IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received May 24, 2020, accepted June 6, 2020, date of publication June 17, 2020, date of current version June 30, 2020.

*Digital Object Identifier 10.1109/ACCESS.2020.3003067*

# SCHOOLTHY: Automatic Menu Planner for Healthy and Balanced School Meals

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This work was supported by the Spanish Ministry of Economy, Industry and Competitiveness as part of the Program I+D+i Orientada a los Retos de la Sociedad under Contract TIN2016-78410-R.

**ABSTRACT** SCHOOLTHY: Automatic Menu Planner for Healthy and Balanced School Meals is a decision support tool that addresses the multi-objective menu planning problem in order to automatically produce meal plans for school canteens. Malnutrition is a widespread problem nowadays and is particularly serious when it affects children. In our environment, nutrition experts design healthy and balanced meal plans for children manually, which leaves significant room for improvement in terms of convenience and efficiency. SCHOOLTHY is presented herein as a proposal to improve and facilitate the work of these professionals. We focus on offering healthy and balanced meal plans that not only satisfy the recommended energy and nutrient intakes, but that also have a minimum cost and maximum variety of courses and food groups. Quantitative analyses that compare the meal plans yielded by SCHOOLTHY for meal plans designed by experts at hand and served in regional schools demonstrate the suitability of the proposal. Finally, we note that, thanks to its flexibility, SCHOOLTHY might be easily adapted to deal with other environments, such as hospitals, prisons and retirement homes, among others.

**INDEX TERMS** Evolutionary algorithm, food technology, menu planning, multi-objective optimization, nutrition, public health informatics.

## I. INTRODUCTION

Nowadays, the problem of malnutrition is one that developed countries are not exempt from [1]. We have a population without sufficient resources to benefit from a varied and rich nutrition, especially due to the recent episodes of economic crisis in many developed countries. At the same time, the consumption of prepared and ultra-processed food with a very unfavourable nutritional quality, motivated by the current frenetic pace of life, is increasing [2], [3].

This problem of malnutrition, due to either lack or excess of nutrients, is particularly serious when it affects children. It is highly recommended, therefore, that a varied, healthy and balanced diet be adopted [4], and it is essential that this type of diet be offered to children, not only at home but also in schools. The introduction of changes in nutritional habits is a must if we are to foster a healthy food environment for children [5]. Those changes require the cooperation of families, schools, community stakeholders and policymakers [5]–[7]. Controlling what our children eat inside the home is quite an impossible task for regional administrations. However, they can take steps to improve the nutrition of children in educational institutions, since the vast majority of children eat lunch in school canteens.

This type of varied, healthy and balanced diet must be designed by experts in nutrition who are able to determine the nutritional requirements of those people for whom it is intended. Normally, experts manually design and revise those meal plans, a work process that leaves considerable room for improvement nowadays. In order to facilitate that work process, in this paper, we introduce *SCHOOLTHY: Automatic Menu Planner for Healthy and Balanced School Meals*, a desktop application that allows school menus to be planned in a simple, fast and automatic manner. Our objectives focus on planning healthy, balanced and adequate menus from a nutritional point of view, minimising the cost of the menu, while simultaneously maximising the variety or diversity of the courses and food groups that comprise the meal plans.

For doing that, SCHOOLTHY makes use of *Evolutionary Computation* (EC) to deal with a novel multi-objective

The associate editor coordinating the review of this manuscript and approving it for publication was Laurence T. Yang.

formulation of the *Menu Planning Problem* (MPP) [8], that we have termed as *Multi-objective Menu Planning Problem* (MMPP). The making of meal plans for school canteens exclusively is what differentiates this new formulation from other variants of the MPP used in most applications previously proposed [8], since our audience is a group of school-age children at lunchtime.

Hence, the main aspects that we have taken into consideration when defining the novel MMPP, and consequently, to design SCHOOLTHY, are the following:

- Menu plans only consist of lunch, thus excluding the remaining daily meals.
- Menu plans are aimed at children ages 4 to 13, whose recommended daily amounts of energy and nutrients do not differ considerably.
- No gender distinction is made in practice at school canteens, and therefore, menu plans are designed for boys and girls with no distinction.
- Menu plans are intended for groups of people, rather than individuals. Therefore, gathering physical data and user preferences in an effort to design a personalised plan does not make sense in this scenario.
- Possible allergens, illnesses or food incompatibilities, that prevent the consumption of certain foods, could be considered by SCHOOLTHY, in order to provide suitable alternatives that slightly deviate from the general meal plan designed initially.
- Additional aspects, such as the attributes of the meals, their quality, temperature and preparation time are not considered. At school canteens, meals are prepared by cooking professionals that have in mind all the aforementioned criteria.
- The cost and the variety of courses and food groups included in the meal plan are considered as the objectives to be optimised simultaneously.
- The nutritional features of the meals are handled as constraints.

Bearing all the above discussion in mind, the main contributions of this work are as follows:

- SCHOOLTHY, an application that allows planning the courses meals served in schools in a simple, fast and automatic way. The application is easy to use and set up. As far as we know, this is the first decision support tool proposed based on a multi-objective formulation of the MPP to automatically design meal plans through EC for school contexts.
- A multi-objective formulation of the MPP focused on minimising the cost and the degree of repetition of courses and food groups that a meal plan consists of, and always satisfying the established nutritional requirements.
- A quantitative analysis of the meal plans generated automatically by the application in comparison to real meal plans designed by nutrition experts and offered in regional schools.

The remaining content of this paper is structured as follows. A brief description of the MPP is given in Section II, while the particular formulation of the MMPP we are proposing herein is depicted in Section III. Afterwards, a review of different applications that deal with different variants of the MPP is presented in Section IV. The description and the main functionalities of SCHOOLTHY, as well as its configuration, are described in Section V. Section VI contains a comparison between the meal plans generated by the tool and real meal plans that are offered at different schools in the region. Finally, the conclusions and some lines of further research are shared in Section VII.

## II. DESCRIPTION OF THE MENU PLANNING PROBLEM

The MPP [8] is a well-known problem that involves the generation of meal plans, generally for a person, with the aim of establishing specific diet routines. For these meal plans to better adjust to the needs of the user, aspects such as physiological characteristics, food preferences, restrictions due to allergies or different lifestyles and price constraints, among others, are usually considered. In our case, we will design meal plans for groups of people, specifically, children in schools. Herein, a daily lunch meal is designed consisting of a starter, a main course and a dessert. A set of meals, considering a given number of days specified by the user, form a meal plan.

The recommended nutrient intake for children at lunch, as well as additional nutritional advice, were obtained from the *Intervention Program for the Prevention of Childhood Obesity*[1] (PIPO), endorsed by the *Health Service* of the *Government of the Canary Islands*, the *Canary Institute of Agri-food Quality*[2] (ICCA) and the *White Book on Child Nutrition* [9]. We should note at this point that the ICCA is the *Regional School Nutrition Supervisor* (RSNS), which is responsible for assessing, from the nutritional point of view, the meal plans served at school canteens in the region, among other tasks. According to these sources, the recommended intake of nutrients for school-age children differs modestly by age, and, to a lesser extent, by gender. However, in practice, there is usually no distinction when serving meals in schools, and as a result, it will not be taken into consideration in this paper.

Since we are dealing with large groups of children, we will not consider aspects such as user preferences for certain foods. It must be noted, however, that possible allergens, illnesses or food incompatibilities that prevent the consumption of certain foods could be considered. In these cases, a special meal plan will be provided starting from the standard meal plan obtained for the general case.

The MPP is a well-known problem that has been addressed in past research by applying different algorithmic techniques. The following cover a wide range of examples:

[1]The information from this programme can be accessed through http://www.programapipo.com/.

[2]The website of the Institute can be accessed at https://www.gobiernodecanarias.org/agp/icca/.

- Genetic Algorithms: [10]–[16].
- Estimation of Distribution Algorithms: [17].
- Bacterial Foraging Optimisation Algorithm: [18].
- Linear Programming and Mixed Integer Linear Programming: [19]–[22].
- Case-based and Rule-based Reasoning: [23]–[27].
- Fuzzy-based Approaches: [28], [29].
- Branch & Bound: [1], [30].

A good starting point to find information about the application of different mathematical optimisation methods in order to design menu plans or diets can be found in [31]. In that work, a wide range of problem formulations were reviewed, by specifying the objective function to be optimised and the set of restrictions to be satisfied in each case. Furthermore, the different optimisation methods applied to solve each formulation were also described in detail. As a particular example, Linear Programming was applied to generate breakfasts for children and adults in [22]. In this case, breakfasts need to meet energy and nutrient requirements at low cost, while minimising deviation between the current breakfasts of a given population and the breakfasts provided by Linear Programming.

As the above list shows, the application of meta-heuristics, and evolutionary algorithms in particular, to solve this problem is frequent. Furthermore, all the above works consider a single-objective formulation of the MPP. In some cases, although multiple objectives are taken into consideration, a single-objective variant is addressed during the optimisation process due to a transformation of the multi-objective problem into a single-objective one. Finally, it is worth noting that only a few papers consider a real multi-objective variant of the MPP, where multi-objective optimisers are applied to yield solutions. In those cases, multi-objective evolutionary algorithms have been successfully applied [32]–[34].

The issue of what aspects to consider as problem objectives and what to consider as constraints may differ among authors; however, there is a clear tendency to consider the cost of the menu as an objective to be minimised [15]–[17], [30]. Other authors, who do not consider the cost of the menu, usually include user preferences for certain foods, the level of adequacy, the level of acceptance or the deviation between the current practice and the solutions attained, as the objective to be optimised [11], [13], [22], [35], [36].

In general, the most important and common consideration for the MPP is to ensure a healthy and balanced menu from a nutritional point of view. These nutritional requirements are usually grouped into multiple constraints, since they must provide the recommended minimum and maximum amounts of different nutrients [1], [13], [15], [17], [18], [30]. Other common constraints are the variety of the meals, the time required to prepare them, and food that cannot be consumed, among many others [1], [30], [36].

In our case, we propose a novel multi-objective variant of the MPP, where two different objectives must be optimised:

- **Cost**: the total price, in euros, of all the courses that make up the meal plan, to be minimised.
- **Degree of repetition**: also called variety or repetition level, which represents the percentage of courses and food groups repeated throughout the meal plan, with zero being the minimum level of repetition and one the maximum. This objective has to be minimised.

Generally speaking, people, and even more children, need non-repetitive meals, not only for health reasons, but also to avoid detesting certain courses. Additionally, studies have shown that dietary variety and/or diversity are healthy and related to diet quality [37]–[39]. Eating a more varied diet is associated with a higher intake of macro and micronutrients, as well as higher nutritional adequacy and diet quality [40]. As a result, the motivation behind our novel formulation is to offer a meal plan that is not only affordable in the case of school canteens, but also varied and balanced from a nutritional standpoint. Furthermore, we note that one of our main goals is to give the same importance to both objectives. In the field of multi-objective optimisation, it is well-known that a problem completely changes by transforming one of the objective functions considered into a restriction, thus leading to potentially achieve worse solutions. The above is the main reason why we kept a multi-objective formulation of the problem.

In multi-objective optimisation problems, the objectives are often in conflict one with one another. In this case, the cheapest meal plan will be that consisting of the cheapest courses, with a high repetition level not only among courses, but also among different food groups. At the same time, it is likely that a meal plan in which the variety of courses and food groups is large (a low degree of repetition), will include more expensive courses, thus making the total price of the plan higher as well. These two possibilities represent the opposite sides of a Pareto front, with the intermediate solutions being meal plans with a more balanced price and degree of repetition.

Moreover, those solutions have to meet the complete set of constraints previously established. Finally, the decision maker is responsible for selecting the meal plan that best suits the expected requirements. As constraints, we have defined the amount of energy, macronutrients (carbohydrates, fats and proteins), and micronutrients (calcium, folic acid, iodine, iron, magnesium, phosphorus, potassium, selenium, sodium, vitamin A, vitamin B1, vitamin B2, vitamin B6, vitamin B12, vitamin C, vitamin D, vitamin E and zinc). For each solution obtained, the above elements must be within a recommended intake range for the solution to be feasible. At this moment, it is important to remark that the RSNS recommendations for nutrient compliance in meal plans only refer to energy and macronutrients. Bearing the above in mind, micronutrients will not be taken into consideration when the feasibility of a meal plan is assessed. Nevertheless, information about micronutrients of a particular meal plan is provided by SCHOOLTHY.

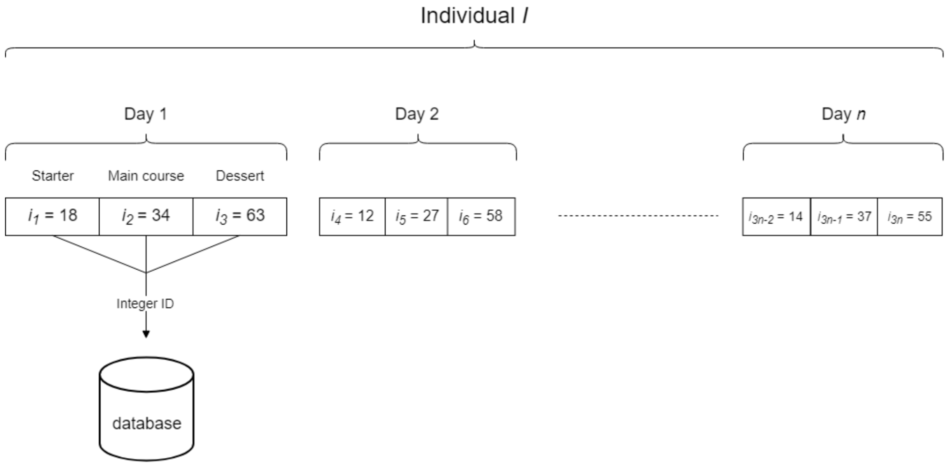


**FIGURE 1.** Example of individual or solution encoding.

## III. FORMULATION OF THE MULTI-OBJECTIVE MENU PLANNING PROBLEM

As we previously mentioned, two objective functions are considered herein. The first objective is the minimisation of the cost of the plan, while the second objective is to minimise the degree of repetition, i.e., how often the courses and food groups included in the plan are repeated. At the same time, the degree of repetition also depends on the number of days for which the plan is designed, since the time intervals between repetitions are also considered. Typically, the repetition, of either some food groups or specific courses, in the menu involves a penalty value that increases with the degree of repetition defined. Therefore, a non-feasible solution would be one whose penalty value is sufficiently high, depending on the particular constraint established. The nutritional quality of the meal plans is treated as the problem constraints. Finally, we note that in an effort to design appropriate meal plans, it was necessary to design a database of courses and ingredients with information on their respective nutritional specifications and nutritional advice, as well as on their allergens.

### A. ENCODING OF INDIVIDUALS

An individual represents a meal plan in which there are as many meals—consisting of a starter, main course and dessert—as there are days for which the plan is going to be designed. Computationally, an individual is represented as a one-dimensional vector of integers $I$ with length $|I| = 3 \cdot n$, where $n$ is the number of days considered in the plan. Each element $i_{q=1,\ldots,3\cdot n} \in I$ corresponds to the identification number ($id$) of a course in the course database. For each course considered, all of its related information, i.e., its name, price, amount in grams, nutritional data, food groups, allergens and food incompatibilities, is also available in the database. Figure 1 graphically represents the above.

Considering a given number of starters $l_{st}$, main courses $l_{mc}$ and desserts $l_{ds}$, the size of the search space $S$ is given by Equation 1. We note that the size of the search space exponentially increases with the number of days that the plan is designed for. For instance, by only considering $l_{st} = l_{mc} = l_{ds} = 10$ and a weekly meal plan, i.e., $n = 5$ days, the number of potential solutions $|S|$ would be equal to $10^{15}$.

$$|S| = (l_{st} \cdot l_{mc} \cdot l_{ds})^n \tag{1}$$

### B. OBJECTIVE FUNCTIONS

The total cost of a meal plan for $n$ days is calculated as follows:

$$C = \sum_{j=1}^{n} c_{st_j} + c_{mc_j} + c_{ds_j} \tag{2}$$

where $c_{st_j}$, $c_{mc_j}$ and $c_{ds_j}$ are the costs for the starter, main course and dessert, respectively, for day $j$. In individual $I$, $st_j$, $mc_j$, and $ds_j$ correspond to elements $i_{3\cdot j-2}$, $i_{3\cdot j-1}$ and $i_{3\cdot j}$, respectively. The cost for a given course is calculated as the sum of the costs of its ingredients. For each ingredient, the database stores its price per kilogram, and for each course, the number of grams of a given ingredient required to prepare that course is also stored.

The novel objective function modelling the degree of repetition of courses and food groups is calculated as:

$$R = \sum_{j=1}^{n} v_{MC_j} + \frac{p_{st}}{d_{st_j}} + \frac{p_{mc}}{d_{mc_j}} + \frac{p_{ds}}{d_{ds_j}} + v_{FG_j} \tag{3}$$

where $v_{MC_j}$ represents the compatibility, in terms of food groups, among courses $st$, $mc$ and $ds$ for day $j$; $p_{st}$, $p_{mc}$ and $p_{ds}$ are the penalty constants, one per course type; $d_{st_j}$, $d_{mc_j}$ and $d_{ds_j}$ are the number of days since the corresponding course last appeared in previous days with respect to day $j$; and $v_{FG_j}$ is the penalty value for repeating food groups in the last five days with respect to day $j$. The food groups considered for the meals available in this work are $G = \{$*other, meat, cereal, fruit, dairy, legume, shellfish, pasta, fish, vegetable*$\}$,

**TABLE 1. Types of penalties defined to compute the second objective function.**

| Penalty | Description | Value |
|---|---|---|
| $p_1$ | penalty for repeating *other* food group | 0.1 |
| $p_2$ | penalty for repeating *meat* food group | 3 |
| $p_3$ | penalty for repeating *cereal* food group | 0.3 |
| $p_4$ | penalty for repeating *fruit* food group | 0.1 |
| $p_5$ | penalty for repeating *dairy* food group | 0.3 |
| $p_6$ | penalty for repeating *legume* food group | 0.3 |
| $p_7$ | penalty for repeating *shellfish* food group | 2 |
| $p_8$ | penalty for repeating *pasta* food group | 1.5 |
| $p_9$ | penalty for repeating *fish* food group | 0.5 |
| $p_{10}$ | penalty for repeating *vegetable* food group | 0.1 |
| $p_{11}$ | penalty for repeating the same food group one day earlier | 3 |
| $p_{12}$ | penalty for repeating the same food group two days earlier | 2.5 |
| $p_{13}$ | penalty for repeating the same food group three days earlier | 1.8 |
| $p_{14}$ | penalty for repeating the same food group four days earlier | 1 |
| $p_{15}$ | penalty for repeating the same food group five days earlier | 0.2 |
| $p_{16} = p_{st}$ | penalty for repeating a starter | 8 |
| $p_{17} = p_{mc}$ | penalty for repeating a main course | 10 |
| $p_{18} = p_{ds}$ | penalty for repeating a dessert | 2 |

in keeping with the suggestions given by the *Intervention Programme for the Prevention of Childhood Obesity*.

A healthy meal plan should be well-balanced, and therefore, specific courses and food groups should not be repeated frequently. Penalties are operations performed on the second objective function in order to determine the quality and variety of a meal plan. They directly affect the way a meal plan is obtained and can be used by the decision-maker in order to establish preferences. Penalties are represented by float constants. The higher the values, the greater the penalties. The different types of penalties considered are shown in Table 1.

As we can see, the penalties are determined by the repetition of food groups ($p_1$–$p_{10}$), the repetition of the same food group from one to five days prior to the current day ($p_{11}$–$p_{15}$), and the repetition of specific courses ($p_{16} = p_{st}$, $p_{17} = p_{mc}$, and $p_{18} = p_{ds}$). Penalty values were set by performing a preliminary study where the features of the solutions obtained were analysed in terms of repeated courses and food groups.

In the case of penalties for repeating food groups ($p_1$–$p_{10}$), if the penalty value of a given food group is very large in comparison to the remaining food group penalty values, then a plan with a lower number of courses belonging to that food group will likely be provided. For instance, we have given preference to those courses consisting primarily of vegetables ($p_{10} = 0.1$) over courses composed primarily of meat ($p_2 = 3$). These penalties are used in the computation of $v_{FG}$ in Equation 4, and $v_{MC}$ in Equation 5.

In the case of penalties for repeating the same food group in previous days ($p_{11}$–$p_{15}$), the more days that have passed since a food group was repeated, the lower the penalty. A time window $T = 5$ days was set because a weekly school menu typically involves planning five meals, one per day. Penalties for repeating food groups are less restrictive in comparison to penalties for repeating specific courses. A particular course should not be repeated in short periods of time. A particular food group, however, will likely be repeated since different courses could belong to the same food group. These penalties are considered in the calculation of $v_{FG}$ in Equation 4.

Finally, in the case of the penalties for repeating a specific course, i.e., $p_{16} = p_{st}$, $p_{17} = p_{mc}$, and $p_{18} = p_{ds}$, their value is set depending on the quantity of a course type, i.e., the number of starters, main courses or desserts, available in the database. Since there are fewer desserts than starters and main courses, desserts will inevitably be repeated more often and thus their penalty value will be lower in comparison to the penalty values for repeating starters and main courses. We note that if a course of a given day $j$ has not been repeated on any previous day, then the corresponding value for $d_{st_j}$, $d_{mc_j}$ or $d_{ds_j}$ will be infinite. As a result, the corresponding fraction in Equation 3 will be equal to zero.

Equation 4 is used to compute $v_{FG_j}$, where $T = 5$ days is the number of previous days considered, $|G|$ is the number of food groups, $x_{g_i} \in \{0, 1\}$ indicates whether the food group $g$ is repeated on day $j - i$ ($x_{g_i} = 1$) or not ($x_{g_i} = 0$) with respect to day $j$, $y_i \in \{0, 1\}$ indicates whether any food group was repeated $i$ day(s) before the current day $j$ ($y_i = 1$) or not ($y_i = 0$), and $p_g$ and $p_{|G|+i}$ are the corresponding penalty values.

$$v_{FG_j} = \sum_{i=1}^{min(j-1,T)} (\sum_{g=1}^{|G|} x_{g_i} \cdot p_g) + (y_i \cdot p_{|G|+i}) \tag{4}$$

Equation 5 allows the value of $v_{MC_j}$ to be calculated, where $|G|$ is the number of food groups, $x_g \in \{0, 1, 2, 3\}$ is the number of times a particular food group is contained in the three courses (starter, main course and dessert) of the menu for day $j$, and $p_g$ is the corresponding penalty value for repeating the food group $g$.

$$v_{MC_j} = \sum_{g=1}^{|G|} x_g \cdot p_g \tag{5}$$

### C. CONSTRAINTS

As we mentioned before, every feasible meal plan must comply with a recommended amount of energy and macronutrients given by $H = \{$*energy, carbohydrates, proteins and fat*$\}$. For each meal plan generated, all of its nutrients will be calculated. For each of the nutrients, its value has to be within the acceptable range of its recommendation; otherwise, the individual will be considered non-feasible. At this point, we note that, since we are only considering lunch in the meal plan, recommendation ranges apply to quantities to be proportionally ingested at lunch time. The amount of nutrient $h$ to be ingested every day at lunch time is denoted as $r_h$, by following the recommendations of the RSNS. There is therefore a set $R$ of pairs $(r_{min}, r_{max})$ and size $|H|$, where the elements $r_{min_h}$ and $r_{max_h}$ represent the minimum and maximum proportion of nutrient $h$ allowed within the global plan for $n$ days. The set of nutrients and corresponding recommendation and ranges considered in this work are shown in Table 2. Formally, a feasible individual $I$, from a nutritional point of view, should fulfil the following constraints:

$$\forall h \in H : n \cdot r_{min_h} \cdot r_h \leq in(I, h) \leq n \cdot r_{max_h} \cdot r_h \tag{6}$$

where $in(I, h)$ denotes the global intake of element $h$ in the whole menu plan.

**TABLE 2. Intakes of energy and macronutrients per day ($r_h$) recommended by the RSNS. Minimum ($r_{min}$) and maximum ($r_{max}$) proportions of the nutrients allowed within the global plan for $n$ days are also shown.**

| Nutrient | $r_h$ | $r_{min_h}$ | $r_{max_h}$ |
|---|---|---|---|
| Energy | 700 kcal | 0.85 | 1.15 |
| Carbohydrates | 87.5 g | 0.75 | 1.25 |
| Fat | 27.2 g | 0.75 | 1.25 |
| Proteins | 26.25 g | 0.75 | 1.25 |

## IV. RELATED SOFTWARE

There are several applications that deal with the MPP. A review of many of these nutrition-related tools is provided in [42]. In this section, we will present the main features of some of the most popular web and mobile applications. In order to make the selection of applications to be compared, it is important to note that only free options have been reviewed. At the same time, we have only taken into consideration applications that could provide menu plans for school canteens or similar scenarios, such as retirement homes and prisons, among others. As we mentioned at the beginning of Section II, in these scenarios, it is common to provide a menu for large groups of people, and then, modify it somehow attending to the particular lifestyles or special requirements of some individuals of the group, such as food intolerances and allergies, among others. Finally, each selected application allows some (and not all) of the remaining aspects of our particular formulation of the problem—also given at the beginning of Section II—to be properly managed. The specific aspects considered when classifying the tools analysed are as follows:

1) **Number of people (NP)**: this aspect indicates if an application is intended for one individual or a group of people. Generally, tools focused on a single person ask for physiological data and/or food preferences in order to make a more personalised meal plan.
2) **Food preferences (FP)**: this feature determines if the application considers, when designing the menu, types of meals that are preferred or disliked by the user.
3) **Allergies (AL)**: this aspect denotes whether the application takes into consideration the user's potential allergies and/or food intolerances to completely rule out those menus with prohibited ingredients.
4) **Nutritional information of the meal plan (NI)**: this characteristic determines if detailed information on the nutritional values (macro and/or micronutrients) of the meal plans is shown by the application. An application with nutritional information denoted as *adequate* usually shows the total amount of energy and macronutrients. If it is categorised as *remarkable*, it will also offer information about micronutrients.
5) **Cost (C)**: this parameter specifies if the application provides an estimate of the price associated with the meal plans given.
6) **Generation of meal plan (GMP)**: this indicator describes how the application obtains meal plans. Three different ways are usually considered: automatically, user-driven and predefined. In most applications, once generated, automatic plans can be altered in some way by the decision maker.
7) **Number of meals per day (MPD)**: this aspect refers to the maximum number of meals per day that the application is able to manage (breakfast, lunch, snack, dinner).
8) **Type of software (TS)**: this feature denotes if the planner is provided through a desktop, web or mobile application.

Table 3 shows a summary of tools classified according to the aforementioned aspects. As the table shows, most of the applications are intended for a single individual. These applications, however, could be used to produce a general plan for a group of people as well. For instance, rather than providing physiological data of an individual to obtain a personalised plan, we could calculate mean physiological data by considering a group of people, for instance, school-age children, and then provide the application with that mean data to produce the meal plan. Additionally, we can distinguish between two main groups: those that provide meal plans automatically and those that do not, in which either the menus are already defined or the user creates them.

Applications that provide meal plans automatically (ETM, FMP, ML, SPO, TRF) usually ask the user for information on their food preferences, and some even ask the user about their allergies and/or food intolerances. Furthermore, these applications usually allow the meal plans generated to be modified by the user. In the cases of ETM, FMP and ML, on the one hand, the preferences involving diet types, and on the other hand, the specific intolerances and courses to avoid, can be selected separately. Particularly, the section focused on food restrictions is the most complete in the case of these

**TABLE 3. Taxonomy of applications regarding different features.**

| Acronym | Application | NP | FP | AL | NI | C | GMP | MPD | TS |
|---|---|---|---|---|---|---|---|---|---|
| SCL | SCHOOLTHY | group | no | yes | remarkable | yes | automatic | 3 | desktop |
| DWL | Diet Point-Weight Loss | group | no | no | no | no | predefined | 5 | mobile |
| EMP | Easy Menu Planner | individual | no | no | no | no | user-driven | 7 | mobile |
| ETM | Eat This Much | individual | yes | yes | remarkable | yes | automatic | 4 | mobile |
| FMP | Fitness Meal Planner | individual | yes | yes | adequate | no | automatic | 8 | mobile |
| LWH | Lose Weight Healthily | group | no | no | adequate | no | predefined | 6 | mobile |
| ML | Mealime | individual | yes | yes | adequate | no | automatic | 6 | mobile |
| PP | Prepear | individual | no | no | remarkable | no | user-driven | 4 | mobile |
| SC | Sidechef | individual | no | no | no | no | user-driven | 3 | mobile |
| SPA | SPARE [41] | group | no | no | adequate | no | user-driven | 4 | web |
| SPO | Spoonacular | individual | yes | yes | remarkable | yes | automatic | 3 | web |
| TRF | Tesco Real Food | individual | yes | yes | adequate | no | automatic | 3 | web |

three tools, since they include a long list of allergies, and courses grouped by food groups, which the user can select from to set their preferences.

Considering SPO, the election of the types of diets is very similar to that provided by the aforementioned apps. In terms of restrictions, however, it considers a smaller number of allergies and intolerances. TRF implements an additional feature with respect to the remaining tools: the possibility of including specific courses in the meal plan as a preference, and not as something to avoid. However, regarding food restrictions, it only contemplates some types of diets that, by their nature, exclude certain types of courses, such as those usually consumed by vegetarians.

Applications that provide predefined meal plans (DWL, LWH) are normally focused on groups of people, since they do not consider specific information about particular food preferences and/or restrictions. DWL offers a much wider variety of diet types than LWH, although most of them are only accessible through a prepaid plan. LWH has a smaller amount of courses, but the information provided is much richer, since it not only details the ingredients that a particular course consists of, but also information about how to cook them.

It is common for some of the tools analysed to ask the user for their physiological characteristics in order to generate or recommend meal plans that are much more suitable based on their physical condition and weight goals. DWL and ETM implement a simple weight goal system in which the user simply has to indicate their current weight and goal weight. FMP has a more sophisticated system that asks not only for the weight goal, but also for the level of physical activity and body type.

The applications where the user has to design their own meal plan include EMP, PP, SC and SPA. These applications allow their users to design a complete meal manually by directly considering their preferences. Hence, PP and SC offer a varied set of courses grouped by different categories, such as cooking methods, cooking times and suitable times of day to be consumed, among others. EMP provides a smaller variety of courses, and works almost like a simple meal notebook. In SPARE, the user also has to design their own meal plans, although, in contrast to the other applications belonging to this group, it focuses on groups of people rather than a single person. SPARE will be discussed in more detail below.

Finally, we should note that only a few applications (ETM, SPO) provide an estimated cost of the meal plans generated. They show the estimated price of each course based on its ingredients and the number of servings.

Our proposal, SCHOOLTHY, is focused on groups of children, i.e., a single general meal plan is provided. However, specific restrictions, such as allergies and food incompatibilities, may be also considered in order to slightly modify that general plan. The goal would be to provide a more tailored plan for a specific person. As a result, meal plans are generated such that they are accessible to a significant number of children in schools. Plans are generated automatically according to parameters such as: the number of days for which it will be designed, a database containing specific ingredients and courses, the main food group of those courses and the ranges of recommended nutritional intakes. Among all the potential solutions based on those parameters, the application will show the optimal meal plans sorted by a variety-cost ratio.

Of all the applications analysed, SPARE [41] is perhaps the most similar tool when compared to SCHOOLTHY, since it was specifically designed having in mind school meal plans. It considers national and international nutritional recommendations to evaluate meal plans for Portuguese schools. Meal plans are designed by the decision maker at hand through the interface provided, and are subsequently assessed taking into consideration aspects such as energy and macronutrient requirements, the variety of the meal plan, cooking methods and seasonality, among other features. The decision maker has to provide all the information of every course in the form of technical sheets that include data about ingredients, preparation and cooking methods, among others. Afterwards, once the database has enough technical sheets, the decision

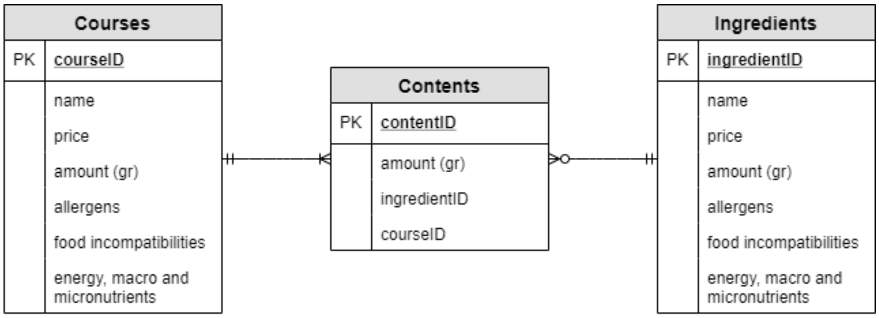


**FIGURE 2. SCHOOLTHY: Database design.**

maker has to select the different courses and assign them for every day that the meal plan consists of, which can be a weekly or monthly plan. Finally, SPARE will indicate whether the menu plan designed by the decision maker is feasible or not from the nutritional point of view. If not, the decision maker will have to redesign the plan. The above is the main drawback of SPARE with respect to SCHOOLTHY.

As we will explain later in Section V, SCHOOLTHY designs and provides meal plans automatically by using an optimisation procedure. The decision maker has to provide information about ingredients and courses in a similar way. Then, different options can be configured, such as the number of days of the plan, the particular courses of the database considered to generate the plan, allergens to avoid, food incompatibilities and recommended intake of nutrients, among others. Once the application has enough information about ingredients and courses in its database, and all the options are properly set up, the optimiser will provide feasible meal plans automatically. The user does not have to check if the meal plans are suitable from the nutritional standpoint and redesign them if not. The above is the main advantage of SCHOOLTHY, since it allows a significant amount of time to be saved by the decision maker in comparison to the usage of SPARE.

In brief, while SPARE focuses on evaluating a set of user-designed meal plans, SCHOOLTHY focuses on optimising the MMPP to provide feasible meal plans automatically.

## V. SCHOOLTHY: AUTOMATIC MENU PLANNER FOR HEALTHY AND BALANCED SCHOOL MEALS

This section presents *SCHOOLTHY: Automatic Menu Planner for Healthy and Balanced School Meals*, which is a desktop application written in C++ and Qt [43]. It is designed to allow the automatic generation of meal plans for schools. SCHOOLTHY provides a simple user interface, which consists of different sections grouped by tabs.

All the ingredients and courses with their respective information are stored in a MySQL database. As Fig. 2 shows, the design of the database is simple, consisting of three different tables: `Ingredients`, `Contents` and `Courses`. The `Ingredients` table refers to raw food, such as carrots. The ingredients are stored in the database and include the nutritional information for 100 grams of product. The `Courses` table refers to the courses/recipes, for instance, carrot soup, that can be prepared with the available ingredients. The `Contents` table sets a relationship between the `Ingredients` and `Courses` tables and lists the ingredients, as well as their quantities in grams, that a particular course consists of. Hence, a particular course may contain one or more ingredients, and a particular ingredient may be used to cook one or several courses. For each ingredient, its name, price per quantity, amount in grams, allergens, food incompatibilities and nutritional information are stored in the database. By extension, the price, amount in grams, allergens, food incompatibilities and nutritional information of a course are automatically calculated depending on the ingredients it contains. We should note that the nutritional information on the ingredients in the database was taken from the *Spanish Database of Food Composition*[3] (BEDCA).

The procedure for using the application is very straightforward and will be explained in more detail in the following subsections. First of all, the decision maker has to add information on ingredients in the application, which will be stored in the database. Then, with those ingredients, the decision maker can store different courses, which will be used later by the SCHOOLTHY planner to produce meal plans. The planner is also configured at this time, including the decision maker preferences. Finally, the multi-objective evolutionary engine will generate different feasible solutions or meal plans by considering all the information provided. Decision makers will be able to select any of those feasible meal plans and enter any modifications deemed necessary. The diagram in Fig. 3 illustrates the aforementioned workflow.

### A. ADDING INGREDIENTS

SCHOOLTHY requires a set of ingredients to be specified. These ingredients will be used to define courses in a later step. The information needed to define an ingredient is: its name, quantity in grams, price per kilo in euros, food group (cereal, dairy, fish, fruit, legume, meat, pasta, seafood, vegetable or other), amount of energy, macronutrients (carbohydrates, fats and proteins), micronutrients (calcium, folic acid, iodine, iron, magnesium, phosphorus, potassium, selenium,

[3] The food composition database is available at http://www.bedca.net/.

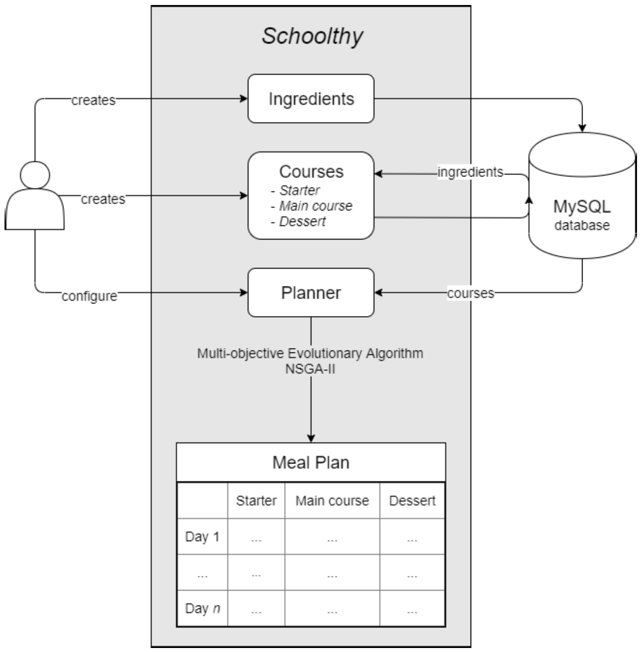


**FIGURE 3.** SCHOOLTHY: **Application architecture.**

sodium, vitamin A, vitamin B1, vitamin B2, vitamin B6, vitamin B12, vitamin C, vitamin D, vitamin E and zinc), seasonal period, allergens (cereals, cow milk protein, egg protein, fish, legumes, nuts, seafood), diseases (coeliac disease, diabetes) and lifestyles (semi-vegetarian, vegetarian, vegan). The prices per kilo of the ingredients were obtained by consulting various local food markets.[4] Anyway, information about prices could be taken from any database. Finally, we should note that, when introducing ingredients into the SCHOOLTHY database, a distinction is made taking into consideration their particular preparation. Hence, the nutritional information of boiled chicken will be different from that specified for fried chicken, for instance. Fig. 4 shows the interface used to insert, edit and/or remove ingredients.

### B. DEFINING COURSES

Once the ingredients have been defined, courses can be created. In order to add a course to SCHOOLTHY, the user only needs to select the ingredients and their respective quantities in grams. The above information is usually provided by nutritionists through technical sheets, one per course to be added into the system. Courses are classified as starters, main courses or desserts, and for this first implementation of SCHOOLTHY, a total of 37 starters, 55 main courses and 14 desserts are available. Furthermore, for all the data related to the price, nutrients, allergens and food incompatibilities,

[4] An example of food market is *MercaTenerife* (https://mercatenerife.com/), which is focused on wholesale, where public schools in the region usually buy the ingredients required to prepare the meals.

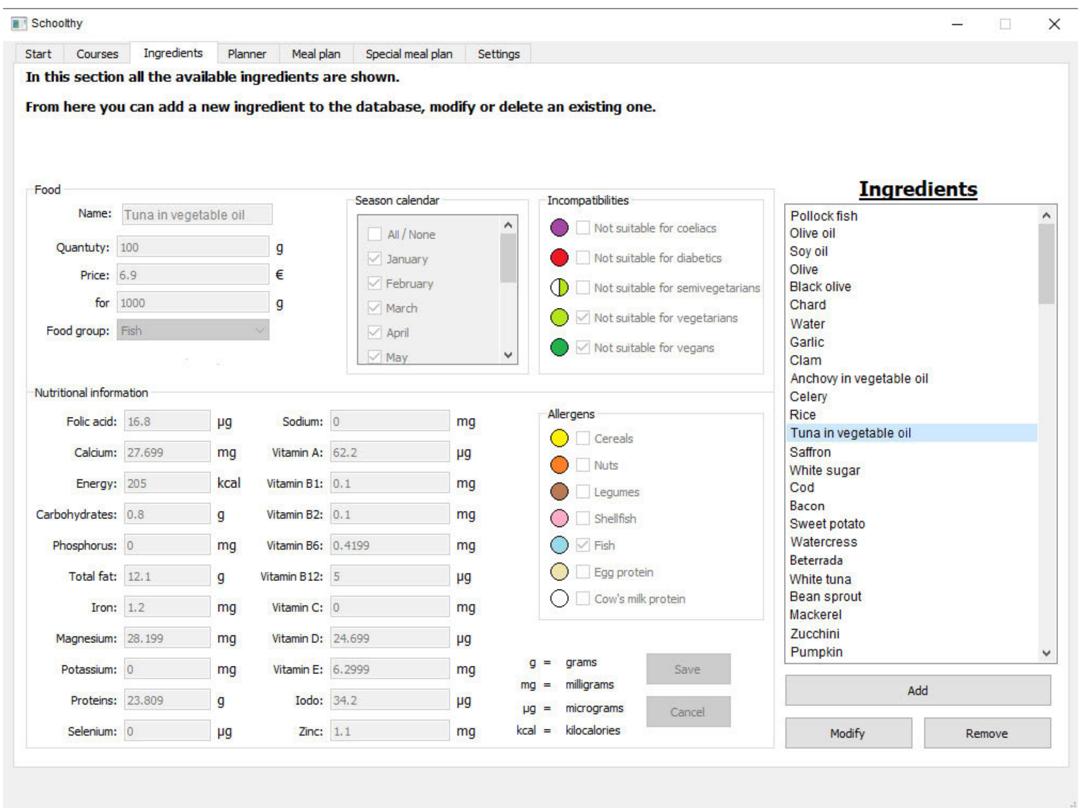


**FIGURE 4.** SCHOOLTHY: **Ingredients management interface.**

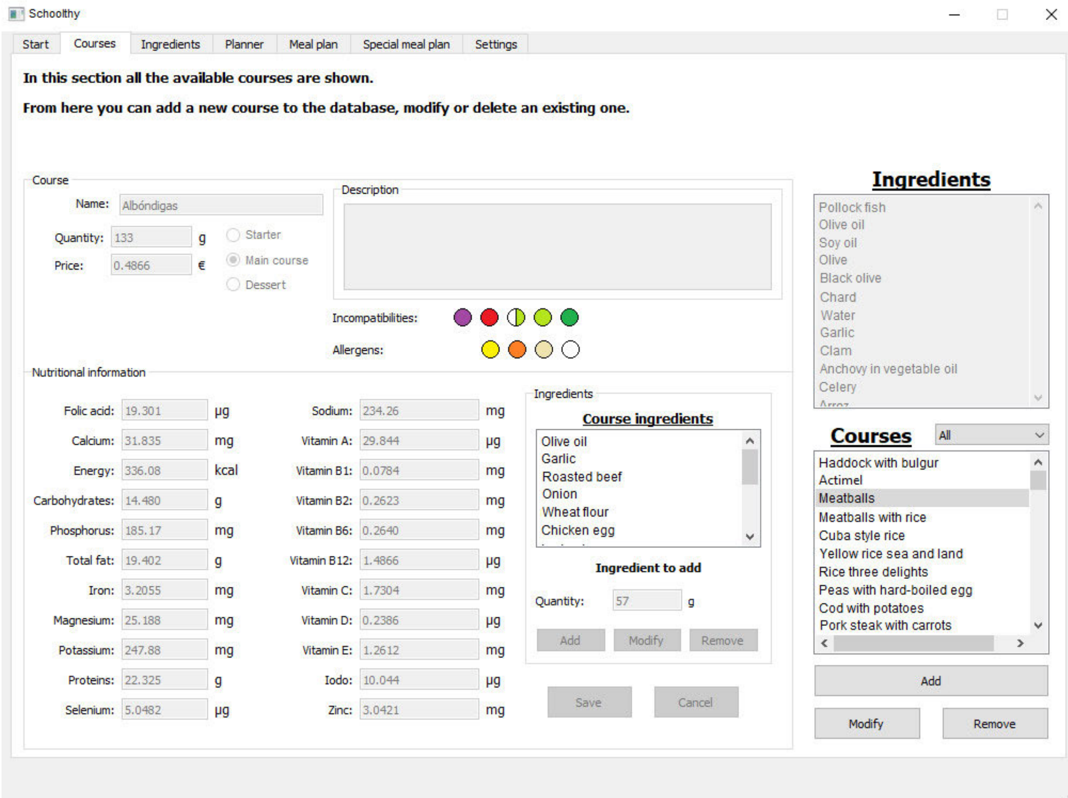


**FIGURE 5.** SCHOOLTHY: **Courses management interface.**

an optional description field can be completed for each course. Details about the particular preparation and cooking time, for instance, could be included in this field. The information on a course is calculated automatically when its ingredients and their amounts in that course are entered. The price is automatically calculated as well. The interface that is used to add, edit or delete courses is shown in Fig. 5.

### C. SETTING UP THE MEAL PLANNER

Once the ingredients and courses are defined, the menu planner—shown in Fig. 6—allows the user to configure the corresponding options to generate a meal plan, i.e., selecting the number of days for which the plan will be designed, courses considered, allergens to avoid, food incompatibilities to take into consideration, and recommended intake of nutrients. Once all the required options are set up, the application will execute an optimiser based on the well-known multi-objective evolutionary algorithm *Non-dominated Sorting Genetic Algorithm II* (NSGA-II) [44] to generate and display different proposals for meal plans based on the cost and degree of repetition of the menus. NSGA-II parameters cannot be set by the user from the interface. Note that the particular parameterisation applied by the SCHOOLTHY planner is the one that yielded the best performance in a preliminary study. This decision was made bearing in mind the ease of utilisation of the tool by the decision maker, thus hiding the details regarding the optimisation phase based on evolutionary algorithms.

Specifically, the population size of the NSGA-II was set to 250 individuals. The crossover and mutation operators were applied with probabilities $p_c = 0.8$ and $p_m = 0.1$, respectively. The crossover operator uniformly combines two individuals or solutions, $I$ and $I'$, to produce a new offspring. The operator is applied with probability $p_c$, and each pair of values $i_q \in I$ and $i'_q \in I'$ with $q = \{1, \ldots, |I|\}$, will be exchanged with a probability equal to 50%. The mutation operator allows each gene of an individual, i.e., a daily meal consisting of a starter, a main course and a dessert, to be replaced with probability $p_m$ by another daily meal generated at random. Finally, a repair method responsible for assessing each newly produced individual according to the nutritional value constraints is also applied. Specifically, a daily meal for an unfeasible individual will be modified by following the same procedure implemented in the mutation operator. However, no rate is considered by the repair operation, meaning the modification will always occur. The above steps will be repeated for each daily meal until the individual becomes feasible.

### D. DEFINING NUTRITIONAL CONSTRAINTS, PENALTIES AND OBJECTIVES

SCHOOLTHY gives the user the ability to configure the application in such a way that the generation of meal plans is

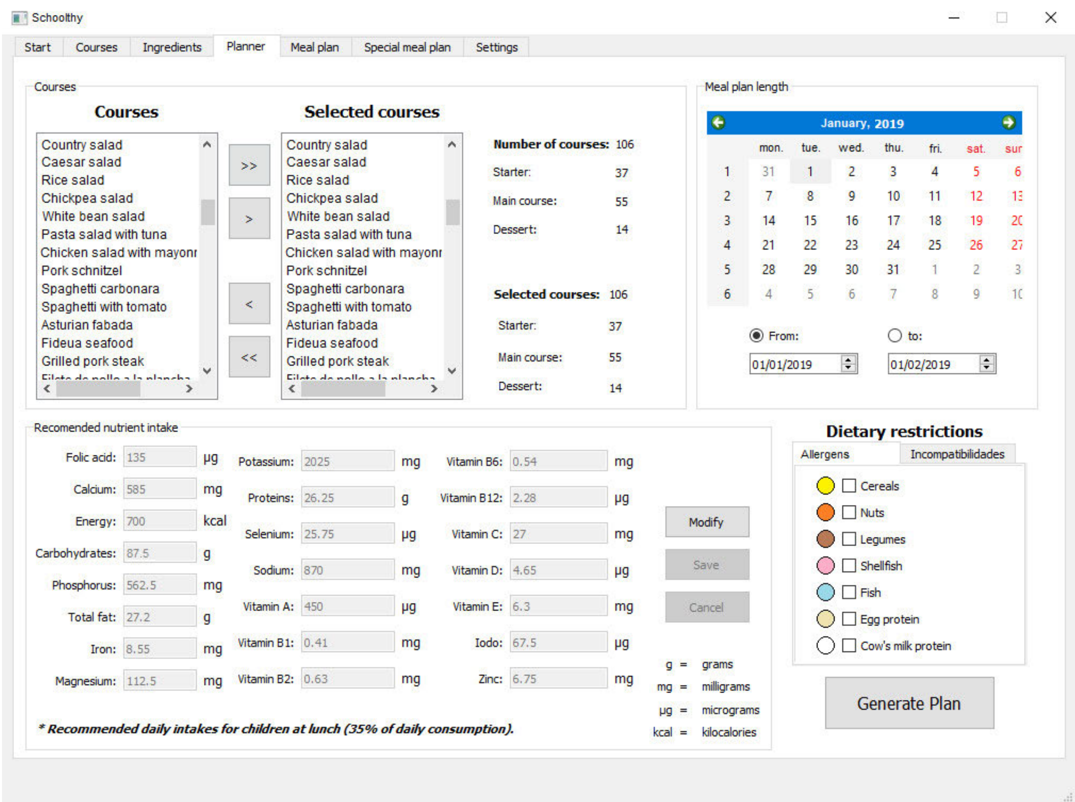


**FIGURE 6.** SCHOOLTHY: **Planner configuration interface.**

adapted to the nutritional needs of the school in question. First, the user can set the recommended amount of nutrients needed for a child at lunch. This information will directly influence the meal plans provided by the tool, i.e., whether a particular meal plan is suitable or not, and therefore, if it should be proposed to the decision maker.

Secondly, the configuration of penalties is very important, since they will greatly affect the design of meal plans. The above can be done through the interface `Settings` tab by assigning a decimal number from 0 (lowest penalisation) to 10 (highest penalisation) to different types of penalties. As we previously mentioned, there are three types of penalties. The first one is for repeating food groups. The user can set preferences for certain food groups by penalising the appearance of other groups. For example, if we want vegetable-based courses to abound over meat-based courses, a penalty value will be specified for the meat food group, such that the tool will regard those plans with a larger number of vegetable-based courses as better.

The second type of penalty refers to the repetition of starters, main courses and desserts in the plan. Hence, the user can set the importance that is assigned to the repetition of courses according to their type. For instance, the number of main courses is usually larger in comparison to the number of desserts. Therefore, the repetition of main courses could involve a larger penalty in comparison to the repetition of desserts.

Finally, the third penalty is based on the repetition of courses with respect to previous days. This means that the decision maker can establish how much they want to penalise the fact that a menu generated today includes a course that was served yesterday, the day before yesterday, and up to a total of five days before the current day. After five days, which corresponds to a week of school meals, the SCHOOLTHY planner will not consider the penalty for repetition of courses in previous days.

Through all these penalties, the degree of repetition can be computed. It is important to recall that the degree of repetition is one of the objective functions to be minimised in the MMPP defined in Section III. In this way, we ensure that the choice of menus is as varied as possible within the user's requirements.

### *E. OBTAINING FEASIBLE MEAL PLANS*

The interface shown in Fig. 7 is used to display the meal plans generated by the optimisation procedure based on their cost and degree of repetition. As it can be observed, a list of seven different meal plans is shown in this example, one per each solution belonging to the Pareto front generated. For each of those meal plans, the decision maker can obtain information, not only about the different courses that the plan consists of, but also about its total amount of energy and nutrients. Depending on their needs, the decision maker will decide which is the most suitable plan. If the user decides to produce a meal plan considering any allergen restrictions

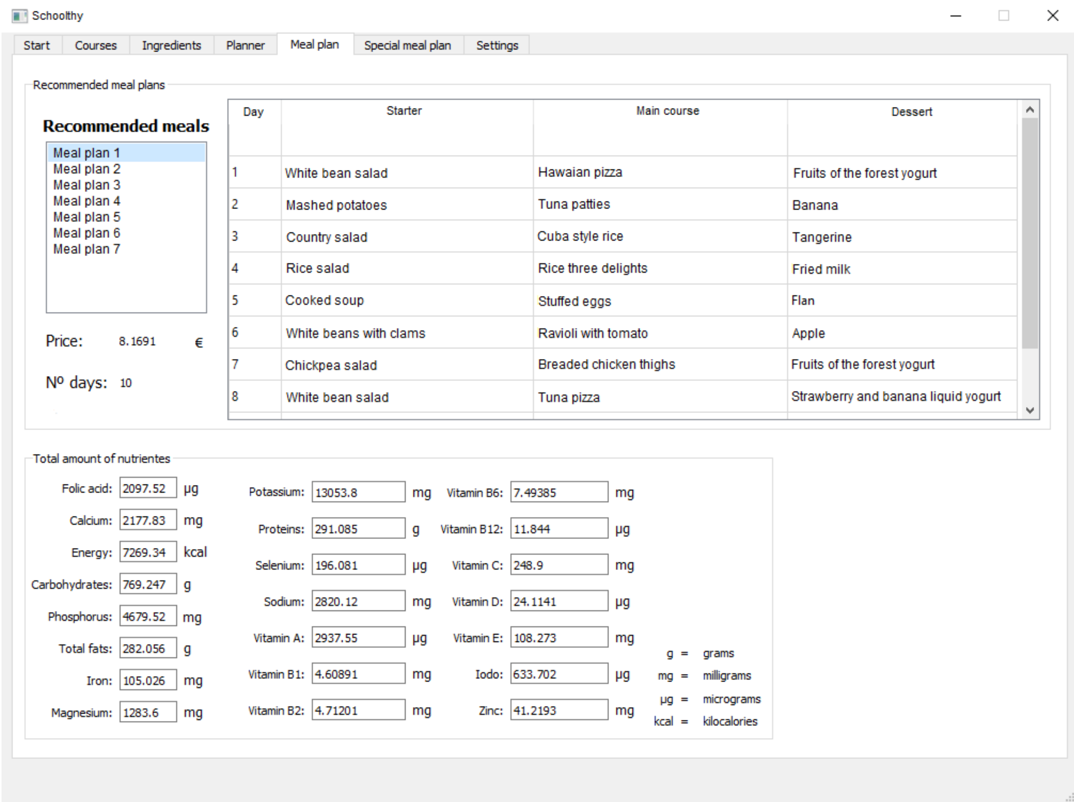


**FIGURE 7.** SCHOOLTHY**: Proposed meal plan interface.**

or food incompatibilities, two different types of meal plans will be provided: first, meal plans with no restrictions on allergens or food incompatibilities; and second, additional meal plans where courses which are not compatible with the restrictions defined are replaced by compatible ones. The first type of plan will be displayed in the `Meal plan` tab of the application, while the second type of plan will be shown in the `Special meal plan` tab. In both cases, the composition of the meal plan, i.e., the starter, main course and dessert selected for each day, as well as the cost of the meal plan, the total amount of energy, macro and micronutrients provided, will be also shown. By means of this interface, the decision maker can also load, visualise and edit a meal plan that was previously generated by the application.

## VI. EXPERIMENTAL ASSESSMENT, RESULTS AND DISCUSSION

This section is aimed to validate the usage of SCHOOLTHY. First of all, in Section VI-A, various meal plans with different prices and degrees of repetition that were obtained through SCHOOLTHY are analysed. Then, in Section VI-B, the aforementioned meal plans are compared to those designed manually by nutritional experts.

### A. EVALUATION OF THE MEAL PLANS PRODUCED AUTOMATICALLY BY SCHOOLTHY

Currently, meal plans are designed manually and separately in each school, thus hindering the existence of a consensus in this area among them. For each meal plan designed at every school, a unique nutritionist from the RSNS is responsible for validating the meal plans from the nutritional point of view at hand. If a plan is not suitable, then the nutritionist has to give advice in order to modify it. With the aim of controlling whether schools have taken into consideration the advice given, from time to time, they have to report the details of the meals served. The above involves a huge effort for both schools and the RSNS, and particularly, for its nutritionist. As a result, we think the above bottom-up procedure is inefficient.

From our point of view, a much more appropriate and efficient protocol would be based on a top-down approximation. By using SCHOOLTHY, nutritionists could automatically design a general meal plan to be provided to all schools. At the same time, for those cases with special needs, they could generate alternative meal plans as well. Anyway, the meal plans obtained through SCHOOLTHY would be feasible from the nutritional standpoint. The above procedure would release schools from having to design the menus, and nutritionists from validating all the meal plans designed and providing feedback about their nutritional feasibility, thus allowing a significant amount of time and resources to be saved. Moreover, the total number of meal plans would decrease significantly, and therefore, a consensus among the different entities involved could be achieved in a simpler way.

Once this first version of the application was developed, and as a part of its testing phase, several meetings were arranged between the research team and nutrition

**TABLE 4.** SCHOOLTHY meal plan I for 10 days. Information about the main food group of each course is also included: vegetable (v), cereal (c), legume (l), meat (m), fish (f), shellfish (s), pasta (p), fruit (fr), dairy (d), other (o).

| Day | Starter | Main course | Dessert |
|---|---|---|---|
| **1** | Pasta salad with tuna (v) | Yellow rice Sea and Land (c,m) | Tangerine (fr) |
| **2** | Rice soup (c) | Meatballs (m) | Apple (fr) |
| **3** | Fish soup (f) | Pollock with tomatoes and bulgur (f) | Fried milk (d) |
| **4** | Composed chickpeas (l) | Lasagna with meat and bechamel (m) | Strawberry and banana liquid yogurt (d) |
| **5** | White bean salad (l) | Tuna patties (f) | Fruit liquid yogurt (d) |
| **6** | Pumpkin cream (v) | Grilled chicken steak (m) | Banana (fr) |
| **7** | Mashed vegetables (v) | Macaroni with tomato (p) | Flan (d) |
| **8** | Mushroom soup (v) | Hawaian pizza (p,m) | Pear (fr) |
| **9** | Leeks cream (v) | Marinera potatoes (v) | Tangerine (fr) |
| **10** | Rice soup (c) | Scrambled eggs with ham and cheese (o) | Fruit salad (fr) |
| **Cost** | 15.24 € | | |
| **Degree of repetition** | 0.36 | | |

professionals for the purpose of obtaining feedback on the usefulness of the application and, mainly, on all the nutritional aspects addressed in the software. It was necessary that experts validate the tool for its application to real environments. The objective of the meetings was also to receive, from health specialists, reliable and concise nutritional information, real data on the nutritional aspects considered in regional schools, as well as potential areas for improvement of the application, such as the addition of new features and other restrictions that should be taken into consideration. The meetings were held with the staff of the RSNS: one nutritionist, agronomists and management personnel. The feedback that we obtained on SCHOOLTHY was significantly positive, since currently there is no computer-aided system that allows meal plans for schools in the region to be accurately managed and automatically generated. All these professionals who had the opportunity to test SCHOOLTHY agreed that, with the recommended nutritional considerations and the ability to adapt the tool to the specific needs of each school, it would be highly useful in real environments.

From those meetings, we also gathered all the information required to generate accurate meal plans. Considering school-age children and the nutritional recommendations given by the RSNS, the daily amount of energy is 2,000 *kcal*, on average. Approximately, 35% of the daily intake is consumed during lunch, meaning it should provide 700 *kcal* of energy. With regard to the macronutrients, carbohydrates should contribute 50% of the energy intake, which corresponds to 350 *kcal*. One gram of carbohydrate contains 4 *kcal*, and thus a lunch should contain approximately 87.5 *g* of carbohydrates. Fats should not contribute more than 35% of the total amount of energy. One gram of fat provides 9 *kcal*; consequently, a lunch should contain 27.2 *g* of fat. The recommended amount of protein is 15% of the total energy contribution. One gram of protein provides 4 *kcal*, so a lunch should contain 26.25 *g* of protein. At this point, we should note that the above information has been used to set the constraints of the problem, as it was previously mentioned when describing Table 2.

With respect to the penalties for repeating courses and food groups (Table 1), by following the recommendations of the experts, a lower preference was assigned to food groups like meat, shellfish and pasta over other groups like vegetables, cereals and legumes, the goal being to have the latter repeated more frequently. In the case of dessert, fruits and dairy products are predominant, with a slight preference for fruits. Finally, as mentioned in Section V-D, note that all the above parameters can be easily modified depending on the decision maker's requirements and the target group for which the meal plans will be designed.

Once the tool is set up properly, it is able to provide a list of meal plans for a particular number of days fixed by the decision maker, for which all constraints regarding the minimum and maximum recommended nutritional values are satisfied, and all preferences modelled through penalties are also considered. One of the main advantages of the application is that the user can decide which of the recommended meal plans best suits their requirements, depending on the importance given to the cost of the meal plan and its degree of repetition in terms of the courses and food groups. Bearing the above in mind, three different 10-day meal plans generated by the application, with different prices and degrees of repetition, were selected for analysis. The meal plan with the highest cost and lowest degree of repetition was selected. The meal plan with lowest cost but highest degree of repetition was also included in the comparison. Finally, a meal plan with a more balanced cost and degree of repetition was chosen. These three meal plans are shown in Tables 4, 5 and 6, respectively.

**TABLE 5.** SCHOOLTHY meal plan II for 10 days. Information about the main food group of each course is also included: vegetable (v), cereal (c), legume (l), meat (m), fish (f), shellfish (s), pasta (p), fruit (fr), dairy (d), other (o).

| Day | Starter | Main course | Dessert |
|---|---|---|---|
| 1 | Vegetable soup (v) | Hawaiian pizza (p,m) | Strawberry and banana liquid yogurt (d) |
| 2 | Mashed potatoes (v) | Noodles with vegetables (p) | Tangerine (fr) |
| 3 | White bean salad (l) | Stuffed eggs (o) | Strawberry Petit Suisse (d) |
| 4 | Canary meal (v) | Rice three delicacies (c) | Fried milk (d) |
| 5 | White bean salad (l) | Hawaiian pizza (p,m) | Banana (fr) |
| 6 | Mashed potatoes (v) | Tuna patties (f) | Fried milk (d) |
| 7 | Lentil soup (l) | Roman pizza (p,f) | Flan (d) |
| 8 | Mashed vegetables (v) | Cannelloni with bechamel sauce (m) | Fruits of the forest yogurt (d) |
| 9 | Carrot cream (v) | Noodles with vegetables (p) | Tangerine (fr) |
| 10 | Caesar salad (v) | Spaghetti with tomato (p) | Apple (fr) |
| **Cost** | 7.99 € | | |
| **Degree of repetition** | 0.76 | | |

**TABLE 6.** SCHOOLTHY meal plan III for 10 days. Information about the main food group of each course is also included: vegetable (v), cereal (c), legume (l), meat (m), fish (f), shellfish (s), pasta (p), fruit (fr), dairy (d), other (o).

| Day | Starter | Main course | Dessert |
|---|---|---|---|
| 1 | Pasta salad with tuna (v) | Breaded hake (f) | Flan (d) |
| 2 | Lentil soup (l,v) | Cuba style rice (c) | Watermelon (fr) |
| 3 | Pumpkin cream (v) | Cannelloni with bechamel sauce (m) | Actimel (d) |
| 4 | Composed chickpeas (l) | Grilled fish with salad (f) | Fruits of the forest yogurt (d) |
| 5 | Rice soup (c) | Homemade burger (m) | Fruit liquid yogurt (d) |
| 6 | Mashed vegetables (v) | Baked fish with potatoes (f,v) | Fruit salad (fr) |
| 7 | Canary meal (v) | Tuna pizza (p,f) | Apple (fr) |
| 8 | Mashed potatoes (v) | Cuttlefish in sauce (s) | Banana (fr) |
| 9 | Leeks cream (v) | Meatballs with rice (m) | Fruits of the forest yogurt (d) |
| 10 | Rice salad (c) | Spaghetti with tomato (p) | Fruit salad (fr) |
| **Cost** | 10.99 € | | |
| **Degree of repetition** | 0.54 | | |

Note that the meal plan shown in Table 4 has the highest price and the lowest degree of repetition, i.e., the most varied set of courses and food groups. The presence of less penalised food groups is apparent, and variety is maintained in the courses. Only in two out of ten days (days 3 and 9), food groups were repeated among courses of the same day. The food groups repeated were fish and vegetable, which have low penalty values assigned. Moreover, the food groups of a particular day were repeated in the five previous days 35 times. Regarding specific courses, only the rice soup and tangerine were repeated within the plan, and after eight days in each case. Furthermore, the food groups of the courses repeated were cereal and fruit, which also have low penalty values associated. Finally, it can be observed how the most repeated food groups were vegetable, meat and fruit, in opposition to pasta, legume and other, which were some of the less repeated groups. No course whose main food group is shellfish, one with the largest penalty values, was included into the plan.

Table 5 shows, in opposition to the previous case, the meal plan with the lowest price of the comparison, at the expense of providing the highest degree of repetition of specific courses and food groups. Although in any case food groups were repeated among courses of the same day, the food groups of a particular day were repeated in the five previous days 46 times, which is a larger number of repetitions in comparison to the first meal plan. At the same time, six different courses were repeated in this plan, while only two courses were repeated in the case of the first meal plan. For instance, Hawaiian pizza and fried milk were repeated after four and two days, respectively, which are closer periods of time, in comparison to the period of time where the repetition of courses arose in the first plan (eight days). Moreover, the main food groups of the aforementioned courses are pasta, meat and dairy, which have larger penalty values when compared to the penalty values of the food groups of the specific courses repeated in the first plan (cereal and fruit). As in the case of the first meal plan, no course whose main food group is shellfish was included into the plan. Finally, it can be observed how the most repeated food groups were vegetable, pasta and dairy, in opposition to cereal, fish and other, which were some of the less repeated groups. The above is probably due to the prioritisation of the cost against the variety of courses and food groups.

Table 6 shows an intermediate solution, in which the cost and the degree of repetition of the meal plan are more balanced in comparison to the other two meal plans discussed above. For this particular meal plan, the unique food group repeated among courses of the same day was vegetables at day six. The food groups of a particular day were repeated in the five previous days 45 times, almost the same number in comparison to the second meal plan (46 times). Nevertheless, only two different courses were repeated, as in the case of the first meal plan. Particularly, fruit salad and fruits of the forest yogurt were repeated after four and five days, respectively, which are intermediate periods of time, in comparison to the periods of time where the repetition of specific courses arose in the other two plans. It can be observed how the most repeated food groups were vegetable, fruit and dairy, in opposition to shellfish, pasta and legume, which were some of the less repeated groups.

With this range of potential solutions, depending on the importance given to each of the two objectives, the decision maker can establish which meal plan best suits their needs, as discussed at the beginning of this section. A suitable trade-off between the price of the meal plan and its variety in terms of specific courses and food groups has to be chosen. Three different scenarios may appear, which have been exemplified through the three cases analysed above:

- **Highest cost and lowest degree of repetition**. A large variety in courses and food groups involves the selection of more expensive courses, which consequently increases the total price of the plan. This is one of the opposite sides of the Pareto front of the MMPP.
- **Lowest cost and highest degree of repetition**. Some of the cheapest courses are repeated through the plan in order to minimise its total price, which involves a large degree of repetition. This is the other opposite side of the Pareto front of the MMPP.
- **Trade-off between cost and degree of repetition**. All the remaining solutions belonging to the Pareto front of the MMPP.

Finally, something important to recall is that, through the configuration of the different penalty values, preference was given to some food groups with respect to other. Considering the three meal plans studied, the most frequently repeated food group was vegetables which, in fact, was one of the food groups with the lowest penalty value assigned. Through a suitable configuration of the nutritional requirements and penalty values, as well as the selection of a proper trade-off between the cost and the variety of the meal plans generated by SCHOOLTHY, the decision maker has a huge number of possibilities.

### B. EVALUATION OF MEAL PLANS DESIGNED AT HAND BY PROFESSIONALS

The main goal of SCHOOLTHY is its application to real environments involving the design and management of meals at schools. For this reason, it is essential to verify that the application is able to simulate the work that nutrition professionals are currently doing manually. In this section, the nutritional aspects of two 10-day meal plans designed at hand by professionals, which have been used in two schools in the Canary Islands, referred to as School I and School II, are compared to those of the 10-day meal plans described in Section VI-A, which were automatically generated by SCHOOLTHY. The idea behind this comparison is to see which meal plans are closer to the nutritional recommendations given by the RSNS.

To ensure a fair comparison between the meal plans designed at hand and the SCHOOLTHY meal plans, we entered the different information of the former into the SCHOOLTHY database by specifying their corresponding ingredients and courses. Hence, all the nutritional information of both the plans designed at hand and the SCHOOLTHY plans was compared equally, since the same data source, i.e., the BEDCA food database, was taken into consideration. The price of the meal plans was also calculated in a similar way.

Tables 7 and 8 show the meal plans designed at hand of Schools I and II, respectively. As in the case of the plans generated through SCHOOLTHY, their cost and degree of repetition are also shown. We can see how, despite the fact that there is no repetition among starters and main courses, since these meal plans were manually designed, the repetition of food groups is frequent, especially in the case of desserts, where dairy products are not included in any case. In fact, considering both the SCHOOLTHY and the meal plans designed at hand, the latter have associated some of the largest degrees of repetition, 0.66 in the case of the School I meal plan, and 0.78 in the case of the School II meal plan, being the latter the highest degree of repetition of the whole comparative. The above demonstrates that it is not only important to guide the search of feasible and optimal meal plans by considering the repetition of specific courses, but also the repetition of food groups.

Moreover, note that although the value of the degree of repetition increases in the case of the School II meal plan with respect to the School I meal plan, its cost does not decrease, unlike the meal plans provided by SCHOOLTHY (Tables 4, 5, and 6). The importance of defining a proper multi-objective formulation of the problem, in this case, of the MMPP that

**TABLE 7.** School I meal plan for 10 days. Information about the main food group of each course is also included: vegetable (v), cereal (c), legume (l), meat (m), fish (f), shellfish (s), pasta (p), fruit (fr), dairy (d), other (o).

| Day | Starter | Main course | Dessert |
|---|---|---|---|
| 1 | Zucchini cream (v) | Baked chicken with baked potatoes (m,v) | Apple (fr) |
| 2 | Vegetable soup (v) | Squids in sauce with rice (s) | Pear (fr) |
| 3 | Pumpkin cream (v) | Spaghetti Bolognese (p,m) | Tangerine (fr) |
| 4 | Peas soup (v) | Veal with mushrooms and french fries (m,v) | Watermelon (fr) |
| 5 | Chicken soup (p) | Turkey fillets with salad (m) | Melon (fr) |
| 6 | Carrot cream (v) | Meatballs with rice (m) | Banana (fr) |
| 7 | Lentil soup (l,v) | Grilled fish with salad (f) | Pear (fr) |
| 8 | Leeks cream (v) | Macaroni with tuna and hard-boiled egg (p) | Tangerine (fr) |
| 9 | Fish soup (f) | Loin ribbon with salad (m) | Apple (fr) |
| 10 | Chicharos cream (v) | Baked fish with potatoes (f,v) | Banana (fr) |
| **Cost** | 14.48 € | | |
| **Degree of repetition** | 0.66 | | |

**TABLE 8.** School II meal plan for 10 days. Information about the main food group of each course is also included: vegetable (v), cereal (c), legume (l), meat (m), fish (f), shellfish(s), pasta (p), fruit (fr), dairy (d), other (o).

| Day | Starter | Main course | Dessert |
|---|---|---|---|
| 1 | Pumpkin cream (v) | Spanish omelette with ham (v) | Banana (fr) |
| 2 | Vegetable soup (v) | Chickpeas and fried sardines (f) | Apple (fr) |
| 3 | Composed chickpeas (l) | Pork steak with carrot (m,v) | Pear (fr) |
| 4 | Canary meal (v) | Baked chicken (m) | Watermelon (fr) |
| 5 | Peas with hard-boiled egg (l,v) | Meat with potatoes (m) | Tangerine (fr) |
| 6 | Rice salad (c) | Cuttlefish in sauce (s) | Apple (fr) |
| 7 | Lentil soup (l,v) | Pollock with tomatoes and bulgur (f) | Banana (fr) |
| 8 | Zucchini cream (v) | Yellow rice Sea and Land (c,m) | Pear (fr) |
| 9 | Composite beans (l) | Fish croquettes (f) | Tangerine (fr) |
| 10 | Bolognese noodles (m) | Chicken breast with tomato and cheese (m) | Banana (fr) |
| **Cost** | 16.5 € | | |
| **Degree of repetition** | 0.78 | | |

**TABLE 9.** Total amount of energy and macronutrients of the SCHOOLTHY, School I and School II meal plans. The daily amounts recommended by the RSNS have been multiplied by $n = 10$, since the comparison takes into account 10-day meal plans.

| | RSNS **rec.** $(n \cdot r_h)$ | **Schoolthy MP I** | **Schoolthy MP II** | **Schoolthy MP III** | **School I** | **School II** |
|---|---|---|---|---|---|---|
| Energy (kcal) | 7000 | 7527.87 | 7410.59 | 7797.27 | 10239.3 | 7188.75 |
| Carbohydrates (g) | 875 | 745.27 | 726.943 | 747.772 | 636.2 | 409.69 |
| Total fat (g) | 272 | 253.9 | 286.368 | 259.72 | 257 | 200.4 |
| Proteins (g) | 262.5 | 327.33 | 248.476 | 299.301 | 466.13 | 360.2 |

we propose herein, where the objectives to be optimised are contradictory, is thus shown.

The total amount of energy and macronutrients that make up the different meal plans, as well as the quantities recommended by the RSNS, are shown in Table 9. The corresponding deviations with respect to the recommendations given by the RSNS are shown in Table 10, as well as the cost and degree of repetition of each meal plan, as a summary.

**TABLE 10.** Deviations of the SCHOOLTHY, School I and School II meal plans with respect to the daily amounts recommended by the RSNS. The largest absolute deviation is shown in boldface for each case. A comparison about the price and the degree of repetition is also included.

| | Schoolthy MP I | Schoolthy MP II | Schoolthy MP III | School I | School II |
|---|---|---|---|---|---|
| Energy (kcal) | +7.54% | +5.87% | +11.39% | **+46.28%** | +2.69% |
| Carbohydrates (g) | -14.82% | -16.92% | -14.54% | -27.29% | **-53.17%** |
| Total fat (g) | -6.65% | +5.28% | -4.51% | -5.51% | **-26.32%** |
| Proteins (g) | +24.7% | -5.34% | +14.02% | **+77.57%** | +37.22% |
| Cost (€) | 15.24 | 7.99 | 10.99 | 14.48 | 16.5 |
| Degree of rep. | 0.36 | 0.76 | 0.54 | 0.66 | 0.78 |

Answering to the question set out at the beginning of this section, the meal plans generated by SCHOOLTHY not only adapt better to the amounts of energy and macronutrients recommended by the RSNS, but are also cheaper and have a degree of repetition similar to, or in some cases even lower than, the meal plans designed at hand for Schools I and II. In fact, as it can be observed, the largest deviations with respect to the quantities recommended by the RSNS, which are shown in boldface, arose for the meal plans designed at hand in every case. Deviations exceeded 50% in the case of proteins for School I and carbohydrates for School II.

The search for a solution to this problem through a decision system allows us to consider and compare multiple and different solutions to one another in order to obtain the one that best fits the nutritional requirements demanded by the user, whether based on the amount of nutrients present in the menus, a preference for certain courses or food groups or the best possible price. These requirements can be easily modified to quickly obtain another solution to the problem. Similarly, a solution given by SCHOOLTHY can be partially modified as necessary by the decision maker. Bearing all the above in mind, the effectiveness and convenience of using a tool like SCHOOLTHY to automatically perform a task that is currently done manually is thus demonstrated.

## VII. CONCLUSION AND FURTHER RESEARCH

### A. CONCLUSIONS

There is a real need for varied and adequate meal plans in schools. In this paper, we have introduced SCHOOLTHY: *Automatic Menu Planner for Healthy and Balanced School Meals* as a response to this need. As far as we know, this is the first decision support tool proposed based on a multi-objective formulation of the MPP to automatically design meal plans through EC for school contexts. We have also proposed a novel multi-objective formulation of the MPP, which we refer to as the MMPP, which not only considers the cost of the meal plans, but also the degree of repetition of specific courses and food groups through them, as the objectives to be optimised. The recommended intakes of energy and macronutrients are considered as the constraints of the said formulation. The multi-objective suitability of this novel formulation has been demonstrated from the point of view of the contradictory nature of its objective functions.

There are currently many applications and services that can be used to create meal plans based on various nutritional and dietary requirements. However, the majority of those tools focus on a single individual, usually an adult, and not intended for school contexts. There is no computer-aided system that allows this work to be carried out in an easier, automatic and precise way, and that provides a nutritional consensus that can be used in the different schools of a particular region. SCHOOLTHY has been shown to be able to perform this task in a way that is much more efficient and more compliant with the nutritional recommendations set by experts. With the proper advice and use by child nutrition professionals, this decision support system might become a significantly useful tool for devising meal plans in schools.

### B. FURTHER RESEARCH

SCHOOLTHY is presented as a first approach to solve the MMPP in real schools in our region. Experts in nutrition have given positive feedback on the application; as a result, it could be truly useful for improving how meal plans are currently designed. A potential area for further development would be the addition of a more extensive set of courses to the database, including those which are being prepared currently at schools, the goal being to improve the ability to make varied and diverse meal plans. It would also be interesting to transfer the concept of this tool to other platforms, such as the web and mobile field, thus improving its accessibility and management. Regarding the usefulness of SCHOOLTHY, an interesting line of future work would be to carry out a study from the user experience perspective. For doing that, we would need a representative sample of experts, consisting of nutritionists, agronomists and cooks, among others. The above would allow many aspects of the tool to be significantly improved. This application is intended to be used to create meal plans for schools, but with small changes in the recommended intake of nutrients and courses, it could be useful to other institutions, such as hospitals, retirement homes and prisons, among others.

## ACKNOWLEDGMENT

The problem formulation and restrictions follow the recommendations of the School Canteen Programme of the Government of the Canary Islands: Programa de Eco-comedores Escolares de Canarias, which is a Joint Priority Action of the

Instituto Canario de Calidad Agroalimentaria, the Dirección General de Salud Pública del Gobierno de Canarias, and the Dirección General de Ordenación, Innovación y Promoción Educativa.

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