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Comparative predictive performance of anthropometric indices and associated risk factors for obesity among Beninese adults: A cross-sectional study

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ABSTRACT

Sub-Saharan Africa is undergoing an epidemiological transition marked by an alarming rise in obesity. This study compared the predictive performance of several anthropometric indices for obesity and identified independent factors associated with its occurrence among Beninese adults. A comparative cross-sectional study was conducted between February 2025 and February 2026 in two departments of Benin (Borgou and Littoral), enrolling 462 adults: 154 obese cases (Body Mass Index, BMI ≥ 30 kg/m²) and 308 age- and sex-matched non-obese controls. Discriminative performance was evaluated using binary logistic regression, receiver operating characteristic (ROC) curve analysis with Youden's index, DeLong's test for area under the curve (AUC) comparison, and classification and regression tree (CART) modeling. Participants were predominantly female (67.1%) with a mean age of 45.2 ± 12.8 years. After adjusting for confounders, obesity was significantly associated with employment status, family history of hypertension or type 2 diabetes, physical inactivity, and waist-to-height ratio (WHtR). The Ponderal Index (PI) demonstrated the highest discriminative capacity (AUC = 0.921), followed by the Abdominal Volume Index (AVI); AUC = 0.903), the Body Roundness Index (BRI); AUC = 0.896), and WHtR (AUC= 0.896). The CART decision tree utilizing AVI and Body Adiposity Index (BAI) achieved an accuracy of 84.1%, with 76.1% sensitivity and 88.0% specificity. This study identifies key risk factors for obesity and highlights the excellent predictive performance of weight-independent anthropometric indices, particularly PI, AVI, WHtR, and BRI. Given their simplicity and low cost, these indices represent highly valuable tools for early screening and monitoring in resource-limited settings.

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INTRODUCTION

Obesity, defined as an excessive accumulation of fat mass, constitutes a major global public health challenge owing to its strong association with severe metabolic complications (Poosri *et al.*, 2024). This multifactorial condition results primarily from a persistent imbalance between energy intake and expenditure, as well as from genetic, behavioral, environmental, and socioeconomic determinants (WHO, 2025). It is one of the main risk factors for noncommunicable diseases-cardiovascular disease, type 2 diabetes, and certain cancers- and places a considerable burden on national health systems (Safaei *et al.*, 2021; Bashir *et al.*, 2025).

In 2021, a body mass index above the optimal level was responsible for approximately 3.7 million deaths worldwide (GBD 2021 Risk Factor Collaborators, 2024). Globally, 2.5 billion adults were overweight in 2022, of whom 890 million were living with obesity; projections indicate that this figure could reach 3.80 billion by 2050 (GBD 2021 Adult BMI Collaborators, 2025; WHO, 2025).

This trend takes on a particularly worrying dimension in sub-Saharan Africa, which is projected to experience the largest global increase in the number of people affected (+254.8% between 2021 and 2050) (GBD 2021 Adult BMI Collaborators, 2025). This dynamic is part of a nutritional transition marked by urbanization, sedentary lifestyles, and increasing consumption of processed foods (Popkin *et al.*, 2020), exposing these countries to a double epidemiological burden in which noncommunicable diseases and undernutrition coexist in settings with limited health resources (Atsu *et al.*, 2024). In Benin, the 2015 national STEPS survey estimated the prevalence of obesity at 7.4% among adults aged 18 to 69 years, with a marked female predominance (10.1% vs 4.6%) (Agueh *et al.*, 2015; World Health Organization, 2015). These findings underscore the urgent need for simple, reliable screening tools adapted to local realities.

Body mass index (BMI) remains the reference tool for classifying weight status (Nuttall, 2015; GBD 2021 Adult BMI Collaborators, 2025), but presents several major conceptual limitations: it does not distinguish fat mass from lean mass, does not provide information on the topographic distribution of adiposity, and its fixed height exponent does not adapt to interindividual and interethnic morphological variation, which is particularly problematic in African populations (Krakauer and Krakauer, 2012; Nuttall, 2015; Haregu *et al.*, 2016).

Given these limitations, several alternative anthropometric indices have been developed to better characterize body morphology and central adiposity: the waist-to-height ratio (WHtR), proposed as a more effective tool than the Body Mass Index (BMI) for cardiometabolic risk (Ashwell *et al.*, 2012); the body roundness index (BRI), based on geometric modeling (Thomas *et al.*, 2013); the body shape index (ABSI), designed to quantify the risk associated with abdominal adiposity independently of Body Mass Index, (BMI) (Krakauer and Krakauer, 2012); as well as the Body Adiposity Index (BAI), the abdominal volume index (AVI), the conicity index (CI), the weight-adjusted waist index (WWI), and the ponderal index (PI). Most of these indices have been evaluated mainly about cardiovascular and metabolic risk (Maessen *et al.*, 2014; Ensan *et al.*, 2025), and more rarely for their own diagnostic capacity with respect to obesity, particularly in sub-Saharan Africa, where thresholds established in Western populations often prove unsuitable (Haregu *et al.*, 2016; Engwa *et al.*, 2021). It is within this perspective that the present study is situated, its objective being to assess, within an adults Beninese population, the factors associated with obesity as well as the predictive performance of the various anthropometric indices, in order to identify the most relevant screening tools for this context.

MATERIALS AND METHODS

Design and study population

This was an analytical cross-sectional epidemiological study comparing two contrasting groups according to weight status (BMI ≥ 30 kg/m² vs BMI < 30 kg/m²), frequency-matched for age and sex at a 2:1 ratio. This design differs from a conventional case-control study in that the outcome (weight status) and all exposures (anthropometric indices, lifestyle factors, and medical history) were measured simultaneously, without any time lag. Therefore, it does not allow causal inference in the strict sense but provides appropriate statistical power for identifying associated factors and comparatively assessing the predictive performance of several anthropometric indices.

The study received academic approval from the Doctoral School of Life and Earth Sciences (University of Abomey-Calavi), ethical approval from the Local Committee for Biomedical Research Ethics of the University of Parakou (No. 647/2024/CLERB-UP/P/SP/R/SA, 24 May 2024), and authorization from the Office of Health Education and Research of the Ministry of Health (No. 0646/MS/DC/SGM/DFRS/SRS/SA, 28 February 2025).

Sample collection and analysis

Two groups were formed: the case group with BMI ≥ 30 kg/m² (18–69 years) and the controls group with BMI < 30 kg/m² (18–69 years), with similarity of age and sex distributions sought between the two groups, in a 2:1 ratio. Common criteria: permanent residence at the collection site for at least six months.

The minimum sample size was estimated using the Fleiss, Levin, and Paik (2013) formula, adapted for case-control studies with a multiple control group (Fleiss *et al.*, 2013).

Applying the formula yields a required minimum of n ≈ 84 subjects for the case group. The number of subjects actually included (154 cases, 308 controls, for a total of 462) therefore far exceeds this minimum, giving the study a comfortable margin of statistical power above the targeted nominal threshold.

A total of 556 adults were surveyed in the two cities (Cotonou and Parakou). After applying the inclusion and exclusion criteria, 94 individuals were excluded: refusal to participate (n = 28), incomplete anthropometric data (n = 18), pregnancy (n = 14), lack of consent for the biological component (n = 12), condition or treatment likely to alter anthropometric measurements independently of nutritional status (n = 10), or other exclusion criteria (n = 12). The final analysis included 462 participants, comprising 154 cases (BMI ≥ 30 kg/m²) and 308 controls (BMI < 30 kg/m²), corresponding to a participation rate of 83.1%. Individual case-control matching was performed at a 1:2 ratio, by age (± 5 years) and sex.

The dependent variable is the presence of obesity, defined as a BMI ≥ 30 kg/m² according to World Health Organization (WHO) criteria (World Health Organization, 2000). The independent variables included sociodemographic characteristics, dietary habits (Dietary Diversity Score (DDS) and Food Consumption Score (FCS)), physical activity level (PAL) score, Global Physical Activity Questionnaire (GPAQ), medical and family history, risk behaviors, and anthropometric indices (BMI, WHtR, BRI, AVI, BAI, PI, ABSI, CI, WWI).

Statistical analyses

All analyses were performed using R software (version 4.5.2; R Core Team, 2025). The statistical significance threshold used was $p < 0.05$.

Quantitative variables were described by their median and interquartile range (Q1–Q3), while qualitative variables were summarized by their frequencies and proportions. Participant characteristics were compared between groups using the χ^2 test (or Fisher's exact test when application conditions were not met) for qualitative variables. Associations between each explanatory variable and obesity were then assessed by univariate logistic regression, with estimation of crude odds ratios (OR), their 95% confidence intervals (95% CI), and p-values.

Variables showing an association with obesity at the $p < 0.20$ threshold, as well as those considered clinically relevant, were retained as candidates for multivariate modeling. The matching variables (age and sex), used for frequency matching when forming the groups, were systematically considered in the multivariate model regardless of their level of significance in univariate analysis.

Construction of the multivariate model followed a hierarchical approach. A saturated model including clinically relevant variables and those associated with obesity in bivariate analysis ($p < 0.20$) was first fitted. Multicollinearity was then assessed using variance inflation factors (VIF).

Given the strong mathematical dependence between several anthropometric indices (WHtR, BRI, AVI, PI, BAI, and ABSI), these variables were not entered simultaneously into the same model.

When several indices were collinear, the one showing the best diagnostic performance (highest AUC) and the strongest discriminant power was preferred. A bidirectional stepwise selection based on Akaike's Information Criterion (AIC) was then applied to obtain the most parsimonious final model. The matching variables (age and sex) were entered into the initial model but were not retained in the final model. Estimates are reported as adjusted odds ratios (aOR) with their 95% CI, and a significance threshold of $p < 0.05$ was used.

The Receiver Operating Characteristic (ROC) curves were constructed for each anthropometric indicator. The area under the curve (AUC) with 95% CI was calculated for each indicator. Optimal diagnostic thresholds were determined by maximizing the Youden index (J = Sensitivity + Specificity – 1). For each optimal threshold, sensitivity, specificity, positive and negative predictive values (PPV and NPV), and positive and negative likelihood ratios (PLR) and Negative Likelihood Ratio (NLR) were estimated. Comparison of AUCs between indices was performed using the DeLong test (1988).

A CART decision tree was constructed to identify the optimal combination of anthropometric indices for the diagnosis of obesity. Data were randomly and stratified partitioned into a training set (70%, n= 323) and an independent test set (30%, n = 138), with a fixed random seed (seed = 123) to ensure reproducibility. The eight anthropometric indices (PI, WHtR, AVI, BRI, BAI, ABSI, CI, WWI) were entered simultaneously as predictive variables, with the dependent variable being weight status (obese vs non-obese). The node-splitting criterion was the Gini impurity. The initial tree was pruned by 10-fold cross-validation to select the optimal complexity parameter (cp), limiting overfitting. The relative importance of each variable was estimated by the total reduction in Gini impurity. The performance of the final model was assessed on the test set by calculating overall accuracy, sensitivity, specificity, and AUC with 95% CI (bootstrap, 1,000 resamples). Analyses were performed using the rpart package in R (version 4.5.2; R Core Team, 2025).

RESULTS

General sample description

Table 1 describes the general characteristics of the study population according to their respective weight status. The population comprises a total of 462 subjects, including 308 controls (BMI < 30) and 154 cases (BMI ≥ 30). It is predominantly female (67.1%) and of Fon ethnicity (77.9%). Among the sociodemographic variables examined, only education level shows a statistically significant difference between cases and controls ($p = 0.037$), with a higher proportion of subjects with a university education among cases (20.1% vs 11.4%). Regarding medical history, family history of diabetes ($p= 0.020$) and hypertension ($p = 0.004$) differ significantly between the two groups. For continuous variables, the PAL score ($p < 0.001$), DDS score ($p= 0.032$), and FCS score ($p = 0.033$) differ significantly between cases and controls, with consistently higher median values observed among cases for all three variables.

Table 1. General characteristics of the population by weight status (n = 462)

Variable	Total N = 462	95% CI	Controls N = 308	Cases N = 154	p-value
Sex					0.806
Male	152 (32.90%)	29%, 37%	103 (33.44%)	49 (31.82%)	
Female	310 (67.10%)	63%, 71%	205 (66.56%)	105 (68.18%)	
Ethnicity					0.071
Fon	360 (77.92%)	74%, 82%	228 (74.03%)	132 (85.71%)	
Nago	65 (14.07%)	11%, 18%	52 (16.88%)	13 (8.44%)	
Bariba	11 (2.38%)	1.3%, 4.3%	8 (2.60%)	3 (1.95%)	
Dendi	15 (3.25%)	1.9%, 5.4%	11 (3.57%)	4 (2.60%)	
Otamari	11 (2.38%)	1.3%, 4.3%	9 (2.92%)	2 (1.30%)	
Education level					0.037*
Illiterate	76 (16.45%)	13%, 20%	55 (17.86%)	21 (13.64%)	
Literate	41 (8.87%)	6.5%, 12%	29 (9.42%)	12 (7.79%)	
Primary	127 (27.49%)	24%, 32%	93 (30.19%)	34 (22.08%)	
Secondary	152 (32.90%)	29%, 37%	96 (31.17%)	56 (36.36%)	
University	66 (14.29%)	11%, 18%	35 (11.36%)	31 (20.13%)	
Marital status					0.335
Single	44 (9.52%)	7.1%, 13%	32 (10.39%)	12 (7.79%)	
Married	346 (74.89%)	71%, 79%	234 (75.97%)	112 (72.73%)	
Widowed	53 (11.47%)	8.8%, 15%	30 (9.74%)	23 (14.94%)	
Separated	19 (4.11%)	2.6%, 6.5%	12 (3.90%)	7 (4.55%)	
Occupational status					0.058
Civil servant	108 (23.38%)	20%, 28%	63 (20.45%)	45 (29.22%)	
Artisan	251 (54.33%)	50%, 59%	167 (54.22%)	84 (54.55%)	
Student	69 (14.94%)	12%, 19%	51 (16.56%)	18 (11.69%)	
Retired	34 (7.36%)	5.2%, 10%	27 (8.77%)	7 (4.55%)	
Mean monthly income (FCFA)					0.164
< 50,000	178 (38.53%)	34%, 43%	122 (39.61%)	56 (36.36%)	
50,000 - 100,000	136 (29.44%)	25%, 34%	98 (31.82%)	38 (24.68%)	
100,000 - 150,000	88 (19.05%)	16%, 23%	53 (17.21%)	35 (22.73%)	
150,000 - 200,000	27 (5.84%)	4.0%, 8.5%	14 (4.55%)	13 (8.44%)	
> 200,000	33 (7.14%)	5.0%, 10%	21 (6.82%)	12 (7.79%)	
Personal history of diabetes					0.965
No	386 (83.55%)	80%, 87%	258 (83.77%)	128 (83.12%)	
Yes	76 (16.45%)	13%, 20%	50 (16.23%)	26 (16.88%)	
Personal history of hypertension					>0.999
No	398 (86.15%)	83%, 89%	265 (86.04%)	133 (86.36%)	
Yes	64 (13.85%)	11%, 17%	43 (13.96%)	21 (13.64%)	
Family history of diabetes					0.020*
No	230 (49.78%)	45%, 54%	141 (45.78%)	89 (57.79%)	
Yes	232 (50.22%)	46%, 55%	167 (54.22%)	65 (42.21%)	
Family history of hypertension					0.004*
No	296 (64.07%)	59%, 68%	183 (59.42%)	113 (73.38%)	
Yes	166 (35.93%)	32%, 41%	125 (40.58%)	41 (26.62%)	
Age (years)	45 (36, 54)	44, 46	45 (35, 54)	45 (38, 55)	0.322
PAL score	15 (12, 22)	16, 18	14 (11, 20)	17 (12, 23)	<0.001*
DDS score	5.00 (3.00, 7.00)	4.8, 5.2	4.00 (3.00, 6.00)	5.00 (3.00, 7.00)	0.032*
FCS score	39 (30, 53)	39, 42	37 (28, 52)	42 (30, 56)	0.033*

Data are expressed as frequency (%) for qualitative variables and as median [Q1–Q3] for continuous variables. 95% CI = 95% confidence interval. p-values from the χ^2 test for qualitative variables and the Wilcoxon-Mann-Whitney test for continuous variables. * $p < 0.05$ (bold). PAL = Physical Activity Level; DDS = Dietary Diversity Score; FCS = Food Consumption Score.

Factors associated with obesity

The factors associated with obesity are shown in Table 2: crude ORs from univariate logistic regression. Univariate analysis reveals that age greater than 35 years is significantly associated with obesity (OR = 1.63; 95% CI: 1.02–2.68; p= 0.041), as is university-level education (OR= 2.32; 95% CI: 1.16–4.71; p= 0.039). Family history of diabetes (OR = 0.62; 95% CI: 0.42–0.91; p= 0.015) and of hypertension (OR= 0.53; 95% CI: 0.35–0.81; p =

0.003) are significantly associated with a reduced risk of obesity. WHtR > 0.5 shows the strongest association with obesity (OR = 28.4; 95% CI: 10.4–117; p < 0.001). The AVI (OR = 1.42; p < 0.001), BAI (OR= 1.16; p < 0.001), BRI (OR= 2.72; p < 0.001), and PI (OR = 1.27; p < 0.001) indices are all significantly associated with obesity. ABSI shows a significant association but with an OR of 0.01 (95% CI: 0.00–0.03; p < 0.001). The PAL score, whether treated as a continuous variable (OR = 1.05; p < 0.001) or dichotomized at the threshold of 18 (OR = 0.57; p= 0.006), is significantly associated with obesity, as are the FCS (OR = 1.01; p = 0.005) and DDS (OR = 1.11; p = 0.008) scores.

Table 2. Factors associated with obesity: crude ORs from univariate logistic regression (n = 462)

Variable	Crude OR	95% CI	*p*-value
Female sex	1.08	0.71 – 1.64	0.700
Age > 35 years	1.63	1.02 – 2.68	0.041*
University level	2.32	1.16 – 4.71	0.039*
Occupational status	—	—	0.054
Student	0.49	0.25 – 0.94	
Retired	0.36	0.14 – 0.87	
Personal history of diabetes	1.05	0.62 – 1.76	0.86
Personal history of hypertension	0.97	0.55 – 1.71	0.92
Family history of diabetes	0.62	0.42 – 0.91	0.015*
Family history of hypertension	0.53	0.35 – 0.81	0.003*
WHtR > 0.5	28.4	10.4 – 117	<0.001*
AVI	1.42	1.33 – 1.53	<0.001*
BAI	1.16	1.13 – 1.21	<0.001*
BRI	2.72	2.27 – 3.33	<0.001*
PI	1.27	1.22 – 1.33	<0.001*
ABSI	0.01	0.00 – 0.03	<0.001*
WWI	0.94	0.80 – 1.09	0.400
CI	5.82	1.41 – 23.9	0.015*
PAL score < 18 (sedentary)	0.57	0.39 – 0.85	0.006*
PAL score	1.05	1.02 – 1.07	<0.001*
FCS score	1.01	1.00 – 1.03	0.005*
DDS score	1.11	1.03 – 1.19	0.008*

* p < 0.05; OR = Odds Ratio; 95% CI = 95% confidence interval; AVI = Abdominal Volume Index; BAI = Body Adiposity Index; BRI = Body Roundness Index; PI= Ponderal Index; ABSI= A Body Shape Index; WHtR= Waist-to-Height Ratio; PAL= Physical Activity Level; FCS= Food Consumption Score; DDS= Dietary Diversity Score; CI= Conicity Index; WWI = Weight-adjusted Waist Index.

Table 3. Independent factors associated with obesity in multivariate analysis — Adjusted Odds Ratios (aOR), n = 462

Characteristic	aOR	95% CI	p-value
Family history of hypertension			
No	—	—	
Yes	0.57	0.35, 0.90	0.017*
WHtR > 0.5			
No	—	—	
Yes	26.0	9.49, 108	<0.001*
PAL score (physical activity)	1.05	1.02, 1.08	<0.001*
Occupational status			
Artisan	—	—	
Civil servant	0.77	0.46, 1.29	0.3
Student	0.56	0.27, 1.16	0.13
Retired	0.33	0.11, 0.86	0.030*

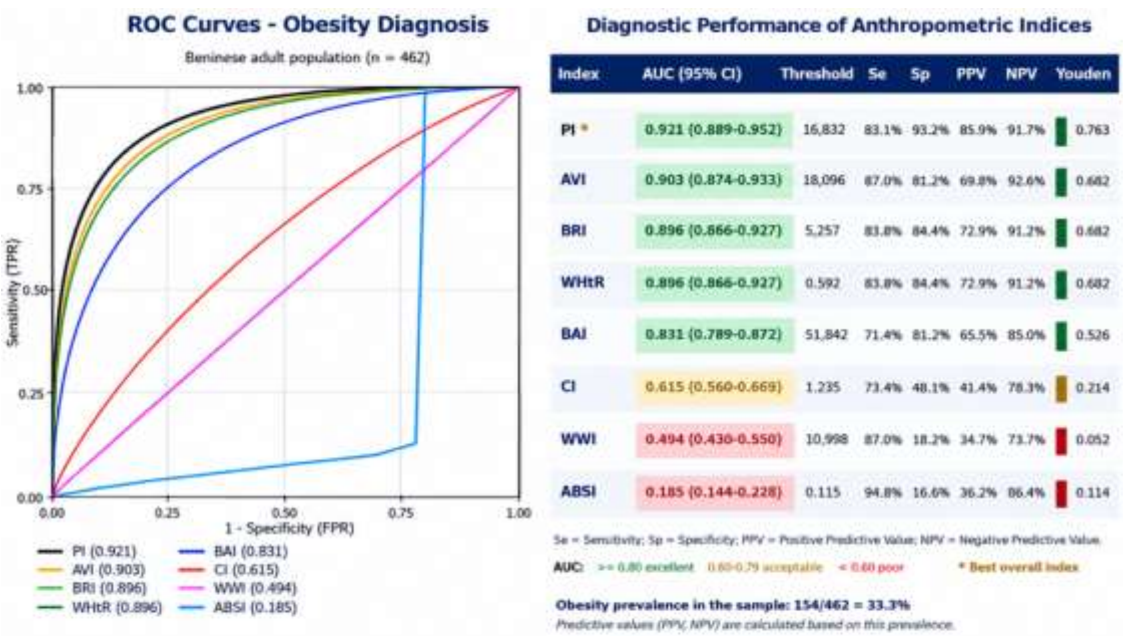
aOR = Adjusted Odds Ratio; 95% CI = 95% confidence interval; WHtR = Waist-to-Height Ratio; PAL = Physical Activity Level; HTN = Hypertension. Reference WHtR: ≤ 0.5; Reference occupational status: Artisan. Values in bold: p < 0.05.

Predictive factors of obesity

Table 3 shows the independent factors associated with obesity in multivariate analysis- Adjusted Odds Ratios (aOR). Multivariate analysis identified four independent determinants of obesity after mutual adjustment. Waist-to-height ratio (WHtR) greater than 0.5 is the factor most strongly associated with obesity (aOR= 26.0; 95% CI: 9.49–108; $p < 0.001$). Family history of hypertension is associated with a reduced risk of obesity (aOR = 0.57; 95% CI: 0.35–0.90; p = 0.017). The PAL score, treated as a continuous variable, remains significantly associated with obesity after adjustment, each additional point increasing the odds of being obese by 5% (aOR = 1.05; 95% CI: 1.02–1.08; $p < 0.001$). Among occupational categories, retirees show a significantly lower risk than artisans, taken as the reference group (aOR = 0.33; 95% CI: 0.11–0.86; p = 0.030).

Predictive performance of the anthropometric indices

Fig. 1 displays the ROC curves and predictive performance of anthropometric indices for obesity screening in an adult Beninese population. Analysis of the ROC curves reveals variable diagnostic performance across the indices studied. PI shows the best performance, with an AUC of 0.921 (95% CI: 0.889–0.952), a sensitivity of 83.1%, a specificity of 93.2%, and a Youden index of 0.763. AVI shows an AUC of 0.903 (95% CI: 0.874–0.933), with an optimal threshold of 18.096, a sensitivity of 87.0%, and a specificity of 81.2%. BRI and WHtR show identical performance (AUC = 0.896; 95% CI: 0.866–0.927), with a sensitivity of 83.8% and a specificity of 84.4% for respective thresholds of 5.257 and 0.592. BAI shows an AUC of 0.831 (95% CI: 0.789–0.872), a sensitivity of 71.4%, and a specificity of 81.2% for a threshold of 51.842. CI shows an AUC of 0.615 (95% CI: 0.560–0.669) and WWI an AUC of 0.494 (95% CI: 0.439–0.550). ABSI shows an AUC of 0.185 (95% CI: 0.144–0.226), below the 0.5 threshold. Pairwise comparisons of AUCs (DeLong test) confirmed that PI's superiority over other indices is statistically significant only relative to BAI, ABSI, WWI, and CI, and not relative to AVI, BRI, or WHtR.



Index	AUC (95% CI)	Threshold	Se	Sp	PPV	NPV	Youden
PI *	0.921 (0.889-0.952)	16,832	83.1%	93.2%	85.9%	91.7%	0.763
AVI	0.903 (0.874-0.933)	18,096	87.0%	81.2%	69.8%	92.6%	0.682
BRI	0.896 (0.866-0.927)	5,257	83.8%	84.4%	72.9%	91.2%	0.682
WHtR	0.896 (0.866-0.927)	0.592	83.8%	84.4%	72.9%	91.2%	0.682
BAI	0.831 (0.789-0.872)	51,842	71.4%	81.2%	65.5%	85.0%	0.526
CI	0.615 (0.560-0.669)	1.235	73.4%	48.1%	41.4%	78.3%	0.214
WWI	0.494 (0.430-0.550)	10,998	87.0%	18.2%	34.7%	73.7%	0.052
ABSI	0.185 (0.144-0.228)	0.115	94.8%	16.6%	36.2%	86.4%	0.114

Fig. 1. ROC curves and predictive performance of anthropometric indices for obesity screening in an adult Beninese population (n = 462)

Fig. 2 shows the performance of the decision tree model for predicting obesity: decision structure and distribution of predicted probabilities (Accuracy= 84.1%; n= 138). AVI and BAI were selected for their complementary nature. AVI reflects abdominal adiposity and is associated with obesity as well as insulin resistance, while BAI estimates total body fat mass independently of weight, with DEXA validation. Their combination thus makes it possible to simultaneously capture the central and global dimensions of adiposity, which may contribute differently to cardiometabolic risk.

Analysis of this decision tree model identified a first node based on the AVI < 19 threshold, directing subjects predominantly toward the "non-obese" class and, above this threshold, toward the "obese" class. Subsequent splits rely mainly on BAI (<54, <48, ≥38, <57) and secondarily on AVI (<15), leading to terminal leaves grouping mainly non-obese (55%) or obese (26%) subjects. On the test set (n = 138).

The model achieved an accuracy of 84.1% (TP = 35; TN= 81; FP = 11; FN = 11), with a sensitivity of 76.1% and a specificity of 88.0%. The distribution of predicted probabilities shows a clear separation of classes around the decision threshold of 0.50: most controls show probabilities below 0.15, whereas cases show probabilities above 0.85, reflecting good discriminant capacity of the model.

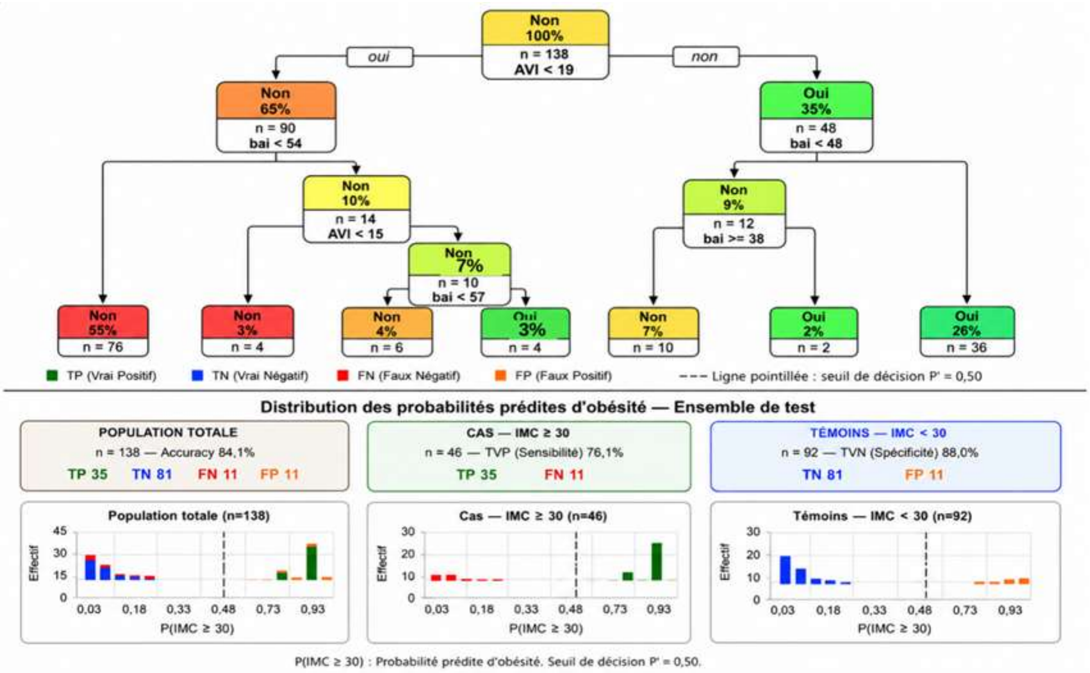


Fig. 2. Performance of the decision tree model for predicting obesity: decision structure and distribution of predicted probabilities (Accuracy = 84.1%; n = 138)

DISCUSSION

The population studied comprises 462 subjects (154 cases, 308 controls), predominantly female (67.1%) and of Fon ethnicity (77.9%), with a median age of 45 years [36–54]. This composition faithfully reflects the demography of Cotonou and the coastal region of Benin (World Health Organization, 2015), which confers good external validity on the results for this context. The female over-representation among cases (68.2%) fits a well-documented African trend: the 2015 Benin STEPS survey reports an obesity prevalence of 10.1% among women versus 4.6% among men, and the study by Agboyibor *et al.*, covering 36 countries in the WHO African region, finds odds of obesity five times higher among women (Agboyibor *et al.*, 2026). At the pan-African level, Osborne observes this predominance in almost all of the 47 countries analyzed, with a gap that can exceed 30 percentage points (Osborne, 2025). These sex disparities relate to biological determinants (estrogen-dependent adipogenesis, effects of parity), sociocultural determinants (valuing higher body fat in women in sub-Saharan Africa), and behavioral determinants (lower leisure-time physical activity) (El Mabchour *et al.*, 2015; Agboyibor *et al.*, 2026).

Education level is the only sociodemographic factor associated with obesity in descriptive analysis ($p = 0.037$), with a proportion of subjects with a university level nearly twice as high among cases as among controls (20.1% vs 11.4%). In univariate analysis, university level is associated with an increased risk of obesity (OR = 2.32; 95% CI: 1.16–4.71; $p = 0.039$). This association, frequently observed in sub-Saharan Africa, is generally attributed to the adoption of more sedentary lifestyles and to a nutritional transition linked to urbanization and rising socioeconomic status (El Mabchour *et al.*, 2015; Haregu *et al.*, 2016). However, its disappearance in the multivariate model suggests that this effect is largely mediated by other behavioral and anthropometric factors. Regarding occupational category, retirees show a significantly lower risk of obesity than artisans after adjustment (aOR = 0.33; 95% CI: 0.11–0.86; $p = 0.030$). This finding could reflect lifestyle differences, notably a more traditional diet and a higher level of daily activity. Nevertheless, given the small number of retirees included in the study, this result should be interpreted with caution and confirmed by larger-scale studies.

Family history of hypertension is associated with a significant decrease in the risk of obesity, both in univariate analysis (OR = 0.53; 95% CI: 0.35–0.81; $p = 0.003$) and in multivariate analysis (aOR = 0.57; 95% CI: 0.35–0.90; $p= 0.017$). This inverse association could reflect a heightened perception of cardiovascular risk among subjects from hypertensive families, favoring the adoption of preventive behaviors and better weight control (El Mabchour *et al.*, 2015). It could also reflect more regular medical follow-up and early awareness of risk factors (Haregu *et al.*, 2016). Family history of diabetes is also associated with a reduced risk of obesity in univariate analysis (OR = 0.62; 95% CI: 0.42–0.91; $p = 0.015$), but this association disappears after adjustment. This loss of significance suggests a shared effect with family history of hypertension, common in the context of metabolic syndrome, and underscores the need to interpret associations observed in bivariate analysis with caution.

In bivariate analysis, the FCS (OR = 1.01; 95% CI: 1.00–1.02; $p= 0.005$) and the Dietary Diversity Score (DDS) (OR = 1.11; 95% CI: 1.03–1.20; $p = 0.008$) are associated with an increased risk of obesity. In a context of nutritional transition, greater dietary diversity may reflect higher consumption of energy-dense and ultra-processed foods rather than a balanced diet (Poosri *et al.*, 2024). However, these associations disappear in the multivariate model, probably owing to their mediation by abdominal adiposity as measured by WHtR and to the inherent limitations of self-reported dietary data, which are subject to recall and social desirability biases (Poosri *et al.*, 2024). These results highlight the value of using more objective dietary measures in future studies.

The PAL score is higher among obese subjects and remains associated with obesity after adjustment (aOR = 1.05; 95% CI: 1.02–1.08; $p < 0.001$). This paradoxical result could be explained by the limitations of self-reported measures, which are subject to social desirability bias, as well as by the score's inability to distinguish activity of necessity from leisure-time physical activity (Bull *et al.*, 2020; Rubino *et al.*, 2025). However, when PAL is dichotomized at the threshold of 18, a high level of activity (PAL ≥ 18) is associated with a reduced risk of obesity (OR = 0.57; 95% CI: 0.38–0.84; $p = 0.006$). This finding suggests a threshold effect, whereby only sufficient physical activity exerts a protective effect, consistent with WHO recommendations (Bull *et al.*, 2020). Objective measures, such as accelerometry, would be needed to confirm this interpretation.

Analysis of the ROC curves shows a clear superiority of PI (AUC = 0.921), followed by AVI (AUC = 0.903), then BRI and WHtR (AUC = 0.896 each). However, the high performance of PI must be interpreted with caution given its mathematical proximity to BMI, used as the reference criterion, which exposes it to incorporation bias (Mohajan and Mohajan, 2023). Among the weight-independent indices, AVI appears to be the most effective, with excellent sensitivity (87.0%) and a strong negative predictive value, confirming its value for screening abdominal obesity (Cai *et al.*, 2022; Ensan *et al.*, 2025). BRI and WHtR show identical performance, consistent with their close mathematical relationship (Thomas *et al.*, 2013). In practice, WHtR remains the simplest tool to use. The optimal threshold observed (0.592) is higher than the universal threshold of 0.50, suggesting the need for thresholds adapted to sub-Saharan populations (Agueh *et al.*, 2015; El Mabchour *et al.*, 2015; Rubino *et al.*, 2025). Furthermore, WHtR > 0.5 is the factor most strongly associated with obesity in the multivariate model (aOR= 26.0; $p < 0.001$). BAI shows fair discriminant performance but significantly lower than that of AVI, BRI, and WHtR. Its dependence on hip circumference and moderate sensitivity limit its value as a first-line screening tool (Haregu *et al.*, 2016; Ensan *et al.*, 2025). In contrast, ABSI, WWI, and CI show weak or null discriminant capacity (AUC ≤ 0.62) and do not appear suited to screening for BMI-defined obesity. These results are consistent with limitations already reported for these indices in other populations, despite their potential value for other metabolic or cardiovascular outcomes (Suliga *et al.*, 2019; Jayawardena *et al.*, 2020; Piqueras *et al.*, 2021; Mohajan and Mohajan, 2023).

The decision tree based on AVI and BAI achieved, on the test set (n = 138), an accuracy of 84.1%, with a sensitivity of 76.1% and a specificity of 88.0%. Although its overall performance is lower than that of PI taken in isolation (which is expected given the incorporation bias affecting the latter), this tree has the advantage of being simple, interpretable, and achievable using only a measuring tape (waist circumference, hip circumference, and height), without scales or laboratory testing, which strengthens its practical value in resource-limited settings such as Benin. This structure highlights the complementarity between visceral and peripheral adiposity in identifying obesity (Tian *et al.*, 2020).

The hormonal status of the women in this cohort (median age 45 years) deserves mention as a potential unmeasured confounding factor: the perimenopausal period is accompanied by an android redistribution of fat mass likely to alter the performance of abdominal adiposity indices (WHtR, BRI, AVI) among women in this age group. This dimension could not be explored in the present study, owing to the lack of data on the menopausal status of participants, and is noted as an avenue for future research.

Several limitations must be considered when interpreting these results. First, the use of BMI as the reference criterion for defining obesity may introduce an incorporation bias for indices derived from weight and height, notably PI. The performance observed for these indices therefore partly reflects their mathematical proximity to BMI rather than their ability to measure actual adiposity. Validation using reference methods such as Dual-energy X-ray Absorptiometry (DXA) or multifrequency bioimpedance would be desirable. Second, physical activity levels and dietary habits were assessed using self-reported data, which are subject to recall and social desirability biases. This limitation may have affected the measurement of these behaviors and influenced the associations observed. Third, the matched case-control design allows identification of factors associated with obesity but does not allow causal relationships or temporality between exposure and the outcome studied to be established. Prospective studies are needed to confirm these associations.

Despite these limitations, the quality of matching, the sample size, the geographic diversity of participants, and the use of robust statistical methods strengthen the validity and relevance of the results for the Beninese context.

CONCLUSION

This study highlights four independent determinants of obesity in multivariate analysis: the waist-to-height ratio (WHtR > 0.5), by far the most strongly associated (aOR = 26.0), the level of physical activity, and family history of hypertension and retirement status, both protective.

Diagnostically, the ponderal index (PI) shows the best performance (AUC = 0.921), its superiority being confirmed by the DeLong test, while AVI offers the best sensitivity (87.0%) and WHtR (threshold 0.592) remains a simple, first-line tool suited to resource-limited care settings. Finally, a decision tree based solely on the AVI and BAI indices provides a clinical algorithm achievable with a simple measuring tape and scale, without laboratory testing, achieving on an independent test sample an accuracy of 84.1%, a sensitivity of 76.1%, and a specificity of 88.0%. These cross-sectional findings warrant longitudinal studies and multicenter validation to consolidate thresholds specific to the Beninese population and to assess their predictive value for long-term metabolic complications.

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