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Cocoa Butter and Cake Yield Prediction for Production Planning In Cocoa Processing Industry

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Abstract

Crushing of dried Cocoa beans and pressing of the paste that comes out of it, called "Cocoa Liquior" yields cocoa butter and cake. Both are of high economic value and boost the Internal Generated Revenue (IGR) of any Nation producing them. In planning for future production of butter and cake, there is need for a tool capable of predicting the quantity of butter and cake that can be gotten from any quantity of dried cocoa beans pushed into the processing plant. This study developed an empirical model which stands as a production decision support system (DSS) to determine net cocoa beans processed, cocoa nibs available for grinding into liquor, butter and cake yied from the mass of liquor pressed for production planning of cocoa processing in industry. The developed empirical model predicted total yield of 374.41 tonnes of liquor cocoa beans, out of which butter was 174.50 tonnes and cake was 200.28 tonnes when 522.30 tonnes through put was processed for six months, January to June 2015. The waste materials (beans, nibs, liquor, butter and cake), mass of shell removed, and the materials unprocessed left on the production line was 148.02 tonnes. The actual results collected from the factory floor for the same six months are: liquor yield 377.83 tonnes out of which butter was 175.59 tonnes, Cake 202.24 tonnes, the waste materials, mass of shell removed and the unprocessed left on the production line was 149.06 tonnes the efficiency of the model is 99.08% and the results correlation (r) is +1 this shows that both results have strong relation.

Keywords: Cocoa liquor pressing, empirical model development, products yield forecasting.

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Introduction

Cocoa fruit, often termed as the cocoa or cocoa ''pod'' exhibits wide variety of shapes, texture, color and sizes. Each pod on an average has 30-40 seeds (cocoa beans) embidded in a mucilaginous pulp called an aril (WCF, 2010) and (Cadbury, 2013). Cocoa (Theobroma cocoa) and kola belongs to the botanical family sterculiaceae. Both serve as beverages and stimulants. Cocoa is used in the preparation of several industrial products: food as chocolate and confectionery, drinks as cocoa powder, cocoa milk and cocoa liquor, cosmetics, in perfumes etc., soap making, from the husk ash, livestock feed, as cocoa cakes and medicine, from the bark and root (Autonio, 1979), (Awua, 2002) and (Adzimah and Asiam, 2010). It requires the best soil shell drained with good depth of top soil which is porous and loose, has a low-based water table and is rich in humus. It thrives best in an equatorial tropical climate, with an annual rainfall of 100-140 cm, a temperature of not less than 17^{oC} and a relatively high humidity. It cannot withstand a long period of drought (Ntiamoah and Afrane, 2008), (ICCO, 2008).

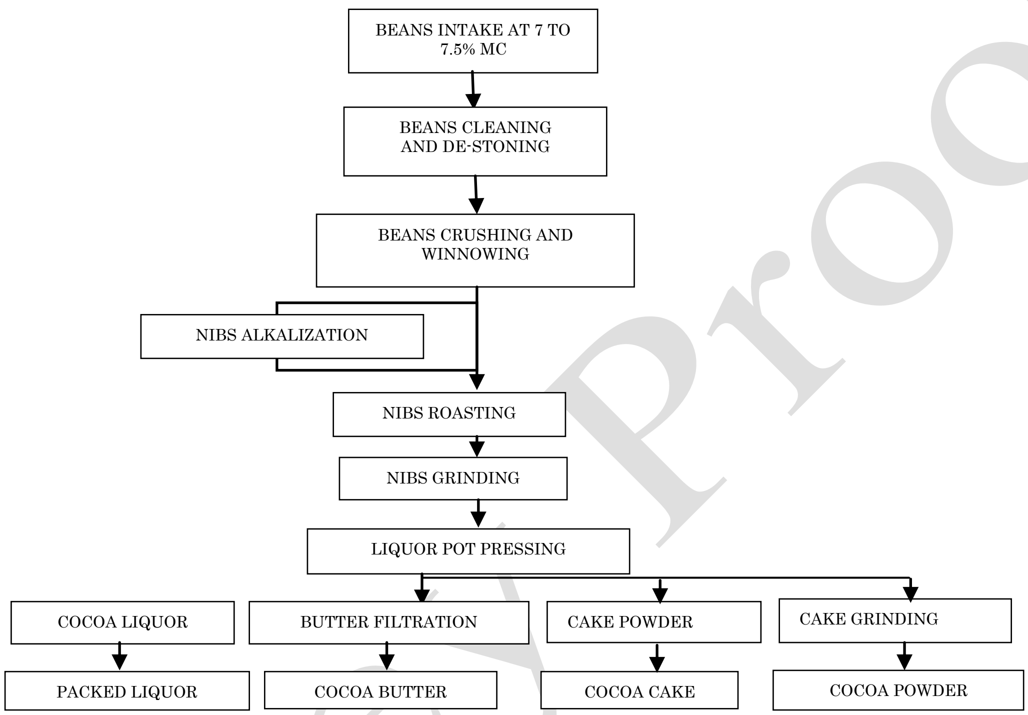

Figure 1: Cocoa Bean Process Flow chart
Source: (Adenuoye, 2011) and (Akinnuli *et al*., 2014)

Description of Processing Layout

The processing of cocoa beans passes through some processing layout from the initial to final points: the above figure shows the layout diagram. The dried Cocoa beans are usually received into the factories at 7-7.5 moisture content and then pass through the cleaning state where all the foreign materials and bad ones are removed, crushing and winnowing is the next stage when the beans are broken into nibs and shell blown off. After this process, alkalization of the nibs may be effected, then the roasting process follows, or the nibs are moved directly to this stage from the crushing/winnowing section. The roasted nibs are now ground to liquor from where it is packed as final product to be marked or it is further pressed into Butter and Cake.

Modelling In Cocoa Processing

Ajayi *et al*. (2014), modeled temperature as a constraint factor of Cocoa yield in Ondo State. Hill *et al*. (2008), modelled thin layer drying kinetics of cocoa beans during artificial and natural drying. While (Osun, 2011) analyzed socio-economic factor affecting cocoa production in Ondo State using Idanre and Ondo East Local Government Areas as case study. Akmel *et al*. (2012), came up with model for sun drying kinetics of thin layer of cocoa beans. Foster *et al*. (1994) carried out convective drying of cocoa beans which resulted into drying curves for various external conditions. The process simulation and debottlenecking for an industrial cocoa manufacturing process was conducted by (Omar *et al*., 2010).

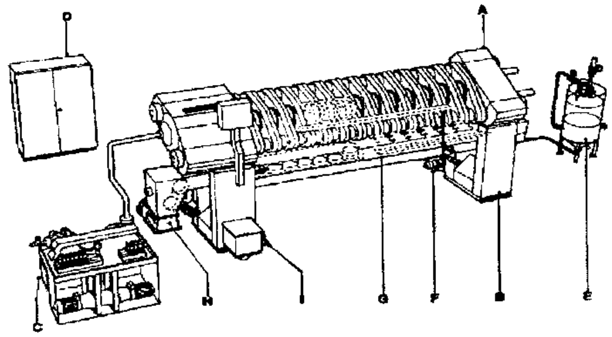

Figure 2: Cocoa press with auxiliary equipment (Duyvis)
Sources: (http://www.cacaochocolade.nl/main.php?p), (Nickless, 1996).

Equipment for Cocoa Liquor Press for Butter Extraction

The following are the cocoa pressers' components: cocoa press, support structures, hydraulic pump unit, control panel conditioning tank, liquor pump, cake conveyor, cake breaker, butter pump. Details of this are found in Lorenzi *et al*., (2006), (Awua, 2002), (Lipp and Anklam, (1998) and (Whitefied, 2005). A lot of effort has been put in place to get quality product from crushed cocoa beans at primary and secondary processing level. These are confirmed by: (Pontillon, 1998), (SAU, 2005), (FEC 1973) and (Selemat *et al*., 1996). At every phase of production, products were analyzed to ascertain quality. But tool to predict the yield of cocoa liquor, butter and cake before processing at planning level is not available hence development of this empirical model to serve this purpose which is a gap in literature. Barnerjee *et al.,* 2017 carried out the economic analysis of demands and untainty delay of information sharing in a third party under managed supply chain. A conceptual hybrid framework for industrial process improvement by integrating taguchi methods Shamon system and six sigma was a focus of rasher, (2016). Banahi and Bilac, (2014) developed a framework to improve construction process by integrating Lean, Green and Six Sigma. Gijo *et al*. (2014) applied six sigma method to a small-scale foundry industry while Lucato *et al.* (2014) integrates the environmental variables into the six sigma technologies for production planning and control decision making. A carbon market sensitive optimization model was developed by chondhary *et al*. (2015) for integration of forward-reverse logic. The success factors when implementation agree-manufacturing system was research by Chuang and Yang, (2014). But comprehensive review to explore the future using reverse logistic and closed-loop supply chain was done by Govindan *et al*. (2015).

Material and Methods

Cocoa processing industries in Ondo State (Olam, Akure, Cocoa, Ile-Oluji, Stanmark in Ondo, and Osun State cocoa Industry, and Ogun State (Tulip Cocoa processing Industry were visited to confirm the availability of this decision supporting tool if any of them having this type of decision support tool for their production planning. The operations and processing information required for the model development such as: the mass of cocoa beans available for crushing, some of foreign materials found admist of cocoa beans, waste at every workstation, time for resumption and closing at work. Others like mass of cocoa shell removed, Nibs waste, liquor waste, Butter, Cake and beans waste are all the input required parameters.

Model Development

Nomenclature

A_{LP} is Available cocoa liqour
N_{BP} is Available cocoa beans to be processed
M_{BU} is Mass unprocessed cocoa bean
M_{fm} is Mass of foreign materials (stone, metals, etc. in cocoa)
W_B is Mass of waste cocoa beans
P_{nm} is Mass of cocoa nibs produced
Mshr is Mass of cocoa shell removed
G_n is Mass of nibs actually grounded
C_{nw} is Mass of cocoa nibs wasted
A_{lq} is Actual mass of cocoa liquor produced
W_{CL} is Mass of liquor wasted
Y_b is Mass of butter yield from liquor
$\%P_b$ is Percentage of butter produced
P_{bw} is Mass of butter wasted
Y_c is Mass of Cake yield
P_c is Percentage of cake produced
P_{cw} is Mass of cake wasted
Ty is Total mass yield (Butter and Cake)
Note: All mass mentioned above are measured in "tonnes".

Determination of Net Cocoa beans Processed (NB_P)

$$NB_P = M_{BU} - (M_{fm} + W_B)$$
(1)

Determination of Cocoa nibs available (P_{nm})

$$P_{nm} = N_{Bp} - M_{shr}$$
(2)

Determination of actual mass of nibs ground (G_n)

$$G_n = P_{nm} - C_{nw}$$
(3)

Determination of cocoa liquor available (A_{lp})

$$A_{lp} = G_n - w_{cl}$$
(4)

Determination of butter yield (Y_b)

$$Y_b = A_{lq}(\%P_b) - P_{bw}$$
(5)

Determination of Cake yield (Y_c)

$$Y_c = A_{lq}(\%P_c) - P_{cw}$$
(6)

Determination of total yield (T_y)

$$T_y = Y_b + Y_c \quad (7)$$

The flow chart that integrated all these 7 models is shown in figure 3

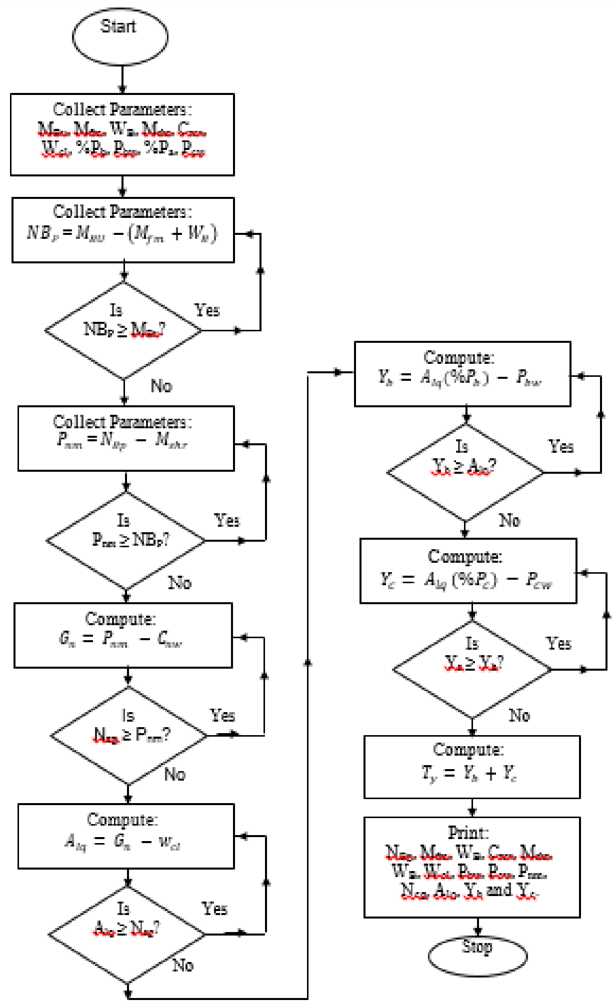

Figure 3: Flow Chart that integrated the models for Computation Software development.

Monthly percentage losses in each work station were collected and analyzed and mass of cocoa shells removed from through put as well as the cocoa beans left on the production line were determined. These were deducted from the mass of beans fed into the plant for processing. The collected data for computation covered (4) years of processing period 2012, 2013, 2014 and 2015. Average to each loss for the period of 4 years was used as a multiplication coefficient to determine expected loss at each work station. Record of products in percentage of butter and cake were also known. The addition of both made the percentage total yield of liquor processed into cake and butter less loss of the liquor.

Results and Discussion

The percentages of losses as it affects aforementioned materials losses, as well as percentage of the cocoa shell removed from cocoa beans they are shown in table 1.

Table 1: Percentages of losses and Yield collected at the Work Stations for four years of processing.

M_{ar}	% C_{nw}	% W_{cl}	% P_{bw}	% Pcw	% T_w	% Y_{cl}	% P_c	% T_y		
Jan. 2012	1.290	7.681	6.678	5.343	4.007	2.671	27.630	33.780	38.590	72.370
Feb. 2012	1.320	7.764	6.674	4.921	4.122	2.562	27.383	34.129	38.488	72.617
Mar. 2012	1.220	7.634	7.214	4.678	4.000	2.634	27.380	34.130	38.490	72.620
Apr. 2012	1.634	8.420	6.632	4.226	4.142	2.554	27.608	34.022	38.370	72.392
May 2012	1.520	7.923	6.680	5.125	3.977	2.667	27.896	33.887	38.217	72.104
Jun. 2012	1.330	8.231	7.411	5.164	3.965	3.001	29.102	33.320	37.578	70.898
Jul. 2012	1.721	7.443	7.262	5.321	3.826	3.243	28.816	33.454	37.730	71.184
Aug. 2012	1.450	7.325	6.674	5.225	4.126	2.234	27.034	34.291	38.675	72.966
Sep. 2012	1.378	8.211	6.538	6.302	4.341	2.222	28.912	33.405	37.608	71.008
Oct. 2012	1.446	8.000	6.544	6.421	4.641	2.464	29.516	32.792	37.691	70.484
Nov. 2012	1.738	7.262	6.674	5.321	4.326	2.543	27.864	33.560	38.576	72.136
Dec. 2012	2.001	7.244	6.842	5.662	5.232	2.611	29.691	32.710	37.599	70.309
Jan. 2013	1.782	7.321	7.221	5.367	4.006	2.624	28.321	33.347	38.332	71.679
Feb. 2013	1.662	7.345	7.322	5.422	4.206	2.342	28.299	33.359	38.344	71.701
Mar. 2013	1.321	7.458	6.988	5.376	4.145	2.446	27.734	33.620	38.646	72.266
Apr. 2013	1.468	7.323	6.456	5.478	4.097	2.544	27.363	33.792	38.844	72.637
May 2013	1.842	7.421	6.554	6.002	4.008	2.649	28.576	33.228	38.196	71.424
Jun. 2013	1.771	7.482	6.674	6.142	4.262	3.004	29.335	32.875	37.790	70.665
Jul. 2013	2.020	8.000	6.821	6.210	4.241	2.225	29.517	32.790	37.693	70.483
Aug. 2013	1.667	7.941	7.214	5.542	4.006	2.438	28.862	33.095	38.043	71.138
Sep. 2013	1.742	7.477	6.554	5.682	3.862	2.631	27.998	33.497	38.523	72.002
Oct. 2013	1.328	7.562	6.428	5.322	3.924	2.674	27.238	33.850	38.912	72.762
Nov. 2013	1.527	7.328	6.327	5.323	4.325	2.268	26.988	33.966	39.046	73.012
Dec. 2013	1.349	7.349	6.412	5.235	4.145	2.463	26.953	33.982	39.065	73.047
Jan. 2014	1.434	7.794	6.742	5.221	4.324	2.456	27.971	33.508	38.521	72.029
Feb. 2014	2.004	7.842	6.635	5.334	5.225	2.521	29.559	32.650	37.791	70.441
Mar. 2014	1.678	8.321	6.528	5.662	4.275	2.627	29.091	32.867	38.042	70.909
Apr. 2014	1.872	8.225	6.524	6.354	4.314	2.545	29.834	32.523	37.643	70.166
May 2014	1.538	7.673	6.554	6.300	4.462	2.348	28.875	32.968	38.157	71.125
Jun. 2014	1.942	7.545	6.632	6.114	4.004	2.626	28.803	32.974	38.163	71.137
Jul. 2014	1.438	7.732	7.001	5.221	4.007	2.624	28.023	33.363	38.614	71.977
Aug. 2014	1.329	7.778	6.255	5.321	4.012	2.454	27.149	33.768	39.083	72.851
Sep. 2014	1.204	7.642	6.466	5.774	4.621	2.274	27.981	33.382	38.637	72.019
Oct. 2014	1.448	7.840	6.328	5.314	4.712	2.228	27.870	33.433	38.697	72.130
Nov. 2014	1.254	8.234	6.429	5.225	4.676	3.041	28.859	32.975	38.166	71.141
Dec. 2014	1.233	8.424	6.329	5.426	4.664	2.245	28.321	33.224	38.455	71.679
Jan. 2015	1.262	7.466	7.121	5.549	4.724	2.636	28.758	33.021	38.221	71.242
Feb. 2015	1.451	7.526	6.748	5.337	5.320	2.545	28.927	32.943	38.130	71.073
Mar. 2015	1.472	7.328	6.327	5.264	5.421	2.468	28.487	33.147	39.366	71.513
Apr. 2015	1.221	7.647	6.445	6.321	4.784	2.363	28.781	33.011	38.208	71.219
May 2015	1.236	8.421	6.523	6.304	4.605	2.245	29.394	32.726	37.880	70.606
Jun. 2015	1.278	7.456	6.423	5.992	4.004	2.682	27.835	33.449	38.716	72.165
Jul. 2015	1.254	7.794	7.234	5.832	4.002	3.242	29.358	32.743	37.899	70.642
Aug. 2015	1.250	8.341	6.664	5.745	4.008	2.651	28.659	33/067	38.274	71.341
Sep. 2015	1.223	7.336	6.428	5.245	4.244	2.663	27.139	33.772	39.089	72.861
Oct. 2015	1.246	7.278	6.547	5.334	4.630	2.582	27.617	35.550	38.833	72.383
Nov. 2015	1.378	8.041	7.211	5.262	4.548	2.484	28.924	32.944	38.132	71.076
Dec. 2015	1.326	7.736	6.380	5.427	4.363	2.524	27.756	33.485	38.759	72.244
TOTAL (CUMULATIVE %)							1360.127	1600.372	1840.489	3440.861
AVERAGE = $\frac{\text{CUMULATIVE}}{48}$							28.341%	33.341%	38.344%	71.685%

LEGEND: % T_w = 28.31, % Y_{cl} = 33.341, % P_c = 38.344, % T_y = 71.685

The results in table 1 simply means that from the 4 years of record data collected, the model developed predicted that to any amount of throughput (materials) released into the processing line 71.684% shall be total yield. Out of this total yield, 33.41% shall be butter product and 38.343% shall be cake product while out of the material processed 28.34% shall be for material loss, shell of cocoa removed and left over materials on the process line.

Model Validation

This model was used to predict yield for the months of January, February, March, April, May and June 2015. The results were tabulated in Table 2.

Table 2: Application of the Developed Model for Yield Prediction before Operations.

Month 2015	Beans Input (ws)	Waste 28.341%	Butter Yield 33.341%	Cake Yield 38.344%	Total Yield 71.685%
January	34.40	34.40×28.34%(9.75 Tons)	34.40 ×33.41%(11.49 Tons)	34.40×38.344%(13.19 Tons)	34.40×71.685%(24.66 Tons)
February	70.30	70.30×28.34%(19.92 Tons)	70.30 ×33.41%(23.49 Tons)	70.30×38.344%(26.96 Tons)	70.30×71.685%(50.39 Tons)
March	58.00	58.00×28.34%(16.44 Tons)	58.00 ×33.41%(19.38 Tons)	58.00×38.344% (22.24 Tons)	58.00×71.685%(41.58 Tons)
April	119.10	119.10×28.34%(33.75 Tons)	119.10 ×33.41%(39.79 Tons)	119.10×38.344%(45.67 Tons)	119.10×71.685%(85.38 Tons)
May	103.90	103.90×28.34%(29.45 Tons)	103.90 ×33.41%(34.71 Tons)	103.90×38.344%(39.84 Tons)	103.90×71.685%(74.48 Tons)
June	136.60	136.60×28.34%(38.71 Tons)	136.60 ×33.41%(45.64 Tons)	136.60×38.344%(52.38 Tons)	136.60×71.685% (97.92 Tons)
TOTAL	522.30	148.02	174.50	200.28	374.41

The actual results after processing of the beans made available for crushing the results is as shown in table 3.

Table 3: Actual Processing Mass Yield after Processing

Months 2015	Cocoa Beans Input (TNS) [a]	Waste (TNS) [b]	Butter Yield (TNS) [c]	Cake Yield (TNS) [d]	Total Yield (TNS) [e] = c + d
January	34.40	9.82	11.57	13.32	24.89
February	70.30	20.06	23.63	27.23	50.86
March	58.00	16.55	19.49	22.46	41.95
April	119.10	33.99	40.04	46.13	86.17
May	103.90	29.65	34.93	40.24	75.17
June	136.60	38.99	45.93	52.91	98.84
TOTAL	522.30	149.06	175.59	202.24	377.83

This six months processing yield data collected from the factory floor was compared with the predicted yield in table 2 to determine the level of deviation. The summary of these data is shown in Table 4.

Table 4: Table for Summarizing the Model and factory Floor Results and the difference in the data collected.

Months		Mass Waste (TNS)	Mass Butter (TNS)	Cake Mass (TNS)	Total Yield Mass (TNS)
January	Factory	9.82	11.57	13.32	24.89
	Model	9.75	11.49	13.19	24.66
	Difference	0.07	00.08	00.23	00.23
February	Factory	20.06	23.63	27.23	50.86
	Model	19.92	23.49	26.96	50.39
	Difference	00.14	00.14	00.27	00.47
March	Factory	16.55	19.49	22.46	41.95
	Model	16.44	19.38	22.24	41.58
	Difference	00.11	00.11	00.22	00.37
April	Factory	33.99	40.04	46.13	86.17
	Model	33.75	39.79	45.67	85.38
	Difference	00.24	00.25	00.46	00.79
May	Factory	29.65	34.93	40.24	75.17
	Model	29.45	34.71	39.84	74.48
	Difference	00.20	00.22	00.40	00.69
June	Factory	38.99	45.93	52.91	98.84
	Model	38.71	45.64	52.38	97.92
	Difference	00.18	00.31	00.53	00.92

Table 4 gave details performance of the model in each month by showing the differences in every month through put as it affect waste, mass of butter and cake produced as well as the total yield.

The data collected from the model developed and adopted for prediction and the actual data collected from factory floor were examined for correlation Table 5 was used for this computation.

Table 5: Table for correlation determination of the data collected "X" and the predicted data "Y"

Month	Observed (X)	Expected Model (Y)	X^2	Y^2	XY
January	24.89	24.66	619.5121	608.1156	613.7874
February	50.86	50.39	2586.7596	2539.1521	2562.8354
March	41.95	41.58	1759.8025	1728.8964	1744.281
April	86.17	85.38	7425.2689	7289.7444	7357.1946
May	75.17	74.48	5650.5289	5547.2704	5598.6616
June	98.84	97.92	9769.3456	9588.3264	9678.4128
TOTAL	$(\sum X) = 377.88$	$(\sum Y) = 374.41$	$(\sum X^2) = 27811.1976$	$(\sum Y^2) = 27301.5053$	$(\sum XY) = 27555.1914$

$$r = \frac{n\sum xy - \sum xy \sum y}{\sqrt{n\sum x^2 - (\sum x)^2}.\sqrt{n\sum y^2 - (\sum y)^2}}$$

$$r = \frac{6 \times 27555.1914 - (377.88 \times 374.41)}{\sqrt{6(27811.1976)(377.88)^2} \times \sqrt{6(27301.5053) - (374.41)^2}}$$

$$r = \frac{23849.097}{23848.9874}$$

$$r = 1.0000046$$

$$r = 1$$

Since r = +1 it means there is perfect positive relationship between the predicted and the actual collected results from the factory floor. This proofed the developed model highly effective. The graph of this relationship is shown in figure 4 using data on table 4.

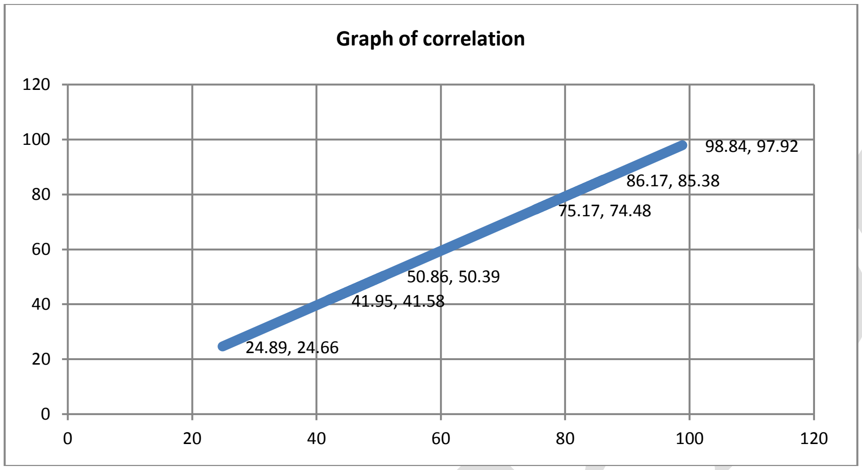

Figure 4: Graph of correlation for the predicted and actual collected data.

Efficiency of the Model Developed

Efficiency of the model developed was determined by considering the total mass of yield predicted for the six months and the actual mass collected after production in six months.

$$\text{Efficiency } \xi = \frac{\text{Mass Yield Predicted}}{\text{Actual Mass Yield Collected}} \times 100$$

$$\xi = \frac{MYP}{AMC} \times 100$$

From Table 5 total mass yield predicted $\sum Y$ = 374.41 tonnes while the actual mass yield collected $\sum X$ = 377.88 tonnes

$$\xi = \frac{\sum Y}{\sum X} \times \frac{100}{1}$$

$$\xi = \frac{374.41}{377.88} \times \frac{100}{1}$$

$$\xi = 99.08\%$$

Conclusion

The study ascertained the major strategic decisions required for the empirical model development as: net cocoa beans processed, cocoa nibs available for process after shells of the bean removed, the actual nibs ground after deducting the nib waste, cocoa liquor available, then butter and the cake yield. Past data for four years (48 months) was collected on percentage waste and the average percentage was calculated for waste, butter yield and cake yield as 28.330%, 33.341% and 38.344% respectively. These figures stood as the coefficient for the unknown value of waste, butter yield and cake yield to be predicted. This model developed was evaluated using case study of Stanmark Cocoa Processing Industry, Ondo. The throughput into this plant for January to June (six months) in 2015 were: 34.40, 70.30, 58.00, 119.10, 103.90, and 136.60 tonnes respectively. The model predicted the expected butter yield to be: 11.49, 23.49, 19.39, 39.79, 34.71 and 45.64 Tonnes respectively. While the yield for cake was predicted to be: 13.19, 26.96, 22.24, 45.67, 39.84 and 45.93 Tonnes. The waste are: 9.75, 19.92, 16.44, 33.75, 29.45 and 38.71 Tonnes. When the mass of cocoa beans for each month was crushed the actual results collected from the factory floor from January to June, 2015 are: 11.57, 23.63, 19.49, 40.04, 39.93 and 45.93 Tonnes. The cake yield was: 13.32, 27.23, 22.46, 46.13, 40.24 and 52.91 Tonnes respectively. Concerning the waste involved in the 6 months processing of the cocoa beans are: 9.82, 20.06, 16.55, 33.99, 29.65, and 38.99 Tonnes. The efficiency of this developed model was determined to be 99.08% with correlation (r) value of +1.00 which shows that the results of the model compared to that of results collected from the factory floor shows strong association or relationship.

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