Defining a dichotomous indicator for population-level assessment of dietary diversity among pregnant adolescent girls and women: a secondary analysis of quantitative 24-h recalls from rural settings in Bangladesh, Burkina Faso, India and Nepal

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Defining a dichotomous indicator for population-level assessment of dietary diversity among pregnant adolescent girls and women: a secondary analysis of quantitative 24-h recalls from rural settings in Bangladesh, Burkina Faso, India and Nepal

Author names and affiliations

Eric O. Verger[a], Sabrina Eymard-Duvernay[a], Dang Bahya-Batinda[a], Giles T. Hanley-Cook[b], Alemayehu Argaw[b,c], Elodie Becquey[d], Loty Diop[d], Aulo Gelli[e], , Helen Harris-Fry[f], Shivani Kachwaha[g], Sunny S. Kim[e], Phuong Hong Nguyen[e], Naomi M. Saville[h], Lan Mai Tran[i], Rock R. Zagré[d], Edwige Landais[a], Mathilde Savy[a], Yves Martin-Prevel[a] and Carl Lachat[b].

[a] MoISA, Univ Montpellier, CIRAD, CIHEAM-IAMM, INRAE, Institut Agro, IRD, Montpellier, France; [b] Department of Food Technology, Safety and Health, Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium; [c] Department of Population and Family Health, Institute of Health, Jimma University, Jimma, Ethiopia; [d] International Food Policy Research Institute (IFPRI), Dakar, Senegal; [e] International Food Policy Research Institute (IFPRI), Washington, DC, USA; [f] Department Population Health, London School of Hygiene & Tropical Medicine, London, UK; [g] Johns Hopkins University, Baltimore, Maryland, USA; [h] UCL Institute for Global Health, London, United Kingdom; [i] Emory University, Atlanta, Georgia, USA

Corresponding author

Eric O. Verger, MoISA, IRD, 911 avenue d'Agropolis, 34000 Montpellier, France. Email: eric.verger@ird.fr

1 **Abstract (300 words maximum)**

2 **Background**: The Minimum Dietary Diversity for Women of Reproductive Age (MDD-W)

3 indicator was validated as a proxy of micronutrient adequacy among non-pregnant women in

4 low- and middle-income countries (LMICs). At that time, indeed, there was insufficient data to

5 validate the indicator among pregnant women, who face higher micronutrient requirements.

6 **Objective**: This study aimed to validate a minimum food group consumption threshold, out of

7 the 10 food groups used to construct MDD-W, to be used as a population-level indicator of

8 higher micronutrient adequacy among pregnant women aged 15-49 years in LMICs.

9 **Methods**: We used secondary quantitative 24-hour recall data from 6 surveys in 4 LMICs

10 (Bangladesh, Burkina Faso, India and Nepal, total n=4909). We computed the 10-food group

11 Women's Dietary Diversity Score (WDDS-10) and calculated the mean probability of adequacy

12 (MPA) of 11 micronutrients. Linear regression models were fitted to assess the associations

13 between WDDS-10 and MPA. Sensitivity, specificity and proportion of individuals correctly

14 classified were used to assess the performance of MDD-W in predicting an MPA >0.60.

15 **Results**: In the pooled sample, median values (interquartile range) of WDDS-10 and MPA were

16 3 (1) and 0.20 (0.34), respectively, while the proportion of pregnant women with an MPA >0.60

17 was 9.6%. The WDDS-10 was significantly positively associated with MPA in each survey.

18 Although the acceptable food group consumption threshold varied between 4 and 6 food groups

19 across surveys, the threshold of 5 showed the highest performance in the pooled sample with

20 good sensitivity (62%), and very good specificity (81%) and percentage of correctly classified

21 individuals (79%).

22 **Conclusions**: The WDDS-10 is a good predictor of dietary micronutrient adequacy among

23 pregnant women aged 15-49 years in LMICs. Moreover, the threshold of 5 or more food group

24 for the MDD-W indicator may be extended to all women of reproductive age, regardless of

25 their physiological status.

26 **Teaser Text**

27 This study aimed to validate whether the threshold of 5 or more food group for the MDD-W

28 indicator can to be used among pregnant women aged 15-49 years in low- and middle-income

29 countries.

30

31 **Abbreviations**:

32 BLUP: Best linear unbiased predictor

33 EAR: Estimated Average Requirement

34 LMIC: Low- and Middle-Income Country

35 MDD-W: Minimum Dietary Diversity for Women

36 MPA: Mean probability of adequacy

37 PA: Probability of adequacy

38 WDDS-10: 10-food group Women's Dietary Diversity Score

39

40 **Keywords**: dietary diversity; indicator; micronutrient adequacy; minimum dietary diversity for

41 women; pregnant; resource-poor settings.

Introduction

42

43 Micronutrients are essential vitamins and minerals whose subclinical deficiencies contribute

44 to an increased risk of morbidity and mortality (1). A recent analysis suggested that two-thirds

45 of non-pregnant women of reproductive age have one or more micronutrient deficiencies

46 worldwide, with higher prevalence in low- and middle-income countries (LMICs) (2). There

47 are important changes in dietary requirements driven by physiological processes during

48 pregnancy, including increased requirements for folate, iron, vitamin B12 and B6, and zinc

49 (3). These deficiencies are exacerbated during pregnancy due to an additional demand for

50 nutrients to support both fetal growth and development and maternal metabolism (4), and can

51 result in adverse outcomes of pregnancy and birth (5), as well as maternal depression and

52 cognitive impairment (6).

53 Dietary diversification is a food-based strategy that has been widely promoted to address

54 micronutrient deficiencies (7). To help achieve healthy diets, eating a diversity of foods is

55 needed to help achieve healthy diets (8,9) as recommended by most dietary guidelines (10).

56 As a result, a large range of interventions and programmes to improve nutrition through

57 dietary diversification has been developed, and has subsequently triggered a demand for a set

58 of harmonized indicators to monitor progress. Subsequently, several simple indicators

59 assessing dietary diversity were developed, primarily for use in global and national

60 monitoring, and in survey contexts where more detailed dietary methods that include

61 estimation of food quantities are infeasible.

62 In this context, the Women's Dietary Diversity Project developed and validated simple food

63 group indicators with consistent and relevant meaning across different contexts and over time.

64 The most recent example is the Minimum Dietary Diversity for Women of Reproductive Age

65 (MDD-W), a simple population-level dichotomous indicator expressed as the proportion of

66 non-pregnant women of reproductive age who consumed at least 5 out of 10 defined food

4

67 groups over the previous 24 hours (11). MDD-W was validated using nine datasets from 6

68 distinct LMICs as a proxy for a minimally acceptable level of intake adequacy of 11

69 micronutrients among non-pregnant women of reproductive age (12,13).

70 While the initial MDD-W validation study was able to assess the performance of the indicator

71 for non-pregnant non-lactating women and non-pregnant lactating women, this was not

72 possible for pregnant women due to the lack of data. Recent studies have used the threshold of

73 5 or more food groups to determine whether pregnant women had more adequate

74 micronutrient intakes but without further validation of this dichotomous indicator in this

75 population group (14–16). However, pregnant women generally have higher micronutrient

76 requirements than non-pregnant women (3), which may change the performance of food

77 group indicators in predicting adequate micronutrient adequacy in this specific population.

78 The only validation study among pregnant women we are aware of showed that an adapted 6

79 or more food group threshold markedly improved performance of the indicator in predicting

80 micronutrient adequacy among pregnant girls and pregnant women in Bangladesh (17). Using

81 secondary quantitative 24-hour recall data from 6 surveys in 4 LMICs, this study aimed to

82 validate a minimum food group consumption threshold, out of the 10 food groups used to

83 construct MDD-W, to be used as a population-level indicator of higher micronutrient

84 adequacy among pregnant women aged 15-49 years in LMICs. We followed the methods

85 used by previous studies on the development and validation of MDD-W to ensure

86 comparability of the analysis and facilitate the interpretation of findings (12,13).

87

Methods

Selection of surveys

90 This study was based on a pre-identified set of datasets that was completed by a systematic

91 review of studies which collected dietary intakes from pregnant adolescent girls and women

5

92   in LMICs, using one or multiple 24-hour dietary recalls. Inclusion criteria were: (i) food

93   consumption data collected among pregnant women (15–49 y) in LMICs; (ii) quantitative

94   dietary intake data collected through one or multiple 24-hour dietary recalls; (iii) use of

95   relevant local food composition data with information on the 11 micronutrients included in

96   the initial development and validation of MDD-W (vitamin A expressed in retinol activity

97   equivalents (RAE), thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C,

98   calcium, iron and zinc); (iv) minimum sample size of 100 pregnant adolescent girls and

99   women and (v) repeated 24-hour dietary recalls from at least 10% of the study sample or

100 being able to be matched with a relevant dietary intake survey with two non-consecutive days

101 of recall to estimate external within-person variance.

102

103 **Study design and participants**

104 Six datasets with quantitative 24-hour recall data collected from rural areas in Bangladesh in

105 2015 (17), Burkina Faso in 2017/2019/2020 (BF1, (18)), 2020 (BF2, (19)) and 2019/2021

106 (BF3, (20)), India in 2019 (21) and Nepal in 2015 (22) were selected for analysis. Each

107 dataset is described in more detail in **Supplemental table 1**, which includes their selection

108 process. Briefly, there were 5 pre-identified datasets (Bangladesh, BF1, BF2, BF3 and India)

109 and we undertook a literature research to identify others, leading to add the dataset from

110 Nepal. The included studies' primary objectives were to assess the feasibility and impact of

111 maternal nutrition packages or integrated agriculture-nutrition interventions (Bangladesh,

112 BF1, BF3 and India), to assess the efficacy of fortified balanced energy-protein

113 supplementation (BF2), or to characterize the status and determinants of intra-household food

114 and nutrient allocation, and test the effect of pregnancy interventions upon dietary intake

115 (Nepal). None of the study samples was nationally representative. Data quality control was

116 carried out by the data providers, including the exclusion of outliers. The representativeness

117   of each sample has been discussed in the original articles and primary study protocols for all

118   sites were approved by ethical review committees or institutional review boards (17–19,21–

119   25).

120

121   **Dietary data collection**

122   In all studies, dietary data were collected using one to three quantitative multiple-pass 24-hour

123   dietary recalls conducted by enumerators specially trained for this purpose (26). Participants

124   were asked to describe all foods and beverages consumed during the preceding 24 hours.

125   Recipes were usually collected from the household member who was responsible for cooking.

126   Portion sizes were estimated using methods best suited to local foods and contexts (e.g.

127   previously distributed plates and bowls, common household measures, water volume, rice,

128   images, clay or wooden models, etc.). Only two datasets had repeated 24-hour dietary recalls

129   on non-consecutive days, with two recalls for 19% of the sample (BF1) and three recalls for

130   87% of the sample (Nepal). Dietary data were converted into nutrient intakes using country

131   specific food composition tables; the application of yields and nutrient retention factors was

132   done by data providers according to their own practice and information is available from

133   original studies (17–19,21–23).

134

135   **MDD-W and WDDS-10**

136   Among the various indicators with different food groupings developed and tested as part of

137   the Women's Dietary Diversity Project I and II, the dichotomous MDD-W indicator has been

138   shown to have a strong relationship to micronutrient adequacy and high consistency in terms

139   of threshold which best discriminated higher versus lower micronutrient adequacy across

140   various countries (12,27). The MDD-W was constructed considering 10 mutually exclusive

141   food groups consisting of: 1) starchy staple foods, 2) pulses; 3) nuts and seeds; 4) dairy

142 products; 5) flesh foods; 6) eggs; 7) dark green leafy vegetables; 8) vitamin A-rich fruits and

143 vegetables; 9) other vegetables; and 10) other fruits. The 10 food groups are summed into a

144 score (WDDS-10) ranging from 0 to 10, starting with a score of 0 and adding 1 point per food

145 group consumed (if the total consumption of the foods in the food group was at least 15

146 g/day)[1]. The WDDS-10 was computed using a single day recall (the first day in case of

147 repeated recalls). MDD-W was coded as 1 if WDDS-10 reached 5 food groups or more, and 0

148 if 4 or lower.

149

150 **Micronutrient requirements, usual intakes and probability of adequacy**

151 We used the Estimated Average Requirements (EAR) and coefficients of variations proposed

152 by Nguyen *et al.* (17), that are based on the information from the WHO/FAO (29), the

153 National Academy of Medicine (formerly the Institute of Medicine) (30,31) and the

154 International Zinc Nutrition Consultative Group (IZiNCG) (32). These requirements were

155 used regardless of the pregnancy trimester, age or country context of the participants

156 (**Supplemental table 2**). These requirements were chosen rather than those proposed by Allen

157 *et al.* (33) to enhance comparability and facilitate interpretation of findings with previous

158 studies on the development and validation of MDD-W (12,13,17).

159

160 Analogous to previous studies on the development and validation of MDD-W (12,13), we

161 used the probability approach to estimate the micronutrient adequacies of each of the 11

162 micronutrients (28). This approach is based on information or assumption about both the

163 distribution of nutrient requirements in the population and the day-to-day variations (within-

164 person) of nutrient intakes. We applied a Box-Cox transformation to the nutrient intake

---

[1] This is of course not easy to do in practice, when collecting data; therefore, what is recommended in the FAO MDD-W guidelines is to apply the 15g limit to each food. However, we decided here to stick to the methodology used for the validation of the MDD-W for the sake of comparability.

165   distribution of every micronutrient to obtain normal distributions. For each participant and

166   micronutrient in each separate dataset, we calculated the best linear unbiased predictor

167   (BLUP) of the individual's usual intake (34) which was then used to calculate the probability

168   of adequacy for every micronutrient (see **Supplemental Methods**). All usual nutrient intakes

169   have been calculated solely on the basis of food intakes, excluding intakes from food

170   supplements (e.g. fortified balanced energy-protein supplementation in BF2). When datasets

171   contained repeated 24-hour dietary recalls, the within person variance was defined as the

172   mean of squared intra-individual SDs. When datasets contained only one 24-hour dietary

173   recall, we used an external within-person variance estimate from a relevant dietary intake

174   survey with two non-consecutive days of recall (35,36). We used the external within-person

175   variance to between-person variance ratio multiplied by the between-person variance of our

176   dataset as the within-person variance in the BLUP calculations. A relevant dietary intake

177   survey was defined as a survey conducted in the same geographical and seasonal context

178   among pregnant adolescent girls or women. For Bangladesh, we used the within-person

179   variance estimate from a subsample of the baseline study (~20%) that also participated in the

180   endline study conducted a year later (37). For BF2 and BF3, we used the within-person

181   variance estimate from BF1 due to the fact that these three surveys were conducted in the

182   same context (Boucle du Mouhoun, Centre-Ouest and Haut-Bassins for BF1, Haut-Bassins for

183   BF2 and Boucle du Mouhoun for BF3) among pregnant adolescent girls and women. For

184   India, we used the within-person variance estimate from repeated 24-hour dietary recall used

185   to validate a Food Frequency Questionnaire among pregnant women living with or without

186   HIV in Pune, India (38).

187

188   Probability of adequacy (PA) was calculated as the probability that a woman's usual intake

189   was at or above the EAR during pregnancy (28). For each individual, we averaged the mean

9

190   of the individual PAs for the 11 micronutrients to form the mean probability of adequacy

191   (MPA). Like individual PAs, the MPA has a possible range of 0–1.

192

193   **Data analysis**

194   Data were analyzed with Stata 17 (Statacorp, College Station, TX) and the Stata syntax that

195   was used for MDD-W validation in non-pregnant women (12,13), with a few minor revisions

196   to match the aims of our analyses. Descriptive statistics are reported as medians (interquartile

197   ranges) due to skewness of the distributions, except for age, height, weight and energy intake,

198   which are reported as means (SDs). Associations between the WDDS-10 and MPA (with or

199   without adjustment for total energy intake) were assessed by fitting simple linear regressions.

200   For the pooled sample, a mixed-effects regression model was used to examine the association

201   between WDDS-10 and MPA, with random effect at dataset level to take into account the

202   within-survey correlation. The MPA variable was previously transformed by BoX-Cox

203   transformation for all the regression models.

204   We used receiver operating characteristic (ROC) analysis and area under the curve (AUC) to

205   assess the diagnostic performance of WDDS-10 in predicting a MPA >0.60, with an AUC

206   >0.70 deemed acceptable for predictive capacity. We estimated sensitivity, specificity and

207   percentage of correct classifications for MDD-W across datasets and in a pooled analysis. The

208   MPA level of 0.60, as well as the interpretation thresholds, were selected to ensure

209   comparability with the previous analysis used to validate the MDD-W (12,13). Sensitivity

210   (i.e. ability to correctly detect a person with an MPA >0.60) is defined by the ratio between

211   the true positives and the sum of true positives and false negatives. Specificity (i.e. ability to

212   correctly detect a person with an MPA ≤0.60) is defined by the ratio between the true

213   negatives and the sum of true negatives and false positives. A threshold was considered good

214   when both sensitivity and specificity were >0.60 and it was considered fair enough if only one

215   test characteristic was >0.60 and the other >0.50. Moreover, while we looked for the best

216   balance between sensitivity and specificity, we favored specificity over sensitivity when

217   trade-offs must be made, in order to be certain to identify the highest proportion of

218   participants with a MPA ≤0.60. The percentage of correct classifications is defined by the

219   ratio between the sum of true positives and true negatives and the sum of true positives, false

220   positives, true negatives and false negatives. A threshold was considered as good when the

221   percentage of individuals correctly classified was >0.70 and it was considered fair enough if

222   >0.60.

223   In order to understand the implications of some methodological choices, we conducted

224   additional robustness analyses to estimate sensitivity, specificity and the percentage of correct

225   classifications for MDD-W across datasets and in a pooled analysis according to three distinct

226   scenarios. In the first robustness analysis, we tested 3 scenarios (Sc1, Sc2 and Sc3) where

227   only 1 of the 3 Burkinabe datasets was included in the pooled analysis (BF1, BF2 and BF3,

228   respectively), in order to keep into account the potentially redundant nature of using three

229   surveys from Burkina Faso. In the second robustness analysis, we used the same

230   recommendations from WHO/FAO (29), the National Academy of Medicine (30,31) and the

231   IZiNCG (32) but took into account pregnancy trimester, age and level of bioavailability of

232   iron and zinc (see **Supplemental table 3**). In the third robustness analysis, we used the

233   requirements proposed by Allen *et al.* (33) which take into account age and level of

234   bioavailability of iron and zinc but not pregnancy trimester (see **Supplemental table 4**).

235

Results

Characteristics of participants

238   Data were available for 4909 pregnant adolescent girls and women (**Table 1**), with sample

239   sizes of the datasets ranging from 452 (BF1) to 1912 (BF3). The mean (SD) age of

11

240   participants was 25.7 (6.2) years, with participants from Nepal being on average younger than

241   pregnant women from other countries. The inclusion of adolescent girls (15-18 years) across

242   studies varied from none (India) to up to 26% (Bangladesh), and was 7.1% in the pooled

243   sample. The pregnancy trimester distribution was highly variable across datasets, with a near-

244   even distribution in BF1, whereas almost all participants were in their third trimester in Nepal.

245   Participants in their third trimester represented almost 60% of the pooled sample. Pregnant

246   women in the Burkinabé datasets were on average taller and heavier than participants from

247   other countries.

248

249   **Dietary diversity**

250   The median (interquartile range) WDDS-10 in the pooled sample was 3 (1), with higher

251   median scores in the Bangladeshi, Nepalese, and Indian datasets compared to the three

252   Burkinabe datasets (**Table 1**). **Figure 1** shows the percentage of pregnant adolescent girls and

253   women consuming each of the 10 food groups used to construct MDD-W across the six

254   datasets. Consistently across datasets, the diet of all participants was based on starchy staple

255   foods. Most participants consumed other vegetables, but with large variations ranging from

256   55% in BF1 and BF3 to 91% in Nepal. The prevalence of participants consuming pulses and

257   dairy products greatly differed across datasets: for pulses it was high in Nepal (over 80%),

258   moderate in Bangladesh and India (59 and 46%, respectively), and low in the three Burkinabe

259   datasets (27% in BF1, 14% in BF2 and 15% in BF3). As for the prevalence of consumption of

260   dairy products, it was very high in India (over 80%), moderate in Nepal and Bangladesh (53

261   and 33%, respectively), and low in the three Burkinabe datasets (4% in BF1, 3% in BF2 and

262   11% in BF3). In contrast, the prevalence of participants consuming nuts and seeds, and dark

263   green leafy vegetables was higher in the three Burkinabe datasets. The prevalence of

264   participants consuming flesh foods, eggs, and other fruits was higher in the Bangladeshi

265   datasets.

266

267   **Energy and nutrient intakes and the probability of adequacy**

268   The mean (SD) energy intake of the pregnant adolescent girls and women was 2068 (969)

269   kcal per day in the pooled sample (**Table 2**), ranging from 1816 (838) kcal in BF3 to 2473

270   (1482) kcal in BF2. For all micronutrients apart from zinc, median intakes in the pooled

271   sample were below the EAR (**Supplemental table 5**). However, there were differences

272   between datasets, with median intakes in the Nepalese and Bangladeshi datasets above the

273   EAR for 5 and 4 micronutrients, respectively. Accordingly, PAs varied widely across datasets

274   (**Table 2**). Across surveys, the PAs of vitamin A, riboflavin, folate, vitamin B12, calcium, and

275   iron were <0.50. The median (IQR) MPA of the participants was 0.20 (0.34) in the pooled

276   sample, ranging from 0.09 (0.21) in BF1 to 0.43 (0.32) in Nepal. The proportion of

277   participants with MPA above the threshold of 0.60 was low, at 9.6% in the pooled sample and

278   ranged from 2.4% (BF1) to 23.4% (Nepal).

279

280   **Association between WDDS-10 and MPA**

281   **Figure 2** illustrates non-adjusted associations between WDDS-10 and MPA (see

282   **Supplemental table 6** for details of the number of pregnant women consuming various

283   numbers of food groups by dataset). The WDDS-10 was significantly and positively

284   associated with the MPA in every dataset (all P <0.001) (**Table 3**). Unadjusted regression

285   coefficients ranged from 0.079 (95% CI: 0.070, 0.088) to 0.309 (95% CI: 0.250, 0.367) and

286   was 0.168 (95% CI: 0.157, 0.178) for the pooled sample. The unadjusted models explained

287   between 14% and 33% of the MPA variance, and 28% in the pooled sample. In models

288   including total energy intake (kcal/d) as covariate, associations were attenuated in all datasets

13

289 but remained highly significant. Energy adjusted regression coefficients ranged from 0.038

290 (95% CI: 0.028, 0.050) to 0.166 (95% CI: 0.114, 0.218) and was 0.079 (95% CI: 0.069,

291 0.088) in the pooled sample. The energy adjusted models explained between 29% and 66% of

292 the MPA variance, and 41% in the pooled sample.

293

294 **Food group indicator performance and identification of thresholds**

295 The AUC value in the pooled sample was 0.78 (95% CI: 0.75, 0.80), which indicates an

296 acceptable predicting power, and ranged from 0.61 to 0.81 across datasets which indicates a

297 low to good performance in predicting a MPA >0.60, except for BF1 where the 95% CI (0.43,

298 0.78) included 0.50 which indicates no statistically significant predictive power (**Table 4**). In

299 the sensitivity and specificity analyses in the pooled sample, the threshold of WDDS-10 ≥5

300 food groups had the best performances in predicting an MPA >0.60 (i.e. both sensitivity and

301 specificity >0.60 and percentage of individuals correctly classified >0.70) with good

302 sensitivity (62%) and very good specificity (81%) and percentage of individuals correctly

303 classified (79%). The threshold of ≥4 food groups showed slightly lower performances with

304 very good sensitivity (84%), but fair enough specificity (55%) and a moderate percentage of

305 correctly classified participants (58%). The threshold of ≥6 food groups had lower

306 performances with low sensitivity (32%), but very good specificity (93%) and percentage of

307 correctly classified participants (87%). The other thresholds had worse classification

308 properties. However, findings were heterogeneous across datasets. In summary, when

309 balancing sensitivity, specificity and percentage of correct classification, the most acceptable

310 food group consumption threshold for predicting a MPA >0.60 was WDDS-10 ≥4 in BF1,

311 BF2, and BF3, ≥5 in India and Nepal, and ≥6 in Bangladesh.

312 The three distinct scenarios from our robustness analyses returned similar findings,

313 confirming both the observed heterogeneity across countries and also that the threshold of

14

314   WDDS-10 ≥5 food groups had the best performance in predicting an MPA >0.60 in the

315   pooled sample (data not shown).

316

Discussion

318   Following the approach used for developing and validating MDD-W among non-pregnant

319   women (12,13), we analyzed six dietary datasets to determine the minimum number of food

320   groups consumed, out of the 10 food groups of the MDD-W, which best discriminates

321   between higher versus lower micronutrient adequacy among pregnant adolescent girls and

322   women in four LMICs. At least half of the women in each dataset had PAs of six

323   micronutrients at zero, highlighting the urgency of an emphasis on diet quality and nutrient

324   adequacy population group. Consequently, pregnant adolescent girls and women had low

325   nutrient adequacy, with median MPA values ranging from 0.09 to 0.43 across the datasets.

326   These findings are consistent with those reported among lactating women, who also face

327   higher nutrient requirements, where the MPA ranged from 0.23 to 0.50 in nine datasets from

328   resource-poor settings (12,13). As with other population subgroups (12,13), the WDDS-10

329   was significantly and positively associated with MPA in each dataset. Similarly to the results

330   found during the initial validation of MDD-W for non-pregnant women (12,13), our analyses

331   showed that across the pooled sample a threshold of 5 or more food groups had the best

332   performance in classifying pregnant adolescent girls and women as having a minimally

333   acceptable level of dietary micronutrient adequacy (i.e., MPA >0.60).

334   Nevertheless, we found evidence of heterogeneity across datasets, both in terms of dietary

335   patterns and in the optimal threshold of WDDS-10 to predict a minimally acceptable level of

336   micronutrient adequacy (which varied from 4 to 6). Pulses and dairy were more commonly

337   consumed in South Asian countries, whereas nuts, seeds, and green leafy vegetables were

338   more commonly consumed in Burkina Faso. This could be explained by geographical and

339 temporal differences, such as food availability, prices, budgets, and preferences. For example,

340 each dataset only captured certain months of the year while seasonality could affect food

341 availability and thus dietary diversity in these contexts (39,40). In terms of differences in

342 thresholds, it should be noted that even in the validation study that led to adopt the MDD-W

343 there were differences across datasets regarding the best threshold that predicted a MPA>0.60

344 – which varied from 4 to 6 as in the present study (12). Various food (sub)groups contribute

345 more or less to the MPA than others and/or can be consumed in larger or smaller quantities

346 according to the context. This heterogeneity is not specific to pregnant adolescent girls and

347 women. When recommending the threshold of 5 food groups, that work best in the pooled

348 sample in this study as well as across the 9 datasets of the MDD-W validation study (12), we

349 are pretty confident that this threshold would most likely minimize the gap to the true,

350 context-specific and also probably season-specific optimal threshold that remains unknown in

351 many contexts but was found in the range of 4 to 6 in most if not all published studies

352 (12,17,41).

353 Measuring characteristics of diets and monitoring of their changes at global and national

354 levels are needed to support governments in establishing policies and programmes to promote

355 healthy diets, to assess the effectiveness of their actions and hold them accountable. This is

356 the spirit behind the development of the MDD-W (12,13). Although MDD-W is already

357 widely collected in large multi-topic surveys, such as Demographic and Health Surveys and

358 Gallup World Poll, it only reflects dietary diversity which is one, albeit indispensable,

359 subconstruct of healthy diets (42,43). Other promising metrics were recently designed to

360 assess in a synthetic manner several subconstructs of healthy diets. The Global Diet Quality

361 Score (GDQS), for example, is based on the consumption of 25 food groups that are globally

362 important contributors to nutrient intake, on the one hand, and/or to non-communicable

363 disease risk, on the other hand (44). Although it has been validated using several datasets

364 from various contexts, the validation was performed against several outcomes and by

365 comparisons with the performance of other metrics and not directly to nutrient adequacy. In

366 addition, the GDQS has not yet been widely used in large surveys, probably because some

367 appraisal of quantities or portions consumed is needed for its construction. The Global

368 Dietary Recommendations (GDR) score is another recently developed synthetic metric that

369 was designed to assess the adherence to a dietary pattern respecting 11 global dietary

370 recommendations from WHO, which include dietary factors protective against non-

371 communicable diseases (45). Although the construction of the GDR score is based on a

372 standardized Diet Quality Questionnaire that was validated against 24h-recalls in three

373 different contexts, and has been used since in many other countries, as far as we know the

374 GDR score itself was validated only with data from Brazil and the USA. Additional evidence

375 are needed to establish its validity in various contexts and its equivalence across contexts (43).

376 Thus, MDD-W arguably remains a statically robust and valid indicator, widely collected in

377 large multi-topic surveys, to assess dietary diversity as a cornerstone of diet quality on a

378 global and national scale. This work contributes to ongoing efforts to validate MDD-W in

379 other populations such as adolescents and children (43).

380 The present analyses have some limitations. First, despite our efforts to obtain datasets from a

381 diversity of contexts, our study only includes data from rural contexts in four LMICs among

382 two regions (sub-Saharan Africa and South Asia). Although our findings are not globally

383 representative, they are consistent with other analyses among non-pregnant women from more

384 settings (12,13). Furthermore, the rural locations included in our study are settings where

385 valid scores are arguably much needed, as they typically have a high burden of undernutrition

386 and low dietary diversity (15,39,46,47). In the meantime, more datasets should be made

387 available in settings where a reasonable proportion of pregnant adolescent girls and women

388 reach an acceptable MPA, so that the best predictors of acceptable MPA can be further

389 studied. For example, in the BF1 sample of our study, only 11 (2.4%) pregnant women

390 reached an MPA ≥0.60, which strongly limits the search for the best dichotomous indicator

391 predicting higher MPA. Another limitation concerns the use of an external within-person

392 variance estimate to calculate the MPA in four of the six datasets. This results in more reliable

393 prevalence estimates than when using a single day recall (36), but the use of within-person

394 variance estimates from repeated measures within the samples is preferable (35). Although we

395 tried to find and use an external estimate of within-person variance from a relevant food

396 intake survey, we were limited in our ability to find studies with the same geographical (e.g.

397 for India, the region of the external estimate study is 1500 km away from that of the dataset)

398 or temporal (different seasonality between BF1 and BF3) characteristics. Future analyses

399 from a wider variety of settings and with data containing repeated measures is recommended

400 to confirm that a threshold of 5 or more groups is the best suited to indicate MPA >0.60. A

401 last limitation is the use of a set of nutrient requirements which did not take into account the

402 pregnancy trimester, the age of the participants or the level of bioavailability of iron and zinc.

403 This simpler approach was preferred to take into account the fact that this information might

404 not be accurately collected in large surveys. Nevertheless, taking these characteristics into

405 account in three distinct robustness analyses did not affect our findings in terms of

406 determining the threshold of WDDS-10 with the best classification characteristics.

407 In conclusion, our study suggests that the WDDS-10 is a good predictor of dietary

408 micronutrient adequacy among pregnant adolescent girls and women in LMICs, as it was

409 previously shown among non-pregnant and non-lactating women and lactating women

410 (12,13). When a dichotomous indicator is preferred over a continuous measure, our results

411 suggest that the MDD-W may be used as a proxy indicator for higher micronutrient adequacy

412 in LMIC contexts in all women of reproductive age, regardless of physiological status. This

413 might be particularly useful for international comparisons and when the physiological status

of women is unknown, which is the case in many large surveys. However, our findings

suggest that context-specific thresholds might be more accurate and might therefore be

preferred for research purposes. Given the low micronutrient adequacy in the populations

studied, additional efforts are needed to enhance the diet of women of reproductive age. Even

though the threshold of 5 or more groups might not accurately predict micronutrient adequacy

in all contexts, the indicator allows tracking processes of such efforts over time and enables

benchmarking between populations. However, there is a need to provide complementary

assessment of other dimensions of diet quality, such as consumption of undesired foods, food

safety aspects, and within food group contribution of foods. In addition, in food environments

and diets with a considerable contribution of fortified foods, the validity of the 5 food group

thresholds might require careful reconsideration.

Data Availability

Data described in the manuscript, code book, and analytic code will be made available upon

request pending application and approval by authors of the current study.

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Figures

Fig. 1. Percentage of participants having consumed the 10 food groups used to construct MDD-W in the previous 24-hours. BF1, rural Burkina Faso dataset (2017/2019/2020); BF2, rural Burkina Faso dataset (2020); BF3, rural Burkina Faso dataset (2019/2021).

Fig. 2. Average mean probability of adequacy by WDDS-10 score. BF1, rural Burkina Faso dataset (2017/2019/2020); BF2, rural Burkina Faso dataset (2020); BF3, rural Burkina Faso dataset (2019/2021). Error bars represent mean ± standard error. Data points representing <10 participants are not shown. Details of the number of pregnant women by dataset are given in Supplemental Table 4.

Tables

Table 1. Characteristics of pregnant women[1]

Dataset	n	Repeated recall, n (%)[2]	Mean (SD) age, y	Adolescent, n (%)	First trimester, n (%)	Second trimester, n (%)	Third trimester, n (%)	Mean (SD) height, m	Mean (SD) weight, kg	Median (IQR) WDDS-10
Bangladesh	598	0 (0.0)	24.0 (5.6)	160 (26.0)	0 (0.0)	328 (54.8)	270 (45.2)	1.50 (0.06)	50.3 (8.1)	5 (2)
BF1	452	84 (18.6)	29.6 (5.3)	1 (0.2)	124 (27.4)	173 (38.3)	155 (34.3)	1.61 (0.07)	59.1 (8.0)	3 (2)
BF2	470	0 (0.0)	25.4 (6.4)	37 (7.9)	16 (3.4)	188 (40.0)	266 (56.6)	1.63 (0.06)	58.9 (8.7)	3 (2)
BF3[3]	1912	0 (0.0)	27.5 (6.6)	64 (3.4)	279 (14.7)	828 (43.8)	785 (41.5)	1.63 (0.01)	61.8 (2.5)	3 (2)
India	674	0 (0.0)	25.0 (4.0)	0 (0.0)	0 (0.0)	198 (29.4)	476 (70.6)	1.50 (0.06)	51.0 (8.5)	4 (2)
Nepal	803	745 (92.8)	21.5 (3.8)	88 (11.0)	0 (0.0)	1 (0.1)	802 (99.9)	1.51 (0.05)	52.1 (6.5)	4 (1)
Pooled[3]	4909	N/A	25.7 (6.2)	350 (7.1)	419 (8.5)	1716 (34.9)	2754 (56.1)	1.58 (0.07)	56.7 (8.0)	3 (1)

[1] BF1, rural Burkina Faso dataset (2017/2019/2020); BF2, rural Burkina Faso dataset (2020); BF3, rural Burkina Faso dataset (2019/2021); SD, standard deviation; WDDS-10, 10-food group women dietary diversity score; IQR, Interquartile range. [2] Women in the sample with more than one 24-hour dietary recall; [3] Information about the pregnancy trimester was missing for 20 participants.

Table 2. Energy intakes, probability of adequacy of individual micronutrients and mean probability of adequacy (MPA)[1]

Dataset	Energy intakes, kcal/d[2]	Vitamin A[3]	Thiamin[3]	Riboflavin[3]	Niacin[3]	Vitamin B6[3]	Folate[3]	Vitamin B12[3]	Vitamin C[3]	Calcium[3]	Iron[3]	Zinc[3]	MPA[3]	MPA >0.60, n (%)
Bangladesh	2330 (822)	0.00 (0.60)	1.00 (0.22)	0.00 (0.25)	1.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.07)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.18 (0.70)	0.40 (0.19)	94 (15.7)
BF1	1950 (939)	0.00 (0.10)	0.00 (0.04)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.67)	0.00 (0.00)	0.00 (0.49)	0.40 (0.95)	0.09 (0.21)	11 (2.4)
BF2	2473 (1482)	0.00 (0.48)	0.00 (0.76)	0.00 (0.01)	0.00 (0.22)	0.00 (0.67)	0.00 (0.15)	0.00 (0.00)	0.01 (1.00)	0.00 (0.05)	0.00 (0.95)	0.97 (0.79)	0.16 (0.34)	69 (14.7)
BF3	1816 (838)	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	0.00 (0.03)	0.00 (0.04)	0.00 (0.00)	0.00 (0.00)	0.00 (0.05)	0.00 (0.01)	0.07 (1.00)	0.63 (0.95)	0.13 (0.21)	73 (3.8)
India	2122 (924)	0.00 (0.00)	0.80 (0.99)	0.00 (0.23)	0.20 (0.92)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (1.00)	0.00 (0.08)	0.00 (0.00)	0.62 (0.97)	0.20 (0.32)	35 (5.2)
Nepal	2254 (850)	0.05 (0.46)	0.96 (0.76)	0.06 (0.99)	0.64 (0.83)	1.00 (0.36)	0.00 (0.01)	0.00 (0.00)	1.00 (0.17)	0.00 (0.45)	0.00 (0.00)	0.99 (0.34)	0.43 (0.32)	188 (23.4)
Pooled	2068 (969)	0.00 (0.08)	0.03 (0.98)	0.00 (0.05)	0.03 (0.91)	0.00 (0.99)	0.00 (0.00)	0.00 (0.00)	0.02 (1.00)	0.00 (0.02)	0.00 (0.26)	0.69 (0.93)	0.20 (0.34)	470 (9.6)

[1]BF1, rural Burkina Faso dataset (2017/2019/2020); BF2, rural Burkina Faso dataset (2020); BF3, rural Burkina Faso dataset (2019/2021). [2] Values are means (SD) calculated from a single 24-hour dietary recall (the first one in case of repetitions). [3] Values are medians (interquartile range).

**Table 3**. Linear regression of WDDS-10 with mean probability of adequacy[1,2]

Dataset	Unadjusted			Total energy (kcal/d) adjusted			
	WDDS-10	Constant	Adjusted R²	WDDS-10	Energy intake, kcal/d	Constant	Adjusted R²
Bangladesh	0.079 (0.070, 0.088)	-1.06 (-1.11, -1.01)	0.333	0.055 (0.046, 0.063)	0.0001 (0.0001, 0.0001)	-1.23 (-1.27, -1.18)	0.529
BF1	0.252 (0.195, 0.310)	-2.42 (-2.60, -2.24)	0.142	0.125 (0.067, 0.183)	0.0003 (0.0003, 0.0004)	-2.65 (-2.82, -2.48)	0.291
BF2	0.309 (0.250, 0.367)	-2.20 (-2.38, -2.01)	0.185	0.166 (0.114, 0.218)	0.0002 (0.0002, 0.0003)	-2.37 (-2.52, -2.21)	0.431
BF3	0.214 (0.194, 0.233)	-2.06 (-2.13, -2.00)	0.198	0.091 (0.074, 0.108)	0.0004 (0.0003, 0.0004)	-2.40 (-2.45, -2.34)	0.488
India	0.162 (0.139, 0.186)	-1.73 (-1.83, -1.63)	0.214	0.049 (0.032, 0.067)	0.0003 (0.0003, 0.0004)	-2.00 (-2.07, -1.94)	0.662
Nepal	0.082 (0.068, 0.095)	-0.93 (-0.99, -0.87)	0.149	0.038 (0.028, 0.050)	0.0002 (0.0001, 0.0002)	-1.11 (-1.16, -1.06)	0.465
Pooled[3]	0.168 (0.157, 0.178)	-1.74 (-1.96, -1.51)	0.286	0.079 (0.069, 0.088)	0.0003 (0.0002, 0.0003)	-2.03 (-2.27, -1.78)	0.411

[1] Values are regression coefficients and (95% Confidence Intervals); WDDS-10, 10-food group women dietary diversity score; CI, confident interval; BF1, rural Burkina Faso dataset (2017/2019/2020); BF2, rural Burkina Faso dataset (2020); BF3, rural Burkina Faso dataset (2019/2021). [2] The mean probability of adequacy after Box-Cox transformation was used as dependent variable in all the regression models. All *P*-values are <0.001. [3] A mixed-effects regression model, including a random intercept for survey, was fitted for the pooled sample.

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Table 4. Test characteristics of food group indicators for classifying mean probability of adequacy >0.60 for pregnant adolescents and women[1]

Dataset	AUC	WDDS-10 ≥ 4			WDDS-10 ≥ 5			WDDS-10 ≥ 6		
		Sensitivity	Specificity	PCC	Sensitivity	Specificity	PCC	Sensitivity	Specificity	PCC
Bangladesh	0.81 (95% CI: 0.77, 0.85)	98.9	19.6	32.1	97.9	41.5	50.3	78.7	67.3	69.1
BF1	0.61 (95% CI: 0.43, 0.78)	54.6	69.4	69.0	9.10	93.4	91.4	0.00	98.9	96.5
BF2	0.71 (95% CI: 0.65, 0.78)	55.1	77.3	74.0	21.7	96.8	85.7	2.9	99.8	85.5
BF3	0.74 (95% CI: 0.69, 0.79)	63.0	70.3	70.0	31.5	91.3	89.0	17.8	98.4	95.3
India	0.79 (95% CI: 0.73, 0.86)	97.1	37.7	40.8	77.1	71.5	71.8	34.3	91.6	88.6
Nepal	0.74 (95% CI: 0.71, 0.78)	94.7	30.6	45.6	70.2	70.6	70.5	26.6	92.7	77.2
Pooled	0.78 (95% CI: 0.75, 0.80)	84.0	54.9	57.7	61.7	80.6	78.8	32.1	93.2	87.4

[1] Values are percentages (except for the AUC values); AUC, area under the curve; CI, confident interval; BF1, rural Burkina Faso dataset (2017/2019/2020); BF2, rural Burkina Faso dataset (2020); BF3, rural Burkina Faso dataset (2019/2021). PCC, percentage correctly classified; WDDS-10, 10-food group Women Dietary Diversity Score.

BANGLADESH (*n*=598)
BF1 (*n*=452)
BF2 (*n*=470)
BF3 (*n*=1912)
INDIA (*n*=674)
NEPAL (*n*=803)
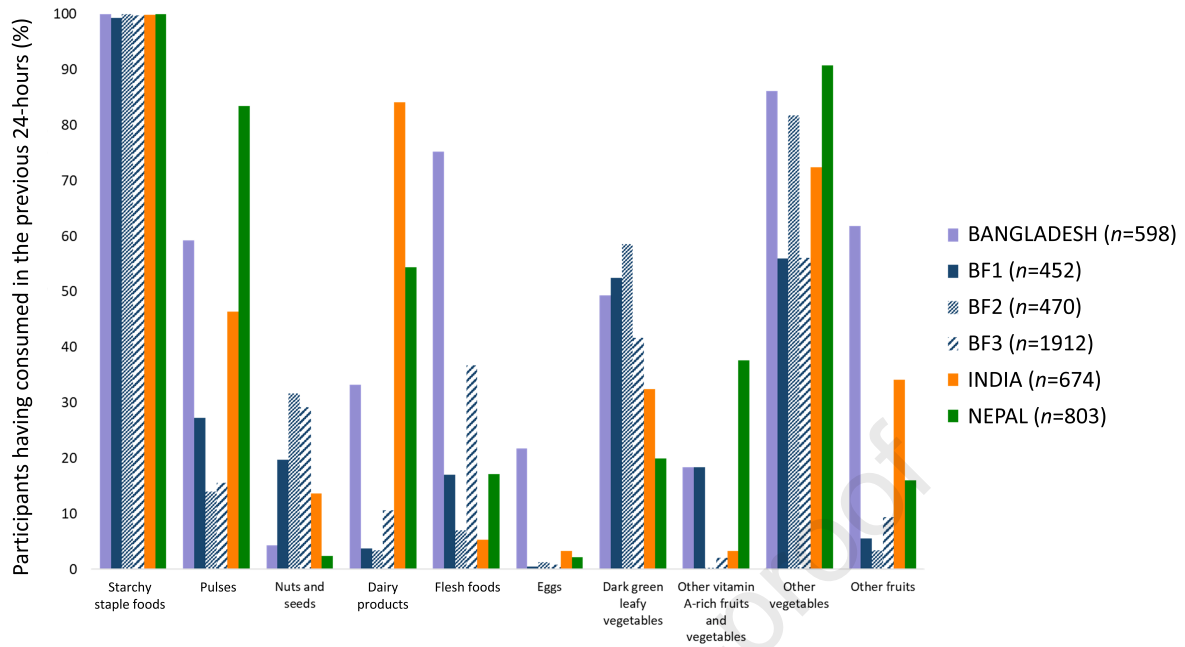
Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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