3. SELECTION OF CROP SPECIES

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3. 1 Nutritional level required by a Japanese person on the moon

3.1.1 Premise of the nutrition level required by a Japanese person on the moon

The target of this working group was Japanese people. The nutritional intake standards for long-term stays on the ISS in space include NASA's planetary exploration missions, but these are considered mainly by Westerners and cannot be applied to Japanese people [1]. At present, the standards for planetary missions are generally in accordance with the US terrestrial standards[1], except for calcium and vitamin D, which emphasize nutritional significance in long-term missions and are used on lunar farms in this working group. Because the criteria for determining the number of crops cultivated in Japan is for Japanese people, we decided to utilize the "Japanese Dietary Intake Standards 2015 Edition" [2] (hereafter, Dietary Intake Standards) by the Ministry of Health, Labor and Welfare. Dietary Intake Standards are intended for healthy individuals and groups and indicate the standards for energy and nutrient intake to maintain and promote people's health and prevent lifestyle-related diseases by gender and age. The study was conducted based on the "meal intake standard" for men aged 30 to 49 (physical activity level 2) (Table 3.1).

Table 3.1 Reference Dietary Intake Values for Men and Women Aged 30–49 Years (Physical Activity Level 2)

			Men	Women	Tolerable upper intake level	Breastfeeding mothers and pregnant women (additional amount)
Calories	kcal/day	Estimated average requirement	2650	2000		
Protein	g/day	Recommended dietary allowance	60	50		
Tentative dietary goal for preventing life-style related diseases	% energy	Tentative dietary goal for preventing life-style related diseases	13–20	13–20		
Fat	% energy	Tentative dietary goal for preventing life-style related diseases	20–30	20–30		
Carbohydrates	% energy	Tentative dietary goal for preventing life-style related diseases	50–65	50–65		
Dietary fiber	g/day	Tentative dietary goal for preventing life-style related diseases	20 or more	18 or more		
Vitamin A	μRAE/day	Recommended dietary allowance	900	700	○	○
Vitamin D	μg/day	Adequate intake	5.5	5.5	○	○
Vitamin E	mg/day	Adequate intake	6.5	6.0	○	○
Vitamin K	μg/day	Adequate intake	150	150		
Vitamin B1	mg/day	Estimated average requirement—recommended dietary allowance	1.2–1.4	0.9–1.1		○
Vitamin B2	mg/day	Estimated average requirement—recommended dietary allowance	1.3–1.6	10–1.1		○
Niacin	mgNE/day	Estimated average requirement—recommended dietary allowance	13–15	8–11	○	○
Vitamin B6	mg/day	Estimated average requirement—recommended dietary allowance	1.2–1.4	1.0–1.2	○	○
Vitamin B12	μg/day	Estimated average requirement—recommended dietary allowance	2.0–2.4	2.0–2.4		○

Folacin	μg/day	Estimated average requirement—recommended dietary allowance	200–240	200–240	○	○
Pantothenic acid	mg/day	Adequate intake	5	4		○
Biotin	μg/day	Adequate intake	50	50		○
Vitamin C	mg/day	Estimated average requirement—recommended dietary allowance	85–100	85–100		○
Sodium	mg/day	Estimated average requirement	600	600		
(Sodium chloride equivalent)	g/day	Estimated average requirement	1.5	1.5		
Potassium	mg/day	Adequate intake	2500	2000		○
Calcium	mg/day	Estimated average requirement—recommended dietary allowance	550–650	550–650	○	
Magnesium	mg/day	Estimated average requirement—recommended dietary allowance	310–370	240–290		
Phosphorus	mg/day	Adequate intake	1000	800	○	○
Iron	mg/day	Estimated average requirement—recommended dietary allowance	6.0–7.0	9.0–10.5 (with menstruation)	○	○
				5.5–6.5 (without menstruation)		
Zinc	mg/day	Estimated average requirement—recommended dietary allowance	8–10	6–8	○	○
Copper	mg/day	Estimated average requirement—recommended dietary allowance	0.7–1.0	0.6–0.8	○	○
Manganese	mg/day	Adequate intake	4.0	3.5	○	○
Iodine	μg/day	Estimated average requirement—recommended dietary allowance	95–130	95–130	○	○
Selenium	μg/day	Adequate intake	25–30	20–25	○	○
Molybdenum	μg/day	Estimated average requirement—recommended dietary allowance	25–30	20–25	○	○

3.1.2 Indicators of energy and nutrients [2)]

Based on the Dietary Intake Standards, an index (estimated energy requirement) was determined for energy to avoid excess or a deficiency of energy intake. There were three types of indicators regarding nutrients to avoid insufficient intake (estimated average requirement, recommended dietary allowance, and adequate intake). There were also indicators to avoid health problems because of overdose (tolerable upper intake level) and indicators to prevent lifestyle-related diseases (tentative dietary goal for preventing lifestyle-related diseases), for a total of six indicators. The six indicators of energy and nutrients are explained in Table 3.2.

Table 3.2. Energy and Nutrient Indicators Demonstrated by Dietary Intake Standards

Index	
Estimated energy requirement	According to the WHO definition, energy requirements are defined as "energy intake that is balanced with energy expenditure when an individual of a certain height/weight and body composition is at a physical activity level that maintains good health for a long period.” Estimated Energy Requirement (kcal/d) = Basal Metabolic Rate (kcal/d) × Physical Activity Level
Estimated average requirement (EAR)	An average value of the required amount in the population is based on the distribution of the required amount measured in a target population and defined as an intake estimated to meet the requirements of 50% of people in the population.
Recommended dietary allowance (RDA)	The amount that satisfies most people (97–98%) in the population, based on the distribution of requirements measured in a target population.
Adequate intake (AI)	An “adequate intake’’ is defined as an amount sufficient to maintain an individual’s nutritional status in a specific population. It shall be calculated when the "estimated average requirement" cannot be calculated because of an insufficient chemical basis. In practice, it is given by the amount that is rarely observed in people who show a deficiency in a particular population.

Tolerable upper intake level (UL)	An amount that provides an upper limit on the habitual intake is considered not at risk of causing health problems. Ingestion beyond this will increase the risk of potential health problems caused by overdose. No set nutrients for which sufficient chemical basis cannot be obtained.
Tentative dietary goal for preventing life-style related diseases (DG)	Set as "the amount of intake that the current Japanese people should aim for to prevent lifestyle-related diseases."

3.2 Selection of crop candidates to cultivate

We will use a plant factory on the lunar farm that can grow crops with artificial light sources and no sunlight. In Japan, commercial cultivation using plant factories is the most widespread worldwide, and related research accumulation and technological development capabilities are among the highest. Because the artificial light-type plant factory developed in Japan can maintain a high degree of closure in the cultivation room, it is easy to control the energy and mass balance. The following points should be considered when selecting candidate crops for production on the moon using an artificial light-type plant factory.

3.2.1 Crop production in plant factories

The main food crops are cereals, legumes, potatoes, nuts and seeds, leafy vegetables, fruit vegetables, root vegetables, and fruit trees. The majority of edible crops can be produced in artificial light plant factories. The artificial light-type plant factory uses a hydroponic cultivation method instead of soil to control temperature and humidity, light, CO_2 gas, O_2 gas, and airflow, which are above-ground environmental factors necessary for plant growth.

Hydroponic cultivation is a method for cultivating plants by feeding them a culture solution containing necessary elements without using soil [3)]. Hydroponic cultivation can be broadly divided into solid medium cultivation that uses sand, rubble, sawdust, rock wool, perlite, vermiculite as the medium, hydroponics, and spray cultivation do not use a solid medium. Leafy vegetables can be cultivated by hydroponics, but many crops are cultivated by solid medium cultivation. Because gravity exists on the lunar surface (1/6 G), it is considered that the technology on the ground can be used for hydroponic cultivation almost in its current state.

3.2.2 Differences between crop species

The productivity (yield of one crop) in a plant factory is approximately 1 to 3 times that of conventional methods if the environmental conditions and cultivation conditions are optimized. In rice (paddy rice), it is possible to obtain twice the paddy fields' average yield. Additionally, because approximately three crops can be cultivated a year, the annual yield is approximately six times that of paddy fields [4)].

The electricity required for cultivation in a plant factory is mainly used for lighting and air conditioning. Because the efficiency of photosynthesis (sugar synthesis), which is the first step of substance synthesis in plants, can be regarded as almost the same regardless of the crop species[5)], the difference in the efficiency of dry matter weight growth per unit power input between plant species is considered to be small. However, the efficiency of the synthesis of proteins, lipids, and secondary metabolites varies among crop species.

Other crop species differences are the edible portion ratio (harvest index) and labor for cultivation management. A large ratio of edible parts indicates few non-edible parts become residue. There is a large difference between crop species in labor, such as cultivation management work and harvest. If cultivation management is complicated or requires a long time, the lunar resident's burden will increase. However, because the amount of labor can be solved by mechanization and robotization, which will be described later, it is not necessary to give much importance to selecting candidate crops regarding the work required.

3.2.3 Virus-freeing

To prevent the spread of viral plant diseases and fungal diseases in the lunar base, it is desirable to take virus-free crops from the earth and bring them to the lunar base. At present, they can be roughly divided into crops that can be virus-free and propagated by the plant tissue culture method and crops for which this technology has not been established. Therefore, it is desirable to focus on the selection of crops. It is also necessary not to bring pests from the earth. Considering the above, pesticide-free cultivation will be possible because an outbreak of pests could be suppressed on the lunar farm.

3.2.4 Traits

Pest resistance, environmental stress resistance, and high-water utilization efficiency emphasized in agricultural breeding are not required in plant factories. Rather, it is useful to determine varieties that exhibit rapid growth under suitable cultivation conditions in plant factories. It is also assumed that genetically modified crops with beneficial traits, such as high-speed growth in plant factories and high content of nutrients and functional components, will be used.

3.2.5 Mechanization, robotization, and ICT use

AI, ICT, mechanization, and robotization in the agricultural field are expected to make significant progress by the time the lunar base is in operation. Therefore, it is assumed that mechanization/robot technology, the possibility of which has already been suggested, could be introduced. It is assumed that robots will perform simple, painful, and dangerous farming tasks that humans dislike. Pollinating insects may be introduced, but if not, it is assumed that the robot will do so, including the spraying of hormones. However, it is necessary to develop elemental technologies to realize this.

Considering the above viewpoints and the dietary intake standards in Section 3.1, the following crops were selected as candidate crops:

Cereals	Rice
Legumes	Soybeans
Tubers	Potato and sweet potatoes
Fruit vegetables	Tomatoes, strawberries, and cucumbers
Leafy vegetables	Lettuce and others (e.g., Komatsuna)

These can be cultivated in a plant factory, made virus-free using a tissue culture method, and can be genetically recombined.

The main cereals are rice, wheat, and barley, but we chose rice to consider the variety of dishes possible, mainly Japanese food. Cultivation in a plant factory has abundant research examples. Among beans, soybeans are a popular crop that can be used as a staple food, side dish, and vegetable oil and can also be used as an ingredient in tofu and patties. Its cultivation in plant factories is abundant at the research level. In open-field agriculture, potatoes and sweet potatoes grow in the soil. There are many research examples of hydroponic cultivation of potatoes and other tubers. Sweet potatoes are an enlarged root, and they are somewhat difficult to cultivate in a hydroponic solution, but research and development are being conducted. Both are highly nutritious and indispensable crops for cooking; consequently, they were selected. We selected fruit vegetables and leaf vegetables produced in large quantities and have a high utility value as foodstuffs. We selected crop species that are popular and have many production cases in plant factories.

Other than the crops selected, there are nuts and seeds, root vegetables, fruit trees, and tea. These crops can be cultivated by any of the eight selected crop cultivation methods. Therefore, in this report, various studies will be reported using a combination of these eight crops.

3.2.6 Characteristics of the selected candidate crops [6)7)8)]

The nutritional characteristics of the selected candidate crops are as follows:

(1) Rice (Brown Rice)

The edible part of rice is the grain. Rice is high in carbohydrates, a major energy source, and a staple food. Brown rice is made by removing rice husks from grains. The bran and germ have more protein, lipids, minerals, and dietary fiber than refined rice, but its digestion and absorption rate is low.

(2) Potatoes

Potatoes are suitable for cultivation in cool climates. It is an important food worldwide because it can be harvested stably and has high storability. Because of its light taste, it is also commonly used as a staple food. The main ingredient is starch, rich in vitamin C, vitamin B1, and potassium. It is also called *pomme de terre* (“Apple of the Earth”) in France. It is cultivated worldwide as a staple food vegetable.

(3) Sweet potatoes

Sweet potatoes were regarded as a salvage crop because they are resistant to weather changes and can be harvested stably. Among potatoes, it has a high sugar content and an intense sweetness. The main ingredient is starch, rich in minerals, such as vitamin C, vitamin E, potassium, calcium, copper, and dietary fiber. Leaves and stems can also be consumed.

(4) Soy

① Soybeans

Soybeans are rich in high-quality protein to the point where they have been referred to as the “meat of the field” and are rich in calcium, vitamin B1, vitamin B2, and vitamin E. Because soybeans have a rigid structure and poor digestion, they are made into various processed products, such as tofu, fried tofu, soymilk, miso, natto, fats and oils, and soy sauce.

② Green soybeans

Green soybeans refer to immature beans harvested before ripening. Like soybeans, they are rich in protein, sugar, vitamin B1, vitamin B2, calcium and contain vitamin C, which is not found in mature soybeans.

(5) Tomatoes (cherry tomatoes)

These are western vegetables of the Solanaceae family that complement dishes with bright colors. In Japan, they are often eaten raw and frequently used. Cherry tomatoes are small, sweet, juicy, and have moderate acidity. The red pigment is called lycopene and has antioxidant properties. It is a green-yellow vegetable that is relatively high in vitamin C and vitamin A and contains potassium.

(6) Cucumbers

Cucumbers are regular vegetables because they have a refreshing aroma and texture and can be eaten raw. Approximately 95% of the cucumber is water, and the remaining 4% contains a small amount of vitamins, minerals, and carbohydrates. It contains an enzyme called ascorbinase that destroys vitamin C (suppressed by acid).

(7) Lettuce (leaf lettuce)

Lettuce is a crisp, versatile vegetable that can be easily adapted to many dishes. Approximately 95% of the total is moisture and includes vitamins C and E, carotene, calcium, potassium, iron, and zinc. Compared with head lettuce, leaf lettuce has a higher potassium content, vitamins, and minerals.

(8) Strawberries

Strawberries can be eaten quickly after washing and have a favor that has refreshing sweetness and fragrance. Among the fruits, it contains a high vitamin C content, and the flesh is juicy and has a moderate sweetness and sourness.

Table 3.3 Nutritional value of the eight crop species (per 100 g) [9)]

	Calories (kcal)	Protein g	Fat g	Carbohydrates g	Dietary fiber g	Sodium mg	Potassium mg	Calcium mg	Magnesium mg	Phosphorus mg	Iron mg	Zinc mg	Copper mg	Manganese mg	Iodine µg	Selenium µg	Chromium µg	Molybdenum µg
1) Brown rice	353	6.8	2.7	74.3	3.0	1	230	9	110	290	2.1	1.8	0.27	2.06	0	3	0	64
Refined white rice	358	6.1	0.9	77.6	0.5	1	89	5	23	95	0.8	1.4	0.22	0.81	0	2	0	69
2) Sweet potatoes	134	1.2	0.2	31.9	2.2	11	480	36	24	47	0.6	0.2	0.17	0.41	1	0	1	4
3) Potatoes	76	1.6	0.1	17.6	1.3	1	410	3	20	40	0.4	0.2	0.10	0.11	0	0	5	4
4) Soybeans	422	33.8	19.7	29.5	17.9	1	1900	180	220	490	6.8	3.1	1.07	2.51	0	5	3	350
Edamame	135	11.7	6.2	8.8	5.0	1	590	58	62	170	2.7	1.4	0.41	0.71	0	1	1	240
5) Lettuce	16	1.2	0.2	3.2	2.0	4	410	66	15	31	1.8	0.4	0.05	0.43	0	0	0	0
6) Mini-tomatoes	29	1.1	0.1	7.2	1.4	4	290	12	13	29	0.4	0.2	0.06	0.10	4	0	0	4
7) Cucumbers	14	1.0	0.1	3.0	1.1	1	200	26	15	36	0.3	0.2	0.11	0.07	1	1	1	4
8) Strawberries	17	0.5	0.1	4.3	0.7	0	85	9	7	16	0.2	0.1	0.03	0.10	1	0	0	5

	Retinol activity equivalents µg	Vitamin D µg	α-Tocopherol mg	Vitamin K µg	Vitamin B1 mg	Vitamin B2 mg	Niacin mg	Vitamin B6 mg	Vitamin B12 µg	Folacin µg	Pantothenic acid mg	Biotin µg	Vitamin C Mg	Sodium chloride equivalent g
1) Brown rice	0	0.0	1.2	0	0.41	0.04	6.3	0.45	0.0	27	1.37	6.0	0	0.0
Refined white rice	0	0.0	0.1	0	0.08	0.02	1.2	0.12	0.0	12	0.66	1.4	0	0.0
2) Sweet potatoes	2	0.0	1.5	0	0.11	0.04	0.8	0.26	0.0	49	0.90	4.1	29	0.0
3) Potatoes	0	0.0	0.0	0	0.09	0.03	1.3	0.18	0.0	21	0.47	0.4	35	0.0
4) Soybeans	1	0.0	2.3	18	0.71	0.26	2.0	0.51	0.0	260	1.36	27.5	3	0.0
Edamame	22	0.0	0.8	30	0.31	0.15	1.6	0.15	0.0	320	0.53	11.1	27	0.0
5) Lettuce	170	0.0	1.2	160	0.10	0.10	0.3	0.08	0.0	120	0.14	0.0	17	0.0
6) Mini-tomatoes	80	0.0	0.9	7	0.07	0.05	0.8	0.11	0.0	35	0.17	3.6	32	0.0
7) Cucumbers	28	0.0	0.3	34	0.03	0.03	0.2	0.05	0.0	25	0.33	1.4	14	0.0
8) Strawberries	1	0.0	0.2	0	0.02	0.01	0.2	0.02	0.0	45	0.17	0.4	31	0.0

3.3 Determination of daily consumption quantity on the Lunar Farm [2)9)]

This working group proceeded with the study on the precondition that the plants cultivated on the lunar farm would be self-sufficient without relying on a supply from the earth. Based on each cultivated crop's nutrient characteristics, we aimed for the range indicated by the "dietary intake standard." The daily amount of the eight crop species was determined by considering the balance between energy and the three macronutrients.

For vitamins and minerals, we aimed for the recommended daily allowance (RDA) to the extent possible, and we adjusted the content by setting the target value in a range from the estimated average requirement (EAR) to the tolerable upper intake level (UL). Ultimately, 400 g of brown rice, 150 g of sweet potato, 75 g of potato, 120 g of soy (dried), 50 g of green soybean, 150 g of leaf lettuce, 200 g of tomato, 100 g of cucumber, and 50 g of strawberry were determined as the daily intake in this working group. Table 4 shows a comparison between the supply of the eight crop species and the standard value (* estimated average requirement, recommended dietary allowance, or adequate intake).

Table 3.4 Comparison of the amount of nutrients obtained from the eight crop species with the standard values based on the Japanese dietary intake standard (2015 version)

Food name	Weight (g)	Calorie kcal	Protein g	Fat g	Carbohydrates g	Dietary fiber g	Sodium mg	Potassium mg	Calcium mg	Magnesium mg	Phosphorus mg	Iron mg	Zinc mg	Iron mg	Manganese mg	Iodine µg	Selenium µg	Chromium µg	Molybdenum µg
Brown rice	400	1412	27.2	10.8	297.2	12	4	920	36	440	1160	8.4	7.2	1.08	8.24	0	12	0	256
Sweet potatoes	150	201	1.8	0.3	47.85	3.3	16.5	720	54	36	70.5	0.9	0.3	0.26	0.62	2	0	2	6
Potatoes	75	57	1.2	0.075	13.2	0.975	0.75	307.5	2.25	15	30	0.3	0.15	0.08	0.08	0	0	4	3
Soybeans (dried)	120	506	40.56	23.64	35.4	21.48	1.2	2280	216	264	588	8.16	3.72	1.28	3.01	0	6	4	420
Edamame	50	68	5.85	3.1	4.4	2.5	0.5	295	29	31	85	1.35	0.7	0.21	0.36	0	1	1	120
Soybean oil	30	276	0	30	0	0	0	0	0	0	0	0	0	0.00	0.00	0	0	0	0
Leaf lettuce	150	24	1.8	0.3	4.8	3	6	615	99	22.5	46.5	2.7	0.6	0.08	0.65	0	0	0	0
Mini-tomatoes	200	58	2.2	0.2	14.4	2.8	8	580	24	26	58	0.8	0.4	0.12	0.20	8	0	0	8
Cucumbers	100	14	1	0.1	3	1.1	1	200	26	15	36	0.3	0.2	0.11	0.07	1	1	1	4
Strawberries	50	17	0.45	0.05	4.25	0.7	0	85	8.5	6.5	15.5	0.15	0.1	0.03	0.10	1	0	0	5
Total	1325	2633	82.06	68.565	424.5	47.9	38	6003	495	856	2090	23.1	13.4	3.23	13.32	11	20	10	822
Standard value			P ratio (12%)	F ratio (23%)	C ratio (65%)			2500	650	370	1000	7.5	10	1	4	130	30	10	25
Sufficiency rate								240%	76%	231%	209%	307%	134%	323%	333%	8%	65%	104%	3286%
Evaluation			○	○	○	○	○	Excess	Deficiency	Excess	○	○	○	○	Excess	Deficiency	Deficiency	○	Excess

Food name	Retinol µg	Vitamin D µg	α-Tocopherol mg	Vitamin K µg	Vitamin B1 mg	Vitamin B2 mg	Niacin mg	Vitamin B6 mg	Vitamin B12 µg	Folacin µg	Pantothenic acid mg	Biotin µg	Vitamin C mg	Sodium chloride equivalent g
Brown rice	0	0.0	4.8	0	1.64	0.16	25.2	1.80	0.0	108	5.48	24.0	0	0.0
Sweet potatoes	3	0.0	2.3	0	0.17	0.06	1.2	0.39	0.0	74	1.35	6.2	44	0.0
Potatoes	0	0.0	0.0	0	0.07	0.02	1.0	0.14	0.0	16	0.35	0.3	26	0.0
Soybeans (dried)	1	0.0	2.8	22	0.85	0.31	2.4	0.61	0.0	312	1.63	33.0	4	0.0
Edamame	11	0.0	0.4	15	0.16	0.08	0.8	0.08	0.0	160	0.27	5.6	14	0.0
Soybean oil	0	0.0	3.1	63	0.00	0.00	0.0	0.00	0.0	0	0.00	0.0	0	0.0
Leaf lettuce	255	0.0	1.8	240	0.15	0.15	0.5	0.12	0.0	180	0.21	0.0	26	0.0
Mini-tomatoes	160	0.0	1.8	14	0.14	0.10	1.6	0.22	0.0	70	0.34	7.2	64	0.0
Cucumbers	28	0.0	0.3	34	0.03	0.03	0.2	0.05	0.0	25	0.33	1.4	14	0.0
Strawberries	1	0.0	0.2	0	0.02	0.01	0.2	0.02	0.0	45	0.17	0.4	31	0.0
Total	459	0.0	17.4	388	3.21	0.92	33.0	3.42	0.0	989	10.12	78.0	221	0.0
Standard value	900	5.5	6.5	150	1.4	1.6	15	1.4	2.4	240	5	50	100	
Sufficiency rate	51%	0%	268%	258%	230%	57%	220%	244%	0%	412%	202%	156%	221%	
Evaluation	Deficiency	Deficiency	○	Excess	Excess	Deficiency	○	○	Deficiency	○	Excess	Excess	Excess	

3.4 Necessary cultivation area

Considering the cultivation data, such as growth and yield assumed in plants and the harvest index (H. I.) of the edible part, the required area is as follows:

Table 3.5. Examples of calculating the required cultivation area

	Amount required per person	Productivity in the plant factory			Area required per person	Area required	
		Production per crop	Days needed for cultivation	Daily production		For 6 people	For 100 people
	(g/day)	(g/m^2)	(day)	(g/m^2/day)	(m^2)	(m^2)	(m^2)
Rice	400	900	90	10	40.0	240	4000
Potatoes	75	8000	360	22	3.4	20	338
Sweet potatoes[1)]	150	–	–	20	7.5	45	750
Soybeans	350	1400	100	14	25.0	150	2500
Lettuce	150	2500	30	83	1.8	11	180
Tomatoes	200	83000	360	231	0.9	5	87
Cucumbers	100	70000	360	194	0.5	3	51
Strawberries	50	17000	360	47	1.1	6	106

1) Since there are not enough examples of sweet potato cultivation, the daily production is assumed to be about 90% of that of potatoes.

3.5 Nutrients that may be in excess

Nutrients that can be in excess (more than twice the estimated average requirement or recommended dietary allowance) are potassium, magnesium, vitamin K, vitamin B1, pantothenic acid, vitamin C, copper, α-tocopherol, niacin, vitamin B6, folic acid, iron, manganese, and molybdenum, for a total of 14 nutrients.

Table 3.6 Nutrients that are more than twice the estimated average requirement or recommended dietary allowance (excluding nutrients below the upper level)

<No tolerable upper limit dose>

Food name	Potassium mg	Magnesium mg	Vitamin K µg	Vitamin B1 mg	Pantothenic acid mg	Vitamin C mg
Total daily nutritional value	6003	856	388	3 .21	10 .12	221
Standard value	2500	370	150	1.4	5	100
Sufficiency rate	240%	231%	258%	230%	202%	221%
Tolerable upper limit	-	-	-	-	-	-
Evaluation	Excess	Excess	Excess	Excess	Excess	Excess

<Upper limit of tolerated dose>

Food name	Copper mg	α-Tocopherol mg	Niacin mg	Vitamin B6 mg	Folacin µg	Iron mg	Manganese mg	Molybdenum µg
Total daily nutritional value	3 .23	17 .4	33 .0	3 .42	989	23 .1	13 .32	822
Standard value	1	6.5	15	1.4	240	7.5	4	25
Sufficiency rate	323%	268%	220%	244%	412%	307%	333%	3286%
Tolerable upper limit	10	900	350	60	1000	55	11	550
Evaluation	Excess	Excess	Excess	Excess	Excess	Excess	Excess	Excess

One clear issue from comparing the nutrients based on the supplements of the eight crop species with the "dietary intake standard" is that manganese and molybdenum exceed the tolerable upper limit.

Manganese is present in an adult's body at an amount of 12 to 20 mg and is important in enzyme composition, such as manganese superoxide dismutase, and enzyme activation, such as arginase. It is involved in bone metabolism, glycolipid metabolism, motor function, and skin metabolism. Manganese is abundant in cereals, vegetables, and legumes, and overdose may occur because of peculiar dietary forms, such as strict vegetarian diets, improper use of supplements, and a tolerable upper level has been set. Because manganese is unevenly distributed on the bran side, it can be reduced by 5.0 mg by milling rice (Fig. 3.1). The rice milling process may be necessary to prevent hypervitaminosis.

Furthermore, molybdenum functions as a coenzyme for xanthine oxidase, aldehyde oxidase, and sulfite oxidase. Because molybdenum is also abundant in cereals and legumes, the intake is high in an extremely vegetarian diet. When molybdenum is compared between brown rice and white rice, there is no apparent difference, and it has been reported that molybdenum is distributed almost uniformly throughout the rice [7]; consequently, molybdenum is not expected to decrease by rice milling. However, because it has been clarified that the concentration of trace minerals, such as molybdenum, in plant foods fluctuate depending on the soil and

variety, it is necessary to consider the composition of the nutrient solution.

	Manganese mg
Brown rice: 400 g	8.24
Total for seven crop types	5.08
Total	13.32

	Manganese mg
White rice: 400 g	3.24
Total for seven crop types	5.08
Total	8.32

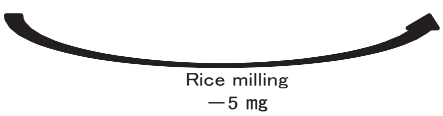

Fig. 3.1. Changes in manganese content caused by rice milling

There are 12 nutrients supplemented by the eight crop species supplement that are more than twice the estimated average requirement or recommended dietary intake. These are considered to have a low risk of health problems because there is no tolerable upper intake level, or they are below the tolerable upper intake level. However, in the space environment, there is a concern that iron may cause tissue damage as an oxidant because of exposure to space radiation; consequently, caution is required regarding excessive intake of iron [1)]. Additionally, among nutrients that may be excessive, such as folic acid, the contents of nutrients other than vitamin K and vitamin C are reduced by rice milling (Table 3.7). Only niacin is slightly below the standard value, but there are concerns regarding health risks because of overdose, such that it is necessary to prioritize reducing the risk of overdose. As with molybdenum and manganese, it is necessary to conduct the rice milling process and to proceed with studies, including the composition of the cultivated nutrient solution.

Additionally, a tolerable upper intake level has not been set for dietary fiber and potassium. However, it is difficult to address these nutrients because there are few studies regarding excessive intake because they are easily deficient in modern times. However, careful consideration is required because even nutrients that do not have a tolerable upper intake level are significantly different from life on earth.

Table 3.7 Nutritional Value Changes by Rice Refining

	Weight g	Calorie kcal	Potassium mg	Magnesium mg	Iron mg	Copper mg	α-Tocopherol mg	Vitamin K µg	Vitamin B1 mg	Niacin mg	Vitamin B6 mg	Folacin µg	Pantothenic acid mg	Vitamin C mg
Brown rice 400 g + seven crop species	1325	2633	6003	856	23.1	3.23	17.4	388	3.21	33.0	3.42	989	10.12	221
Sufficiency rate			240%	231%	307%	323%	268%	258%	230%	220%	244%	412%	202%	221%
White rice 400 g + seven crop species	1325	2653	5439	508	17.9	3.03	13.0	388	1.89	12.6	2.10	929	7.28	221
Sufficiency rate			218%	137%	238%	303%	200%	258%	135%	84%	150%	387%	146%	221%
Impact of rice milling			Decrease	Decrease	Decrease	Decrease	Decrease	None	Decrease	Decrease	Decrease	Decrease	Decrease	None

3.6 Nutrients that may be in shortage

Comparing the dietary intake standards of Japanese people with the amount of supplements from the eight crop species, seven nutrients, including calcium, iodine, selenium, vitamin A (retinol), vitamin D, vitamin B2, and vitamin B12 (sodium is not supplied with vegetables, but it is excluded because it can be expected to be ingested from seasoning during cooking), are less than the estimated average requirement or recommended dietary allowance.

There are a few green and yellow vegetables on the lunar farm, and there is no supply of animal foods (fish, meat, dairy products), such that there may be a shortage of nutrients specifically contained in these foods. Above all, muscle and bone mass are reduced in the space environment; therefore, it is necessary to pay attention to calcium and vitamin D. Nutrients that are deficient in the supplementation from the eight crop species need to be ingested as supplements. The amount of nutrients deficient compared with the standard is 158.9 mg (Table 3.9). Astronauts bring along vitamin D supplements, and these nutrients need to be supplemented to avoid the risk of deficiencies.

Table 3.8 Inadequate Nutrients Table (Left) / 3.9 Inadequate Nutrient Levels (Right)

Food name	Weight g	Calcium mg	Iodine μg	Selenium μg	Retinol μg	Vitamin D μg	Vitamin B2 mg	Vitamin B12 μg
Brown rice	400	36	0	12	0	0.0	0.16	0.0
Sweet potatoes	150	54	2	0	3	0.0	0.06	0.0
Potatoes	75	2.25	0	0	0	0.0	0.02	0.0
Soybeans (dried)	120	216	0	6	1	0.0	0.31	0.0
Edamame	50	29	0	1	11	0.0	0.08	0.0
Soybean oil	30	0	0	0	0	0.0	0.00	0.0
Leaf lettuce	150	99	0	0	255	0.0	0.15	0.0
Mini-tomatoes	200	24	8	0	160	0.0	0.10	0.0
Cucumbers	100	26	1	1	28	0.0	0.03	0.0
Strawberries	50	8.5	1	0	1	0.0	0.01	0.0
Total	1325	495	11	20	459	0 .0	0 .92	0 .0
Standard value		650	130	30	900	5.5	1.6	2.4
Sufficiency rate		76%	8%	65%	51%	0%	57%	0%
Evaluation		Deficiency	Deficiency	Deficiency	Deficiency	Deficiency	Deficiency	Deficiency

	Supply amount	Standard value	Deficient amount	(mg)
Calcium (mg)	495	650	155	155
Iodine (μg)	11	130	119	0.119
Selenium (μg)	20	30	10	0.01
Retinol (μg)	459	900	441	0.441
Vitamin D (μg)	0	5.5	5.5	0.0055
Vitamin B2 (mg)	0.92	1.6	0.68	0.92
Vitamin B12 (mg)	0	2.4	2.4	2.4
			Total (mg)	158.9

3.7 Image of a meal using the eight crop species

With the supplied amount of the eight crop species determined in Section 3.3, a daily meal image was created with reference to general home cooking.

Table 3.10 Daily food image

	Dish name	Photograph	Calories kcal	Protein g	Fat g	Carbohydrates g	Dietary fiber g	Sodium chloride equivalent g
Morning	Rice		469	9.0	3.6	98.8	4.0	0.0
	Cooked beans		156	10.8	5.9	15.7	5.4	1.3
	Gojiru soup		59	4.5	2.5	4.9	2.2	1.1
	Chinese marinated salad		71	1.9	4.2	7.7	1.8	0.9
	Strawberries		17	0.5	0.1	4.3	0.7	0.0
	Total		773	26.8	16.2	131.4	14.1	3.3
Lunch	Soybean curry		860	27.4	28.2	124.2	13.9	1.6
	Sweet vinegar marinated lettuce		31	0.9	0.2	6.5	1.1	0.0
	Total		891	28.3	28.4	130.7	15.0	1.6
Snack	Sweet mashed potato		117	0.7	0.4	27.8	2.1	0.1
	Total		117	0.7	0.4	27.8	2.1	0.1
Dinner	Rice		469	9.0	3.6	98.8	4.0	0.0
	Soybean hamburger steak		433	15.9	23.1	41.3	9.2	2.0
	Boiled sweet potatoes		128	0.7	0.4	30.8	2.1	0.1
	Tomato soup		14	0.6	0.1	3.3	0.8	1.0
	Edamame		34	2.9	1.6	2.2	1.3	0.0
	Total		1078	29.2	28.7	176.4	17.3	3.1
Total for the day			2859	84.9	73.6	466.2	48.4	8.1

A separate recipe was created for the stems and leaves of sweet potatoes since they are edible.

Table 3.11 Sweet potato stem and leaf dishes

Boiled	Kinpira	Buchimgae-style	Chinese stir-fry
		 (Use of grated potatoes to bind)	

The stems and leaves of sweet potatoes are rarely eaten in Japan, but there is no problem doing so, and they can be eaten after cooking for a short time. The Japanese Food Standard Food Composition Table 2015 (7^{th} edition) does not describe the nutritional value of sweet potato stems and leaves, and the exact nutritional value is unknown; therefore, an analysis is required.

3.8 Limitations to nutrient intake based on ingredients from the crop species alone

The dietary environment of the eight crop species is very different from the dietary environment on earth. In particular, there is a wide variety of foods on earth, and the rich dietary environment contributes to the supply of nutrients and mental health. Animal foods, such as meat, fish, eggs, dairy products, and foodstuffs, such as mushrooms, fruit, and seaweed, were excluded from this study, but there is no record of living on a diet of only eight vegetable foods. Many aspects need to be explained.

Space food is created across 16 cycles, but astronauts are demanding regarding the diversification of the menu[11)], and Masuda et al. has stated that it is impossible to conduct long-term closed residence experiments while keeping human psychological stress low with only a few types of crops[12)]. To aim for a long-term stay, it is essential to increase the variety of diets by increasing the number of cultivated items and introducing livestock, such as cattle, pigs, chickens, or fish in the future.

3.9 Summary

It was possible to satisfy the three macronutrient requirements of carbohydrates, proteins, and fat, including energy, with the eight target crop species. However, the problem is the excess and deficiency of vitamins and minerals. There are 14 possible excess nutrients, including manganese and molybdenum. Because there are concerns about health risks caused by overdose, it is necessary to prioritize health risk reduction over deficient nutrients. As a coping method, the rice bran/germ is removed by rice polishing, and the composition of the cultivated nutrient solution is changed.

The deficient nutrients are calcium, iodine, selenium, vitamin A (retinol activity equivalent), vitamin D, vitamin B2, and vitamin B12. The reason is that there are no animal foods, seaweed, mushrooms, or green and yellow vegetables on the lunar farm. Because it is difficult to supply these from the eight crop species examined, supplementation is essential. The amount of supplement required is approximately 158.9 mg/d.

This study was conducted based on men aged 30 to 49 (physical activity level 2); however, other ages or women need to be examined separately.

Citations

1) A. Matsumoto, "Nutrition in space" Aeronautical Environmental Medicine, Vol.45, No.3, 75-97, 2008.
2) Japanese Dietary Intake Standards (2015 edition), Ministry of Health, Labor and Welfare
3) All aspects of nutrient solution cultivation, Japanese Greenhouse Horticulture Association and Japan Solution Cultivation Study Group, Co-eds., Seibundo, 2012.
4) Eiji Goto, Production of pharmaceutical materials using genetically modified plants grown under artificial lighting. Acta Hort. 907: 45-52. 2011.
5) Eiji Goto, Photosynthesis and Material Production of plants in artificial environment, TechnoInnovation, 16(4):18-22, 2006.
6) New visual food ingredient list with food commentary, Meeting to Think About New Eating Habits. Taishukan Shoten, 2016.
7) Vegetable and Fruit Item Guide, Haruna Shimomura, Agricultural Newspaper, 2014.
8) Convenient book of delicious vegetables for the body, Toshitaka Sakaki, Takahashi Shoten, 2008.
9) Japan Food Standard Food Composition Table 2015 (7th edition), Ministry of Education, Culture, Sports, Science and Technology.
10) Y. Qi, C. Shimojo, M. Yoshida, "Manganese and Molybdenum contents in rice", Biomedical Research on Trace Elements 26(1), 23-26, 2015.
11) S. Tachibana, T. Nakazawa, K. Shibukawa, "Stress factors under space environment and space food", Journal of the Japanese Society of Food Science and Engineering, Volume 55, Issue 12, December 2008.
12) T. Masuda, Y. Tako, “Preparation status for closed habitation experiment (1): food supply on the closed ecology experiment facilities (CEEF)”, Eco-Engineering, 17 (3), 183-189, 2005.