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The Effect of Binders on the Mechanical Properties of Pellets

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Abstract:- This study investigated the effect of binders on the mechanical properties of pellets, focusing on their strength. Compression tests were conducted to analyze the effects of the water-to-meal ratio, binder type (guar gum and okoho gum), binder/die diameter combinations, and mixed ratios on various parameters. The results revealed that as the water-to-meal ratio increased, the force at peak decreased. Absolute values of energy at both peak and yield were lower in the binder/die diameter and mixed ratio combinations. The guar gum binder consistently exhibited higher absolute values compared to the okoho gum binder across different water-to-meal ratios. Analysis of mean values indicated significant effects of the guar gum binder on peak force, peak strain, and peak energy at different mixed ratios. The water-to-meal ratio and its interactions were also found to be influential. For yield parameters, significant effects were observed in relation to the force at yield, while deflection at yield showed no significant differences. Only the binder had a significant effect on strain at yield, while the mixed ratio solely affected the mean values of energy at yield. These findings contribute to our understanding of how binders impact pellet properties and can be valuable in optimizing pellet formulation and production processes. Further research is recommended to explore additional factors and optimize binder selection for specific pellet applications.

Keywords:- *Okoho Gum, Guar Gum and Pellets.*

I. INTRODUCTION

The use of binders in pellet manufacturing has gained significant attention in recent years due to their significant impact on the mechanical properties of pellets. Binders play a crucial role in improving the strength, durability, and handling characteristics of pellets (Ju *et al.*, 2020), making them an essential component in various industries like pharmaceuticals, agriculture, and construction (Edom, 2023).

The demand for high-quality pellets with enhanced mechanical properties has led to extensive research in the field of binder technology. Binders are substances that help in holding the particles together, preventing their disintegration or breakage during handling, transportation, and application processes. By improving the cohesion and adhesion properties of pellets, binders contribute to their strength, durability, and resistance to environmental factors.

Several research endeavors have been undertaken to explore how binders influence the mechanical characteristics of pellets. For instance, Smith *et al,* (2018) found that the incorporation of a polymeric binder significantly improved the compression strength of agricultural pellets. The study by Johnson and Brown (2019) focused on the impact of binder concentration on the tensile strength of pharmaceutical pellets, revealing an optimum binder concentration for maximum mechanical properties. These studies highlight the potential benefits of using binders to improve the mechanical properties of pellets.

Despite the importance of binders to improve the mechanical properties of pellets, there is a lack of comprehensive understanding regarding their optimal usage, selection, and impact on different types of materials. This knowledge gap hinders the development of efficient pellet manufacturing processes and limits the potential applications of pellets in various industries. Thus, it is imperative to investigate the effect of locally sourced binder materials (okoho gum and guar gum) on the mechanical properties of pellets to optimize their performance and explore new possibilities. This article aims to explore the effect of binders on the mechanical properties of pellets and this can be achieved through the following objectives; to evaluate the influence of different binders on the mechanical strength of pellets and to investigate the effect of binders on the durability and resistance of pellets under different environmental conditions.

II. MATERIALS AND METHOD

The materials used were guar gum, okoho (Cissus populnea) fresh stem, sieve, water bath and distilled water. The C. populnea stems utilized in this study were sourced from the surrounding forest near Joseph Sarwuan Tarka Makurdi, Nigeria, and were meticulously cleaned to remove any adhering dirt and foreign substances. The fresh stem underwent cleaning through scraping with a kitchen knife. The "fleshy" bark was peeled off, and the remaining portion was finely sliced into strips. It was immersed in one liter of distilled water at 55°C for a duration of 24 hours. Following this, the strips were gently squeezed under the water to eliminate any exudates. The resultant sample was then filtered through a sieve to obtain fresh stem exudate for pellet production. However, guar gum and okoho were used for pellets feed production.

III. RESULTS AND DISCUSSION

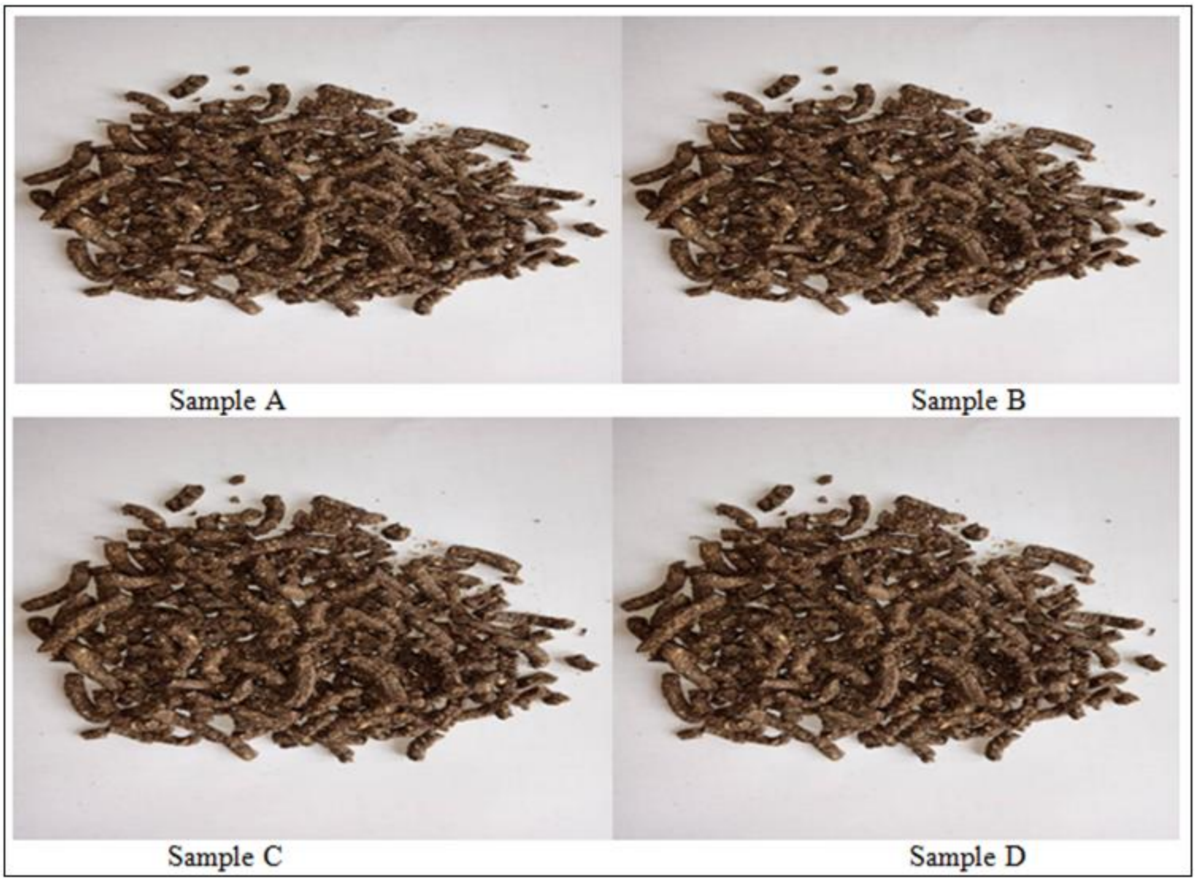

Plate 1: Guar Gum Samples @ Water to Feed Ratio of 500ml/1000g

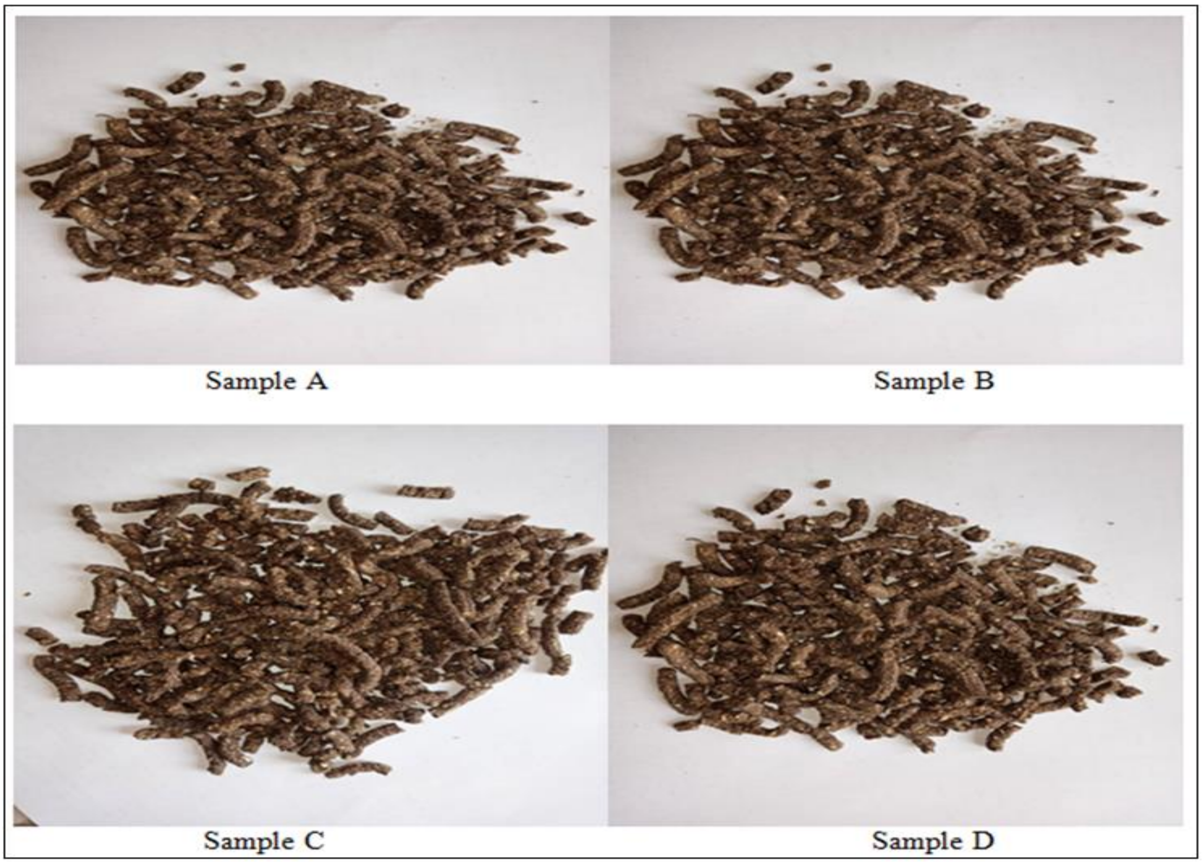

Plate 2: Okoho Samples @ Water to Feed Ratio of 500ml/1000g

Table 1: Extruded Feed Pellet Compression Load of Guar Gum Sample A (SA)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	451.97	2.084	1.115	0.324	252.91	1.31	0.701	0.049
2	7	292.36	2.007	1.072	0.179	99.05	1.182	0.631	0.023
3	7	437.76	1.264	0.676	0.185	437.76	1.264	0.676	0.185
4	7	429.47	1.616	0.864	0.297	169.43	0.637	0.341	0.035

Table 2: Extruded Feed Pellet Compression Load of Guar Gum Sample B (SB)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	430.71	1.436	0.769	0.265	399.71	1.224	0.656	0.176
2	7	493.46	2.514	1.348	0.687	159.93	0.523	0.28	0.038
3	7	418.45	1.071	0.573	0.22	418.45	1.071	0.573	0.22
4	7	490.93	2.507	1.344	0.787	321.01	0.76	0.407	0.099

Table 3: Extruded Feed Pellet Compression Load of Guar Gum Sample C (SC)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	407.41	1.377	0.739	0.29	158.38	0.483	0.259	0.028
2	7	480.42	2.511	1.349	0.727	190.28	0.504	0.271	0.035
3	7	474.78	2.511	1.345	0.779	383.7	1.012	0.542	0.152
4	7	448.67	1.6	0.856	0.307	343.1	1.149	0.615	0.134

Table 4: Extruded Feed Pellet Compression Load of Guar Gum Sample D (SD)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	451.73	1.242	0.664	0.191	123.14	0.654	0.35	0.027
2	7	473.75	1.128	0.606	0.28	283.34	0.531	0.285	0.058
3	7	635.9	2.508	1.347	1.004	611.8	1.439	0.773	0.41
4	7	415.12	0.952	0.512	0.145	184.03	0.586	0.315	0.031

Table 5: Extruded Feed Pellet Compression Load of Okoho binder Sample A (SA)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	281.58	1.817	0.972	0.208	102.07	0.974	0.521	0.023
2	7	191.79	2.328	1.242	0.164	39.71	0.759	0.405	0.017
3	7	215.18	0.852	0.456	0.077	215.18	0.852	0.456	0.077
4	7	189.88	2.102	1.12	0.175	46.02	0.775	0.413	0.016

Table 6: Extruded Feed Pellet Compression Load of Okoho binder Sample B (SB)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	148.28	1.798	0.96	0.119	37.05	0.329	0.176	0.007
2	7	125.87	1.709	0.914	0.089	43.17	0.521	0.279	0.007
3	7	156.87	2.431	1.3	0.21	36.1	0.444	0.237	0.008
4	7	155.29	2.313	1.235	0.202	33.78	0.471	0.251	0.01

Table 7: Extruded Feed Pellet Compression Load of Okoho binder Sample C (SC)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	222.34	2.057	1.096	0.161	44.69	0.844	0.45	0.02
2	7	280.59	2.508	1.337	0.211	275.66	2.42	1.29	0.187

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3	7	200.84	2.294	1.225	0.25	89.7	0.643	0.343	0.029
4	7	153.69	1.633	0.871	0.069	30.86	0.413	0.22	0.006

Table 8: Extruded Feed Pellet Compression Load of Okoho binder Sample D (SD)

Test No.	Height (mm)	Force @ Peak (N)	Def. @ Peak (mm)	Strain @ Peak (%)	Energy to Peak (N.m)	Force @ Yield (N)	Def. @ Yield (mm)	Strain @ Yield (%)	Energy to Yield (N.m)
1	7	80.85	1.337	0.677	0.050	80.85	1.337	0.677	0.05
2	7	132.51	5.362	2.735	0.398	44.78	1.314	0.67	0.017
3	7	168.65	5.353	2.729	0.631	39.68	0.538	0.274	0.01
4	7	104.77	1.414	0.712	0.086	81.55	0.896	0.451	0.038

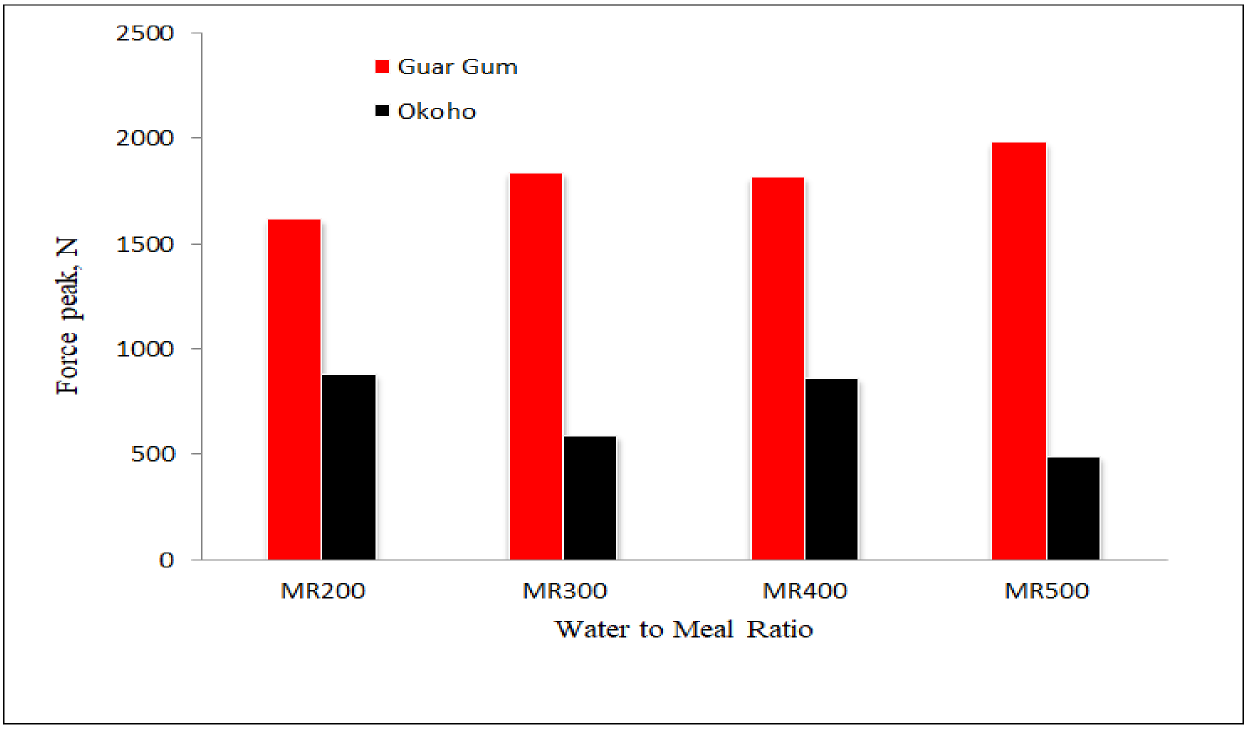

Fig 1 Plot of Water to Meal Ratio vs Peak Force values for Guar gum and Okoho

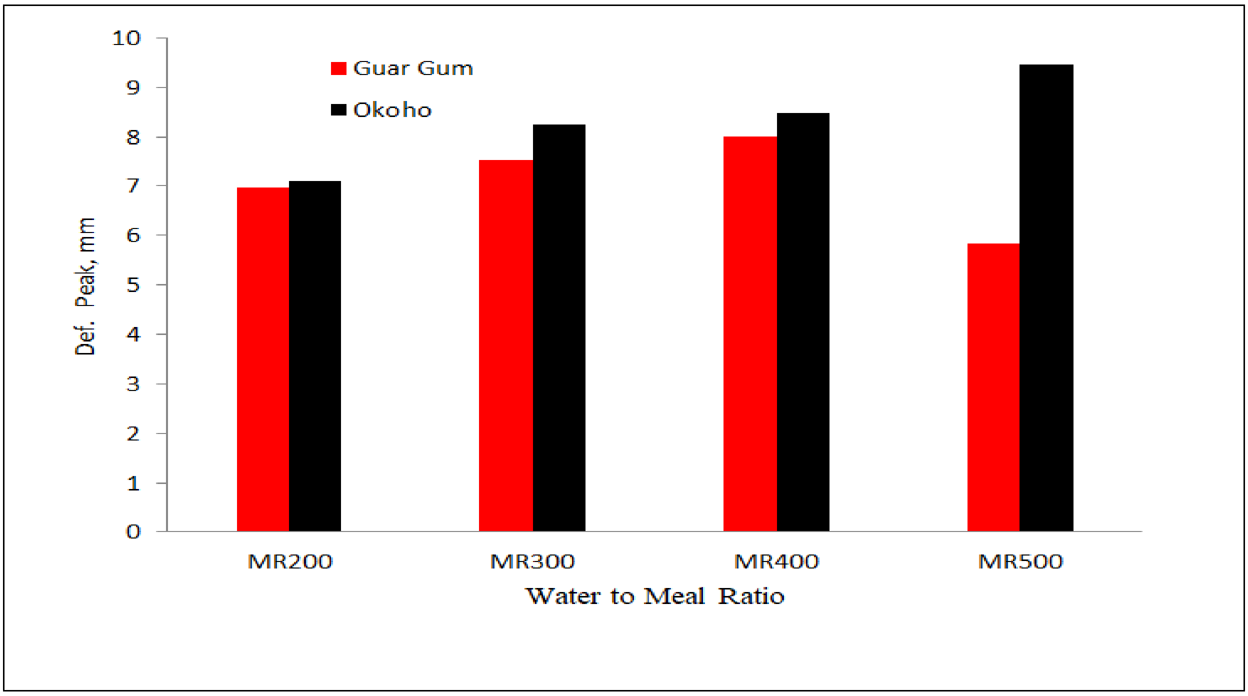

Fig 2 Plot of Water to Meal Ratio vs Def. Peak values for Guar gum and Okoho

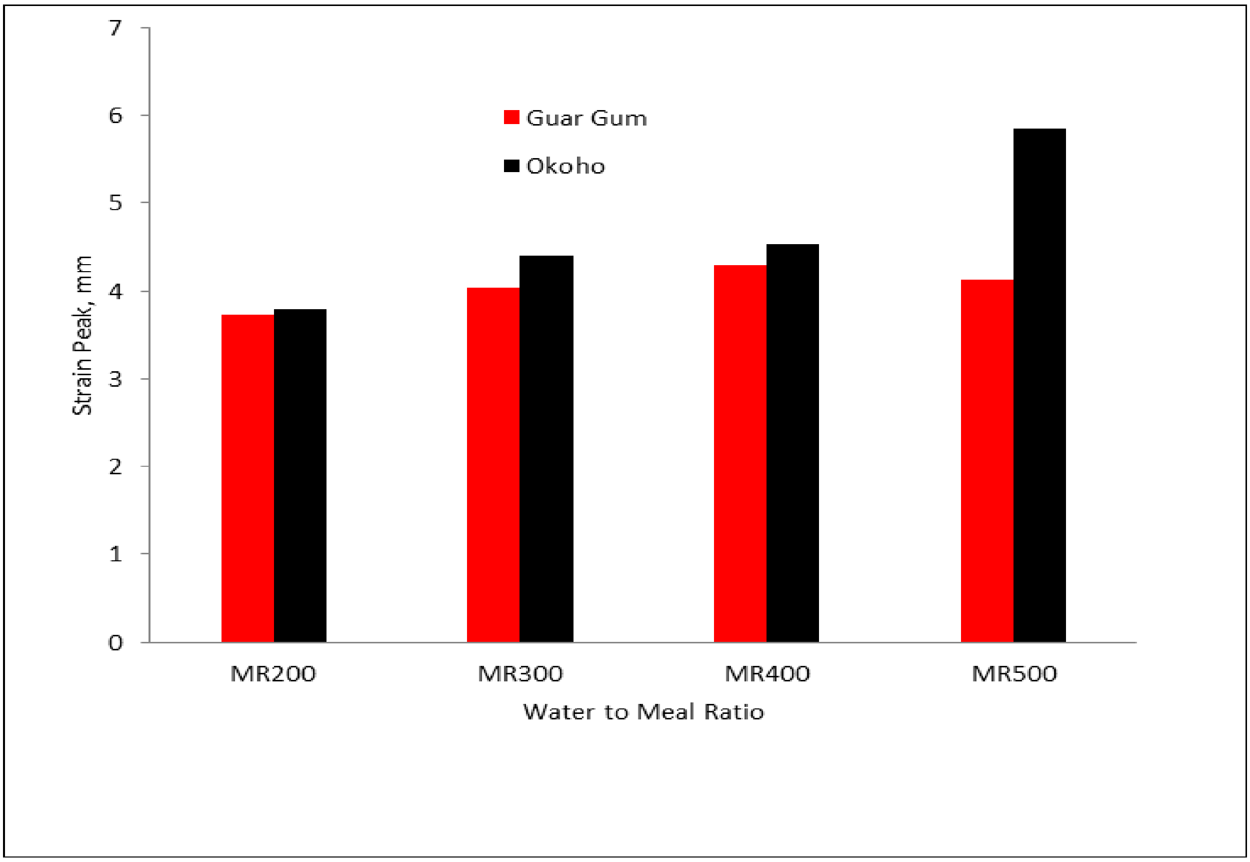

Fig 3 Plot of Water to Meal Ratio vs Strain Peak values for Guar gum and Okoho

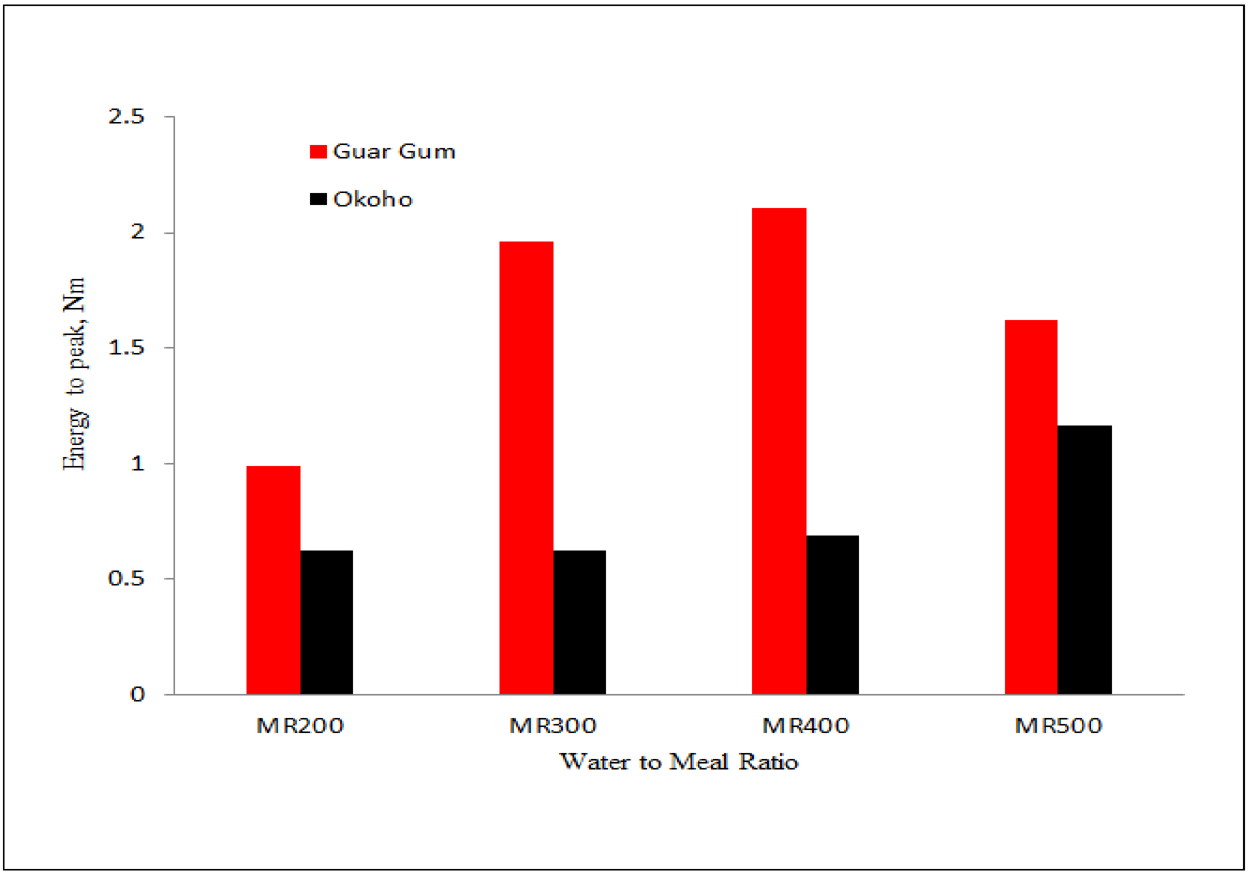

Fig 4 Plot of Water to Meal Ratio vs Energy to Peak values for Guar gum and Okoho

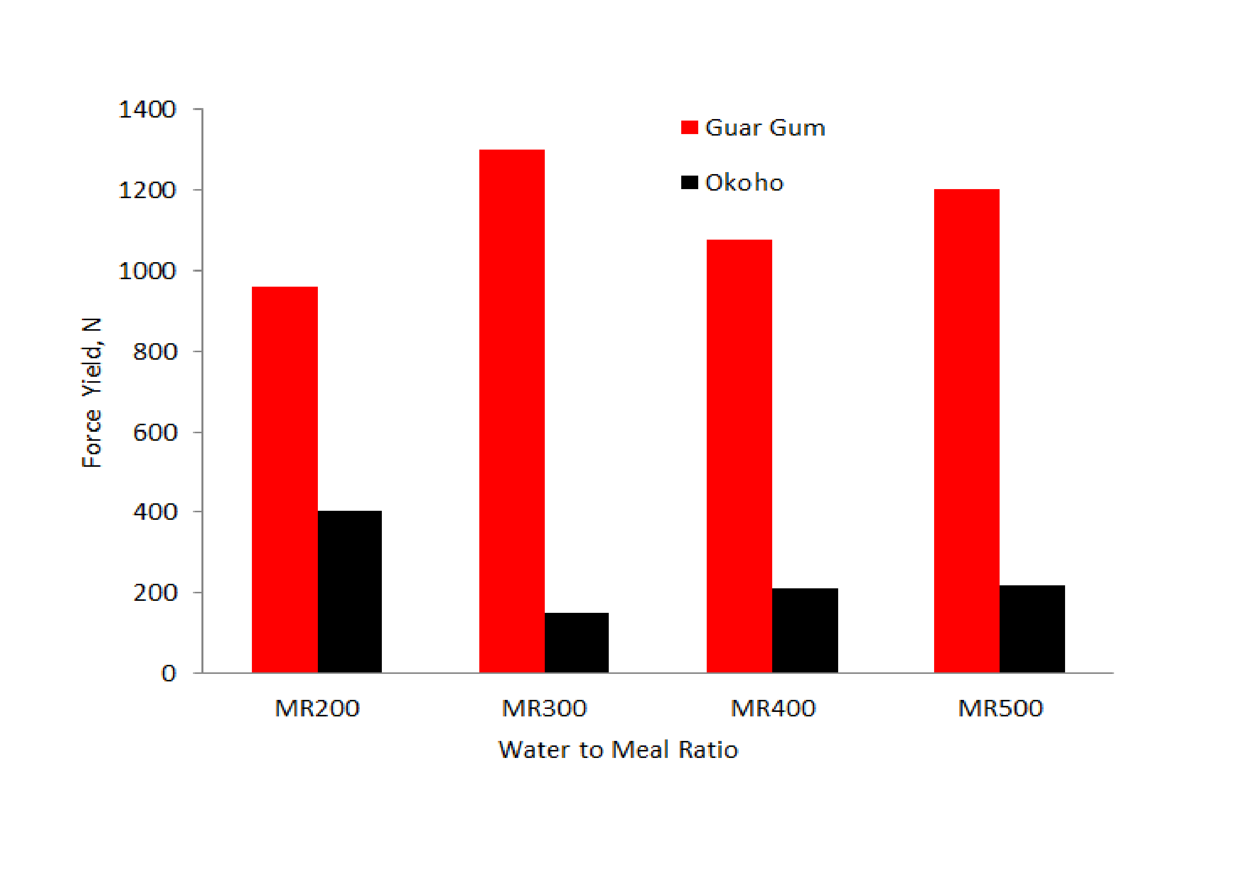

Fig 5 Plot of Water to Meal Ratio vs Force Yield values for Guar gum and Okoho

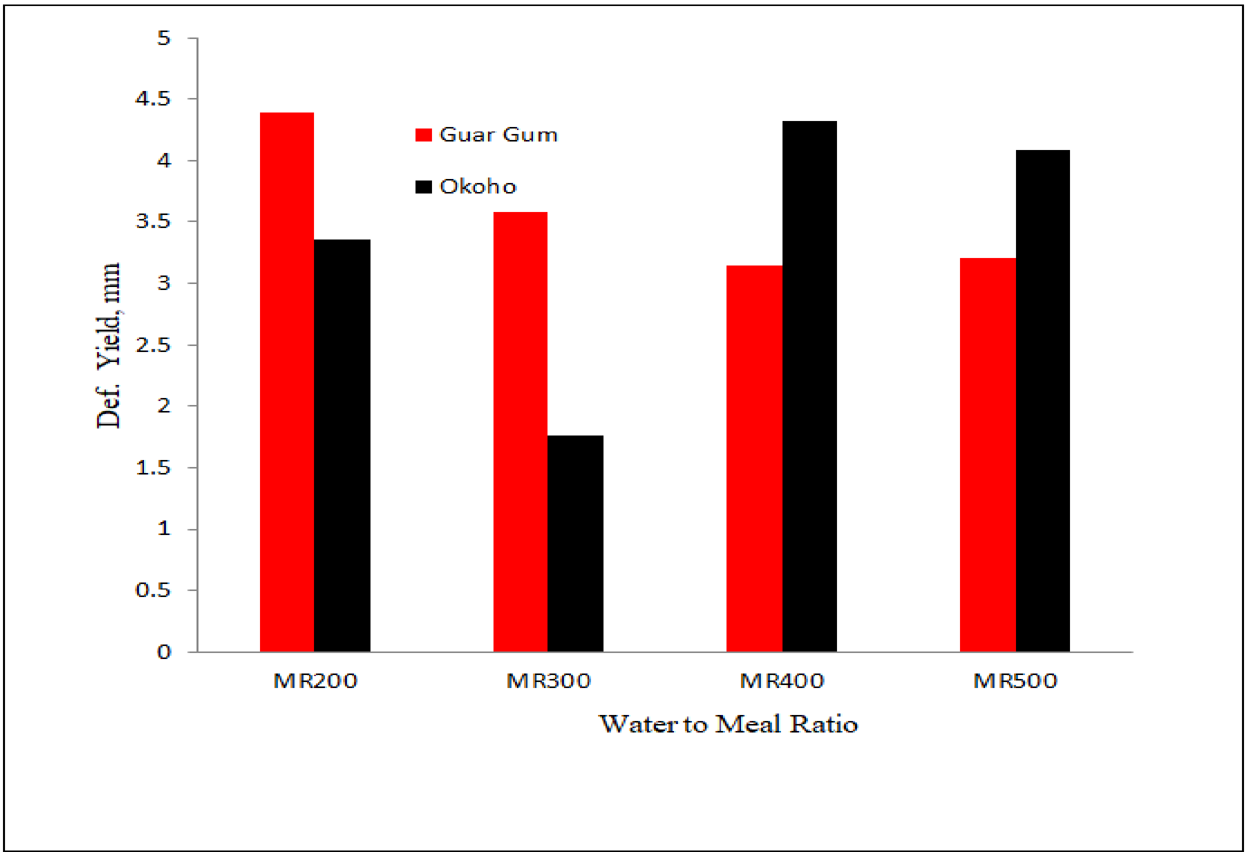

Fig 6 Plot of Water to Meal Ratio vs Def. Yield values for Guar gum and Okoho

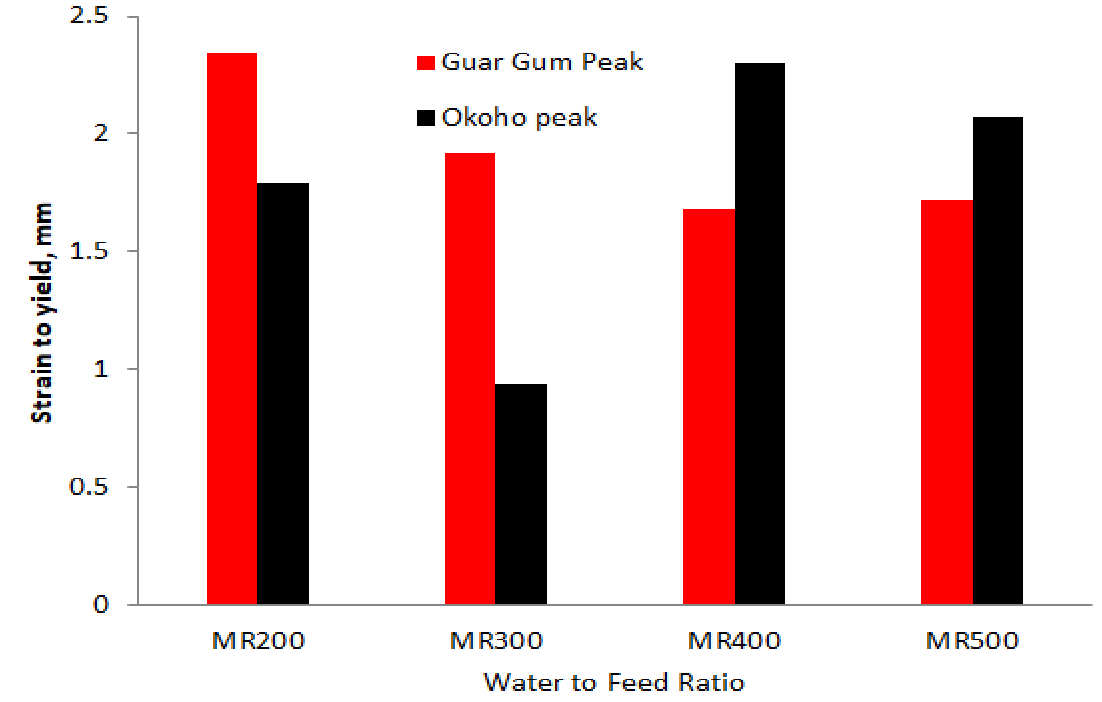

Fig 7 Plot of Water to Meal Ratio vs Strain Yield values for Guar gum and Okoho

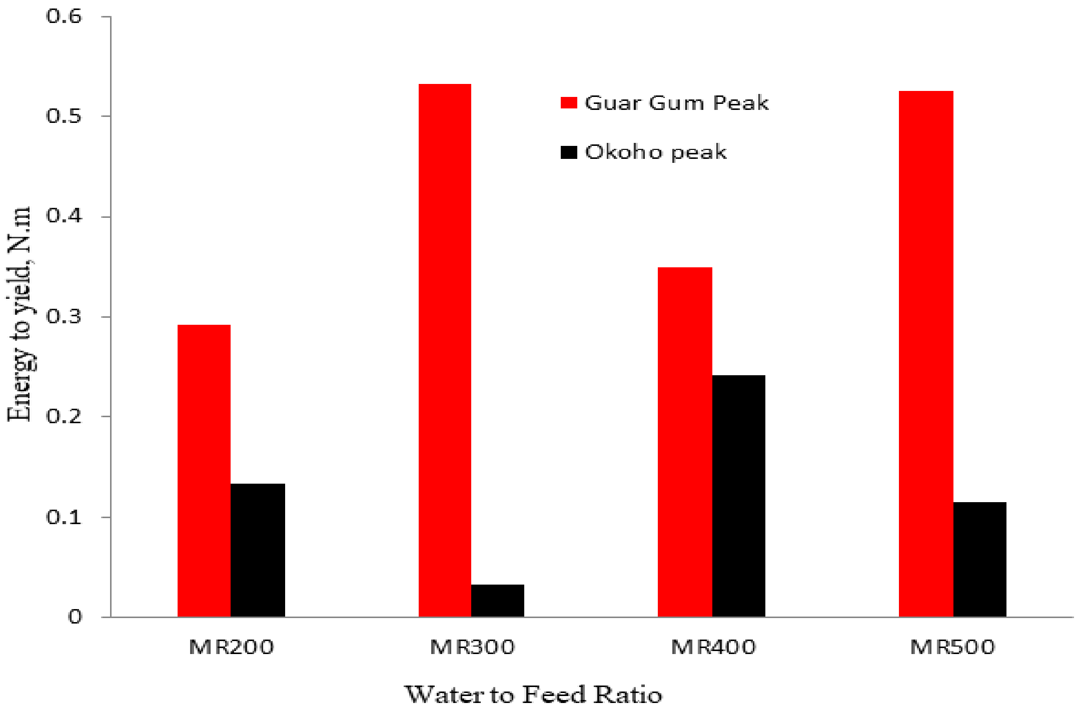

Fig 8 Plot of Water to Meal Ratio vs Energy Yield values for Guar gum and Okoho

Table 9 Summary of ANOVA on the Effect of Binder on the Compression Tests of Mixed Ratio of Extruded Feed

Parameter	Source	Df	Mean square	F-ratio
Peak Force	Binder	1	611593.115**	380.051
	Mixed Ratio	3	1496.079^{NS}	0.450
	Interaction	3	13724.19*	4.129
Peak Def.	Binder	1	2.520^{NS}	7.522
	Mixed Ratio	3	0.592^{NS}	0.609
	Interaction	3	1.622^{NS}	1.667
Peak Strain	Binder	1	0.606^{NS}	7.214
	Mixed Ratio	3	0.13**	0.628
	Interaction	3	0.716*	3.459
	Binder	1	0.398**	56.857
Peak Energy	Mixed Ratio	3	0.0397^{NS}	1.517
	Interaction	3	0.212**	8.102
Force @ Yield	Binder	1	40180.726^{NS}	8.684
	Mixed Ratio	3	686.684^{NS}	0.234
	Interaction	3	814.524^{NS}	0.277
Def. @ Yield	Binder	1	0.020^{NS}	0.045
	Mixed Ratio	3	0.151^{NS}	1.156
	Interaction	3	0.421*	3.222
Strain @ Yield	Die Dia	1	0.010^{NS}	0.079
	Mixed Ratio	3	0.042^{NS}	0.946
	Interaction	3	0.070^{NS}	1.577
Energy to Yield	Binder	1	0.043^{NS}	2.263
	Mixed Ratio	3	0.001^{NS}	0.243
	Interaction	3	0.005^{NS}	1.216
$F_{1,3,0.05}$ = 10.1	$F_{1,3,0.01}$ = 34.1		NS = Not significant	
$F_{3,18,0.05}$ = 3.16	$F_{3,18,0.01}$= 5.09		* = significant @ P≤5%	
			** = significant @ P≤1%	

➢ *Absolute Values of Guar-Gum Pellet Samples under Compression*

From Table 1 to 4, the values of peak force, peak deflection, peak strain and peak energy were found to be between 292.36 – 451.97N, 1.264 - 2.084mm, 0.676 - 1.115 % and 0.179 - 0.324 N.m respectively under a compression load of H_2O/Meal Ratio of 200ml/1000g.

Table 1 to 4 also shows that value of the force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to be between 169.43 - 437.76 N, 0.637 - 1.31mm, 0.341 - 0.701 % and 0.023 - 0.185 N.m respectively under the operating compression load @ H_2O/Meal Ratio of 200ml/1000g.

This pattern of data behaviour was recorded for the various compression tests at different water to meal ratios (Mościcki, and Van Zuilichem, 2011). Under the same compression load @ H_2O/Meal Ratio of 200 ml/1000g at a height of 20 mm, the values of peak force, peak deflection, peak strain and peak energy and that of the force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to have ranged between 82.750 - 82.850 N, 2.209 - 5.080 mm, 1.159 - 2.183 %, 0.046 - 0.142 N.m and 37.350 - 21.110 N, 1.410 - 1.790 mm, 0.740 - 0.769 % and 0.013 - 0.009 N.m respectively.

For the compression load @ H_2O/Meal Ratio of 300ml/1000g, the values of peak force, peak deflection, peak strain and peak energy were found to be between 407.41 - 480.42 N, 1.377 - 2.511mm, 0.739 - 1.349 % and 0.29 = 0.779 N.m respectively. The force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to have ranged between 158.38 - 383.7 N, 0.483 - 1.149 mm, 0.259 - 0.615 % and 0.028 - 0.152 N.m respectively.

When compression load @ H_2O/Meal Ratio of 400 ml/1000 gm was carried out, the values of peak force, peak deflection, peak strain and peak energy were found to be between 415.12 - 635.9 N, 0.952 - 2.508 mm, 0.512 - 1.349 % and 0.28 - 1.004 N.m respectively while the values of the force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to be between 123.14 - 611.8 N, 0.531 - 1.439 mm, 0.285 - 0.773 % and 0.027 - 0.041 N.m respectively this is in consonance with methodology recommended by Yousif et al., (2012), Fang, and Hanna, (2010).

➢ *Absolute Values of Okoho-Gum Pellet Samples under Compression*

Table 5 to 8 shows the compression values **@** H_2O/Meal Ratio of 100ml/1000 gm, the Force @ Peak ranged between 189.88 - 281.58 N, Def. @ Peak between 0.852 - 2.328 mm, Strain @ Peak 0.456 - 1.242% and Energy @ Peak 0.077 - 0.208 N.m. On the other hand, Force @ Yield has values between 39.71 - 215.18 N; Def. @ Yield between 0.759 - 0.974 mm; Strain @ Yield 0.405 - 0.521 % and Energy @ Yield 0.017 - 0.077 N.m.

For compression, load @ H_2O/Meal Ratio of 200 ml/1000 gm, the values of peak force, peak deflection, peak strain and peak energy and that of the force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to have ranged between 125.87 - 156.87 N, 1.709 - 2.431 mm, 0.96 - 1.3 %, 0.089 - 0.21 N.m and 33.78 - 43.17 N, 0.329 - 0.521 mm, 0.176 - 0.279 % and 0.007 - 0.01N.m respectively.

For the compression load @ H_2O/Meal Ratio of 300 ml/1000 gm, the values of peak force, peak deflection, peak strain and peak energy were found to be between 153 .69 - 280.59 N, 1.633 - 2.508 mm, 0.871 - 1.337 % and 0.069 - 0.25 N.m respectively. These trends agreed with results from Hutchinson et al. 1987; Baroni, D. 1988). The force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to have ranged between 30.86 - 89.7 N, 0.413 - 2.42 mm, 0.22 - 1.29 % and 0.006 - 0.187 N.m respectively. This pattern also was in line with Hahn (1990).

When compression load was @ H_2O/Meal Ratio of 400 ml/1000g was carried out, the values of peak force, peak deflection, peak strain and peak energy were found to be between 80.85 - 168.65 N, 1.337 - 5.362 mm, 0.677 - 2.735 % and 0.005 - 0.631N.m respectively while the values of the force @ yield, deflection @ yield, strain @ yield and energy @ yield were found to be between 39.68 - 80.85 N, 0.538 - 1.337 mm, 0.274 - 0.677 % and 0.01 - 0.05 N.m respectively. This method agrees with results obtained by Liu *et al.* (2012).

➢ *General Observations in these Absolute Values Obtained in the Compression Parameters showed:*

- As the H2O/ Meal ratio increases, the force both at peak decreases
- Absolute values of Energy in both at peak and yield appeared least in both cases of the binder/die diameter and mixed ratio combinations
- For each of the parameters in the compression tests, the absolute values of the guar gum are greater than those of the okoho gum at the different conditions of the water to meal ratios.
- In all the compression tests, 8 parameters were monitored. These were the Peak Values which comprise of Peak force, peak deflection, peak strain and peak energy. Then the Yield Values which comprised of Yield force, yield deflection, yield strain, and yield energy.
- Between the Guar gum and Okoho gum type of binders, compression tests indicated higher values for Guar gum products than for the *Okoho* gum binder as observed by Bharath and Pichan, (2015).

➢ *Effect of Binder on the Compression Tests of Mixed Ratio*

From Table 9, the effect of binder (guar gum) on the compression tests at various mixed ratios and was observed that the means of these parameters were significant @ $P \leq 0.01$ for the peak force, and not significant at any levels for the peak deflection but significant @ $P \leq 0.05$ for peak strain though significant@ $P \leq 0.05$ for peak energy and especially the water to meal ratio and the interaction of these parameters. Also, the analysis of the mean indicated that Force @ yield was significant @ $P \leq 0.05$ for the parameters and their interactions. Def. @ yield has no significance difference on the mean values. However, only the binder has significant @ $P \leq 0.05$strain @ yield. The observation showed that mixed ratio was the only factor affecting the mean values of energy @ yield which was @ $P \leq 0.05$.

IV. CONCLUSION

In conclusion, binders significantly influence the mechanical properties of pellets, including their strength, durability, and resistance. The results of the compression tests indicate that as the water-to-meal ratio increases, the force at peak decreases. The absolute values of energy at both peak and yield were found to be lower in both the binder/die diameter and mixed ratio combinations. Furthermore, the guar gum binder demonstrated higher absolute values for the compression test parameters compared to the okoho gum binder, across different water-to-meal ratios. The analysis of the mean values indicated that the parameters related to peak force, peak strain, and peak energy were significantly affected by the binder (guar gum) at various mixed ratios. The water-to-meal ratio and its interaction with other parameters also showed significance in influencing the compression test results. On the other hand, the parameters related to yield force, yield deflection, yield strain, and yield energy were found to be significant in relation to the force at yield, but not in relation to deflection at yield. Only the binder had a significant effect on strain at yield, while the mixed ratio was the sole factor affecting the mean values of energy at yield.

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