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Article

Micronutrient Availability in Alternative Foods During Agricultural Catastrophes

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Abstract: A number of catastrophes could block the sun, including asteroid/comet impact, super volcanic eruption, and nuclear war with the burning of cities (nuclear winter). Previous work has analyzed alternate food supplies (e.g. mushrooms growing on dead trees, bacteria growing on natural gas). This was shown to be technically capable of feeding everyone with macronutrients (protein, carbohydrates, and lipids) and minerals, although economics and politics remain uncertain. The present work analyses vitamin availability in such alternative food scenarios. The vitamin content of various alternate foods is compared to the U.S. recommended daily allowance (RDA) as well as the average requirement defined by the European Food Safety Authority (EFSA) and insufficiencies of single food sources are discussed. Single alternate food sources are always deficient in some vitamins, and the problems associated with this are discussed. It is clear that to prevent disease in an alternative food scenario a wide range of foods must be consumed or the diet must be supplemented. Backup plans discussed include chemical synthesis of vitamins, plants grown with artificial light and growing bacteria rich in certain vitamins. Finally, insights from this analysis are provided for combating existing micronutritional deficiencies using alternative foods today.

Keywords: alternate food; alternative food; essential nutrients; existential risk; global catastrophic risk; nuclear war; micronutrients; nutrients; public health; vitamins

1. Introduction

Agriculture and the global human civilization dependent on it relies on access to sunlight. A number of global catastrophes could partially block the sun, which would result in significant reductions in agricultural output and the potential for mass human starvation. The three most probable sun-obscuring scenarios include: (1) bolide (asteroid/comet) impact, (2) a super volcanic eruption or continental basalt flows, or (3) and nuclear war with the burning of cities (nuclear winter) [1,2]. Although these are low probability events, they have finite non zero probabilities [3], with the most probable being nuclear war. Two estimates based on quantitative models indicate the chance of full-scale nuclear war is ~1% per year [4,5]. This is significant as the majority of the nuclear powers possess more than the pragmatic limit of nuclear weapons (where the direct physical negative consequences of nuclear weapons use are counter to national interests) [6]. Even a modest release of nuclear weapons on target cities as a one-sided [6] or regional nuclear war [7,8] could create a nuclear autumn that would starve millions throughout the world [6-10]. In addition, there are other less-severe risks to the agricultural system. These include: (1) abrupt climate change [11], (2) super weed [12], (3) extirpating crop pathogen [13], (4) complete loss of pollinators [14], (5) super bacterium [15], or (6) super crop pest [16]. Prevention of these catastrophes would obviously be preferable, but despite the highest probability severe sun-blocking risk being under human control, at present global de-nuclearization appears unlikely in the short term and there are not reliable options for the other large risks.

Therefore, a backup plan is desirable. Previous work has analyzed *alternative food* supplies that could be viable in these scenarios and optimistically found that the global human population could be maintained even in the most severe catastrophes (e.g. 5 years of blocked sunlight) converting wood and fossil fuels to food [3,17]. These calculations were, however, based on macronutrients and although the number of kilocalories could be produced to feed everyone globally, micronutrients were not evaluated in detail. Micronutrients play a central part in metabolism and in the maintenance of human tissue function and are therefore critical for human health [18]. To provide a complete viable backup food supply for conventional agricultural collapse further research is required [19]. Previous work has been done on the basics of minerals [17] and therefore this paper will focus on vitamins in order to begin to fill in these knowledge gaps. This preliminary study briefly summarizes the alternative food pathways and then evaluates the micronutrients (specifically vitamins) available to meet the percent of the U.S. recommended daily allowance (US RDA) as well as the average requirement defined by the European Food Safety Authority (EFSA) with these foods and closest analogous foods when data are not available. In some global catastrophes some human populations may only have access to a single alternate food. For these situations, the micronutrient profile for a person on a 2,100 kcal diet of each alternate food is evaluated for risk of disease. Ideally, populations would have access to an array of alternative foods. For these scenarios, a representative alternative food diet with adequate micronutrients is developed and analyzed. These results are discussed to develop a method to viably produce vitamins to fortify the entire human population for this sun blocking scenario and other agricultural catastrophic scenarios.

2. Materials and Methods

2.1. Alternative food routes and assumptions

Although it is still possible to provide for the calories necessary for human existence in the worst scenarios even without industry [20], in most cases these catastrophes would destroy industry only regionally. The majority of global industry would still function under these global catastrophic risk scenarios (particularly the six crop killing scenarios). If the sun were not completely blocked, algae would grow in the ocean vigorously because the cooling climate would bring deep nutrient rich water to the surface [17]. Also, the algae would be protected from the high ultraviolet light levels produced especially by nuclear winter [8] and therefore feed significant amounts of fish, which humans already rely on for a major source of food. Currently, 13.8% to 16.5% of the animal protein intake of the global human population are from fish, crustaceans and mollusks [21]. Moving to a more fish based diet is therefore the least radical form of alternative food.

Solutions independent of the sun include those that can convert wood into food. This would include converting wood to food with mushrooms directly, but also indirectly wood softened with mushrooms or non-woody material could be converted into food via cellulose digesting beetles [22], rats [23] and ruminants (e.g. cows, sheep, goats, etc.) [24]. Mushrooms, cows, sheep and other ruminants are currently widely used as food sources, whereas beetles and rats are less commonly eaten. Another method to turn wood to food is to use chemical engineering. Current cellulosic biofuel systems transform cellulose into sugar and then feed the sugar to a fungus to create ethanol [25]. However, to produce human edible food this process could be stopped at sugar. If the pre-digestion of fiber were done very carefully, even a non-cellulose digester could be fed, such as chickens, which are already raised widely raised for human food.

Another alternative food route, which is particularly important in the transition from conventional agriculture to alternative foods because of ramp rates [6], is taking leaves from woody and non-woody plants and making tea, chewing and spitting out the solids, or making leaf protein concentrate [26].

A final set of routes is the use of fossil fuels to alternative foods. Mushrooms can be grown on coal similar to growing on peat [27]. In addition, natural gas digesting bacteria [28] could be fed to humans. These alternate foods were shown to be technically capable of feeding everyone with macronutrients (protein, carbohydrates, and lipids) and minerals could be extracted from the ground [17].

2.2. Alternative food micronutrient data and analogues

First, the vitamin content of various alternate foods is determined as a percent of the U.S. recommended daily allowance (US RDA) and is summarized in Appendix A Table A1. Many of these alternate foods are not commonly used as food at this point, so the closest available proxy was used for the vitamin content of some of these foods. Tuna was used for fish, beef and milk for ruminants, liver to represent eating the organs, chicken and eggs for chicken (and the analog for rats), shitake and oyster mushrooms for fungi, bacteria data from Unibio, and Arborvitae tea (a type of tree needle), and dandelions (to represent non-woody plant leaves) for killed leaves.

2.3. Analysis

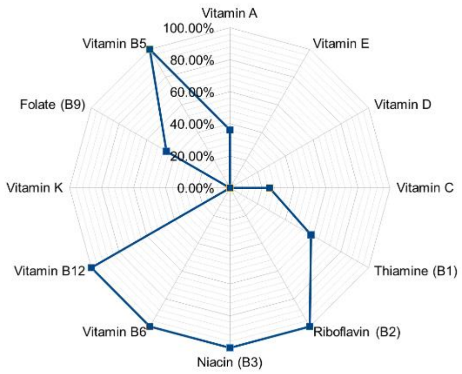
For scenarios where a population would be limited to a single alternative food the micronutrient profile for a person on a 2,100 kcal/day (8.79 MJ/day) diet of each alternate food is evaluated for risk of disease. This diet represents the calorie level average of males and females 19-50 and the US RDA is set to meet or exceed the specific nutrient requirements to be sufficient for 97.5% of the population. This is thus treated as the conservative vitamin requirement. For scenarios where populations would have access to the full range of alternative foods a representative alternative food diet with adequate micronutrients is developed and analyzed. The feasibility of the different alternate food sources was estimated to construct an example diet and the calories from each alternative food is tabulated.

Then a second type of micronutrient analysis is presented. Rather than only rely on the values that represent the ideal food intake from the developed world (the percentages of US RDA) a second estimate is determined. This less conservative analysis is presented for the average requirement (AR), which is defined by the European Food Safety Authority (EFSA) as the level of (nutrient) intake that is adequate for half of the people in a population group, given a normal distribution of requirements [29]. The percentage of the average requirement for a 30-39 year old female with a physical activity level (PAL) of 1.6 (moderately active) were used (corresponding to the same 8.7 MJ/day as shown in Table A2) [29]. It should be noted that nutrients outside of the US RDA were excluded, but omega-3 fatty acids could be provided by eating fish.

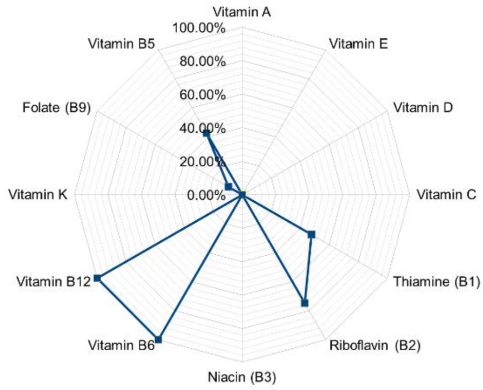
3. Results

3.1. Single Alternative Food Micronutrient Profiles

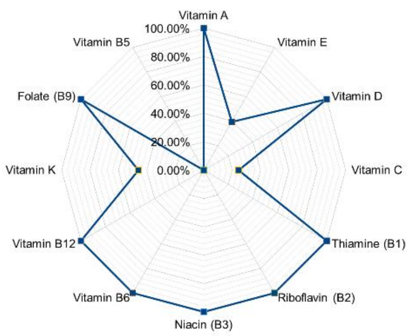
Vitamin data from Table A1 on tuna, beef, beef liver, chicken, shiitake and oyster mushrooms (which can grow on trees), cow milk, chicken eggs, natural gas digesting bacteria, arborvitae, and dandelions was used to determine the nutrient profiles for humans eating a 2,100 kcal per day diet made up of each alternative food only. The results of US RDA percentages are shown in Figure 1 for vitamin A, B5, B9, K, B12, B6, B3, B2, B1, C, D, and E. US RDA percentages above 100% are capped at 100% for clarity.



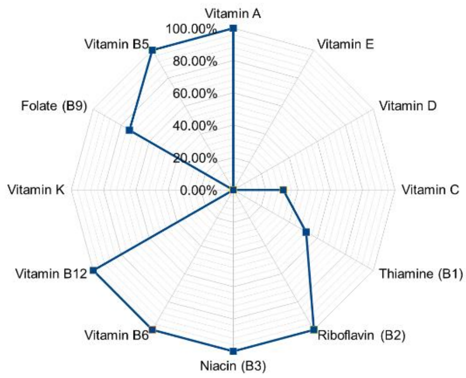
(a) Tuna



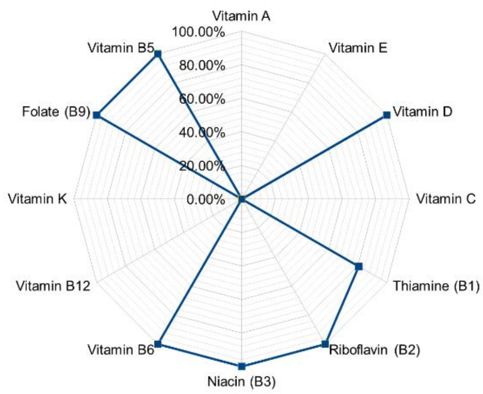
(b) Beef



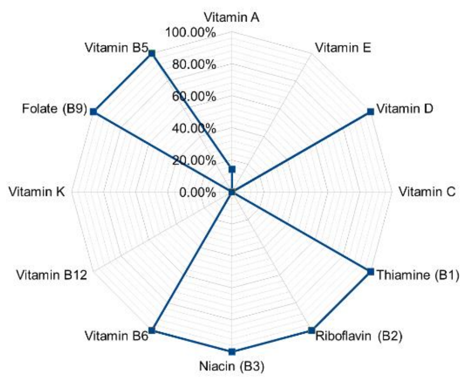
(b) Liver



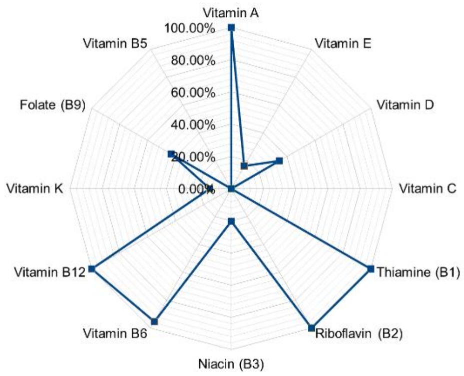
(d) Chicken



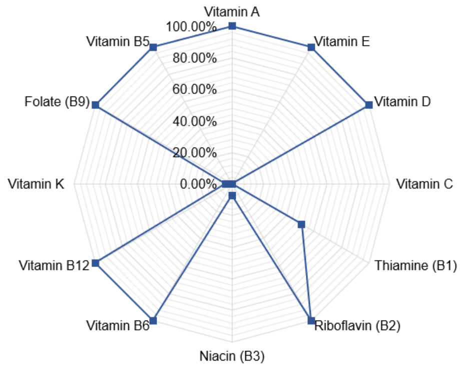
(e) Shiitake Mushrooms



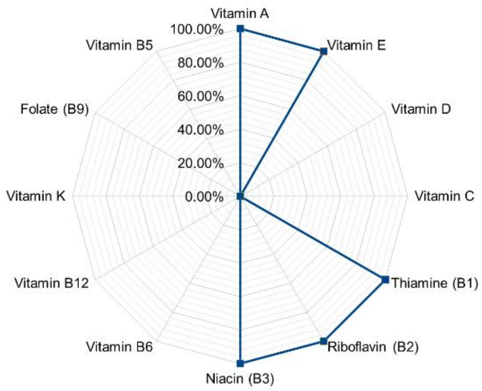
(f) Oyster Mushrooms



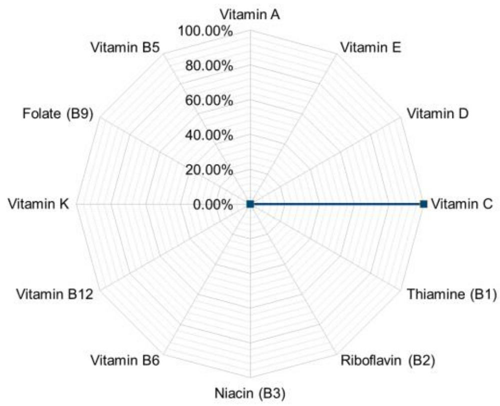
(g) Milk



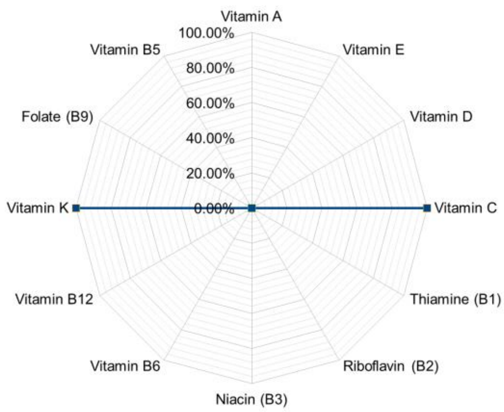
(h) Eggs



(i) Bacteria



(j) ArborVitae Tea



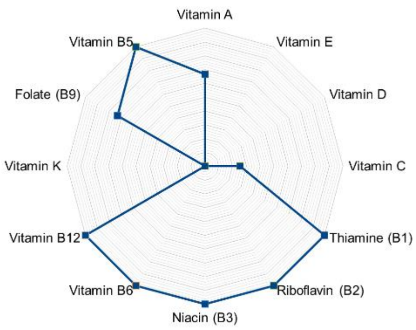
(k) Dandelion

Figure 1. Micronutrients of 100% diet from single alternative food with US RDA percentages of vitamin A, E, D, C, B1, B2, B3, B6, B12, K, B9, and B5: (**a**) tuna, (**b**) beef, (**c**) liver, (**d**) chicken, (**e**) shiitake mushrooms, (**f**) oyster mushrooms, (**g**) milk, (**h**) eggs, (**i**) bacteria, (**j**) ArborVitae tea, and (**k**)

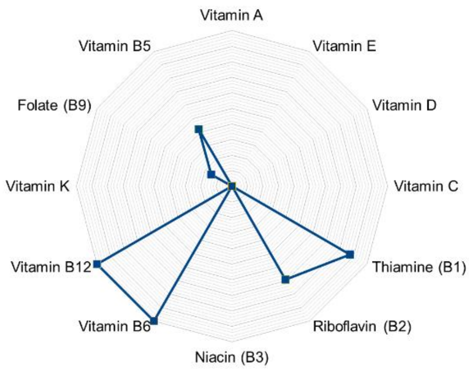
dandelion. Note that ArborVitae tea and dandelion did not have full nutrient profiles. Radial scale by 20% increments.

As can be seen from Figure 1, none of the single alternative food diets provide all of the micronutrients to prevent disease alone. Even grouping likely combinations of alternative foods (e.g. beef and milk) creates severe deficiencies. For example, 50:50 percent of calories from beef and milk produce deficiencies in all nutrients other than B12, B6, B2 (with A and B1 being nearly enough). Similarly, although chickens and eggs is an improvement in terms of human nutrition, there are severe deficiencies in K, C and B1 and only abut 50% of vitamin E is realized. It is clear that to prevent disease in an alternative food scenario a wide range of foods must be consumed or the diet must be supplemented.

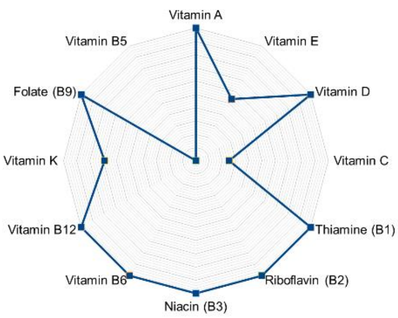
The results of the EFSA percentages are shown in Figure 2 for vitamin A, E, D, C, B1, B2, B3, B6, B12, K, B9, and B5. EFSA percentages above 100% are capped at 100% for clarity.



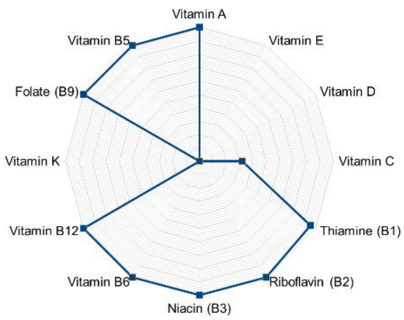
(a) Tuna



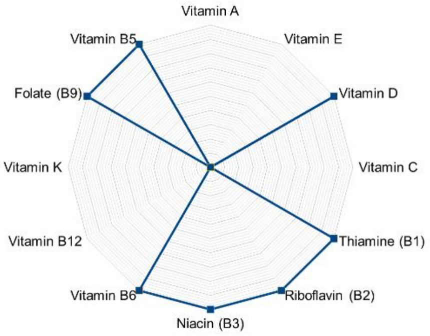
(b) Beef



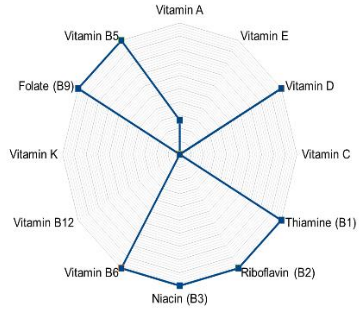
(b) Liver



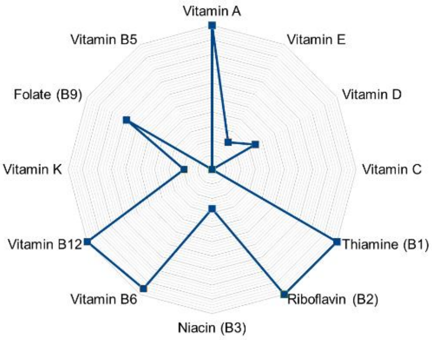
(d) Chicken



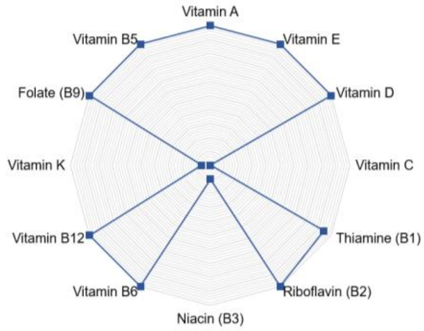
(e) Shiitake Mushrooms



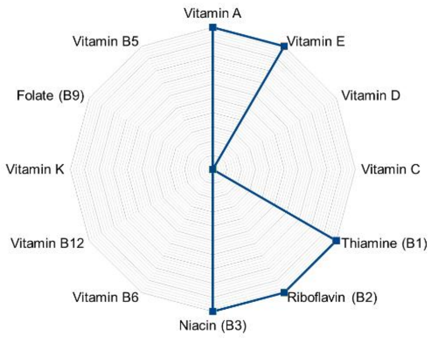
(f) Oyster Mushrooms



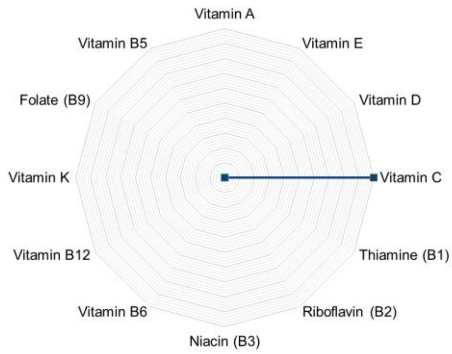
(g) Milk



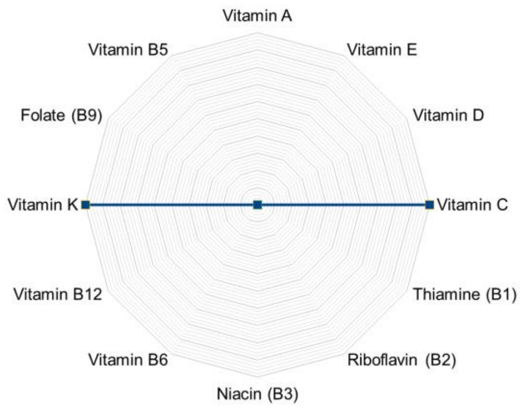
(h) Eggs



(i) Bacteria



(j) ArborVitae Tea



(k) Dandelion

Figure 2. Micronutrients of 100% diet from single alternative food with ERSA percentages of vitamin A, E, D, C, B1, B2, B3, B6, B12, K, B9, and B5: (**a**) tuna, (**b**) beef, (**c**) liver, (**d**) chicken, (**e**) shiitake mushrooms, (**f**) oyster mushrooms, (**g**) milk, (**h**) eggs, (**i**) bacteria, (**j**) ArborVitae tea, and (**k**) dandelion. Note that ArborVitae tea and dandelion did not have full nutrient profiles. Radial scale by 20% increments.

As can be seen by comparing the values for a given alternative food between Figure 1 and Figure 2, in general the US RDA has higher requirements and thus the alternative foods have lower percentages of micronutrients with the exception of vitamin D, B6 and B5 being the same and riboflavin and B12 being higher. These values that were not lower were based on adequate intake (AI) values from the EU.

3.2. Diseases Caused by Inadequate Micronutrients from Single Alternative Food Diets

The diseases associated with inadequate micronutrient intake because of consuming a single alternative food diet are reviewed. In addition, insights from this analysis are provided for combating existing micronutritional deficiencies using alternative foods today.

3.2.1. Vitamin A

Only liver, chicken, milk, eggs and bacteria provide sufficient vitamin A if eaten alone according to Figures 1 and 2. Vitamin A deficiency resultant from the other diets would first cause nyctalopia (night blindness) and then xerophthalmia, keratomalacia, and complete blindness can also occur as vitamin A has a major role in phototransduction. In addition, low vitamin A diminishes the ability of people to fight infections, which would also increase mortality if adequate calories were present in a global catastrophe where it was not available. Vitamin A deficiency is shockingly common today, affecting 21.1% of pre-school children and 5.6% of pregnant women worldwide [30]. Of the non-standard alternative foods, consumption of bacteria directly or vitamin A supplements derived from them could help improve this global issue today.

3.2.2. Vitamin B1 (Thiamine)

Only liver, oyster mushrooms, milk and bacteria provide adequate levels of B1 Following Figures 1 and 2. Severe vitamin B1 deficiency occurs as beriberi in the tropics and is distinguished from the less severe degree of deprivation occurring in temperate climates [31]. The former affects the cardiovascular system resulting in a fast heart rate, shortness of breath, and leg swelling, while the latter affects the nervous system resulting in numbness of the hands and feet, confusion, and pain [31]. Even in the developed world alcohol abuse, dialysis and taking high doses of diuretics increases the risk of developing B1 deficiency [31]. The growth and supplementation of the diet with oyster mushrooms or bacteria could be uncommon alterative foods that could help this condition today. It is interesting to note that the type of mushroom grown determines its micronutrient level and significantly more research is thus needed to determine if growing a wide range of mushroom in an alternative food scenario may be of assistance in micronutrient availability.

3.2.3. Vitamin B2 (Riboflavin)

Tuna, liver, chicken, both mushrooms, milk, eggs and bacteria all provide enough vitamin B2 as can be seen in Figure 1 and Figure 2. The consequences of vitamin B2 deficiency can lead to weakness and fatigue and can influence drug and lipid metabolism [32].

3.2.4. Vitamin B3 (Niacin)

Figures 1 and 2 show that beef, milk, eggs, tea, and dandelion do not provide enough B3 in a single alternative food diet. B3 is essential in all cells for energy production, metabolism and DNA repair. Severe deficiency of vitamin B3 results in pellagra, which results in primarily dermatitis, diarrhea, dementia and eventually death [33]. Pellagra is common developing regions as well as among those living in poverty, those who are homeless, refugees and other displaced people due to their dependence on food aid. Current B3 deficiencies can be solved with alternative food growth of mushrooms or bacteria.

3.2.5. Vitamin B5 (Pantothenic Acid)

Tuna, chicken, eggs, and both mushroom varieties are the only single source alternative foods providing enough vitamin B5 according to Figures 1 and 2. Vitamin B5 deficiencies are rare and normally result in fatigue and other symptoms.

3.2.6. Vitamin B6

As can be seen in Figures 1 and 2, only bacteria, tea and dandelion single-source alternative foods do not provide enough B6. Vitamin B6 deficiency causes microcytic anemia, electroencephalographic abnormalities, dermatitis with cheilosis (scaling on the lips and cracks at the corners of the mouth), depression and confusion, and weakened immune functioning [34,35].

3.2.7. Vitamin B9 (Folate)

Only liver, both mushrooms, and eggs provide enough vitamin B9 when on only a single alternative food diet. Deficiency in vitamin B9 [36] causes megaloblastic anemia, a condition in which the bone marrow produces oversized immature red blood cells. In pregnant women, lack of vitamin B9 can cause severe or even fatal birth defects.

3.2.8. Vitamin B12 (Cobalamin)

Only mushrooms, bacteria, tea and dandelions did not have sufficient B12 by either standard, while all of the meat-based sources of alternative foods provided the necessary B12 even on a single source diet. Vitamin B12 deficiency is a common cause of macrocytic anemia and has been implicated in a spectrum of neuropsychiatric disorders [37].

3.2.9. Vitamin C (Ascorbic acid)

Only the tea and dandelions have adequate vitamin C. Without vitamin C, scurvy occurs after 3 months and is normally due to lack of consumption fresh fruits and vegetables [38]. Initially those suffering from scurvy have weakness, feel tired, and have sore extremities, then decreased red blood cells, gum disease, and bleeding from the skin occur, poor wound healing, personality changes, and finally death from infection or bleeding [39,40]. A remarkable 6-8% of the current global population is suffering from scurvy and this can be higher in regions suffering from extreme poverty [41]. Public education about the potential to cure the disease even without access to common fruits and vegetables either by eating what is often considered weeds (dandelions) or making teas from common plant leaves could reduce scurvy today.

3.2.1.0. Vitamin D

Only liver, both types of mushrooms, eggs and bacteria provided the US RDA of vitamin D on a single alternative food diet. Vitamin D deficiency causes rickets (a condition that results in soft bones in children, which result in bowed legs, stunted growth, and bone pain [42]). It can also cause growth retardation, skeletal deformities, and increase risks of fractures. For adults not enough vitamin D results in osteopenia and osteoporosis, osteomalacia and muscle weakness [43]. Again the use of bacteria and mushrooms could reduce current vitamin D deficiencies.

3.2.1.1. Vitamin E

Only eggs and bacteria provide enough vitamin E on a single alternative food diet as shown in Figure 1. Vitamin E is important for normal neurological function [44]. Vitamin E deficiency can cause significant health issues [44,45].

3.2.1.2. Vitamin K (phylloquinone, K1; menaquinone, K2)

As can be seen from Figure 1, only the dandelion provides an adequate amount of vitamin K. Vitamin K is an essential cofactor for the synthesis of the coagulation protein factors [47]. Vitamin K1 deficiency can result anemia, bruising, nosebleeds and bleeding of the gums, heavy menstrual bleeding and coagulopathy; while inadequate K2 can lead to osteoporosis and coronary heart disease.

3.3. Representative Balanced Diet of Alternative Food

To determine if it is possible to meet micronutrient requirements without supplementation while surviving solely on alternative foods, a representative balanced diet of alternative foods was determined. Table 1 shows the number of kilocalories per day provided by the alternative food sources [48]. This was an estimate based on feasibility of the different alternate food sources (e.g. chickens and their eggs have uncertain feasibility and the supply of leaves is limited). The natural gas digesting bacteria portion of the diet needed to be high to provide adequate vitamin E. Bacteria are already ingested in limited amounts through foods such as yogurt and sauerkraut. The mitochondria and chloroplasts in animal and plant cells, respectively, are generally recognized as being descended from bacteria, and some even argue that mitochondria should be considered bacteria even now [49]. However, with a large amount of bacteria, the nucleic acids would need to be neutralized [50]. Sugar is produced by enzymes acting on cellulose, which is assumed here would have negligible vitamins.

Table 1. Number of kilocalories per day provided by the alternative food sources in a representative balanced diet using US RDA data.

Food	kcal/day
Sugar	400
Tuna	300
Beef	300
Liver	100
Chicken	50
Shitake Mushroom	150
Oyster Mushroom	150
Milk	100
Egg	50
Bacteria	400
Arborvitae Tea	50
Dandelions	50
Total	*2,100*

In Table 2, the nutritional content of the sample diet is displayed as a percent of daily nutritional need. The intake of all of these vitamins is below the toxic limit [51]. It is readily apparent that this combination, and many others, are capable of sustaining the nutritional needs of an average human life. Absorbability is a factor, but there is already a safety margin in the US RDA, and it is possible that processing could increase absorbability. Furthermore, some additional vitamins could be obtained from food that happen to be stored when the catastrophe hit.

Table 2. Sample diet of alternative foods and US RDA micronutrients. Solubility data provided by [51].

Nutrient	Vitamin A	Vitamin E	Vitamin D	Vitamin C	Thiamine (B1)	Riboflavin
Unit	μg	μg	Mg	mg	mg	Mg
Amounts	4240	16600	16.2	359	7.4	43.9
%US RDA	470%	110%	108%	435%	645%	3660%
Solubility	Oil	Oil	Oil	Water	Water	Water

Nutrient	Niacin (B3)	Vitamin B6	Vitamin B12	Vitamin K	Folate (B9)	Vitamin B5
Unit	mg	mg	Mg	μg	μg	Mg
Amounts	164.0	5.6	53.5	3240	508	14.8
%US RDA	1100%	429%	2230%	3090%	127%	296%
Solubility	Water	Water	Water	Oil	Water	Water

4. Discussion

There is good evidence of having complete access to micronutrients (vitamins + minerals) to benefit patients suffering from critical illnesses [18]. Most benefits from micronutrients appear to come from a well-balanced diet [18], which is what should be the goal of each community in an alternative-food scenario. The minerals could largely be mined and have been investigated previously. Though this mix of alternative foods shown in the sample diet shown in Table 1 and 2 would provide adequate vitamins, not every person may have access to this mix. In particular, poorer people would only have access to the lower cost alternative foods. Based on current prices, these would likely be bacteria, enzymatic sugar, fish, and leaf extract [52]. In addition, vitamin requirements could be different for different people at various stages of their lives. Therefore, it is useful to have additional ways of providing vitamins. One method would be removing vitamins from certain alternate foods to use as supplements for those people who do not eat those particular alternate foods. For instance, if many people do not want to eat significant amounts of bacteria (and the other major nutrient sources shown in Figure 1 are not available), the vitamin E could be removed from the methane-digesting bacteria and fed as a supplement. Another potentially low-cost source of vitamins would be bacteria that can grow on fiber. A higher cost source of vitamins would be bacteria that can grow on food that is digestible by humans.

Humanity has already established methods to synthesize some vitamins [53]. This could potentially be expanded in catastrophic scenarios which block the sun, but retain industry, and potentially form a multivitamin pill. However, this would not be feasible in scenarios where industry is disabled: electricity could be disrupted by a solar storm, high-altitude electromagnetic pulses from nuclear detonations, or a super computer virus [54,55]. Non-industry scenarios would generally still have sunlight, so farming nearly any crop by hand would be feasible. However, it may be that high calorie per hectare crops need to be favored, which could have less than optimal nutrition.

One other option for vitamins would be growing plants with artificial light. However, this is very inefficient and therefore expensive, so it should only be used as a last resort [56]. And again, this would not be feasible without industry and electricity.

The most extreme scenario is losing industry and the sun. This could occur if the sun is blocked and if international cooperation breaks down. Alternatively, if there is high solar dependent renewable energy penetration (photovoltaics, concentrating solar power, wind power, hydropower, and biofuels), a loss of the sun could mean a collapse of industry as well in the short term. The benefits of making the transition to renewable energy anyway is that large stores of fossil fuel assets would be preserved and could be tapped over time to both provide for energy needs in an extreme sunlight-blocking catastrophe as well as act as a source of alternative foods. Finally, full-scale nuclear war could be coupled with multiple high altitude electromagnetic pulses (HEMPs). In these scenarios, alternate foods would be required, but industrial synthesis of vitamins would not be possible. Therefore, other techniques such as growing bacteria rich in certain vitamins may be required.

It is clear, however, from this study that far more work needs to be done in this area. First, much better nutritional information is needed about the alternative foods themselves, which are less common (e.g. extracting tea from leaves of different species). Thus, future work is needed to quantify the vitamin content of some of the actual alternative foods (instead of proxies). In addition, detailed nutritional profiles of all the variants of different alternative foods must be analyzed carefully for strategic application (e.g. for a region capable of only producing fish, what is the ideal mushroom types needed to compliment the fish nutrient profile?). In addition, a more granular analysis is needed for the available specific alternative foods in a given area (e.g. what type of fish is available in a given region and what is its nutritional profile). Similarly, the nutritional information (both macro and micro) of secondary sources of alterative foods must be quantified (e.g. the nutritional makeup of chicken is well known, however, how does that change if chicken is grown on only bacterial-pre-digested wood?). This information would allow for the analysis of a bare minimum of alternative food diversity that would prevent major diseases like scurvy. In addition, the nutritional requirements of a low-calorie diet should also be looked at carefully in the cases where human activity would reduce if inadequate calories were available from any of the alternative food pathways in a particular region. Once an alternate food diet is estimated to be safe with analytical methods, trials on animals and eventually humans would provide final validation.

In the Hyogo Framework for Action [57], this study supports preparedness and identifying risks. Previous work has shown that investing in interventions using alternative foods is cost effective in both the U.S. [58] and globally [59]. However, in order to be prepared, these solutions for food catastrophes must be distributed, so this is a gap in the Post 2015 Framework for Disaster Risk Reduction in that this area is not adequately addressed. Training for these type of catastrophes could be integrated into existing training efforts. In the scenarios that are the focus of this work (sun being blocked) or lesser agricultural tragedies, industry will still generally be functioning, and so will cities. Future work could be quantifying vitamins for the scenarios of losing industry and losing industry and the sun (and also vitamins for animals in all the scenarios). Ensuring that everyone could have adequate nutrition would reduce the chance of civilization collapsing, from which humanity might not recover. This reduced chance would benefit the far future, which has been-argued to have overwhelming importance [60]. Finally, malnutrition and hunger-related disease, results in about 6 million preventable deaths per year in children under 5 years old currently [61]. This problem when the global agricultural system is functioning is trivial compared to any of the catastrophic situations when it is not. Although research in alternative foods could help feed today's starving, the fact there are still millions of hungry people when there is adequate food shows that the economics and politics of feeding people both now and in a catastrophe are also important future projects.

5. Conclusions

If the sun is blocked by a large asteroid or comet, super volcanic eruption, or nuclear war, alternate foods would be required. Single alternate food sources are always deficient in some vitamins, and the problems associated with this are discussed. However, the analysis shows that a diversity of these foods could provide adequate vitamins. Processing might be required to aid digestibility of these vitamins. If this diversity is not feasible for all people, alternate methods could be used such as growing bacteria rich in certain vitamins and industrial synthesis. In the cases of losing industry, people would likely have adequate nutrition. In the case of losing the sun and industry, people would likely require growing bacteria rich in certain vitamins.

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Appendix A

Table A1. Nutrition of 2,100 kcal of each selected alternative food analogue.

Food	Vitamin A %US RDA	Vitamin E %US RDA	Vitamin D %US RDA	Vitamin C %US RDA	Thiamine (B1) %US RDA	Riboflavin (B2) %US RDA	Sources
Tuna	36.2				58.5	170	[62]
Beef					47.7	74.8	[63]
Liver	8580	39.4	252		256	3570	[64]
Chicken	254				52.2	150	[65]
Shitake Mushroom			350		80.5	1120	[66]
Oyster Mushroom			902		692	1850	[67]

Milk	176	16.1			138	485	[68]
Egg	261	103	201		51.1	559	[69]
Bacteria	184	553			2910	16800	[28]
Arborvitae Tea				10600			[70]
Dandelions				7420			[71]

Food	Niacin (B3) %US RDA	Vitamin B6 %US RDA	Vitamin B12 %US RDA	Vitamin K %US RDA	Folate (B9) %US RDA	Vitamin B5 %US RDA
Tuna	2090	1330	1610		45.8	171
Beef		170	813		9.5	42.5
Liver	1370	1290	38400	45.9	1130	
Chicken	437	258	456		74.0	211
Shitake Mushroom	1590	1390			201	1850
Oyster Mushroom	2100	539			605	1650
Milk	20.4	95.3	646	13.1	43.0	
Egg	7.3	192	545	4.2	173	450
Bacteria	2390					
Arborvitae Tea						
Dandelions				130000		

Table A2. AR from EFSA for a 30-39 year old female with a PAL of 1.6 [29].

Nutrient	Vitamin A	Vitamin E	Vitamin D	Vitamin C	Thiamine (B1)	Riboflavin
Unit	μg/day	μg/day	μg/day	mg/day	mg/day	μg/day
Amounts	490	11000	15	80	0.63	1.3
Solubility	Oil	Oil	Oil	Water	Water	Water

Nutrient	Niacin (B3)	Vitamin B6	Vitamin B12	Vitamin K	Folate (B9)	Vitamin B5
Unit	mg/day	mg/day	μg/day	μg/day	μg/day	mg/day
Amounts	11.3	1.3	4	70	70	5
Solubility	Water	Water	Water	Oil	Water	Water

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