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Original Research Article

Effect of Vegetables with Carbohydrate Meal on Glucose Excursions and Glycemic Control among Healthy Adults in Port Harcourt

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Abstract

Aim: This study aimed to investigate the impact of different meal compositions on glycemic control in healthy adults in the University of Port Harcourt by examining the order and combination of carbohydrate and vegetable consumption. ***Method:*** A randomized crossover trial was conducted with 30 male and female participants. Three groups were formed, each consuming meals consisting of carbohydrates and vegetables in different sequences. Continuous glucose monitoring and postprandial glucose tests were employed to assess blood glucose levels. The glycemic index (GI) of the meals was also determined. ***Results:*** Participants who consumed vegetables before carbohydrates exhibited significantly lower mean glucose levels compared to the other groups. The Vegetable before Carbohydrate group demonstrated a lower overall glycemic response, as indicated by the lower GI values at various time intervals. ***Conclusion:*** The findings suggest that consuming vegetables before carbohydrates can lead to better glycemic control in healthy adults. The order of food consumption plays a role in regulating postprandial blood glucose levels. Including vegetables, which have a low glycemic index, in carbohydrate meals can mitigate rapid spikes in blood glucose levels.

Keywords: Vegetables, Carbohydrate meal, Glucose excursions, Glycemic control, Healthy adults, Port Harcourt.

INTRODUCTION

Diabetes mellitus is a major and growing public health concern worldwide. According to the International Diabetes Federation (IDF), the global prevalence of diabetes was approximately 463 million in 2019, and it is expected to increase to 700 million by 2045 (IDF, 2019). The incidence rates of diabetes have been rapidly increasing in sub-Saharan Africa, including Nigeria. In Nigeria, the prevalence of diabetes has also been on the rise, with an estimated 4 million people living with the disease as of 2019 (IDF, 2019). Poor dietary habits have been identified as one of the contributing factors to the development of diabetes (Barnard *et al.*, 2019; Malik *et al.*, 2020). In particular, consuming carbohydrate-rich meals without adequate amounts of vegetables has been shown to cause rapid spikes in blood glucose levels, which can lead to poor glycemic control over time (Bazzano *et al.*, 2013; Jenkins *et al.*, 2014; Akoko *et al.*, 2022).

One of the most important macronutrients in our diet is carbohydrates which are a major source of energy for the body (Slavin, 2013). However, it is important to note that not all carbohydrates are equal and some can have a greater impact on blood glucose levels than others (Brand-Miller *et al.*, 2003). Glycemic control is an important subject of concern, especially in the era of nutrition-related chronic metabolic diseases and the prevalence of type 2 diabetes mellitus (T2DM) globally (Danaei *et al.*, 2011; Akoko *et al.*, 2022). The potential to improve glycemic control through dietary interventions targeted at reducing carbohydrate intake has gained much attention worldwide, with emphasis placed on the nutritional benefits of vegetables (Rees *et al.*, 2018; Tanaka *et al.*, 2019). Vegetables contain complex carbohydrates that often have a low glycemic index, indicating that they cause a lower rise in blood glucose levels after consumption compared to simple carbohydrates (Foster-Powell *et al.*, 2002; Trichopoulou *et al.*, 2003).

Given the impact of diet on glucose control, it is important to investigate the role of vegetable consumption with carbohydrate meals and its effect on glycemic control in healthy adults. In addition, the extent to which the combination of vegetables with carbohydrate meals affects glycemic control needs to be explored. This investigation will provide information that will be useful for dietary recommendations in individuals with preexisting cases of chronic metabolic conditions such as obesity and T2DM.

MATERIALS AND METHODS

Recruitment of Participants

The recruited subjects were students of the University of Port Harcourt, Rivers State, Nigeria. Subjects who met the inclusion criteria of a fasting glucose range of 3.5 – 5.5mmol/L, had fasted for 12 hours overnight prior to the study, had a normal systolic blood pressure of 110 - 120mmhg and a normal diastolic blood pressure of 75 to 89 mmHg, is not diabetic or having any disease conditions (e.g., hyperthyroidism and liver or kidney dysfunctions). Non-healthy participants were excluded from the study, and participants that did not fast prior to the study were also excluded from the study. All participants provided written informed consent.

Study design

The study is a randomized crossover trial in which 30 male and female healthy participants were classified into 3 groups of 10 participants each, consumed an equal amount of isocaloric meals of carbohydrates together with vegetables (group A), carbohydrates before vegetables (group B) and vegetables before carbohydrates (group C) respectively. Participants' glucose levels and blood pressure before meals were recorded before consumption of the different meal patterns. After serving the meals, the glucose levels were checked every 30 minutes interval for 4 consecutive times. The glucose concentration in interstitial fluid (glucose levels) of all participants was determined using a handheld Accu-Chek glucometer (Accu-Chek Model GB 923). Also, a postprandial glucose test was carried out on all participants in the experimental group, and the values were recorded using a handheld Accu-Chek glucometer. This was done two days after the continuous glucose monitoring process and the participants were made to also consume the same amount of carbohydrate and vegetable meals.

Diet Protocol

Meal sequences were divided into three groups. The first group designated as Group A was made to consume 200g of jollof rice (800kcal) together with 120g of vegetables (12kcal); the second group designated as Group B was made to consume 200g of jollof rice first, allowed to rest for 10 minutes before consumption of 120g of vegetables and the third group designated as Group C were made to consume 120g of vegetables first and allowed to rest for 10 minutes before consumption of 200g of jollof rice.

Equipment Reliability

The determination of blood glucose was done using Accu-Chek glucometer (Accu-Chek Model GB 923). Test strips with identical lot numbers (Accu-Chek, Lot 2030381, Sensocard Lot FT01EA88C, and One Touch Horizon Lot 2838983) were used for the study. The glucometer was tested for reliability by carrying out glucose level determination on a single participant three times to check the difference in values. A difference of ±0.1 was obtained. Hence, the equipment was reliable for use in the study.

Calorific Value of Carbohydrates and Vegetables

The following parameters were evaluated and collected as data during the study. Quantity of Carbohydrate (Jollof Rice); the Carbohydrate (Jollof Rice) was weighed to get an accurate measurement of 200 grams for each carbohydrate that was consumed. Furthermore, the vegetables were also weighed, and an accurate measurement of 120 grams was used. The data obtained were used to complete the daily carbohydrate intake for the study. The total calories in carbohydrate was eight hundred (800kcal) and twelve (12kcal) calories in vegetables.

Data collection

Data collected for this study includes; the sex of participants, age of participants, the weight of participants, blood pressure of participants, the glucose level of participants before consumption of meal, and glucose level of participants every 30 minutes upon consumption of meal, and 2 hours postprandial glucose level upon consumption of meal.

Glycemic Index

The glycemic index (GI) is a concept that ranks the glycemic potency of foods (Jenkins *et al.*, 1981). GI is a scale that ranks carbohydrates based on how quickly they raise blood sugar levels after consumption compared to a reference food, usually glucose or white bread. Foods with a high glycemic index are quickly digested and absorbed, leading to a rapid increase in blood sugar levels. Tests were undertaken with more conventional meals containing sources of carbohydrates and vegetables to investigate whether predictable variations in blood glucose concentrations could be found. The GI of the foods was determined through testing and comparing the blood sugar response to a specific amount of that food to a reference food (typically glucose or white bread). The formula for calculating the GI of a food is as follows:

$$Glycemic\ Index\ (GI) = \frac{iAUC\ of\ test\ food}{iAUC\ of\ Reference\ food}\ x\ 100$$

Where:

iAUC refers to the "incremental Area Under the Curve," which represents the blood sugar response over a specific time period after consuming the test food or reference food. iAUC of the test food is the area under the blood sugar response curve after consuming a specific amount of the test food. The iAUC of the reference food is the area under the blood sugar response curve after consuming a specific amount of the reference food.

Method of Data Analysis

Data obtained were analyzed using Statistical Package for Social Science (IBM SPSS) version 25.0. Descriptive statistics to get the mean value of data was carried out, and inferential statistics using analysis of variance (ANOVA) was done to check for significance difference at 95% ($p<0.05$) confidence interval between the trial groups followed by a Bonferroni post-hoc and then mean plot.

RESULTS

Demographic Parameters of Participants

Table 1 shows the demographic parameters of participants in three groups: those who ate carbohydrates and vegetables together, those who ate vegetables before carbohydrates, and those who ate carbohydrates before vegetables. The parameters measured include age, weight, systolic blood pressure, and diastolic blood pressure. The table presents the mean values for each parameter for each group. There was no significant ($p<0.05$) difference in the age, weight, and blood pressure of participants in each group.

Effect of carbohydrate and vegetable meals on continuous glucose monitoring (GGM)

Table 2 and Figure 1 show the continuous glucose monitoring (CGM) data of participants who ate different meals. The data were recorded at 0, 30, 60, 90, and 120 minutes after the meals. The mean glucose levels for each group were calculated, and the group that ate vegetables before carbohydrates had a significantly lower mean glucose level compared to the other groups. Table 3 presents the results of an ANOVA test conducted on continuous glucose monitoring (CGM) data of participants who ate different meals. The table includes mean differences, standard error, and significance levels for each time point (initial, 30 min, 60 min, 90 min, 120 min). It indicates significant differences in mean differences at some time points for some groups. Specifically, the mean difference was significant at the $p<0.05$ level at 30 min, 60 min, 90 min, and 120 min time points for some group comparisons.

Table 4 displays the glycemic index (GI) values for different meal groups at various time intervals (30, 60, 90, and 120 minutes) after consumption and the Mean GI for each meal group across the different time intervals. The carbohydrate + vegetable together group showed a relatively high blood sugar response 30 minutes after consuming the meal. The GI value increased slightly at 60 minutes (90.3), 90 minutes (94.1), and then decreased at 120 minutes (91.5). The mean GI for this group is 90.8, suggesting an overall moderate to high glycemic response. The vegetables before carbohydrate group demonstrated a GI of 86.0 at 30 minutes, which is slightly lower than the Carbohydrate + Vegetable group. The GI values continue to decrease at 60 minutes (84.5), 90 minutes (80.8), and 120 minutes (77.8). The mean GI for this group is 82.3, indicating a lower overall glycemic response compared to the other groups. The carbohydrate-before-vegetables group started with a higher GI of 92.6 at 30 minutes, suggesting a relatively rapid increase in blood sugar levels. The GI values decrease slightly at 60 minutes (90.8), 90 minutes (88.6), and 120 minutes (85.4). The mean GI for this group is 89.4, indicating a moderate to high glycemic response overall, but slightly lower than the Carbohydrate + Vegetable together group. Based on the data, consuming vegetables before carbohydrates appears to result in a lower glycemic response compared to consuming carbohydrates before vegetables. The Carbohydrate + Vegetable together group shows a moderately high GI, while the Vegetables before Carbohydrate group demonstrates a lower glycemic response.

Table 1: Demographic Parameters of Participants

Group	Age(Years)	Weight (kg)	Blood Pressure (mmHg)	
			Systolic	Diastolic
Carbohydrate + Vegetable together	24.90±0.62	67.20±1.89	115.5±2.61	79.5±2.17
Vegetables before Carbohydrate	25.90±1.06	70.80±1.69	117.0±2.13	76.0±2.33
Carbohydrate before Vegetables	25.20±0.74	70.10±1.39	114.0±2.67	79.5±1.74

*Statistically significant ($p<0.05$), n=10

Table 2: Continuous Glucose Monitoring (CGM) data of Participants that ate different meals

Group	0 min (Initial)	30min	60min	90min	120min	Mean± SEM
Carbohydrate + Vegetable together	5.05±0.12	5.86±0.11	5.54±0.05	5.31±0.08	5.10±0.12	5.45±0.07
Vegetables before Carbohydrate	4.95±0.13	5.41±0.08	5.21±0.08	5.15±0.09	4.82±0.10	5.14±0.09*
Carbohydrate before Vegetables	4.78±0.10	5.55±0.11	5.86±0.12	5.32±0.08	4.92±0.13	5.41±0.11

*Statistically significant ($p<0.05$), n=10

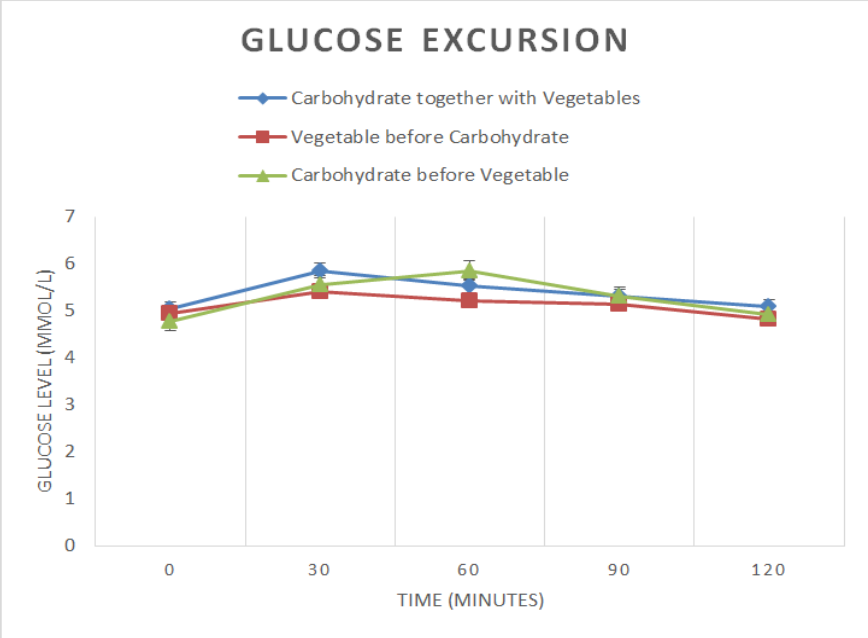

Figure 1: Bar chart showing the effect of vegetables in Continuous Glucose Monitoring (CGM) of Participants

Table 3: ANOVA of Continuous Glucose Monitoring (CGM) data of Participants that ate different meals

Dependent Variable	(I) Group	(J) Group	Mean Diff. (I-J)	Std. Error	Sig.
0 min (Initial)	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	.0900	.1701	1.000
		Carbohydrate before Vegetables	.2700	.1701	.372
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	-.0900	.1701	1.000
		Carbohydrate before Vegetables	.1800	.1701	.898
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	-.2700	.1701	.372
		Vegetables before Carbohydrate	-.1800	.1701	.898
30min	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	.5500*	.1377	**.001***
		Carbohydrate before Vegetables	.3100	.1377	.098
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	-.5500*	.1377	**.001***
		Carbohydrate before Vegetables	-.2400	.1377	.278
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	-.3100	.1377	.098
		Vegetables before Carbohydrate	.2400	.1377	.278
60min	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	-.3500*	.1204	**.022***
		Carbohydrate before Vegetables	-.2200	.1204	.236
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	.3500*	.1204	**.022***
		Carbohydrate before Vegetables	.1300	.1204	.869
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	.2200	.1204	.236
		Vegetables before Carbohydrate	-.1300	.1204	.869
90min	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	.0200	.1117	1.000
		Carbohydrate before Vegetables	-.3400*	.1117	**.015***
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	-.0200	.1117	1.000
		Carbohydrate before Vegetables	-.3600*	.1117	**.010***
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	.3400*	.1117	**.015***
		Vegetables before Carbohydrate	.3600*	.1117	**.010***
120min	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	-.3400	.1657	.150
		Carbohydrate before Vegetables	-.4400*	.1657	**.039***
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	.3400	.1657	.150
		Carbohydrate before Vegetables	-.1000	.1657	1.000
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	.4400*	.1657	**.039***
		Vegetables before Carbohydrate	.1000	.1657	1.000

*Statistically significant (p<0.05), n=10

Table 4: Glycemic Index of Continuous Glucose Monitoring (CGM) data of Participants that ate different meals

Group	Glycemic Index				Mean GI
	30min	60min	90min	120min	
Carbohydrate + Vegetable together	87.2	90.3	94.1	91.5	90.8

Vegetables before Carbohydrate	86.0	84.5	80.8	77.8	**82.3***
Carbohydrate before Vegetables	92.6	90.8	88.6	85.4	89.4

*Statistically significant (p<0.05), n=10

Effect of different meals on postprandial blood glucose and Glycemic index of Participants

Table 5 presents the effect of different meals on postprandial (after-meal) blood glucose levels at various time intervals (initial, 1 hour, and 2 hours) for three different meal groups. The vegetables before carbohydrate group showed a statistically significant lower mean blood glucose level compared to the other groups. This suggests that consuming vegetables before carbohydrates may lead to a more favorable impact on blood glucose regulation after the meal. Table 6 presents the results of an ANOVA comparing the postprandial (after-meal) glucose levels between and within different meal groups. The ANOVA results indicate that there are statistically significant differences in the 1-hour and 2-hour postprandial glucose levels between different meal groups. Specifically, the Carbohydrate + Vegetable together group and the Vegetables before Carbohydrate group consistently show significant differences in glucose levels compared to each other and to the Carbohydrate before Vegetables group. These findings suggest that the order of consuming vegetables and carbohydrates in a meal may have an impact on postprandial glucose responses. Table 7 presents the glycemic index (GI) values for different meal groups at the 1-hour and 2-hour postprandial (after-meal) time intervals. The vegetables before carbohydrate group showed a statistically significant lower mean GI compared to the other groups. This suggests that consuming vegetables before carbohydrates may result in a lower overall glycemic response after the meal.

Table 5: Effect of different meals on postprandial blood glucose of Participants

Group	Initial	1hr	2hrs	Mean
Carbohydrate + Vegetable together	5.15±0.14	5.37±0.06	5.34±0.09	5.36±0.08
Vegetables before Carbohydrate	4.89±0.16	4.74±0.11	4.51±0.08	4.63±0.10*
Carbohydrate before Vegetables	4.72±0.11	5.53±0.12	5.21±0.15	5.37±0.14

*Statistically significant (p<0.05), n=10

Table 6: ANOVA comparing postprandial glucose between and within groups

1hr	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	-.6300*	.1416	**0.000***
		Carbohydrate before Vegetables	-.7900*	.1416	**0.000***
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	.6300*	.1416	**0.000***
		Carbohydrate before Vegetables	-.1600	.1416	0.805
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	.7900*	.1416	**0.000***
		Vegetables before Carbohydrate	.1600	.1416	0.805
2hrs	Carbohydrate + Vegetable together	Vegetables before Carbohydrate	.8300*	.1540	**0.000***
		Carbohydrate before Vegetables	.2300	.1540	0.441
	Vegetables before Carbohydrate	Carbohydrate + Vegetable together	-.8300*	.1540	**0.000***
		Carbohydrate before Vegetables	-.6000*	.1540	**0.002***
	Carbohydrate before Vegetables	Carbohydrate + Vegetable together	-.2300	.1540	0.441
		Vegetables before Carbohydrate	.6000*	.1540	**0.002***

*Statistically significant (p<0.05), n=10

Table 7: Glycemic index of postprandial blood glucose of Participants

Group	Glycemic Index 1hr	Glycemic Index 2hrs	Mean GI
Carbohydrate + Vegetable together	106.5	94.6	100.6
Vegetables before Carbohydrate	67.6	65.5	**66.6***
Carbohydrate before Vegetables	110	92.4	101.2

*Statistically significant (p<0.05), n=10

DISCUSSION

The findings from this study have provided valuable insights into the impact of different meal compositions on blood glucose levels, postprandial blood glucose levels, and glycemic response. Firstly, the demographic parameters analysis revealed no significant differences in age, weight, systolic blood pressure, and diastolic blood pressure among the three groups. This suggests that any observed variations in the subsequent analyses are less likely to be influenced by these demographic factors. The continuous glucose monitoring (CGM) data showed that participants who consumed vegetables before carbohydrates had a significantly lower mean glucose level compared to the other groups that consumed carbohydrates with vegetables, and carbohydrates before vegetables. This finding indicates that the order of consuming vegetables and carbohydrates in a meal may play a role in blood glucose regulation. The lower mean glucose level in the vegetables before carbohydrate group suggests a more favorable impact on postprandial blood glucose levels. The ANOVA test results further support the notion that there are significant differences in postprandial glucose levels between different meal groups. Specifically, the significant differences observed at various time points for some group comparisons suggest that meal composition can have an influence on blood glucose responses. These findings highlight the importance of considering the order and combination of food components when designing meals for individuals with glucose regulation concerns.

The glycemic index (GI) values provided additional insights into the glycemic response of the different meal groups. The Carbohydrate + Vegetable together group exhibited a moderately high GI, indicating a relatively higher glycemic response. In contrast, the Vegetables before Carbohydrate group demonstrated a lower overall glycemic response, as reflected by the lower GI values at different time intervals. These findings support the notion that consuming vegetables before carbohydrates can lead to a lower glycemic response, potentially contributing to better blood glucose control. This is supported by the study by Jenkins *et al.*, (2014) and Shukla *et al.*, (2019). The review by Goff and Cowland (2013) also showed that low-glycemic index diets have positive effects on blood lipids, suggesting that controlling the glycemic response through diet can have cardiovascular benefits. It is important to note that while there is general agreement among these studies and the current study regarding the beneficial effect of consuming vegetables before carbohydrates on glycemic control (Järvi *et al*., 1999; Jenkins *et al*., 2002; Pittas *et al.*, 2005; Kimura *et al*., 2010; Ebbeling and Ludwig, 2011), variations in study design, participant characteristics, and specific meal compositions may contribute to some discrepancies in the observed results from studies that do not support our findings. Nonetheless, the overall consensus across multiple studies strengthens the evidence for the impact of meal compositions on blood glucose levels and underscores the importance of considering the order and combination of food components in promoting optimal glycemic control.

CONCLUSION

The findings from this study indicate that consuming vegetables before carbohydrates may lead to a lower glycemic response and more favorable blood glucose regulation after a meal. These findings have implications for individuals seeking to manage their blood glucose levels, as well as for healthcare professionals and dietitians in guiding meal planning and dietary recommendations. However, it's important to note that the findings are based on the specific data provided and may not be generalizable to all individuals or meals. Further research and studies are needed to validate these findings and explore the mechanisms underlying the observed effects.

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