ISSN No:-2456-2165

Comparison of Magnitude of Effect of Hydrocolloid on Functional Properties of Flours and Starches of Cassava And Maize Using Multinomial Logistic Regression

Virate J. Kiprop, Mary N. Omwamba, Symon M. Mahungu
Department of Dairy and Food Science and Technology,
Egerton University, Kenya

Abstract:- Modification of starches and flours from underutilized food crops to obtain some specific desired functional properties is increasingly becoming necessary practice in food processing. The objective of this study was to compare the magnitude of effect of gum Arabic hydrocolloid substitution level on textural, physical and pasting properties between cassava and maize flours and starches. Pasting properties were determined using a Brabender viscograph, textural characteristics of the gels were analyzed using a texture analyzer while various methods were used to measure the physical characteristics of the pastes. Multinomial Logistic Regression (MRL) model was used to compare the effect of magnitude of gum Arabic functional properties on cassava versus maize. Maize starch had significantly highest level of firmness and consistency and also significantly lowest cohesiveness after gelling as compared to other materials. Maize flour and cassava starch did not differ significantly for all the textural properties. Each of the substitution levels did not have a significant difference on the onset pasting temperature in flours and starches for both cassava and maize. Cassava flour showed significant higher values of the selected physical properties as compared to other materials under study. From the results gum Arabic could be used to modify the various properties of flours and starches to achieve desirable qualities. The study recommends incorporation of this hydrocolloid into specific food products based on the aforementioned flours and starches.

Keywords:- *Functional properties, cassava flour and starch, maize flour and starch, gum Arabic, Multinomial Logistic Regression.*

I. INTRODUCTION

Globally, there is a growing interest by the food industry in research of underutilized plant species as a contribution to consumers' diet diversification and the incorporation of ingredients with particular textural and technological properties (Colgrave *et al.*, 2021; Dini *et al.*, 2014). Studies have shown that flour and starch from tubers and roots can be used to replace wheat flour in specific food application, though current world policies and demographic claims have been key drivers to the application of starchy materials. Although a variety of native starches with diverse functionalities are available in the market, there is also an increasing demand for specific starch properties. This has called for exploration of new strategies or alternatively novel sources (Adewale *et al.*, 2022; Aprianita *et al.*, 2012; Charles *et al.*, 2007). This is crucial because native starches in general lack the desired properties for use in processed foods hence they are often chemically modified to improve their properties (Obadi and Xu, 2021; Kim *et al.*, 2013). The conversion of a chemical compound into a derivative has extended the range of functional properties nonetheless owing to consumers demand, starches from other botanical sources including tropical sources are now being assessed for required functional properties thus evading the need for chemical modifications (Aprianita *et al.*, 2012).

According to Kim *et al.* (2013) some of the desired properties of starch include increasing their tolerance to processing conditions, improving paste and gel textures, providing cold storage and/or freeze–thaw stability as well as to control water mobility. It has been suggested that other methods that can improve the quality of nutrient flours and starches as solutions for sensory and technological challenges are welcomed in the food industry (Culetu *et al.*, 2021). Therefore, studies have shown that certain hydrocolloids in combination with certain starches provide some improvement of properties without chemical modification (Kim *et al.*, 2013).

Several hydrocolloids have been tested in improving functional properties of both flours and starches from different sources (Cappelli *et al.*, 2020; Yamul and Navarro, 2020; Salehi, 2019). Though some have recorded successes, some still have not. For example, a study by Dini *et al.* (2014) which tested the addition of xanthan gum, carboxymethylcellulose, carrageenan, alginate and high methoxy hydroxypropyl methylcellulose (HM HPMC) on formulations based on rice flour and cassava starch, reported that the addition of these hydrocolloids solely seemed not to be enough to effectively simulate gluten dough and wheat bread properties. Some studies have shown that Arabic gum improved mechanical properties of doughs from potato flour (Yamul and Navarro, 2020), but there is a gap on use of gum Arabic from *Acacia senagal* var *kerensis* in improving other flours and starches such as development of alternative to commercial waxy maize starch. Gum Arabic a hydrocolloid from *Acacia senagal* is a highly branched structure consisting of a -1, 3-linked D-galactose core with extensive branching through 3- and 6-

linked galactose and 3-linked arabinose. Rhamnose and glucuronic acid are positioned at the periphery of the molecules where they terminate some of the branches (Williams and Phillips, 2009). This unique structural orientation could be explored in flours and starches in developing products with desired functional properties. Flour and starch from tubers and roots as well as cereals can be used to substitute wheat flour in certain food applications besides having possible wider applications either in food or non-food industries. These other possible applications could be in pharmaceuticals, textiles, fuels, biodegradable packaging materials and thin films of thermoplastics (Santos *et al.*, 2021; Egharevba, 2019).

According to Santos *et al.* (2021) and Hsieh *et al.* (2019) exploration of alternatives to commercial waxy maize starch through the development of commercial cassava with starch of low or zero amylose is of high demand in the food industry. This is due to the fact that waxy cassava starch offers advantages for the industry, such as differentiated gel textures with a greater resistance to freezing and thawing than other cereal starches.

Multinomial Logistic Regression (MLR) models stand a better chance in comparing the effect of magnitude of gum Arabic functional properties on cassava versus maize. MLR is a mathematical modelling method majorly used to predict a nominal response variable that has more than two levels (Vilaça *et al.*, 2019; Bayaga, 2010). Though, linear regression can often be used to investigate the relationship between predictor variable(s) and response variable(s), this is not applicable when the response is simply a designation of one of two or more possible outcomes. It is commonly used when the dependent variable has more than two nominal or unordered categories. The most significant factor to consider here is that each one tells the effect of the predictors of risk on the probability of success in that category, in comparison to the reference category. This multinomial analysis does not assume linearity, normality or even homoscedasticity.

Therefore, to understand the magnitude of substitution level of gum Arabic from *Acacia senagal* var *kerensis* on physical, textural and pasting properties of both flour and starch of cassava and maize MLR analysis was employed. It was hypothesized that substitution levels of the hydrocolloid in starches of both cassava and maize did not have a different influence on the magnitude of effect on functional properties as compared to their respective flours.

II. MATERIALS AND METHOD

A. *Materials*

Native cassava and maize flours were purchased from local supermarket whereas the native starches were purchased from Ingredion Holding LLC, Kenya. Gum Arabic from *Acacia senegal* var. *kerensis* (hydrocolloid) was sourced from KEFRI and Kennect Ltd Nairobi, Kenya.

B. *Sample preparation*

Samples were prepared according to the method described by Kiprop *et al.* (2021). Briefly, gum Arabic from *Acacia senegal* var. *kerensis* was sorted by removing dirt, remnants of the bark and any foreign matter prior to milling into powder form. The powder was stored in thermopak containers with proper sealing prior to the analyses. Samples of flour and starch - gum mixture were formulated to obtain slurries made up of 40g. The gum was added at varying levels (0 %, 2.0 %, 4.0 %, 6.0 % and 8.0 % g/g on dry weight basis) by substituting with the amount of starch or flour. The samples were mixed thoroughly using a shaker to obtain a homogenous starch/ flour-gum mixture. Approximately 3g of the sample mixtures and native corn and cassava flours and starches were taken to verify for moisture content using rapid moisture meter set at 105°C. Once the moisture content of each sample was given a correction was made to 14% where the exact amount of flour or starch and water was weighed and mixed into slurry by agitation.

C. *Determination of pasting properties*

Pasting properties of flour and starch were measured using a Brabender Viscograph - E (Brabender GmbH & Co. KG, Duisburg, Germany) at 85rpm and 700cmg torque as described by Onyango (2014) and Kiprop *et al.* (2021). Briefly, slurries made up of 40 g native starch / flour and samples with gum mixture (adjusted to 14% moisture content) and 420 ml distilled water added in the Viscograph-E canister. The resultant slurry of each sample was heated from 30°C to 93°C at a rate of 1.5 °C/min; held at 93°C for 15min; cooled to 30°C at 1.5°C/min and finally held at 30°C for 15min. Resistance to stirring was recorded as viscosity in Brabender Units (BU). The pasting temperature (°C), peak viscosity (BU), breakdown viscosity (peak viscosity minus trough viscosity, BU), setback viscosity (final viscosity minus trough viscosity, BU) and final viscosity (BU) were measured using Viscograph - E correlation software. All the determinations were done in duplicate.

D. *Determination of textural properties*

The Method described by Kiprop *et al.* (2021) were used to analyze for the textural properties. Briefly, the textural properties were analysed through back extrusion force and measured using TA. XT-plus Texture Analyzer (Stable Micro Systems, Surrey, UK). Firmness (maximum positive force, g), consistency (area of the positive region of curve, g.s), cohesiveness (maximum negative force, g) and work of cohesion or index of viscosity (area of the negative region of the curve, g.s) were determined using EXPONENT Texture Analysis software version 6.1.5.0 (Stable Micro Systems, Surrey, UK) (Onyango, 2014).

E. *Determination of physical properties*

Methods described by Wanjala *et al.* (2020) were used for analyzing water holding capacity (WHC), water absorption index (WAI), water solubility index (WSI), swelling capacity (SC), foaming capacity (FC) and oil holding capacity (OHC) of the samples.

F. *Data analysis*

Data obtained was analyzed with SAS® software version 9.4 at 95% confidence level. PROC GLM was used to do analysis of variance (ANOVA) on effect of material type on functional properties while *post-hoc* analysis

ISSN No:-2456-2165

employed Tukey's honestly significant difference (HSD) test. Multinomial logistic regression (MLR) analysis used PROC LOGISTICS with a *glogit* link in the command. For both cassava and maize, the binary response variable was the type of material (flour and starch) while predictor variables were the functional properties analyzed.

III. RESULTS

A. Textural properties

Textural properties of cassava and maize starches and flours are shown in **Fig. 1.** Maize starch had significantly highest level of firmness and consistency as well as significant lowest cohesiveness after gelling as compared to other materials. On the contrary, gels from cassava flour had significantly lowest firmness and consistency but significant highest work of cohesion. Maize flour and cassava starch gels did not differ significantly for all the textural properties.

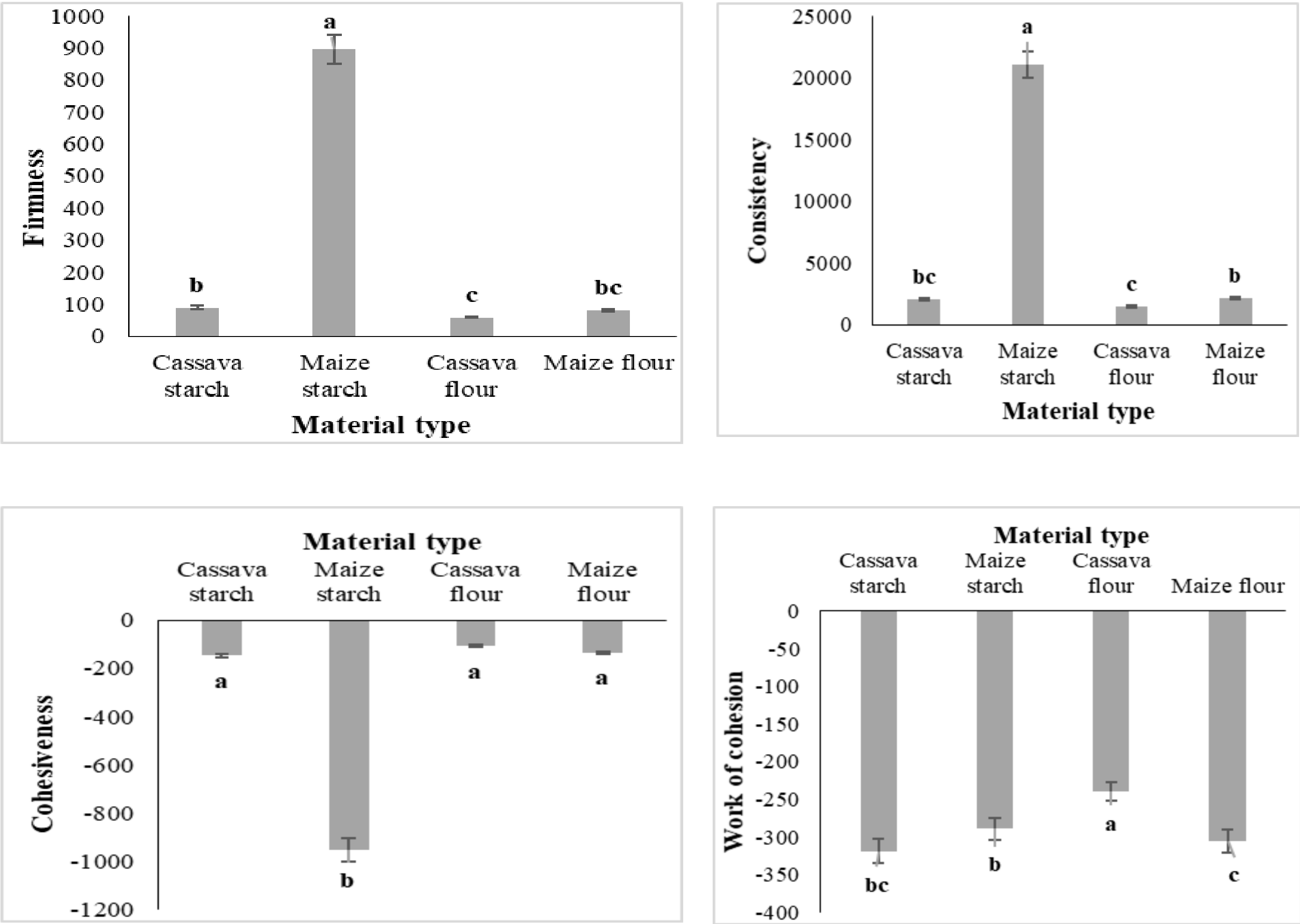

Fig. 1: Textural properties of cassava and maize flours and starches
Error bars with the same letter are not significantly different at $p \leq 0.05$

Odds ratio point estimates of each gum Arabic level of substitution on textural properties of cassava flour and starch compared to maize flour and starch in reference to the control is shown in **Table 1**. Effect of a 2.0% gum Arabic substitution level in cassava flour compared to maize flour on firmness, cohesiveness and work of cohesion was higher but not significantly different though for consistency there was a significant difference. Effect of 4.0, 6.0 and 8.0% levels of substitution in cassava flour compared to maize flour were significantly higher on all textural properties except for consistency at 8.0% level which showed no significance difference.

In the case of starches; gum Arabic substitution levels of 6.0 and 8.0% in cassava starch were the only ones that showed a significantly higher effect on firmness as compared to the maize starch counterparts though 4.0% level showed a non-significant higher effect while 2.0% level showed a non-significant lower effect. Work of cohesion is the only textural property that all levels of gum Arabic substitution in cassava starch showed a significantly lower effect as compared to their maize counterparts. But for consistency, level 2.0% showed a significantly lower effect in cassava starch as compared to maize starch, a higher but not significant difference at 4.0% level and a significantly higher effect at 6.0 and 8.0% levels. For

ISSN No:-2456-2165

cohesiveness, a higher but not significant effect at 4.0 and 6.0% levels was observed in cassava starch as compared to maize starch but in contrary a higher and significant effect was observed at 2.0 and 8.0% levels.

Material	Effect	GA (%)		Firmness	Consistency	Cohesiveness	WOC
Flours	Cassava vs. Maize	2.0	PE	1.217^{ns}	1.228***	1.185^{ns}	1.165^{ns}
			CL	(0.872- 1.698)	(1.150- 1.310)	(0.917- 1.532)	(0.981- 1.384)
	Cassava vs. Maize	4.0	PE	2.310***	2.348***	1.971***	1.922***
			CL	(1.651- 3.234)	(2.198- 2.509)	(1.508- 2.577)	(1.607- 2.297)
	Cassava vs. Maize	6.0	PE	2.980***	3.038***	2.563***	2.456***
			CL	(2.119- 4.192)	(2.841- 3.250)	(1.949- 3.371)	(2.049- 2.944)
	Cassava vs. Maize	8.0	PE	2.803***	2.852^{ns}	2.533***	2.492***
			CL	(1.975- 3.978)	(0.583-1.065)	(1.911- 3.358)	(2.067- 3.006)
Starches	Cassava vs. Maize	2.0	PE	0.938^{ns}	0.917***	1.208*	0.458***
			CL	(0.749- 1.175)	(0.875- 0.960)	(1.012- 1.443)	(0.395- 0.532)
	Cassava vs. Maize	4.0	PE	1.106^{ns}	1.022^{ns}	1.031^{ns}	0.255***
			CL	(0.884- 1.385)	(0.976- 1.070)	(0.861- 1.233)	(0.221- 0.296)
	Cassava vs. Maize	6.0	PE	1.315*	1.252***	1.194^{ns}	0.417***
			CL	(1.054- 1.641)	(1.197- 1.311)	(0.996- 1.431)	(0.358- 0.484)
	Cassava vs. Maize	8.0	PE	1.529***	1.383***	1.312***	0.425***

Table 1: Odds ratio point estimates of gum Arabic level of substitution on textural properties of cassava compared to maize for both flours and starches

Gum Arabic substitution level of 0% is the reference category; GA= Gum Arabic; PE= Point Estimate; CL= 95% Wald confidence Limits; WOC= Work of Cohesion; ***= significant at $p<0.001$; *=significant at $p<0.05$; ns= Not Significant

B. *Pasting properties*

Initial pasting properties of starch and flour from cassava and maize are shown in **Fig 2**. Maize starch had significantly the highest final viscosity and setback but the lowest breakdown compared to other materials. Similarly, maize flour had highest onset pasting temperature but the lowest peak viscosity as compared to other materials. But cassava starch exhibited the significantly highest peak viscosity and breakdown.

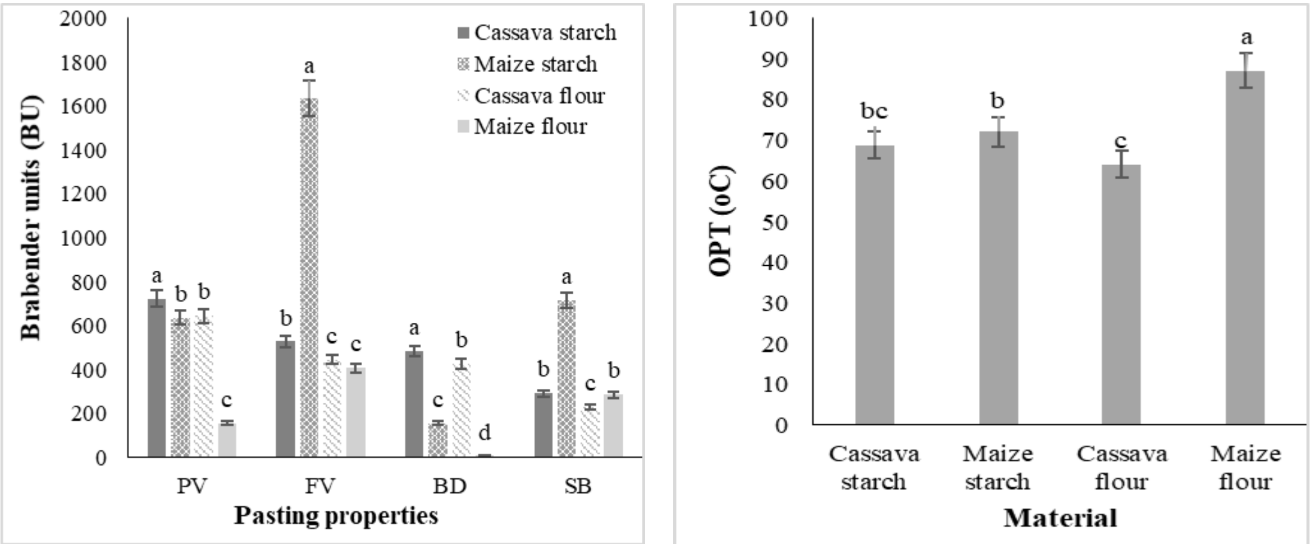

Fig. 2: Initial pasting properties of starch and flour from cassava and maize

Key: OPT= Onset Pasting Temperature; PV= Peak Viscosity; FV= Final Viscosity; BD= Breakdown; SB= Setback. Error bars with same letter for each pasting property are not significantly different.

Odds ratio point estimates of each gum Arabic level of substitution on pasting properties of cassava flour and starch compared to maize flour and starch in reference to the control is shown in **Table 2**. Each of the substitution level did not have any significant difference on onset pasting temperature in cassava flour as compared to maize flour. As compared to other levels, 2.0% level was the only that showed higher but not significant effect in cassava flour compared to maize flour for peak viscosity, final viscosity and setback but for levels 4.0, 6.0 and 8.0% a higher and significant effect was revealed. However, 8.0% level was the only one that showed a higher but not significant effect in cassava flour as compared to maize flour while levels 2.0, 4.0 and 6.0% showed significantly very high effect. For starches, each level of gum Arabic substitution in cassava starch did not have a significantly different effect on onset pasting temperature, breakdown and setback as compared to maize starch. However, for peak viscosity only 8.0% level showed a significantly lower effect in cassava starch as compared to maize starch.

C. Physical properties

Physical properties of cassava and maize starch and flour are shown in **Table 3**. Cassava flour showed significantly highest water holding capacity (WHC), foaming capacity (FC), water solubility index (WSI), water absorption index (WAI) and swelling capacity (SC) but significantly lowest oil holding capacity (OHC) as compared to other materials under study. Cassava starch showed significantly highest bulk density (BD) while maize starch showed significantly highest OHC.

Material	Effect	GA (%)		OPT	PV	FV	Breakdown	Setback
Flours	Cassava vs. Maize	2.0	PE	1.000^{ns}	1.117^{ns}	1.091^{ns}	6.549***	1.099^{ns}
			CL	(0.724-1.381)	(0.928-1.528)	(0.949-1.255)	(1.493-28.735)	(0.918-1.316)
	Cassava vs. Maize	4.0	PE	0.998^{ns}	1.254*	1.282***	5.599*	1.293*
			CL	(0.722-1.379)	(1.029-1.528)	(1.107-1.483)	(1.276-24.574)	(1.073-1.559)
	Cassava vs. Maize	6.0	PE	1.002^{ns}	1.236*	1.367***	4.611*	1.357***
			CL	(0.724-1.386)	(1.005-1.520)	(1.176-1.588)	(1.050-20.241)	(1.121-1.642)
	Cassava vs. Maize	8.0	PE	1.008^{ns}	1.279*	1.393***	3.983^{ns}	1.355***
			CL	(0.728-1.394)	(1.031-1.587)	(1.196-1.624)	(0.907-17.480)	(1.115-1.646)
Starches	Cassava vs. Maize	2.0	PE	1.007^{ns}	1.034^{ns}	1.076^{ns}	1.046^{ns}	1.026^{ns}
			CL	(0.723-1.403)	(0.927-1.154)	(0.974-1.188)	(0.867-1.263)	(0.894-1.177)
	Cassava vs. Maize	4.0	PE	1.007^{ns}	1.022^{ns}	1.173***	1.062^{ns}	1.120^{ns}
			CL	(0.723-1.403)	(0.912-1.145)	(1.059-1.299)	(0.871-1.293)	(0.972-1.291)
	Cassava vs. Maize	6.0	PE	1.000^{ns}	0.953^{ns}	1.129*	1.069^{ns}	1.035^{ns}
			CL	(0.718-1.393)	(0.848-1.071)	(1.017-1.253)	(0.868-1.317)	(0.894-1.197)
	Cassava vs. Maize	8.0	PE	1.014^{ns}	0.851*	1.009^{ns}	1.013^{ns}	0.891^{ns}
			CL	(0.728-1.413)	(0.756-0.959)	(0.908-1.121)	(0.818-1.256)	(0.769-1.032)

Table 2: Odds ratio point estimates of gum Arabic level of substitution on pasting properties of cassava compared to maize for both flours and starches

Gum Arabic substitution level of 0% is the reference category; GA= Gum Arabic; OPT= Onset Pasting Temperature; PV= Peak Viscosity; FV= Final Viscosity PE= Point Estimate; CL= 95% Wald confidence Limits; WOC= Work of Cohesion; ***= significant at p<0.001; *=significant at p<0.05; ns= Not Significant.

Material type	WHC	FC	BD	WSI	WAI	SC	OHC
Cassava starch	0.16±0.00^{a}	2.04±0.08^{c}	0.57±0.00^{a}	0.03±0.00^{c}	0.81±0.01^{b}	0.05±0.00^{c}	0.02±0.00^{b}
Maize starch	0.12±0.01^{b}	0.67±0.10^{d}	0.52±0.01^{a}	0.09±0.00^{b}	0.83±0.05^{b}	0.26±0.05^{b}	0.10±0.01^{a}
Cassava flour	0.18±0.00^{a}	6.68±1.02^{a}	0.36±0.00^{b}	0.14±0.00^{a}	1.24±0.01^{a}	0.34±0.05^{a}	0.01±0.00^{b}
Maize flour	0.14±0.02^{b}	5.00±1.00^{b}	0.55±0.00^{a}	0.01±0.00^{d}	1.03±0.12^{ab}	0.05±0.00^{c}	0.02±0.00^{b}

Table 3: Physical properties of cassava and maize starch and flour

Means with the same letter along the column are not significantly different. WHC= Water Holding Capacity; FC= Foaming Capacity; BD= Bulk Density; WSI= Water Solubility Index; WAI= Water Absorption Index; SC= Swelling Capacity; OHC= Oil Holding capacity

Odds ratio point estimates of each gum Arabic level of substitution on the physical properties of cassava flour and starch compared to maize flour and starch respectively in reference to the control is shown in **Table 4**. For both starch and flour, each level of gum Arabic substitution did not have a significantly different effect on BD of cassava as compared to their respective counterparts in maize. Each level of substitution showed a significant difference in effect on WSI and FC in cassava starch compared to maize starch but no significant difference in cassava and maize flours. On the contrary, each level of substitution showed a significant difference in effect on WAI and WHC in cassava flour compared to maize flour but no significant difference in cassava and maize starches. Although each level of substitution showed a significant difference in effect on SC for both cassava and maize starches and flours, the effect in cassava starch was higher than in maize starch while the effect was lower in cassava flour than in maize flour. A significant difference in effect was observed only at 2.0% and 4.0% substitution levels on OHC in cassava starch as compared to maize starch while only 4.0 and 6.0% levels caused a significant difference in effect of cassava and maize flours.

IV. RELATIONSHIP BETWEEN TEXTURAL, PASTING AND PHYSICAL PROPERTIES DUE TO GUM ARABIC ADDITION

The comparison of functional properties loading matrix on principal components between starch and flours are shown in **Table 5** and **Figure 3**. For starches, there were only two principal components each contributing 61.4% and 24.8% respectively, where all properties loaded on principal one except WAI (0.823), SC (0.796), FC (0.608) and PV (-0.874). On the contrary, for the flours there were three principal components each contributing 57.5%, 23.1% and 9.84 % respectively. Majority of the properties loaded on component one except setback (-0.953) and SC (0.763) while component three had only OHC (0.825) loading.

	Effect	GA (%)		WHC	FC	BD	WSI	WAI	SC	OHC
Flours	Cassava vs. Maize	2.0	PE	0.793*	1.458^{ns}	0.949^{ns}	0.510*	1.203***	0.260***	1.719^{ns}
			CL	(0.642-0.980)	(0.436-4.879)	(0.830-1.084)	(0.271-0.958)	(1.107-1.308)	(0.206-0.330)	(0.901-3.281)
	Cassava vs. Maize	4.0	PE	1.307*	0.952^{ns}	1.111^{ns}	0.591^{ns}	1.286***	0.182***	1.980*
			CL	(1.041-1.640)	(0.316-2.873)	(0.971-1.271)	(0.311-1.124)	(1.181-1.399)	(0.145-0.229)	(1.017-3.855)
	Cassava vs. Maize	6.0	PE	1.255*	1.527^{ns}	1.092^{ns}	0.755^{ns}	1.242***	0.243***	0.733^{ns}
			CL	(1.007-1.563)	(0.511-4.566)	(0.955-1.247)	(0.389-1.466)	(1.144-1.348)	(0.194-0.304)	(0.321-1.673)
	Cassava vs. Maize	8.0	PE	1.183^{ns}	2.332^{ns}	1.102^{ns}	1.109^{ns}	1.184***	0.247***	5.021***
			CL	(0.952-1.471)	(0.771-7.056)	(0.964-1.259)	(0.544-2.258)	(1.092-1.284)	(0.198-0.309)	(2.323-9.851)
Starches	Cassava vs. Maize	2.0	PE	0.924^{ns}	0.734***	1.046^{ns}	1.672***	0.947^{ns}	2.161***	2.063***
			CL	(0.732-1.167)	(0.675-0.798)	(0.927-1.179)	(1.165-2.398)	(0.861-1.042)	(1.648-2.835)	(1.205-5.563)
	Cassava vs. Maize	4.0	PE	0.950^{ns}	0.508***	1.021^{ns}	2.016***	0.945^{ns}	3.296***	3.144***
			CL	(0.756-1.195)	(0.469-0.550)	(0.904-1.152)	(1.419-2.864)	(0.860-1.038)	(2.610-4.161)	(2.046-4.833)
	Cassava vs. Maize	6.0	PE	0.941^{ns}	0.348***	0.958^{ns}	2.120***	0.942^{ns}	3.329***	1.289^{ns}
			CL	(0.750-1.182)	(0.322-0.375)	(0.848-1.081)	(1.501-2.994)	(0.858-1.033)	(2.646-4.189)	(0.790-2.103)
	Cassava vs. Maize	8.0	PE	0.947^{ns}	0.316***	0.915^{ns}	2.212***	0.916^{ns}	3.784***	1.220^{ns}
			CL	(0.754-1.189)	(0.293-0.340)	(0.811-1.033)	(1.580-3.098)	(0.835-1.004)	(3.012-4.754)	(0.737-2.018)

Table 4: Odds ratio point estimates of gum Arabic level of substitution on physical properties of cassava compared to maize for both flours and starches

Gum Arabic substitution level of 0% is the reference category; GA= Gum Arabic; WHC= Water Holding Capacity; FC= Foaming Capacity; BD= Bulk Density; WSI= Water Solubility Index; WAI= Water Absorption Index; SC= Swelling Capacity; OHC= Oil Holding capacity; ***= significant at p<0.001; *=significant at p<0.05; ns= Not Significant

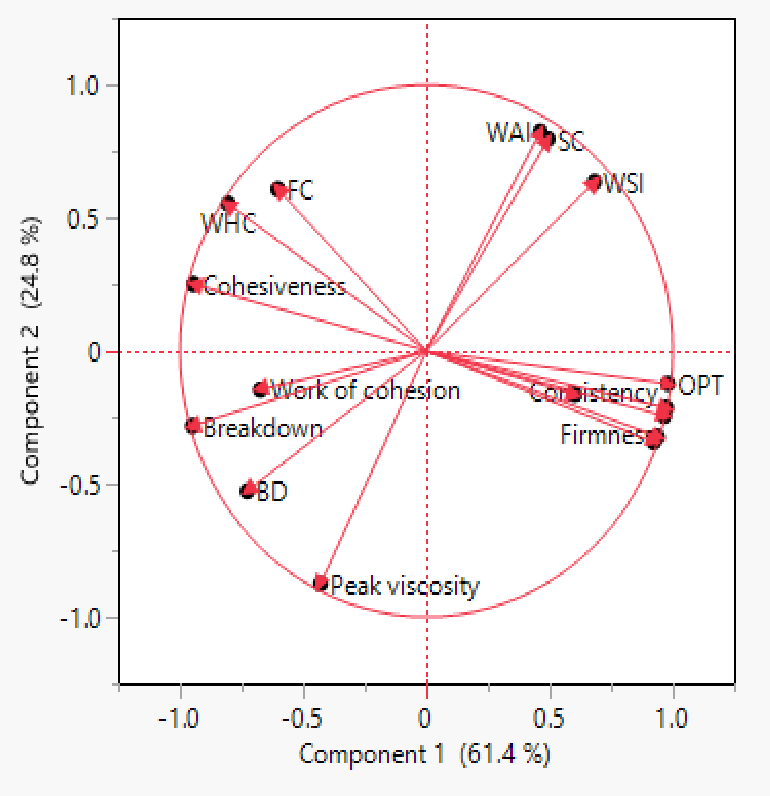

Fig. 3a: Loading of properties of starch

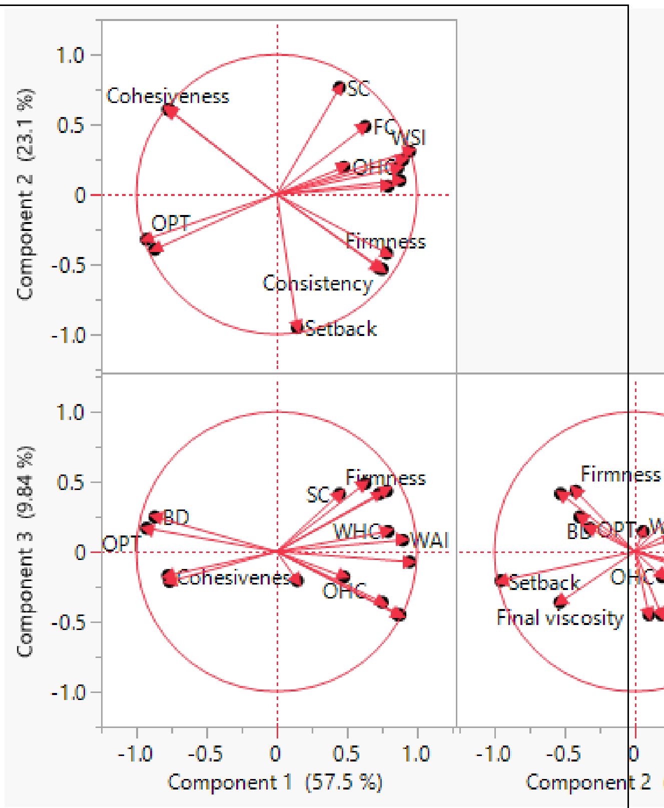

Fig. 3b: Loading of properties of flours

Fig. 3: Functional properties loading matrix on principal components

Property	Starches		Property	Flours		
	Prin. 1	Prin. 2		Prin. 1	Prin. 2	Prin. 3
OPT	0.979732	-	WSI	0.946817	-	-
Consistency	0.972972	-	WAI	0.898294	-	-
Firmness	0.965333	-	Peak viscosity	0.878812	-	-
Final viscosity	0.937861	-	Breakdown	0.862455	-	-
Setback	0.922755	-	WHC	0.793175	-	-
WSI	0.682118	-	Firmness	0.783661	-	-
WAI	-	0.823171	Final viscosity	0.751833	-	-
SC	-	0.795691	Consistency	0.730376	-	-
FC	-	0.607682	FC	0.630150	-	-
WHC	-0.804839	-	Setback	-	-0.953464	-
Cohesiveness	-0.945629	-	SC	-	0.763101	-
OHC	0.600718	-	Cohesiveness	-0.773939	-	-
BD	-0.727243	-	Work of cohesion	-0.763419	-	-
Work of cohesion	-0.674277	-	BD	-0.868309	-	-
Peak viscosity	-	-0.874238	OPT	-0.927315	-	-
Breakdown	-0.949662	-	OHC	-	-	0.825451

Table 5: Comparison of loading matrix coefficients of functional properties on principal components between starch and flours

Prin. = Principal Component; WHC= Water Holding Capacity; FC= Foaming Capacity; BD= Bulk Density; WSI= Water Solubility Index; WAI= Water Absorption Index; SC= Swelling Capacity; OHC= Oil Holding capacity; OPT= Onset Pasting Temperature

V. DISCUSSION

The variation in textural, pasting and physical properties among the different flours are influenced by some factors such as: size of the starch granule, molecular structure of the amylopectin (branch, length and weight), starch, protein and dietary fiber content as well as the presence of other compounds (Culetu *et al.*, 2021).

A. *Textural properties*

Gels formed by the materials used in this study had significantly varying degrees of textural properties as indicated in **Figure 1**. An interesting observation was made between maize starch and cassava flour which behaved in an antagonistic manner for all the textural properties. Besides, proximate composition, this difference could be attributed to maize starch which is characterized by a comparatively high amylose content of above 27% while of cassava flour is 13-17% and predominantly resistant starch (He *et al.*, 2020; Puspita and Hermana, 2019; Zhang *et al.*, 2014). Amylose is less able to bind and hold water than amylopectin making the gel to be firmer through influencing packing of amylopectin to crystallites (Kim *et al.*, 2013; Montgomery and Senti, 1958). Another notable observation was that cassava starch and maize flour did not differ significantly, and this could be attributed to both being categorized as having waxy starch structure (Santos *et al.*, 2021).

Generally, as indicated in **Table 1**, magnitude of effect of gum Arabic substitution on textural properties of flour differed significantly between maize and cassava. Compared to maize flour, the effect of gum substitution level on textural properties was higher in magnitude because of the odds ratio estimates that were above 1.0. However, at 2.0% substitution level, it was only consistency among the textural properties that differed between the two types of flour. Another observation to note was that as the substitution level increased so was the difference in the effect between the two types of flours. Similar to flours, increasing the level of substitution in starches caused a corresponding significant increase in the difference in magnitude of effect on textural properties of gels between the two types of starches. But unlike the flours, magnitude of effect of gum Arabic substitution on textural properties of starches showed mixed abilities. Effect of gum Arabic on cassava starch showed a higher magnitude than on maize starch for gel firmness, consistency and cohesiveness while the magnitude was higher in maize starch than cassava starch on work of cohesion. Similar studies have reported that this observation could be influenced more on amylose content than on added gum (Kim *et al.*, 2013).

Gum substitution level of 2.0% gave a gel that was 22.8% more consistent in cassava flour than in maize flour but 8.3% less consistent and 20.8% more cohesive in cassava starch than in maize starch. A 4.0% substitution level gave a gel that was 2.3 times firmer and more consistent and 1.9 times more cohesive and work of cohesion in cassava flour than in maize flour. The same level gave a gel that was 74.5% less work of cohesion in cassava starch than in maize starch while other properties remained not significantly different. Among the flours, addition of gum at 6.0 and 8.0% gave a gel that was 2.8 to 2.9 times firmer, 2.5 times more cohesive and 2.4 times more work of cohesion in cassava than in maize. But for starches, the same level of substitution gave 31.5- 52.9% more firm, 25.2- 38.8% more consistent and 57.5- 58.3% less work of cohesion in cassava than in maize.

We postulate that these observations could be due to the net chemical, ionic and thermodynamic reactions taking place and were more prominent in the flours than in the starches. Several studies have pointed out that the ionic reactions could be attributed to the differences in interaction of cations. Some cations are present in the gum Arabic powder while some are in the flours. It is important to note that cations are needed for gelation of many hydrocolloids (Edwards-Stuart and Barbar, 2021; Williams and Phillips, 2021; Laaman, 2011). According to Sabet *et al*. (2021) gum Arabic is classified among the charged hydrocolloids. Therefore, since maize flour is rich in many components than cassava flour, some of these components that are contained in maize flour could also positively influence and hence limit the activity of the gum Arabic hydrocolloid activity. On other hand, soluble polymers such gum Arabic usually drive conversion of the gelling starch material to its compact ordered form so as to minimize thermodynamically unfavourable segmental contacts (segregative interactions) between the two polymers (Hoey *et al.*, 2016). This implies that cassava flour and starch were the most affected by this ionic reaction and these could be due to less constituents compared to maize that could contribute cations.

B. Pasting properties

Similar to the textural properties of the gels formed by the materials used in this study, pasting properties were also varied significantly among them as indicated in **Figure 2**. Maize flour exhibited the highest OPT but the lowest PV, FV and BD as compared to other materials. On the contrary, it was observed that maize starch exhibited highest FV and SB but lowest BD. Cassava starch and flour differed significantly for all the pasting properties except for OPT. These inherent differences of the materials under study could be due to differences in amylose content, starch granule size, degree of branching and chain-length distribution of amylopectin (Jin & Xu, 2020; Zhang & Xu 2019). Study by Zhang & Xu (2019) showed that PV and breakdown are negatively correlated with starch granule size, the ratio of long chain and protein type and its concentration, and positively correlated with starch content. The present results showed a decrease in viscosity with addition of gum Arabic. According to Williams & Phillips (2009) gum Arabic which is a polyelectrolyte has the tendency to cause viscosity decreases in a solution in the presence of electrolytes due to charge screening and at low pH when the carboxyl groups become undissociated.

The low viscosity of the flour and starches has been reported to be beneficial for some food applications including confectionary, weaning foods and other liquid foods (Aprianita et al., 2012; Hoover 2001). However, the magnitude of the effect of gum Arabic addition on cassava pasting properties compared to maize for both their starches and flours exhibited varied resulted as indicated in **Table 2.** For both flour and starch, gum Arabic addition did not significantly impact OPT in cassava differently from maize. Gum substitution level of 2.0% in flours gave a gel that had 6.5 times more breakdown in cassava than maize while other properties were not significantly different. Substitution levels of 4.0, 6.0 and 8.0% gave gel that had 23.6 to 27.9% higher PV, 28.2 to 39.3% higher FV, 29.3 to 35.7% higher setback and 3.9 to 5.6 times higher breakdown in cassava flour as compared to maize flour. This could imply that gum Arabic addition, irrespective of the level do not differently affect the starches ability in both maize and cassava to swell and rupture (Kumar and Khatkar, 2017). According to Culetu *et al.* (2021), this swelling and rupture of the starch granule is disturbed by the presence of non-starch compounds such as fat, which leads to higher gelatinization temperatures. As the level of gum Arabic addition increased in cassava flour, the magnitude of effect compared to maize flour was higher and increased significantly for PV, FV and SB but decreased significantly for breakdown. These differences could be attributed to composition of maize flour compared to cassava flour that even affects the aggregation of starch molecules. Studies show that lower PV was correlated with higher protein content (Guo *et al.*, 2022; Uthayakumaran *et al.*, 2000) while FV, SB and breakdown increase was correlated with the aggregation of the solubilized amylose molecules (Pourmohammadi and Abedi, 2020; Blazek and Copeland, 2008). However, between cassava and maize starches, breakdown and SB did not significantly differ in magnitude due to addition of gum Arabic while PV was significantly lower at 8.0% level and FV was significantly higher at 4.0 and 6.0% levels only. This observations in starch indicate that gum Arabic does has very minimal impact on pasting properties but other components present in starches as it is the case with flour has a bigger impact on pasting. Studies have reported that swelling power and amylose content could influence some of the pasting properties of starch since pasting process in itself involves granular swelling, leaching out of amylose with subsequent disruption of granules during heating (Aprianita *et al.*, 2012; Thitipraphunkul *et al.*, 2003).

According to Aprianita *et al.* (2012) low breakdown viscosity of flours and starches reflects the stability of these materials toward heat and mechanical processing. This property is crucial for food production that involves heat and mechanical treatment particularly in canned foods. Furthermore, the same study reported that low setback value of these samples indicates their low retrogradation tendency and is important for frozen or cold storage foods.

C. Physical properties

Materials under study showed that inherently their physicochemical properties were significantly different as given in **Table 3**. According to Dhillon *et al.* (2022) bulk density of the flour describes the degree of compactness of the matrices; therefore, this implies that cassava starch, maize starch and maize flour were most compact while cassava flour was the most porous. Moreover, it can also be implied that the high porosity of cassava flour exposed more hydrophilic site for attachment of water molecules that resulted into WHC, FC, WSI, WAI and SC but lowest OHC in comparison to other materials (Sharma and Kotari, 2017). Maize starch showed lowest WHC and highest OHC and this could be attributed to the possibility of presence of more hydrophobic and lipophilic sites than other materials. Study by Culetu *et al.* (2021) suggested that water and oil absorption capacities of any food depends on the type of protein, amino acid composition and protein polarity and hydrophobicity.

On the other hand, magnitude of the effect of gum Arabic addition on cassava physical properties compared to maize for both their starches and flours exhibited varied resulted as indicated in **Table 4.** Increasing the level of gum increased the magnitude in difference between cassava and maize on all physicochemical properties of both starch and flour except FC, BD, WAI and OHC in starches. Addition of gum Arabic in cassava did not significantly alter the compactness of both flour and starch matrices as compared maize. However, gum addition in cassava flour showed a higher significant magnitude than maize flour on WHC, WSI and OHC but significantly lower magnitude for SC. On the contrary, gum Arabic addition in starches did not have a significant different magnitude in effect between cassava and maize on WHC and WAI. However, there was a higher significant magnitude in cassava than maize on WSI, SC and OHC and a lower significant magnitude on FC.

Gum substitution of 2.0, 4.0, 6.0 and 8.0% gave flours that had 18.4 to 28.6% more WAI and 74.0 to 81.8% less SC in cassava as compared to maize. Also, a 2.0% level gave a blend that had 20.7% less WHC and 49% less WSI in cassava flour compared to maize flour. At 8.0% substitution, OHC was 5 times more in cassava flour compared to maize flour but other levels of substitution were not significantly different. But for starches, gum substitution of 2.0, 4.0, 6.0 and 8.0% gave starch that had 26.6 to 68.4% less FC, 1.6 to 2.2 times higher WSI, and 2.1 to 3.7 times higher SC in cassava compared to maize. Also, substitution levels of 2.0 and 4.0% gave starch that had 2.0 to 3.1 times higher OHC in cassava than in maize while other levels had no significant differences.

D. Relationship between textural, pasting and physical properties due to gum Arabic

The magnitude of hydrocolloid addition in flours was different to the starches as demonstrated by loading matrix on principal components as shown in **Table 5** and **Figure 3**. In starches, OPT, consistency, firmness, FV and setback were the parameters that improved by addition of the hydrocolloid but breakdown and cohesiveness were the most negatively affected. On the other hand, for the flours, WSI was the most improved property by the hydrocolloid addition but setback and OPT were the most negatively affected. Notably, OHC was moderately improved but as a first priority in starches while in flours it strongly improved but as a last priority. Among all the properties studied, SC was improved but as a second priority in both starches and flours.

This observation reveals that gum Arabic affects starches properties in an opposite way to flours. Gum Arabic increases hydration (increased WSI, WHC and WAI) and pasting (lowers OPT, peak viscosity and breakdown) but reduces textural quality (lowers setback, cohesiveness and work of cohesion) in flours. On the contrary, gum Arabic improved the stability of gels (increased consistency and firmness but reduced cohesiveness and work of cohesion) but reduced gelatinization (reduced peak viscosity and breakdown but increased OPT and final viscosity) in starches. Compared to flours, starches are usually relatively free from fibre, proteins and other components usually referred to as impurities (Ren *et al.*, 2021). Typically starches contains above 98-99% starch and less than 0.5% fibre while flours

ISSN No:-2456-2165

contain around 75% starch and 1-3% fibre in the flour (Asare *et al.*, 2021; Majzoobi and Farahnaky, 2021). This makes starches more hygroscopic, hydrolysable and gelatinizable compared to their respective flours (Mitrus *et al.*, 2009). As a result, this is what makes flours generally to have limited functional properties such as low shear stress resistance, susceptibility to thermal decomposition, high retrogradation and syneresis and thus reducing their application in food systems.

VI. CONCLUSION

Magnitude of effect of GA addition on cassava properties compared to maize for both their starches and flours exhibited varied results. Maize starch had significantly higher level of firmness and consistency and also significantly lower cohesiveness after gelling as compared to other materials. Each of the substitution levels did not have a significant difference on onset pasting temperature in cassava flour as compared to maize flour. Addition of GA in cassava did not alter significantly the compactness of both flour and starch matrices as compared to maize. The difference between the flours and starch could be attributed to the nature of flour/starch, granule size difference of flour/starch, varietal difference, amylose content, protein and lipid contents, amylose-lipid complex formation, degree of branching and chain-length distribution of amylopectin. This study suggests that gum Arabic from *acacia senegal* var. *kerensis* could be considered in the preparation of various food products from cassava and maize flours and starches to improve the binding ability, texture, prevent retrogradation as well as enhancing stability and functionality of starchy foods.

AKNOWLEDGEMENT

The authors wish to express their gratitude to the Center of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM), Egerton University, Kenya for funding this research study. The authors also extend their appreciation to the department of Dairy and Food Science Egerton University and the Kenya Industrial Research and Development Institute (KIRDI), Nairobi, Kenya for making the study possible. Profound gratitude goes to Dr. Wafula for great insights in the data analyses and development of this manuscript.

REFERENCES

[1.] Adewale P, Yancheshmeh MS, and Lam E. Starch modification for non-food, industrial applications: Market intelligence and critical review. *Carbohydrate Polymers,* 2022, 119590.

[2.] Aprianita A, Vasiljevic T, Bannikova A, Kasapis S. Physicochemical properties of flours and starches derived from traditional Indonesian tubers and roots. *Journal of Food Science Technology,* 2012, 51 (12):3669–3679.

[3.] Asare IK, Mapengo CR, and Emmambux MN. In vitro starch digestion and physicochemical properties of maize starch and maize meal modified by heat-moisture treatment and stearic acid. *Starch-Stärke*, 2021, 73(3-4): 2000128.

[4.] Bayaga A. Multinomial Logistic Regression: Usage and Application in Risk Analysis. *Journal of applied quantitative methods*, 2010, 5(2).

[5.] Blazek J, and Copeland L. Pasting and swelling properties of wheat flour and starch in relation to amylose content. *Carbohydrate polymers*, 2008,71(3): 380 - 387.

[6.] Cappelli A, Oliva N, and Cini E. A systematic review of gluten-free dough and bread: Dough rheology, bread characteristics, and improvement strategies. *Applied Sciences*, 2020, 10(18): 6559.

[7.] Charles AL, Huang TC, Lai PY, Chen CC, Lee PP, and Chang YH. Study of wheat flour-cassava starch composite mix and the function of cassava mucilage in Chinese noodles. *Food Hydrocolloids*, 2007, 21: 368-378.

[8.] Colgrave ML, Dominik S, Tobin AB, Stockmann R, Simon C, Howitt CA, and Vanhercke T. Perspectives on future protein production. *Journal of Agricultural and Food Chemistry*, 2021, *69*(50), 15076-15083. doi: 10.1021/acs.jafc.1c05989

[9.] Culetu A, Susman IE, Duta DE, and Belc N. Nutritional and Functional Properties of Gluten-Free Flours. *Appl. Sci*. 2021, 11, 6283.

[10.] Dhillon NK, Toor BS, Kaur A, and Kaur J. Characterization and evaluation of yellow pea flour for use in '*Missi Roti'a* traditional Indian flat bread in comparison with Desi chickpea flour, 2022.

[11.] Dini C, Doport MC, Viña SZ, and García MA. Cassava flour and starch as differentiated ingredients for gluten free products. In: F. P. Molinari (Ed.) Cassava. Nova Science Publishers, Inc. 2014.

[12.] Edwards-Stuart R, and Barbar R. Hydrocolloid Usages as Gelling and Emulsifying Agents for Culinary and Industrial Applications. In *Handbook of Molecular Gastronomy*, 2021, pp 385-408. CRC Press.

[13.] Egharevba HO. Chemical properties of starch and its application in the food industry. *Chemical properties of starch*, 2019, 1-26.

[14.] Guo J, Liu F, Gan C, Wang Y, Wang P, Li X, and Hao J. Effects of Konjac glucomannan with different viscosities on the rheological and microstructural properties of dough and the performance of steamed bread. *Food Chemistry*, 2022, 368, 130853.

[15.] He R, Fu NF, Chen HM, Ye JQ, Chen LZ, Pu YF, and Zhang WM. Comparison of the structural characteristics and physicochemical properties of starches from sixteen cassava germplasms cultivated in China. *International Journal of Food Properties*, 2020, *23*(1), 693-707.

[16.] Hoey A., Ryan J.T., Fitzsimons S.M. & Morris E.R. (2016). Segregative interactions in single-phase mixtures of gelling (potato) maltodextrin with other hydrocolloids. In G. O. Phillips and P. A. Williams (Eds.), *Gums and Stabilizers for the Food Industry 18 Hydrocolloid Functionality for Affordable and Sustainable Global Food Solutions*. *The proceedings of the 18th Gums and Stabilizers for the Food Industry Conference held on 23–26 June 2015 at the*

Glyndwr University, Wales, UK. The Royal Society of Chemistry.

[17.] Hoover R. Composition, molecular structure and physicochemical properties of tuber and root starches – a review. *Carbohydrate Polymers*, 2001, 45, 253 - 267

[18.] Hsieh CF, Liu W, Whaley JK, and Shi YC. Structure, properties, and potential applications of waxy tapioca starches–A review. *Trends in Food Science & Technology*, 2019, 83, 225 - 234.

[19.] Jin Q, and Xu X. Microstructure, gelatinization and pasting properties of rice starch under acid and heat treatments. *International journal of biological macromolecules*, 2020, 149: 1098-1108.

[20.] Kim HS, Patel B, and BeMiller JN. Effects of the amylose–amylopectin ratio on starch–hydrocolloid interactions. *Carbohydrate polymers*, 2013, 98(2): 1438-1448.

[21.] Kiprop VJ, Omwamba MN, and Mahungu SM. Influence of Gum Arabic from *Acacia senegal* var. *kerensis* on the Modifications of Pasting and Textural Properties of Cassava and Corn Starches. *Food and Nutrition Sciences*, 2021, 12(11): 1098-1115.

[22.] Kumar R, and Khatkar BS. Thermal, pasting and morphological properties of starch granules of wheat (*Triticum aestivum* L.) varieties. *Journal of food science and technology*, 2017, 54(8) 2403-2410.

[23.] Laaman TR. Hydrocolloids: fifteen practical tips. *Hydrocolloids in food processing*, 2011, 1-18.

[24.] Majzoobi M, and Farahnaky A. Granular cold-water swelling starch; properties, preparation and applications, a review. *Food hydrocolloids*, 2021, 111, 106393.

[25.] Mitrus M, Wojtowicz A, and Moscicki L. Biodegradable polymers and their practical utility. *Thermoplastic starch: a green material for various industries*, 2009, 1-33.

[26.] Montgomery EM, and Senti FR. Separation of amylose from amylopectin of starch by an extraction-sedimentation procedure. *Journal of Polymer Science*, 1958, 28(116): 1-9.

[27.] Obadi M, and Xu B. Review on the physicochemical properties, modifications, and applications of starches and its common modified forms used in noodle products. *Food Hydrocolloids*, 2021, 112, 106286.

[28.] Onyango C. Physical properties of dry-milled maize meals and their relationship with the texture of stiff and thin porridge. *African Journal of Food Science*, 2014, 8(8): 435-443.

[29.] Pourmohammadi K, and Abedi E. The effect of pre and post-ultrasonication on the aggregation structure and physicochemical characteristics of tapioca starch containing sucrose, isomalt and maltodextrin. *International Journal of Biological Macromolecules*, 2020, 163: 485-496.

[30.] Puspita PS, and Hermana W. Effect of isoamylase application on chemical characteristic of cassava root meal starch. In *IOP Conference Series: Earth and Environmental Science*, 2019, (251, No. 1, p. 012058). IOP Publishing.

[31.] Ren Y, Yuan TZ, Chigwedere CM, and Ai Y. A current review of structure, functional properties, and industrial applications of pulse starches for value-added utilization. *Comprehensive Reviews in Food Science and Food Safety*, 2021, 20(3): 3061-3092.

[32.] Sabet S, Rashidinejad A, Melton LD, Zujovic Z, Akbarinejad A, Nieuwoudt M, and McGillivray DJ. The interactions between the two negatively charged polysaccharides: Gum Arabic and alginate. *Food Hydrocolloids*, 2021, 112, 106343.

[33.] Salehi F. Improvement of gluten-free bread and cake properties using natural hydrocolloids: A review. *Food science & nutrition*, 2019, 7(11): 3391-3402.

[34.] Santos TBD, Carvalho CWPD, Oliveira LAD, Oliveira EJD., Villas-Boas F, Franco CM, and Chávez DWH. Functionality of cassava genotypes for waxy starch. *Pesquisa Agropecuária Brasileira*, 2021, 56.

[35.] Sharma P, and Kotari SL. Barley: Impact of processing on physicochemical and thermal properties—A review. *Food Reviews International*, 2017, 33(4): 359-381.

[36.] Thitipraphunkul K, Uttapap D, Piyachomkwan K, Takeda Y. Acomparative study of edible canna (Cannae edulis) starch from different cultivars. Part I. Chemical composition and physicochemical properties. *Carbohydrate Polymers*, 2003, 53: 317-324.

[37.] Uthayakumaran S, Newberry M, Keentok M, Stoddard FL, and Bekes F. Basic rheology of bread dough with modified protein content and glutenin-to-gliadin ratios. *Cereal Chemistry*, 2000, 77(6): 744-749.

[38.] Vilaça M, Macedo E, Tafidis P, and Coelho MC. Multinomial logistic regression for prediction of vulnerable road users risk injuries based on spatial and temporal assessment. *International journal of injury control and safety promotion*, 2019, 26(4): 379-390.

[39.] Wanjala WN, Mary O, and Symon MM. Influence of Feed Rate, Moisture and Mixture Composition from Composites Containing Rice (Oryza sativa), Sorghum [Sorghum bicolor (L.) Moench] and Bamboo (Yushania alpine) Shoots on Physical Properties of Extruded Flour and Mass Transfer. *Food and Nutrition Sciences*, 2020, 11(8): 807-823.

[40.] Williams PA, and Phillips GO. Gum Arabic. In G. O. Phillips and P. A. Williams (Eds.), *Handbook of hydrocolloids*, 2009, pp 252 - 273, Abington Hall, Granta Park, Cambridge, UK, Woodhead Publishing Limited.

[41.] Williams PA, and Phillips GO. Introduction to food hydrocolloids. In *Handbook of hydrocolloids*, 2021, pp. 3-26. Woodhead publishing.

[42.] Yamul DK, and Navarro AS. Effect of hydrocolloids on structural and functional properties of wheat/potato (50/50) flour dough. *Food Structure*, 2020, 24, 100138.

[43.] Zhang H, and Xu G. Physicochemical properties of vitreous and floury endosperm flours in maize. *Food science & nutrition*, 2019, 7(8): 2605-2612.

ISSN No:-2456-2165

[44.] Zhang Z, Chen P, Du X, Xue Z, Chen S, and Yang B. Effects of amylose content on property and microstructure of starch-graft-sodium acrylate copolymers. *Carbohydrate polymers*, 2014), 102: 453-459.