Assessment of the nutritional value and quality of diets offered in popular apps

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Abstract. – *OBJECTIVE:* People commonly use new technologies to promote a healthy lifestyle and help them lose weight through nutritional programs. This study evaluated the quality of individualized meal plans offered by dietary apps.

***MATERIALS AND METHODS:* Ten apps that offer personalized meal plans were selected for the study, weekly meal plans were generated, and the nutritional values of the diets were calculated. The Healthy Diet Indicator and the Diet Quality Index were estimated.**

***RESULTS:* Significant differences between apps were observed in the calculated energy values ($p<0.0001$) and macronutrients ($p<0.05$), the content of vitamins (vitamin A, E, K, B1, B3, B6, folates, C: $p<0.05$) and minerals (potassium, calcium, phosphor, magnesium, iron, zinc, copper, manganese: $p<0.05$), as well as diet quality ($p<0.05$) and food group consumption (vegetables, fruits, grains, dairy products, vegan products, meat, nuts, fats, sweets, beverages: $p<0.05$). Most diets covered the demand for the required nutrients, but the percentage of energy from fats, proteins and carbohydrates differed from the recommendations. Moreover, the nutritional values of the diets provided in the apps significantly differ from the values calculated using the nutritional databases.**

***CONCLUSIONS:* The meal plans from apps significantly differ in nutrients and food group intake. The quality of the diets offered in the app should be improved.**

Key Words:
Weight loss, Health, Apps, Meal plan, Diet.

Introduction

Overweight and obesity are serious conditions that may negatively impact human health and are major global public health issues. According to the World Health Organization (WHO), over 1.9 billion adults were overweight [body mass index (BMI): 25-29.9 kg/m^2] in 2016, of which 650 million were obese (BMI ≥ 30 kg/m^2), accounting for 39% and 13% of the world adult population respectively[1]. Obesity is related to an imbalance between energy intake and expenditure. Improper diet and low physical activity are the main causes of obesity[2,3]. However, spending free time using a computer, smartphone, or watching TV also increases the risk of obesity[3]. Furthermore, overweight and obesity are associated with a higher risk of many complications, such as cardiovascular diseases, dyslipidemias, diabetes, insulin resistance, hypertension, stroke, or certain types of cancer[4]. The incidence of obesity is increasing annually, so there is an urgent need to identify new efficient methods to manage weight. It has been proven that a nutritious and balanced diet is crucial in maintaining proper weight. However, even though the guidance of an educated and experienced dietician can undoubtedly be helpful, many people decide to solve their excessive problems themselves. Hence, special mobile applications supporting weight reduction are gaining increasing popularity.

Implementing digital technology across healthcare systems raises a number of ethical concerns[5]. Nevertheless, the rapid development of new technologies has also affected their use in medicine resulting in the evolution of the mHealth field. mHealth is the practice of using mobile or wireless technologies as a support for health recovery and management[6]. Mobile apps are a part of the mHealth industry and can be used in numerous ways to maintain a healthy lifestyle. In particular, diet apps are becoming increasingly popular

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among health-promoting apps[7], and they are of interest not only to the obese population. Many researchers[7-10] recognize their health and weight management potential and consider such apps attention-worthy. Moreover, there is evidence[11] that mHealth self-monitoring may be more efficient for weight loss than conventional methods. Mobile applications facilitate weight loss because they help to maintain self-control and support adherence to therapeutic recommendations[12-17]. Following the recommendations will lower body weight and keep it at a healthy level[12]. However, the nutritional values of the diets provided in such nutritional apps require further evaluation. Therefore, although such mobile tools may be of great help, checking whether the menus generated in apps are healthy and nutritious is crucial.

Thus, this study assessed the nutritional values and quality of diets recommended by dietary apps.

Materials and Methods

App Selection

Ten diet smartphone apps from the Health and Fitness category available in Google Play and App Store and popular in English-speaking countries such as the United States, United Kingdom and Australia were selected for the study. Applications were included into the study based on the descriptions provided by app suppliers according to the following criteria: offering personalized meal plans, including a variety of foods from all groups, and access in the English language. Records focused on mental health, training (without meal plans), COVID-19, and other healthy lifestyle forms were not considered. In addition, diet trackers, apps allowing the creation of one's nutritional plans based on the available recipes or offering only recipes or specific diets ("thyroid diet", Paleo or based on juices) were excluded. Apps selected for the study were installed by two researchers onto a Xiaomi Redmi 4 smartphone running Android (for Google Play) and an iPhone 8 running iOS (for App Store) and manually checked to confirm access to individualized meal plans. To avoid branding, all the selected apps were labeled with letters A to J.

Nutrition Evaluation

Seven-day standard meal plans were generated for each app and personalized according to the following data: inactive woman, 50 years old, 170 cm high, 92 kg weight, BMI 31.83 kg/m^2. The number of meals offered by the apps, the nutritional value of the meal plans and the value of single dishes were recorded. Based on the recipes, the nutritional values of all diets were analyzed by the Aliant Software (Anmarsoft, Gdańsk, Poland) using the United States Department of Agriculture (USDA) database, assessing the energy, fat, protein, total carbohydrate, digestible carbohydrate, fiber, sugar, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), n-3 and n-6 polyunsaturated fatty acids (PUFA), cholesterol, sodium, potassium, calcium, phosphorus, magnesium, iron, zinc, copper, manganese, selenium, vitamins: A (retinol and β carotene), D, E, K, B_1, B_2, B_3, B_6, B_{12}, C and folate, and compared to the nutrition standards prepared by the Institute of Medicine or National Academies of Sciences, Engineering, and Medicine (**Supplementary Table I**)[18-21]. The caloric requirement was calculated using the Harris-Benedict formula multiplied by the physical activity level (PAL: 1.4), then reduced by 500 kcal. PAL value, corresponding to the sedentary activity, was selected based on the guidelines of the Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University[22]. The consumption of the following food groups: vegetables, legumes, fruit, grains, dairy, vegan dairy (including plant drinks and tofu), fish and seafood, meat and poultry, nuts and seeds (including peanut butter and tahini), eggs, fats, sweets and sweet substances, herbs and spices, and beverages was calculated.

Diet Quality Assessment

Diet qualities were evaluated separately for each application by calculating the Healthy Diet Indicator (HDI) and the Diet Quality Index (DQI). HDI calculation included nine items on a 0-1 scale (SFA, PUFA, cholesterol, protein, complex carbohydrates, dietary fiber, fruit and vegetables, legumes, nuts and seeds, mono- and disaccharides). Nutrition plans that fulfilled recommendations were given 1 point for each component (0 - poor diet, 9 - excellent diet)[23]. DQI was calculated based on eight diet variables (fat, SFA, cholesterol, fruit and vegetables, complex carbohydrates, protein, sodium, and calcium) on a 0-2 scale for each variable (0 points when the dietary goal was achieved, 2 points when the diet was poor). The maximum score of 16 points determined the poor nutritional value of the meal plan, and the score of 0 indicated an excellent quality of diet[24].

Statistical Analysis

Statistical analysis was performed using the Statistica 13 software (Tibco, Palo Alto, CA, USA), with a *p*-value less than 0.05 considered statistically significant. For each app, median, minimum and maximum or interquartile range (Q1-Q3) values were calculated. The Shapiro-Wilk's test was used to verify the normality of the distribution. Since most variables were not normally distributed, non-parametric tests were used. The nutritional value of diets (declared and calculated), percentage coverage of the demand for required nutrients, food group intakes, and quality of diets were compared between apps using the Kruskal-Wallis' test with an appropriate post-hoc test. The Wilcoxon test was used to compare nutritional values declared by apps (when available) with calculated values. Spearman's correlation tests were performed for the app's calculated nutritional values and nutritional values.

Results

Supplementary Table II summarizes the nutritional values of diets generated in ten studied apps. These data were provided by an analysis performed in the Aliant diet program described previously. Diets offered in apps differed significantly in the amounts of almost all analyzed ingredients, except for PUFA n-3 (g and %), PUFA n-6 (g), cholesterol, sodium, selenium, vitamin D, B_2 and B_{12}.

Supplementary Table III presents the percentage of coverage of the requirements for individual nutrients. The amount of energy and most of the vitamins and minerals were generally by the standard. However, the distribution of macronutrients differs from the recommendation and the amount of vitamin D was insufficient. Therefore, except for the sodium, vitamin D, B_2 and B_{12} content, the applications differed significantly in the coverage of the norm for individual ingredients.

Table I summarizes the intake of individual food groups, with most food groups included in the meal plans for all apps. The exceptions were vegan dairy products (were not included in plans from apps B, D and G), sweet and sweet substances (meals from apps E, F, and G did not contain them) and beverages (not included in apps B, G and J). In most cases, apps differed significantly in the number of product groups found on menus, except for legumes, fish and seafood, eggs, herbs and spices.

HDI and DQI scores calculated for meal plans generated in the apps analyzed are presented in Table II, with the total HDI median (minimum - maximum of 5 (1-9) and a DQI of 7 (2-12) indicating the moderate quality of the diets. The highest (best) median HDI was obtained for apps G, H and J, and the lowest (worst) for app A. The best (lowest) median DQI was determined for apps F-H, with apps A, C and I performing the worst. The differences in HDI and DQI scores between apps were significant.

The nutritional values of diets were calculated based on the nutritional database. However, the app A-F and I-J developers also provided information about the amount of energy (in kcals) and proteins, fats, and carbohydrates (in g and %). On the other hand, app H informed only about energy, and app G did not provide nutritional values. As a result, the nutritional values of the diets provided by the developers significantly differ between the apps (Table III).

Table IV presents the comparison of calculated nutritional values and values declared by the app developers, showing that there were significant differences between apps.

The correlation between the nutritional values calculated and the ones provided in the apps is presented in Table V, with statistically significant positive correlations observed for app E [proteins (g and %), fats (%), and carbohydrates (g and %)], and app I [proteins (g and %), fat (%) and carbohydrate (g)]. In app I, calculated energy values of a diet using the USDA database were negatively correlated with the values provided in the app by the developer, which was probably related to the errors in the nutritional value of the meals provided in the app. Although relatively high rho-values were reached for some correlations, these correlations were of no statistical significance due to the small sample size. However, for this type of correlation, very high rho-values were expected.

Discussion

One of the key findings of this study was the existence of significant differences between the app-declared nutritional values and the values calculated based on the USDA nutritional database. Moreover, the meal plans available in popular apps significantly differed in nutrient and food group intakes and diet quality.

The increased number of diet app installations shows the enormous interest in a healthy lifestyle

Table I. Food group intakes.

Product group	Median (minimum-maximum)	Median (Q1-Q3)										
	All	App A	App B	App C	App D	App E	App F	App G	App H	App I	App J	*p*
Vegetables [g]	582 (116-1,263)	498 (302-659)	873 (778-1,178)	661 (448-872)	419 (361-613)	613 (380-990)	535 (492-838)	651 (565-725)	419 (386-659)	834 (545-892)	352 (270-356)	0.0014
Legumes [g]	60 (0-430)	40 (20-260)	60 (0-100)	50 (0-204)	0 (0-100)	60 (0-200)	43 (0-180)	80 (0-230)	120 (0-120)	100 (40-130)	30 (0-80)	0.8372
Fruits [g]	312 (0-997)	272 (270-380)	350 (220-472)	311 (157-467)	275 (63-535)	160 (10-190)	330 (208-430)	454 (395-675)	380 (210-590)	318 (170-350)	144 (128-220)	0.0072
Grains [g]	112 (0-280)	110 (40-120)	150 (110-190)	123 (68-165)	78 (27-113)	70 (48-125)	185 (41-270)	157 (110-180)	0 (0-41)	147 (85-212)	175 (140-210)	0.0035
Dairy products [g]	100 (0-627)	90 (10-160)	120 (40-200)	30 (20-70)	53 (30-64)	220 (100-250)	300 (150-364)	400 (325-455)	215 (55-530)	135 (20-480)	30 (27-160)	0.0002
Vegan products [g]	15 (0-600)	350 (130-400)	0 (0-0)	4 (0-170)	0 (0-0)	150 (0-170)	10 (0-170)	0 (0-0)	0 (0-140)	0 (0-110)	250 (180-250)	0.0003
Fishes and seafoods [g]	20 (0-593)	0 (0-130)	150 (50-180)	0 (0-220)	0 (0-90)	0 (0-120)	0 (0-170)	90 (0-230)	0 (0-140)	0 (0-120)	100 (70-160)	0.5220
Meat and poultry [g]	120 (0-520)	0 (0-70)	130 (0-150)	130 (100-200)	120 (115-248)	120 (0-120)	140 (0-170)	0 (0-100)	170 (150-300)	32 (25-53)	155 (140-210)	0.0004
Nuts and seeds [g]	30 (0-170)	60 (30-65)	32 (20-88)	30 (18-77)	15 (2-52)	80 (0-130)	16 (0-35)	10 (0-21)	62 (22-80)	50 (43-100)	22 (18-57)	0.0368
Eggs [g]	60 (0-200)	100 (100-120)	100 (50-120)	76 (0-100)	15 (0-100)	44 (0-130)	0 (0-60)	60 (0-180)	80 (0-90)	18 (9-20)	0 (0-150)	0.3133
Fats [g]	16 (0-151)	20 (3-35)	15 (5-23)	24 (15-30)	14 (5-21)	25 (14-28)	10 (5-15)	9 (5-13)	55 (40-74)	0 (0-12)	15 (8-15)	0.0012
Sweets and sweet substances [g]	1 (0-70)	10 (5-20)	0 (0-0)	24 (8-32)	3 (0-6)	0 (0-0)	0 (0-0)	0 (0-0)	26 (3-42)	0 (0-12)	5 (0-15)	0.0005
Herbs and spices [g]	17 (0-80)	28 (14-39)	17 (5-32)	20 (12-27)	11 (5-36)	23 (4-32)	31 (6-54)	4 (4-25)	39 (7-60)	14 (8-24)	14 (10-17)	0.3290
Beverages [g]	7 (0-750)	0 (0-2)	0 (0-0)	0 (0-30)	180 (180-210)	130 (0-250)	240 (240-360)	0 (0-0)	3 (0-143)	30 (0-30)	0 (0-0)	< 0.0001

p: Kruskal-Wallis' test. Post-hoc test results: vegetables: app J *vs*. app B: $p = 0.0008$; app J *vs*. app I: $p = 0.0332$; fruits: app G *vs*. app E: $p = 0.0134$; app G *vs*. app J: $p = 0.0049$; grains: app H *vs*. app J: $p = 0.0115$; dairy products: app G *vs*. app C: $p = 0.0018$; app G *vs*. app D: $p = 0.0159$; app G *vs*. app J: $p = 0.0074$; vegan products: app G *vs*. app A: $p = 0.0199$; meat and poultry: app H *vs*. app A: $p = 0.0055$; app J *vs*. app A: $p = 0.0392$; app G *vs*. app H: $p = 0.0176$; fats: app H *vs*. app B: $p = 0.0365$; app H *vs*. app D: $p = 0.0317$; app H *vs*. app F: $p = 0.0103$; app G *vs*. app H: $p = 0.0006$; app J *vs*. app H: $p = 0.0176$; beverages: app A *vs*. app F: $p = 0.0048$; app B *vs*. app F: $p = 0.0037$; app C *vs*. app F: $p = 0.0357$; app J *vs*. app F: $p = 0.0026$.

Table II. Healthy Diet Indicator and Diet Quality Index scores for diets offered in the apps.

Index	Median (minimum-maximum)	Median (Q1-Q3)										
	All	App A	App B	App C	App D	App E	App F	App G	App H	App I	App J	*p*
HDI	5 (1-9)	3 (2-6)	5 (5-6)	4 (4-6)	4 (3-5)	5 (3-7)	5 (4-6)	6 (6-6)	6 (6-6)	4 (3-4)	6 (5-6)	0.0101
DQI	7 (2-12)	8 (8-10)	7 (3-7)	8 (7-8)	5 (5-10)	5 (3-9)	4 (2-7)	4 (2-6)	4 (2-6)	8 (7-9)	6 (6-8)	0.0004

p: Kruskal-Wallis' test. Post-hoc test results: DQI: app A *vs*. app G: $p = 0.0348$; app F *vs*. app H: $p = 0.0055$; app G *vs*. app H: $p = 0.0010$. HDI - Healthy Diet Indicator (a higher score = better quality diet, range: 0-9); DQI - Diet Quality Index (a higher score = lower quality diet, range: 0-16); Q1-Q3 - interquartile range.

Table III. The nutritional values of the diets provided in the apps by developers.

Macronutrients	Median (minimum-maximum)	Median (Q1-Q3)										
	All	**App A**	**App B**	**App C**	**App D**	**App E**	**App F**	**App G**	**App H**	**App I**	**App J**	***p***
Energy [kcal]	1,602 (1,068-1,951)	1,698 (1,676-1,770)	1,604 (1,602-1,622)	1,691 (1,550-1,716)	1,327 (1,310-1,345)	1,580 (1,555-1,602)	1,282 (1,165-1,371)	NI	1,794 (1,755-1,854)	1,501 (1,497-1,505)	1,760 (1,750-1,768)	< 0.0001
Protein [g]	97 (54-136)	81 (80-85)	93 (81-102)	89 (84-111)	82 (54-103)	92 (79-105)	100 (88-106)	NI	NI	130 (130-131)	106 (98-125)	0.0002
Protein [%]	24 (0-38)	19 (18-20)	23 (20-25)	22 (20-26)	25 (16-32)	24 (20-27)	32 (29-35)	NI	NI	35 (35-35)	24 (23-29)	0.0001
Fat [g]	60 (26-95)	85 (82-87)	61 (59-62)	58 (57-63)	42 (27-49)	62 (57-76)	52 (40-55)	NI	NI	60 (60-61)	68 (57-75)	< 0.0001
Fat [%]	34 (0-48)	44 (43-47)	34 (33-34)	33 (31-37)	29 (18-34)	35 (32-44)	38 (27-43)	NI	NI	36 (36-37)	35 (30-39)	0.0049
Carbohydrate [g]	147 (51-418)	125 (114-141)	160 (159-173)	166 (140-208)	84 (79-402)	162 (147-182)	147 (142-157)	NI	NI	110 (110-111)	176 (158-190)	0.0003
Carbohydrate [%]	36 (0-121)	30 (27-32)	40 (40-43)	43 (36-49)	25 (24-121)	41 (35-47)	45 (41-51)	NI	NI	29 (29-30)	40 (36-43)	0.0006

p: Kruskal-Wallis' test. Post-hoc test results: energy: app A *vs*. app F: $p = 0.0016$; app D *vs*. app H: $p < 0.0001$; app D *vs*. app I: $p = 0.0003$; app F *vs*. app H: $p < 0.0001$; app H *vs*. app J: $p = 0.0034$; app J *vs*. app I: $p = 0.0159$; protein [g]: app J *vs*. app A: $p = 0.0003$; app J *vs*. app B: $p = 0.0200$; app J *vs*. app D: $p = 0.0051$; app J *vs*. app E: $p = 0.0194$; protein [%]: app B *vs*. app J: $p = 0.0232$; app J *vs*. app A: $p < 0.0001$; app E *vs*. app J: $p = 0.0349$; fat [g]: app A *vs*. app D: $p < 0.0001$; app A *vs*. app F: $p = 0.0005$; app D *vs*. app E: $p = 0.0246$; app I *vs*. app D: $p = 0.0277$; fat [%]: app A *vs*. app B: $p = 0.0463$; app D *vs*. app A: $p = 0.0010$; carbohydrate [g]: app J *vs*. app B: $p = 0.0349$; app J *vs*. app C: $p = 0.0105$; app J *vs*. app I: $p = 0.0046$; carbohydrate [%]: app A *vs*. app F: $p = 0.0127$; app F *vs*. app J: $p = 0.0105$. NI – no information; Q1-Q3 - interquartile range; Q1-Q3 - interquartile range.

Table IV. Comparison of calculated† and provided‡ nutritional values of the diets.

Macronutrients	*p*								
	App A	App B	App C	App D	App E	App F	App H	App I	App J
Energy [kcal]	0.0180	0.0180	0.0180	0.4990	0.2367	0.0280	0.1978	0.2367	0.0299
Protein [g]	0.1763	0.0280	0.4990	0.7353	0.1763	0.4990	NI	0.0180	0.1282
Protein [%]	0.7353	0.8658	0.0630	0.6121	0.2367	0.0425	NI	0.0180	0.0630
Fat [g]	0.1763	0.0630	0.0180	0.0180	0.4990	0.0630	NI	0.0910	0.1763
Fat [%]	0.7353	0.4990	0.6121	0.0180	0.2367	0.4990	NI	0.0630	0.8658
Carbohydrate [g]	0.0180	0.0180	0.0180	0.8658	0.0630	0.0910	NI	0.0180	0.0280
Carbohydrate [%]	0.2367	0.2367	0.7353	0.8658	0.4990	0.0180	NI	0.0910	0.0280

p: Wilcoxon test. †Nutritional values of a diet analyzed by the Aliant Software (Anmarsoft, Gdańsk, Poland) using the United States Department of Agriculture (USDA) database; ‡Nutritional values provided in the app by the developer. NI – no information.

and the need to change or improve previous habits. Diet apps undoubtedly have many advantages, increasing their popularity and attracting more users. West et al[25] reported that diet apps are beneficial and motivate people to eat healthily, improve self-efficacy, and set or achieve new nutritional goals. The apps are easy to use and helpful in changing nutritional habits. They are free and easily accessible, they track calorie and macronutrient intake, devise personalized meal plans (including the goal of weight loss), offer a variety of diets (for example vegetarian, vegan, lactose-free, gluten-free) and a possibility of exchanging recipes for more preferable ones, shopping lists, and provide intuitional interface. Unfortunately, the data describing the effectiveness of apps is still needs to be improved and consistent. Only some studies[26-31] have proved the efficacy of health apps in improving diet quality[26-28] and weight status[28,29], with some researchers not reporting any significant benefits[30,31]. In their review, Coughlin et al[32] concluded that smartphone app users were more willing to choose lower-calorie, low-fat, and high-fiber foods, which led to more weight loss. Some apps also offer training plans that might be more effective than diet apps alone[33].

Diet apps offering individualized meal plans might be considered a good tool for weight loss. However, the quality of menus significantly differs between apps. Although nutrition and diet apps are recommended by health care professionals (dietitians, doctors, nurses), inconsistency between provided and calculated data, also found in our study, is pointed to as an argument against using them[34,35]. A previous study[36] confirmed the tendency to underestimate macronutrients (total fat, protein) and other compounds (sodium, dietary fibre, cholesterol, SFA, sugars) provided by nutrition tracking apps, based on thirty 24 h dietary recalls entered by the researcher, compared to data from Nutrition Data System for Research. In another study[37], the estimated average calories and macronutrients of a three-day diet from seven diet tracking apps differed significantly from the values calculated on the USDA database. The average differences compared to USDA references were the highest for proteins (10.4%) and fat (-6.5%), followed by calories (1.4%) and carbohydrates (1.0%)[37]. The My Meal Mate (MMM) app (calorie tracker) recorded lower values of energy and macronutrients compared to 24 h recalls. However, there were no statistically significant differences between the MMM app's seven-day means and two-day recalls[38]. Our study found differences between several apps' calculated and declared energy values and macronutrient compositions. Significant differences within apps in calculated energy, macronutrients, and micronutrients [except for PUFA n-3 (g and %), PUFA n-6 (g), cholesterol, sodium, selenium, vitamin D, B_2 and B_{12}] were also observed. A few possible mechanisms explain the obtained results. First, the data in some apps could have been more precise and specified if the nutritional values were calculated according to one serving or the whole dish. Moreover, the number of calories provided in the app did not correspond to the number of calories calculated based on the macronutrient distributions. On the other hand, different food databases could be used in the apps and diet programs to assess the nutritional value. Furthermore, some apps offer users the possibility to add a new product and its nutritional value to the database. As a result, some information entered by users may probably be incorrect. It is worth mentioning that as shown by Ferrara et al[37] apps might be more

Table V. Correlation between calculated† and provided‡ nutritional values of the diets.

Nutrients	App A		App B		App C		App D		App E		App F		App H		App I		App J	
	p	rho	*p*	rho	*p*	rho	*p*	rho	*p*	rho	*p*	rho	*p*	rho	*p*	rho	*p*	rho
Energy [kcal]	0.3739	0.4000	0.6445	-0.2143	0.0579	0.7388	0.8790	-0.0714	0.6445	0.2143	0.7600	0.1429	0.2152	-0.5357	0.0362	-0.7857	0.3833	0.3929
Protein [g]	-	1.0000	0.3833	0.3929	0.3374	0.4286	0.6445	-0.2143	0.0362	0.7857	0.7599	0.1429	NI	NI	0.0362	0.7857	0.7349	-0.1581
Protein [%]	0.3739	0.4000	0.4316	0.3571	0.4316	0.3571	0.7017	0.1786	0.0008	0.9550	0.3833	0.3929	NI	NI	0.0162	0.8469	0.3374	0.4286
Fat [g]	-	1.0000	0.1722	0.5801	0.7017	-0.1786	0.4821	0.3214	0.1194	0.6429	0.0334	0.7928	NI	NI	0.0522	0.7500	0.3503	-0.4183
Fat [%]	0.3739	0.4000	0.1802	0.5714	0.5345	0.2857	0.7599	-0.1429	0.0234	0.8214	0.1482	0.6071	NI	NI	0.0137	0.8571	0.5887	-0.2500
Carbohydrate [g]	0.3739	0.4000	0.9389	-0.0360	0.1802	0.5714	1.0000	0.0000	0.0137	0.8571	0.2532	0.5000	NI	NI	0.0235	0.8214	0.6685	-0.1992
Carbohydrate [%]	0.3739	0.4000	0.8790	0.0714	0.6131	0.2342	0.0522	-0.7500	0.0025	0.9286	0.0713	0.7142	NI	NI	0.0522	0.7500	0.5852	-0.2523

No information for app G; *p*: Spearman's correlation test. †Nutritional values of a diet analyzed by the Aliant Software (Anmarsoft, Gdańsk, Poland) using the United States Department of Agriculture (USDA) database; ‡Nutritional values provided in the app by the developer. NI – no information; rho - Spearman's rank correlation coefficient.

consistent with the food label than the USDA database. Due to the differences in nutritional values of the same products from various producers, the number of delivered calories and macronutrients may differ significantly from the values calculated and provided. In addition, the nutritional values of the products might differ between countries.

In most of the analyzed apps, the amount of energy, vitamins, and minerals was generally by the standard. On the other hand, following the diets offered in some apps may lead to nutritional deficiencies. Of all vitamins, the most significant deficit was observed for vitamin D, which is not surprising due to limited sources of this component (fatty fish, eggs, meat, dairy, and fortified breakfast cereals)[39]. Moreover, five out of ten of the analyzed apps did not fulfil recommendations for iron as a consequence of menus poor in meat (apps A and G), legumes (app D), or grains (app H). A low-calorie diet is well known to be associated with an increased risk of nutritional deficiency. Damms-Machado et al[40] noted micronutrient deficiencies (vitamin D, C, iron, and selenium) in the obese population undergoing a low-calorie diet. Moreover, after three months on a diet, deficits in calcium and zinc were recorded.

Although all diets were generated as the standard (including a full assortment of all food groups), the use of certain food groups was largely limited in some apps. As a result, the proportions of the products could reverse with the long-term use of the app. However, a less frequent occurrence in diets of certain products might also be associated with current trends in diet[41-43].

The limiting of product groups influences the quality of meal plans. Here, we assessed the quality of diet plans using HDI and DQI scores. The scores compare real food and nutrient intake with the reference intake recommended by national dietary guidelines[23,24]. Our results showed the moderate to low quality of the generated diet. Previously, several studies[44-46] assessed the quality of nutrition-related mobile apps. However, the analysis focused on the general assessment of apps (engagement, functionality, aesthetics and information quality) and did not assess the quality of meal plans.

To the best of our knowledge, this is one of the first studies evaluating the quality of individualized meal plans offered by popular apps regarding nutritional standards based on provided and calculated nutritional values. Moreover, a wide range of nutrients was assessed in seven-day menus to avoid the bias of one-day imbalanced diets. Nonetheless, the research was conducted on the most popular applications available in English. Therefore, the results cannot be generalized to fewer common apps, especially in other languages. Another limitation is the possible use of different food databases to estimate the nutritional value of diets by apps and researchers. However, most apps still need to provide information about the nutritional database used by app developers or use several different databases. Furthermore, some apps offer the possibility to add their product or dish to the database. As a result, information entered by users may be incorrect. Moreover, the meal plans were generated for a specific individual regarding anthropometric parameters, age, and sex, so a study including other population groups is required. Additionally, due to the small sample size, some correlations with relatively high rho-values did not reach statistical significance. However, for this type of correlation, very high rho-values were expected.

Conclusions

Diets available in popular apps differ significantly in nutrient and food group intakes and the app-declared nutritional values differ from those calculated using the nutritional database. Therefore, the quality of app-offered individual diet plans should be improved. People who want to use dietary applications should pay attention to the database from which the application developers get information about the nutritional value of food products, whether the project team includes dieticians, or what information about the diet nutritional value is provided. Applications combining diets with training also seem to be a good choice, especially for the obese population.

Conflict of Interest

Małgorzata Jamka worked at the DietLabs company, a diet apps developer. However, none of the apps included in the study was developed by the company. Nina Kaczmarek received personal fees outside the submitted work from the Fitatu Company, which is, among others, the diet apps developer. However, none of the apps included in the paper was developed by this company. Jarosław Walkowiak received personal fees and non-financial support from Biocodex, BGP Products, Chiesi, Hipp, Humana, Mead Johnson Nutrition, Merck Sharp and Dohme, Nestle, Norsa Pharma, Nutricia, Roche, Sequoia Pharmaceuticals, and Vitis Pharma, as well as research grants, personal fees and non-financial support from Nutricia Research Foundation Poland, outside the submitted work. Other authors declare no conflict of interest.

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Ethics Approval

Not applicable.

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Authors' Contribution

Małgorzata Jamka and Jarosław Walkowiak contributed substantially to the study's conception and design. Monika Soczewka, Małgorzata Jamka, Marta Kokot and Nina Kaczmarek acquired the data. Małgorzata Jamka analyzed and interpretated the data. Monika Soczewka, Małgorzata Jamka, Marta Kokot and Nina Kaczmarek drafted the article. Joanna Matysiak, Judyta Cielecka-Piontek, Saule Iskakova and Jarosław Walkowiak made critical revisions related to the relevant intellectual content of the manuscript. Jarosław Walkowiak supervised and validated the project. All authors read and approved the final manuscript.

Availability of Data and Materials

The datasets generated, analyzed, or both during the current study are available from the corresponding author upon reasonable request.

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