 \quad (2)$$

Where,

η = decorticating efficiency;

W_d = weight of decorticated pulp by the machine, kg;

W_u = quantity of un-decorticated leaf sheath, kg.

2.3.3 Fiber cleaning efficiency

The byproduct of the *Enset* was cleaned with high efficiency without damaging it. So, it is used for different function and it must be cleaned as much as possible, to determine the fiber cleaning efficiency of the machine was determined by the Equation 3 (Cantalino et al., 2015).

$$\eta f = \frac{W_f}{F_t} \times 100 \quad (3)$$

Where,

η_f = fiber cleaning efficiency

W_f = weight of unbroken fiber, kg.

F_t = total fiber obtained, kg.

2.3.4 Fuel consumption

Measurement of fuel consumed was made for different factor combinations. The amount of fuel consumed was used to estimate cost operation under varying conditions. The fuel tank was filled to its maximum capacity and machine was operated for each factor. The tank was refilled using a graduated cylinder and funnel to estimate fuel consumed (mL kg^{-1}) during each test run.

2.4 Analysis of the cost of the machine

Economic analysis of the decorticating machine such as cost of operation, payback period and benefit-cost ratio of the machine and construction material cost were analyzed and economic return was estimated.

2.4.1 Operation cost

The variable and fixed cost of the decorticating machine was determined by the following equation and formulas. It must be determined to know how much cost will be invested while using machine. Fixed includes depreciation, interest, tax, insurance and house or shelter. While the variable cost is the type of the cost when operating the machine such as cost of repair and maintenance, fuel or electricity cost, and finally labor cost (Ojha and Michael, 2009). Total machine operation cost was determined by; *Total cost = fixed cost + variable cost*.

The total production cost of Enset decorticator = Cost of raw material + Cost of labor for fabrication + Cost of machine. So the total cost was 200,000 Birr. To determine the cost of operation the following assumptions were made by using the following steps (Workesa et al., 2021).

1. Useful working hours = 3000
2. Useful life years = 5
3. No. of labors per day = 1
4. No. of working hours per year=750 hours (*Enset* decortication takes place during the months of September to December)
5. Salvage value=10% of initial investment
6. The rate of interest on fixed capital=15% of the initial investment
7. Taxes per annum=1.5% of initial investment
8. Housing=1% of the initial investment
9. Repair and maintenance=5% per annum of initial investment

The total fixed cost of the machine was the sum of machine cost, depreciation, interest, insurance, taxes, housing which is 7.85 Birr hr^{-1}. Operating cost of the machine (variable costs), Total operation (variable) cost of the machine was 177.07 ETB hr^{-1}. Total processing / operation cost=Fixed cost + Operating (variable) cost=7.85+ 177.07= 184.92 Birr hr^{-1}.

2.5 PH determination of machine decorticated and traditional decorticated kocho

After the decorticating takes place, a certain mass sample (around 10 g) of each machine and traditional method was taken and put in a blender bag. The pH was measured three times with a pH meter (pH 1100 H) for seven days. The pH meter was first calibrated using standard buffer solutions (pH 4 and 7). To show the results of the pH values, the average of the three measurements was calculated and rounded to two decimal places per each day.

2.5.1 Operation time

For both manual (manual decorticator 1 and 2) and machine, randomly selected five sheath was decorticated and the time required to finish the sheath was recorded and measured. The variation of the time was determined from the record.

2.6 Statistical analysis

The data obtained from field test was analyzed, in to tables and graphs by using software Microsoft Excel (2013) and descriptive statistics and One-WayAnalyisis of variance

3 Results and discussions

Performance evaluation of *Enset* sheave decorticator was carried out by conducting laboratory test and field test at Wolkite University, college of engineering, food laboratory class.

3.1 Laboratory test result

Table 1 shows the result of the test in the laboratory. Some important measurement and observation was recorded in the laboratory for the machine.

3.2 Field test of the machine

The effect of drum speeds, concave clearance and feeding rates on the performance of the prototype decorticating machine such as decorticating capacity (DC) kg hr^{-1}, decorticating efficiency (DE) in percent, sheath loss (SL) in percent and fuel consumption (FC) lit kg^{-1} were assessed as presented below.

3.2.1 Decorticating capacity

The mean decorticating capacity and analysis of variance were presented in Table 2 below. The statistical analysis, ANOVA, clearly indicated that the decorticating capacity of the machine was significantly ($p < 0.05$) affected by drum speed, concave clearance and feeding rate. The effects of drum speed and concave clearance and that of concave clearance and feed rate were significant while drum speed and feeding rate, and the cross effect of the three factors were not significant at $p < 0.05$. The maximum decorticating capacity of 97.88 kg hr^{-1} was obtained at drum speed of 850 rpm, when the concave clearance was 1 mm and the feeding rate was 0.077 kg s^{-1}. Nonetheless, the decorticating capacity of the prototype machine decreased with increasing concave clearance and increased with increasing feeding rate.

Table 1 Laboratory test result

Particulars	Specifications
Machine type	Diesel engine driven Enset decorticator machine
Decorticating drum type	Circular hollow sheet metal with diameter 300 mm, length 450 mm and coated by aluminum sheet
Overall width of the cutter/blade	Length 450 mm, width = 10 mm and thickness 1.5 mm
Power transmission system	Pulley belt system
Number of blade or cutter	12
Input power	HP

Source: own measurement

Table 2 Mean of decorticating capacity (kg hr^{-1}) of the prototype machine at different drum speeds, concave clearances and feed rates

Drum speed (rpm)	Treatments	Feeding rates (kg hr^{-1})			Means
	Concave clearance (mm)	0.040	0.048	0.077	
850	1	3110.5^{a}	3115^{ba}	3150	3125.16
	2.5	2890.25^{c}	2986^{c}	3000.5	2958.91
	4	2850^{d}	2862.5	2879.5	2864
950	1	3111.25^{a}	3112.25	3113.5	3112.33
	2.5	2889.25	2981.5	2995.42^{e}	2955.39
	4	2798.5	2801.25	2811.2	2803.65
1050	1	3100.5^{ba}	3102.2	3108.5	3103.73
	2.5	2880.25	2975.25	2979.5^{e}	2945
	4	2784.5	2799.5^{d}	2802.5	2795.5
Means		2935	2970.606	2982.291	2962.632
LSD	9.24				
CV%	7.18				
SD	6.41				

Source: Own calculation (2024)

Note: LSD: least significant difference; CV: co-efficient of variation; SD: standard deviation; at 5% level of probability

3.2.2 Decorticating efficiency

The effects of drum speeds, concave clearances and feed rates on the decorticating efficiency of the prototype machine are presented in Table 3. The highest decorticating efficiency of 98.98% was obtained at drum speed of 850 rpm, concave clearance of 1 mm and feed rate of 0.077 kg s^{-1} while the lowest decorticating efficiency of 75.63% occurred at drum speed of 950 rpm, concave clearance of 4 mm and feed rate of 0.40 kg s^{-1}. The mean decorticating efficiency with respect to the feeding rates of 0.040, 0.048 and 0.077 kg s^{-1} were 87.65%, 88.66% and 89.57%, respectively.

The decorticating efficiency decreased with increasing speeds and increasing concave clearance. This was manifested by increasing amount of un-decorticated pulp. The decorticating efficiency was almost the same for the same concave clearance at drum speeds of 850, 950 and 1050 rpm, i.e. at given concave clearance the effect of drum speed was almost negligible. The decorticating efficiency increased with increasing the feed rate, and decreased with increase in concave clearances and nearly constant for drum speeds. The decorticating efficiency increased by decreasing concave clearance. The statistical analysis, ANOVA, clearly indicated that the decorticating efficiency of the machine was significantly ($p < 0.05$) affected by main effect of concave clearance, feeding rate, and drum speed.

Table 3 Mean of decorticating efficiency of the prototype machine at different drum speeds, concave clearances and feed rates

Drum speed (rpm)	Treatments	Feeding rates (kg s^{-1})			Means
	Concave clearance (mm)	0.040	0.048	0.077	
850	1	96.44^{a}	96.89^{a}	96.98^{a}	96.77
	2.5	90.33^{dac}	92.12^{bac}	92.40^{ba}	91.61
	4	78.59^{dc}	83.32^{bdc}	85.68	82.53
950	1	94.08^{a}	94.30^{a}	94.43^{a}	98.27
	2.5	87.33^{dc}	87.99	88.21^{bd}	87.84
	4	75.63	76.08^{dc}	79.66^{dc}	77.12
1050	1	92.02^{a}	92.20^{a}	92.27^{a}	98.16
	2.5	85.61	86.00^{bdac}	85.58	85.73
	4	76.89	77.08^{dc}	78.99	77.65
Means		87.65	88.66	89.57	
LSD	4.09				
CV%	0.37				
SD	2.35				

Source: Own calculation (2024)

Note: LSD: Least significant difference; CV: co-efficient of variation; SD: standard deviation; at 5% level of probability

3.2.3 Un-decorticated fiber (Loss of fiber)

The effect of drum speed, concave clearance and feed rate on pulp loss during *Enset* decortication is expressed in Table 4. The maximum un-decorticated pulp was 16.32% occurred at drum speed 1050 rpm, concave clearance 4 mm and feed rate 0.040 kg s^{-1}; while the lowest loss of 1.03% was recorded at drum speed 850 rpm, concave clearance 1 mm and feed rate 0.077 kg s^{-1}. The mean pulp losses at feed rates of 0.040, 0.048 and 0.077 kg s^{-1} were determined to be 13.23%, 10.59% and 10.09%, respectively. From (Table 4) it can be noted that the loss of pulp increased with increasing drum speed and concave clearance, and decreases with increasing feed rate.

Table 4 Mean of un-decorticated fiber (%) of the prototype decorticating machine at different drum speeds, concave clearances, and feed rates

Drum speed (rpm)	Treatments	Feeding rates (kg s^{-1})			Means
	Concave clearance (mm)	0.040	0.048	0.077	
850	1	4.01^{f}	3.92^{f}	3.21^{f}	3.71
	2.5	8.21^{dfc}	7.12^{df}	92.40^{ba}	35.91
	4	9.92^{ba}	9.32^{bdc}	8.68	9.30
950	1	4.18^{f}	4.30^{a}	4.53^{a}	4.33
	2.5	8.91^{dfc}	8.19	7.21^{bd}	8.10
	4	15.81^{f}	14.08^{dc}	13.66^{dc}	14.51
1050	1	2.82^{f}	2.20^{f}	2.27^{f}	2.43
	2.5	8.99	9.00^{bdac}	9.58^{abdc}	9.19
	4	16.32^{f}	15.08^{dc}	14.25	15.21
Means		8.79	8.13	17.31	
LSD	3.91				
CV%	1.09				
SD	12.56				

Source: Own calculation (2024)

Note: LSD: least significant difference; CV: co-efficient of variation; SD: standard deviation; at 5% level of probability

3.2.4 Fuel consumption

Means comparison for machine fuel consumption the experimental treatments is demonstrated in Table 5. It should be technically viable, economically feasible and socially acceptable for its acceptance by farmers. Hence rate fuel consumption becomes one of the important parameters used in the determination of economic viability of innovations and technologies.

The gap/ clearance and feed rate had a statistically significant effect on fuel consumption; fuel consumption increased with increasing feeding rate and decreasing concave clearance. The highest fuel consumption of 15.91 mL kg^{-1} was observed at drum speed 950 rpm, feeding 0.077 kg s^{-1} and concave clearance 1 mm, as can be seen from Table 5.

Table 5 Mean of fuel consumption (mL kg^{-1}) of the prototype decorticating machine at different drum speeds, concave clearances, and feed rates

Drum speed (rpm)	Treatments	Feeding rates (kg s^{-1})			Means
	Concave clearance (mm)	0.040	0.048	0.077	
850	1	10.33	13.24	15.82	13.13
	2.5	8.82	11.02	12.58	10.80
	4	8.91	10.72	13.06	10.89
950	1	11.89	13.03	15.91	13.61
	2.5	9.91	12.99	12.99	11.96
	4	9.01	12.01	13.45	11.49
1050	1	10.23	13.15	15.71	13.03
	2.5	9.89	10.4	13.05	11.11
	4	9.92	11.3	13.01	11.41
Means		9.87	11.98	13.95	
LSD					
CV%	0.097				
SD	1.16				

Source: Own calculation (2024)

Note: LSD: Least significant difference; CV: co-efficient of variation; SD: standard deviation; at 5% level of probability

3.3 Operation time

Means comparison for machine and manual decortication experimental treatments is demonstrated in Table 6. Results showed that for each type of decortication, there is a significant difference (p<0.05). These were due to age and strength or experience for manual and for machine due to feeding input mechanisms. The time taken to finish the single sheath for two manual operators and machine operation was recorded and measured. Even the time taken between two manual operators was different due to strength, age and experience of work for *Enset* decortications. The minimum time to finish single sheath for machine, operator 1 and operator 2 was 0.13 sec, 0.58 sec and 0.53 sec respectively. The manual operation system for both manual operator consume more than machine operation system.

Table 6 Mean of time to decorticated the fiber of the machine and manual at different sheath

Sheath	Times in minute to finish per sheath		
	By Machine	By Manual decorticator 1	By Manual decorticator 2
Sheath 1	0.233	1.6	1.8
Sheath 2	0.13	0.58	0.55
Sheath 3	0.41	1.38	1.25
Sheath 4	0.28	1.18	0.53
Sheath 5	0.24	1.42	1.12
Mean		0.84	
STD		0.34	
CV		0.4	

Source: Own calculation (2024)

Note: LSD: Least significant difference; CV: co-efficient of variation; SD: standard deviation; at 5% level of probability

3.4 Physiochemical dynamics

During fermentation period different microbial activities were observed in the lab class of the test. So different parameters were recorded and measured for both machine and manual decorticated end products or kocho. The measured parameters were PH, which was expresses in the following.

3.4.1 PH values

Means comparison for physiochemical dynamics of the kocho, the experimental treatments is demonstrated in Table 7. Results showed that for each type of days, there is a significant difference (p<0.05).

From data collected, the pH decreases due to the activities of fermenting microorganisms. The pH of the end product lies between 4.0 and 4.3 (Gashe, 1987; Hunduma and Ashenafi, 2011; Karssa et al., 2014). The PH value at the first day for both manual and machine decorticated kocho was large 6.4 and 6.25 respectively. But, after that there was sharp decline between two activities from 5.9 – 4.91 and 6.4 – 5.22 form machine and manual decortication practices. If the PH value was large it means that the environment becomes more favorable for clostridia and the germination of spores is possible (Jay et al., 2005; Wheeldon et al., 2008) and it facilitate fermentation process. And also between two practices there was gradual decline and from each day not more than 2% values were changed. If there was rapid decline in pH inhibits the growth of undesirable microorganisms, such as Enterobacteriaceae and *Clostridium* spp. (Kung, 2001; Pahlow et al., 2003; Weinberg, 2008).

Table 7 Mean of PH for machine and manual decorticated kocho at different days

Days	PH values	
	Machine decorticated kocho	Manual decorticated kocho
Day 1	6.25	6.4
Day 2	5.9	6.18
Day 3	5.64	6.01
Day 4	5.59	5.88
Day 5	5.12	5.32
Day 6	5	5.09
Day 7	4.86	5.01
Mean	4.9	
STD	0.53	
CV	0.1	

Source: Own calculation (2024)

Note: LSD: Least significant difference; CV: co-efficient of variation; SD: standard deviation; at 5% level of probability

4 Conclusion and recommendation

4.1 Conclusion

Enset (*Ensete ventricosum)*, which is fermented to kocho, is a major food security crop in Ethiopia, but different fermentation practices are in use and the quality of kocho is variable. The aim this study was to determine the performance *Enset* decorticator machine which was developed in Wolkite University College of engineering, food engineering department. It had better efficiency in the field with required feed rate and output capacity with minimum damage to fiber at optimum rpm of the drum which was at 1200 rpm. Therefore, it was expected that the developed Enset decorticator was many socio-economic important likely to bring income change, it allows women to spend less time providing basic needs and more time on their preferred productive activities, improves women's businesses, leading to increases in production or to products of higher quality, Women's health improves due to a trend toward less strenuous. For- the last decades the work was given only for women and girls but now this technology had some green light to involve for Enset users.

4.2 Recommendation

The following suggestions were explored to improve the performance of diesel engine motor driven *Enset* decorticator to get it with high quality and quantity of the end product. In generally the traditional method of decorticating *Enset* which is full of drudgery, unhygienic and consuming much time, needs to be modernized through the introduction of appropriate technology. Therefore, the need for decorticating machine is high. Nonetheless, the prototype machine appears to be expensive though the performance is acceptable.

Thus, the following recommendations were made:

To minimize the cost of the machine, use of materials other than stainless steel must be advisable (plastic, aluminum, etc).

The low income farmer should think of buying and owning the machine jointly, or custom use and/or service provision must be thought of.

Drum speed greater than 850 rpm is not required to decorticate *Enset*.

The machine was highly recommended to the end users with the current status.

The capacity of the prototype decorticating machine appears to be low and the levels of feeding rates selected were small in general; this calls for further testing and re-evaluation of the prototype machine other than the predetermined values.

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