

Research Article

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Mauerer M.* , Schubert D., Zabel P., Bamsey M., Kohlberg E., Mengedoht D.

Initial survey on fresh fruit and vegetable preferences of Neumayer Station crew members: Input to crop selection and psychological benefits of space-based plant production systems

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Abstract: The inclusion of higher plants in bio-regenerative life support systems has been suggested to contribute to a nutritious menu, increase food acceptability and provide psychological benefits to the crew. In 2017, the EDEN ISS project will deploy a greenhouse module to the Neumayer Station III in Antarctica. This system will be used to advance bio-regenerative life support system technologies and operations. An initial survey was conducted to improve crop selection for the EDEN ISS greenhouse module by further investigating the aspects of food acceptability and psychological benefits of crop cultivation. Former members of the overwintering crews of the three Neumayer stations were asked about their fresh food and vegetable preferences and about further aspects concerning Antarctic plant production. Results confirm the benefits of growing higher plants in isolated and confined environments and offer insight on the importance of crop selection aspects like taste, texture, pungency and colour.

Keywords: food acceptability, crop selection, bio-regenerative life support systems, space analogue environment, Antarctic plant production

1 Introduction

In bio-regenerative life support systems designed for human spaceflight, higher plants and algae provide food and oxygen for the crew and recycle water and nutrients. Higher plants can contribute to a nutritious menu by providing critical nutrients that have been shown to degrade in pre-packaged space-food systems [1; 2] and by providing a more complete diet than only algae [3]. Aspects such as variety, texture, flavour and colour of fresh fruits and vegetables increase food acceptability and support crew morale [4]. Furthermore, the presence of higher plants in spacecraft has been shown to have additional psychological benefits for crew members [5].

Crop selection for bio-regenerative life support systems has been investigated for decades and continues to be an active research domain [6-13]. Selection criteria that have been considered include plant physiological characteristics, practical aspects for cultivation, biomass productivity, nutritional compounds and organoleptic aspects. As the suitability of a crop and the relative importance of any selection criterion depend on the architecture of a given space mission, a mission specific selection of crops is recommended. The break-even point where higher plant cultivation becomes more cost effective than resupply of food and physicochemical methods for air revitalization and water regeneration has been estimated to be reached between 3 to 15 years [14-16]. However, mission specific cost reduction by aspects such as psychological benefits is difficult to measure. The aspect of food acceptability, for example, has a relatively high importance in missions where the pre-packaged food system is only enhanced by the produce grown in situ and it can significantly increase the benefit of crop cultivation for such a mission.

To research the cultivation of higher plants in a greenhouse module for early missions, the EDEN ISS

*Corresponding author: M. Mauerer, Institute of Space Systems, German Aerospace Center, Bremen, Germany, E-mail: mareikemauerer89@gmail.com

D. Schubert, P. Zabel, M. Bamsey, Institute of Space Systems, German Aerospace Center, Bremen, Germany.

E. Kohlberg, D. Mengedoht, Alfred Wegener Institute, Bremerhaven, Germany.

project is conducting an analogue study at the German Antarctic research station Neumayer Station III of the Alfred Wegener Institute [17;18]. Located at Atka Bay on the Ekström Ice Shelf, the station hosts a larger group of researchers and other staff during the Antarctic summer, while a smaller crew of 9 to 10 individuals stays over the Antarctic winter. The setting of Neumayer Station III can be characterized as being closely analogous to an early crewed mission to the Moon or Mars, as crew members live in a confined space for about a year (Figure 1). Overwintering crew members count on technology for their survival, station systems must exhibit high levels of reliability and the crew is cut-off from resupply for several months [19;20]. Further, like space crews, Antarctic crew members are involved in the conduct of regular scientific or engineering duties and when they egress from the station, they do so in a somewhat analogous manner from the perspective of protective clothing and safety requirements.

As such, it is a relevant setting to investigate higher plant cultivation for early space mission scenarios. The crews that live or have lived in this confined

environment represent a unique population which has experienced a situation similar to an early space mission. There is considerable anecdotal evidence illustrating the psychological benefit of the installation of plant production systems at Antarctic stations [21]. This has been further demonstrated by an elaborate study conducted following the installation of a plant growth facility at the South Korean King Sejong Station [22].

For the EDEN ISS project, a crop selection procedure was developed by researchers from Wageningen University, Netherlands, which took into account, amongst other things, food acceptability [23]. The aim of the survey described in this paper was to investigate the personal preferences of former crew members of the various German Antarctic stations, as a group of people that have experienced living in remote and isolated conditions, thus gaining greater insight into food acceptability and the possible psychological benefits of crop production in a space analogue environment. It should be noted that the survey was a first attempt at capturing food production preferences of crew members from German Antarctic stations. The exercise helped



Figure 1: Neumayer Station III of the Alfred Wegener Institute located at Atka Bay on the Ekström Ice Shelf. The location of Atka Bay is indicated with an 'X' on the inset Antarctica map. (Neumayer Station III image: Alfred Wegener Institute/Stefan Christmann. Inset Antarctic image: Landsat imagery courtesy of NASA Goddard Space Flight Center and U.S. Geological Survey).

develop a baseline preference landscape, but equally important, it has exposed additional questions that will improve future evaluations of food preferences and psychological benefits of in situ food production in remote and isolated environments.

2 Materials and methods

The group of people that were surveyed consisted of former overwintering crew members of the three Neumayer stations: Georg-von-Neumayer-Station from 1982-1992, Neumayer II from 1993-2009 and Neumayer III from 2009-Present [24]. These were primarily German citizens with varied professional backgrounds, such as scientists, cooks, and communications, electrical or diesel engineers. The link to the online questionnaire was sent to approximately 300 individuals, including all former crew members with known contact details. Objectivity was achieved by using a standardized questionnaire with a standardized set of answers (Table 1). It was possible to answer the test in German or in English.

Question 1 examines if the respondent is an overwintering crew member. Although not initially planned, in the analysis presented here only answers of overwintering crew members were included. These represent 97% of the available datasets (104 out of 107) and form a specific community that can be considered even more so as an analogue to a space crew.

Question 2 asked respondents how many times they stayed at the station. However, as there is no indication if this number of stays relates to summers or winters, the data was not directly used in this analysis.

After the general questions (Question 1-3), respondents were asked if the availability of fresh fruit, vegetables and herbs grown at the station would have improved their overall well-being (Question 4). If they chose 'No', the respondents were not required to proceed any further with the survey; remaining respondents were given additional questions concerning their fresh fruit and vegetable preferences. The population sub-sample that did not feel that the availability of fresh produce would have improved their overall well-being were excluded from the analysis based on the assumption that they would not have any specific preferences for any particular fresh commodity versus preserved food rations already available on station. It is the opinion of the authors that priority in food preference selections, the ultimate goal of the exercise, should be focused on the majority of the sampled population that expressed, through a declaration that their well-being would be improved with the provision

of fresh produce (i.e., answer 'yes' to Question 4), a vested interest in the fresh produce that could be made available. All remaining answers were collected and the preferences were evaluated. When analysing the results, percentages of respondents choosing a specific answer, or in the case of multiple response questions the total selections for each response option, were calculated for all questions. This was conducted both for questions where only one answer was possible and for questions where more than one answer was possible. Images of the candidate crops presented in Question 7 were included along with the question in the survey form. Questions 7 and 8 were analysed further: As respondents indicated in Question 8 which food category ('Fruits and vegetables', 'Leafy greens' and 'Herbs/condiments') was most important to them (71.6%, 21.6% and 6.8% respectively) these results were used as weighting factors in analysing the results from questions 7a, 7b and 7c to generate a list of the top ten crops of all three categories (Figure 8).

3 Results and discussion

3.1 Survey respondents

There were 107 respondents to the survey, of which 104 had overwintered at one of the Neumayer stations, the sample size of our analysis is thus 104. Although specific totals were not compiled, 93 out of 104 respondents chose to respond in German and former station crew members are primarily German or at least of European cultural background. Regarding the responsibilities of the respondents at the station, 52.9% answered 'Scientist/Medical Staff', 35.6% answered 'Engineer' and 11.5% answered 'Cook'. This aligns well with the composition of a typical Neumayer station crew, which regularly consists of four scientists, one physician, three engineers and one cook. The survey can thus be considered representative of the population that regularly stays at Neumayer Station III.

3.2 Fresh fruit and vegetable preferences

Of all overwintering respondents, 85% indicated that the availability of fresh fruit, vegetables and herbs grown at the station would have improved their overall well-being. This percentage was a bit higher for 'Scientist/Medical Staff' respondents, but ranged for the three professional groups between 83.3% and 85.5%. Although not directly comparable considering a more explicit focus

Table 1: Questions asked in the survey. For each question respondents had to choose one answer (letter) unless otherwise stated. To questions marked with an asterisk (*) the respondent could add a comment.

Questionnaire layout

- 1) How long did you stay on the Neumayer Station?*
- Winter (14-15 months)
 - Summer (several weeks)
- 2) How many times did you stay on the Neumayer Station?
- Once
 - 2-5 times
 - More than 5 times
- 3) What was your position at the station?*
- Scientist/Medical Staff
 - Engineer
 - Cook
- 4) Would the availability of fresh fruit, vegetables and herbs grown on the Neumayer station have improved your overall well-being?
- Yes
 - No
- 5) Please choose the main reason.
- Pleasure of fresh fruit or vegetable consumption
 - Positive psychological benefit
 - Possibility to spend free time caring for or among plants
 - Other: ...
- 6) If you think back to your time on the Neumayer Station, which aspect of fresh vegetables or fruits would you have enjoyed the most during your stay? (at least one answer)
- Taste (e.g. acidity, sweetness)
 - Pungency (e.g. hot taste, bitterness)
 - Texture (e.g. crispness)
 - Appearance (e.g. fresh colours)
- 7) If you think back to your time on the Neumayer Station, which kind of fresh fruits or vegetables did you miss the most during your stay? (1 to 3 answers in each category)
- a) Fruits and vegetables:*
- | | | | | | | |
|-----------|--------------|-------------|-----------------|---------------|-----------|-----------------|
| i) Tomato | ii) Cucumber | iii) Radish | iv) Bell pepper | v) Strawberry | vi) Onion | vii) Other: ... |
|-----------|--------------|-------------|-----------------|---------------|-----------|-----------------|
- b) Taste intensive leafy greens:* (The leafy greens are vegetables that can (also) be enjoyed raw, without cooking.)
- | | | | | | |
|------------------|-------------------|--------------------------------|-------------------|----------------|-------------|
| i) Green Lettuce | ii) Red Lettuce | iii) Leaf Lettuce | iv) Iceberg Salad | v) Rucola | vi) Mustard |
| vii) Spinach | viii) Swiss Chard | ix) Chinese cabbage (Pak Choi) | x) Water Cress | xi) Other: ... | |
- c) Herbs/ condiments:*
- | | | | | | | | | |
|-----------|-------------|----------------|-----------|---------|----------|-------------|--------------|----------------|
| i) Chives | ii) Parsley | iii) Coriander | iv) Basil | v) Dill | vi) Mint | vii) Chiles | viii) Garlic | ix) Other: ... |
|-----------|-------------|----------------|-----------|---------|----------|-------------|--------------|----------------|
- 8) Which category would be most important to you?
- Fruits and Vegetables
 - Leafy Greens
 - Herbs/Condiments
- 9) What you do with the selected vegetables and herbs?
- Pick them and eat them directly
 - Cut them and make a salad
 - Add them to other dishes/ cook with them
 - Other: ...
- 10) Would you have volunteered to care for plants during your free time on the Neumayer Station?
- Yes
 - No
 - No answer
-

One possible answer, unless stated otherwise.

*=comment possible

on psychological well-being, a South Korean King Sejong Station study showed that 83% of the surveyed station crew members found that the food produced from the new station growth chamber were either ‘very helpful’ or ‘somewhat helpful’ to their mental health [20].

The following six answers were given by 88 respondents in total. They were asked to choose the main reason why their overall well-being would be improved. They could either choose between ‘Pleasure of fresh fruit and vegetable consumption’, ‘Positive psychological benefit’ or ‘Possibility to spend free time caring for or among plants’ or give another answer (Figure 2). The ‘Pleasure of

fresh fruit and vegetable consumption’ was rated as most important by 61% of those respondents and the ‘Positive psychological benefit’ as most important by 21%. Positive effects on crew moral can thus be expected from higher plant cultivation. Respondents were then asked to indicate which aspect of available fresh fruits and vegetables they would have enjoyed most during their stay. Respondents could select between one to four of the four aspects ‘Taste’, ‘Pungency’, ‘Texture’ or ‘Appearance’ (Figure 3). ‘Taste’ and ‘Texture’ have a higher percentage than the average and thus were considered most important by respondents.

For the question ‘If you think back to your time on

Main reason for improved overall well-being due to availability of fresh fruit, vegetables and herbs grown on station

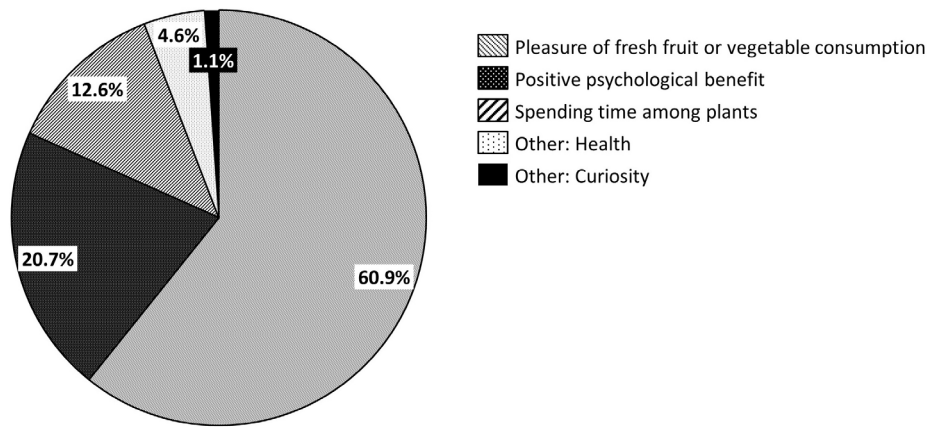


Figure 2: Respondents that indicated that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked to indicate the main reason for this expected improvement. They could either choose one of the given three options or give other answers.

Most important aspects of available fresh vegetables, fruits and herbs

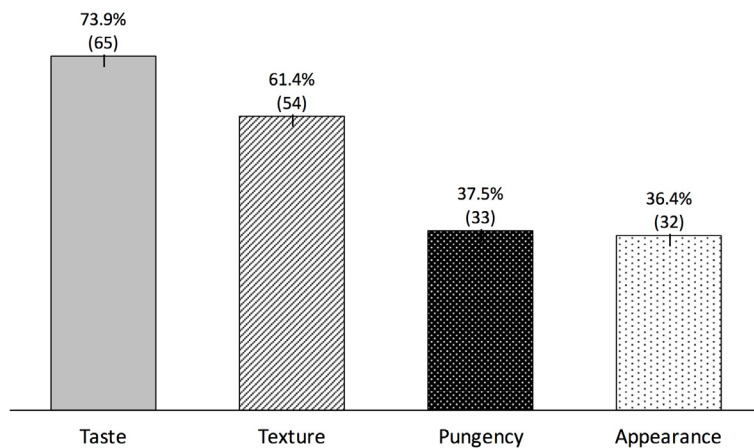


Figure 3: The 85% of respondents indicating that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked to indicate which aspect of available fresh fruits and vegetables they would have enjoyed during their stay. They could choose between one to four of the four aspects. The presented data consists of a total of 184 answers. Numbers in brackets are the total responses for each characteristic.

the station, which kind of fresh fruits or vegetables did you miss the most during your stay?', candidate crops were divided into three categories and in each category, respondents could choose up to three of the choices or make other suggestions. Tomato, strawberry, bell pepper and cucumber were the favourite fruit and vegetable

crops with 77%, 49%, 40% and 40% of the respondents choosing them respectively (Figure 4). Leaf lettuce, green lettuce, rucola (synonym for arugula) and iceberg lettuce (named 'iceberg salad' in the survey) were chosen in the category 'Taste intensive leafy greens' with 56%, 51%, 49% and 39% respectively (Figure 5). In 'Herbs/condiments',

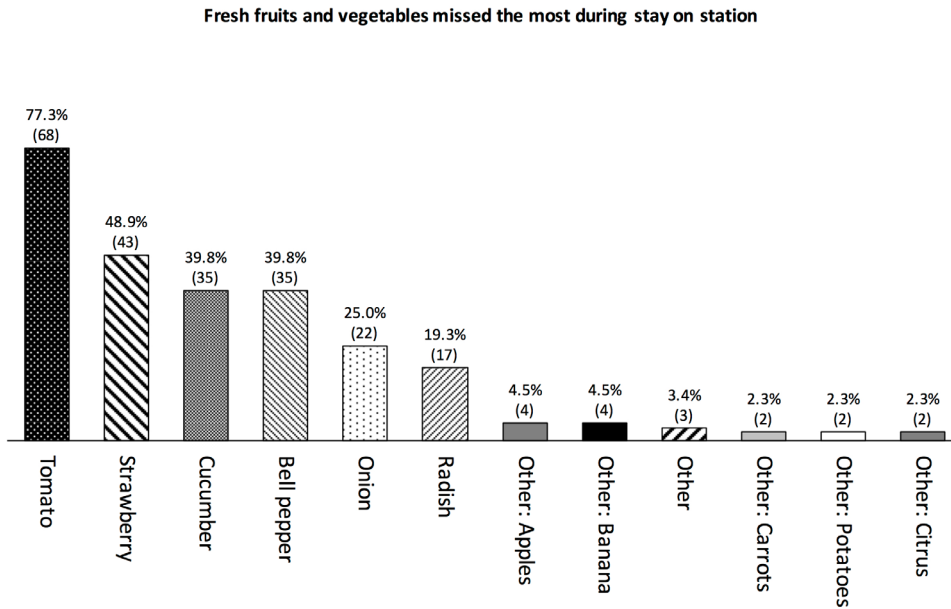


Figure 4: The 85% of respondents indicating that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked to choose up to three crops from the crops listed in the category 'Fruits and vegetables' or to make their own suggestions. The presented data consists of a total of 237 answers.

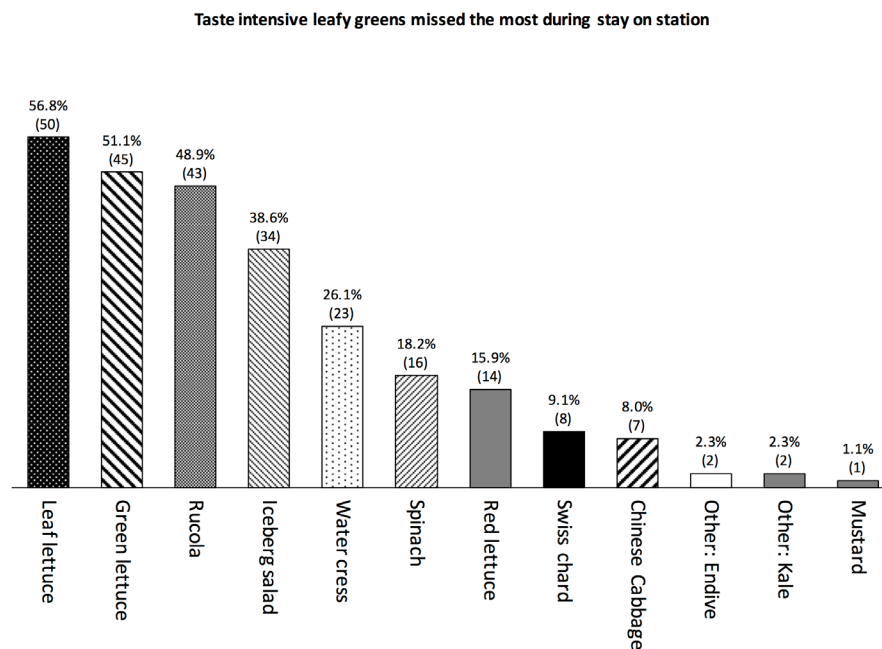


Figure 5: The 85% of respondents indicating that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked to choose up to three crops from the crops listed in the category 'Taste intensive leafy greens' or to make their own suggestions. The presented data consists of a total of 245 answers.

basil, chives and parsley were most selected with 73%, 64% and 45% respectively (Figure 6). When asked to indicate, which category is most important to them, 72% of the respondents chose ‘Fruits and vegetables’, 21% chose ‘Taste intensive leafy greens’ and 7% chose ‘Herbs/condiments’ (Figure 7). Based on these answers, a list of the top ten selected crops of all categories was compiled (Figure 8). It is interesting to note that colourful and tasty fruit crops like tomato, strawberry and bell pepper are the

crew favourites, although appearance was rated the least important of the four organoleptic aspects in Question 6. Respondents are either not consciously aware of the importance colour has to them or it coincides with good taste. More pungent vegetables, such as onion, rucola, and radish also had a high preference rating.

The two final questions related to the purpose of the crop cultivation and if staff members would have volunteered to care for plants during their free time.

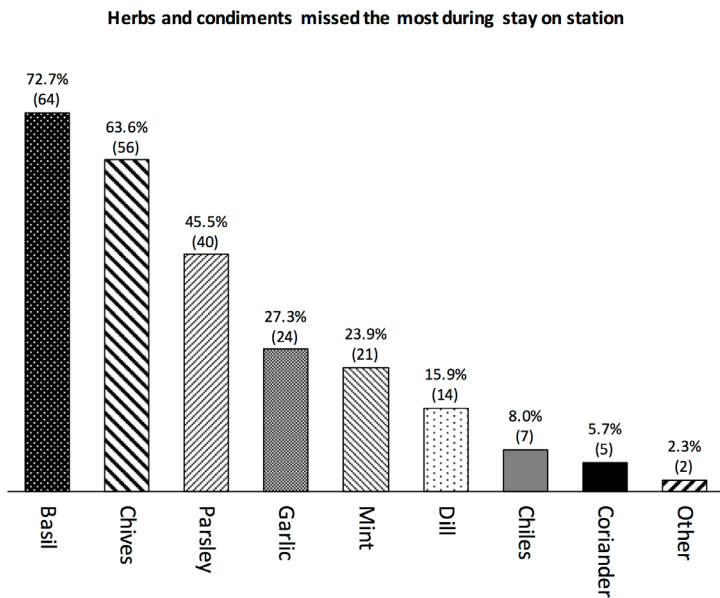


Figure 6: The 85% of respondents indicating that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked to choose up to three from the crops listed in the category ‘Herbs/condiments’ or to make their own suggestions. The presented data consists of a total of 233 answers.

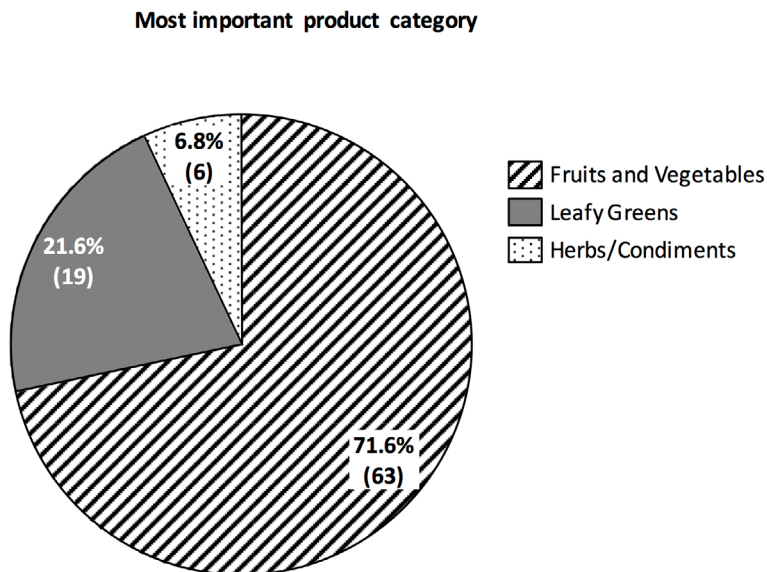


Figure 7: The 85% of respondents indicating that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked to indicate which category was most important to them. Only one answer was possible.

Regarding the purpose of crop cultivation, the three options were ‘Pick them and eat them directly’, ‘Cut them and make a salad’ and ‘Add them to other dishes/cook with them’ (Figure 9). The fact that most respondents wanted to prepare a salad with the harvested produce confirms that texture, and variety are all important attributes to the

crew, as these attributes are maintained in a salad. Crew free time is limited, yet 84% of the respondents indicated that they would have volunteered to care for plants during their free time on the station. This result supports the psychological benefits of higher plant cultivation in a remote and confined environment.

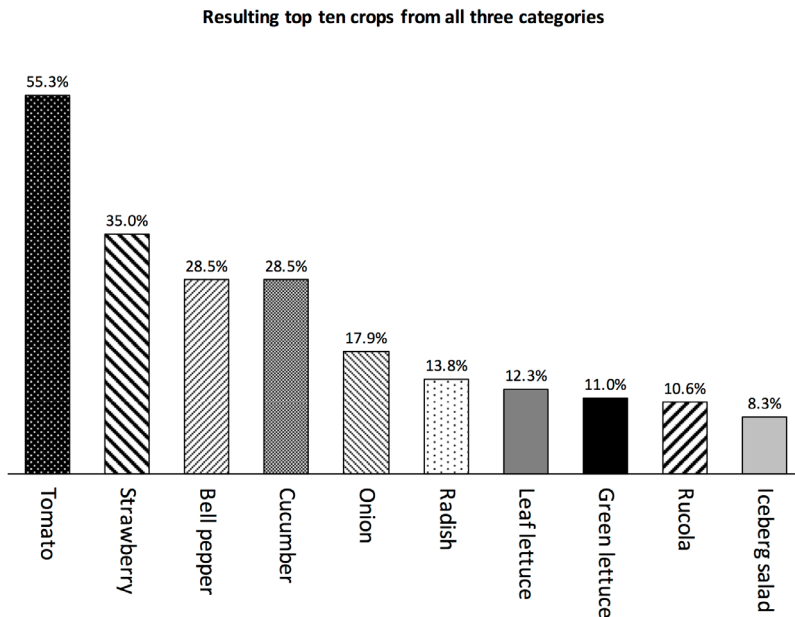


Figure 8: Weighted answers of the three categories ‘Fruits and vegetables’ (Question 7a), ‘Taste intensive leafy greens’ (Question 7b) and ‘Herbs/condiments’ (Question 7c) according to the product category’s relative importance found in Question 8. The product category ‘Fruits & Vegetables’ received 71.6%, ‘Leafy greens’ 21.6% and ‘Herbs/ Condiments’ 6.8% respectively. In each category, up to three crops could be selected.

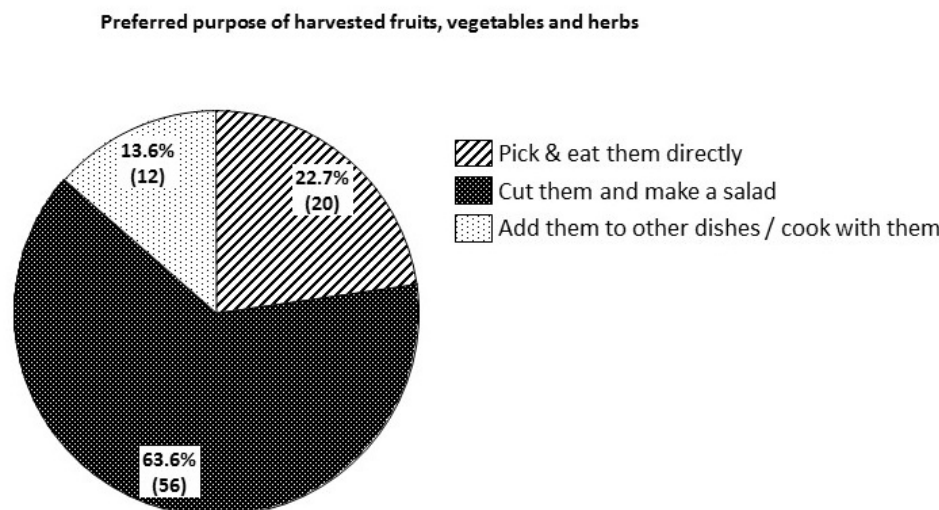


Figure 9: The 85% of respondents indicating that the availability of fresh fruit, vegetables and herbs grown on the Neumayer Station (85%, 88 individuals) would improve their overall well-being were asked the question ‘What would you do with the selected vegetables and herbs’ and to choose one of the indicated answers.

3.3 Cultural background

As previously stated, the respondents to the survey were primarily German and thus were expected to have similar culinary preferences. The studied population having a similar cultural background was also the case in earlier preference studies, e.g. in a Chinese food inclination questionnaire [10] and a NASA sensory panel analysis [2]. It is difficult to compare the results of these three studies, with each study focusing on a different set of candidate crops. Yet, based upon what some could possibly consider as rather bland German cuisine, it could be expected that herbs, condiments and pungent leafy greens would have a higher score with crews from other cultural backgrounds. To adapt a crop selection procedure to the preferences of an international space crew, further studies should be conducted that directly address an international survey population.

3.4 Future survey considerations

The administration of this initial survey has helped define a number of additional questions that will improve future Antarctic fresh food preferences/production surveys. In particular, significantly more insight can be gained by including questions that will capture the nationality and/or ethnicity, age at time of isolation, gender of each crew member, the specific number of times that an individual visited a German Antarctic station, the year of stay, the duration of each stay, and the specific station visited. Such data will allow for the assessment of differences in crew preferences based upon life history of the respondents. In addition, as many survey respondents stayed in the Antarctic dating back as much as 35 years, it is likely that food preparation methods and choices available to the various temporal cohorts have changed. Further, there have been three different stations over this same time frame and there is most likely a station effect that needs to be captured and evaluated in future surveys. This data will also allow for better assessment of how the duration of isolation (summer field season participant, overwinterer, multiple overwinterers) can influence food preferences, which has direct implications on long duration spaceflight. The future survey will also ensure that survey respondents are better informed regarding definitions of the employed food sensory terminology (e.g. pungency and texture). Finally, although in this initial survey respondents who suggested that the availability of fresh food grown in-situ would not improve their overall well-being (Question 4) were removed from answering further

questions, these individuals will be allowed to continue to respond to future questions and will be provided the opportunity to elaborate on their reasoning in future surveys. These survey improvements will further improve the interpretation of the results and it is hoped that such a survey would also be applicable to crew members residing at Antarctic stations of other countries.

4 Conclusions

This initial survey confirmed the benefits of growing fresh fruits and vegetables for crews in confined environments. Most respondents affirmed that the fresh produce grown in situ would have improved their overall well-being and confirmed expectations found in the literature. An interesting result is that especially taste and texture of the produce were found to be most important to crew members. This survey adds to existing literature on food acceptability for life support applications; however, further research is required, particularly when considering diverse culinary preferences typical of international crews. Differences are to be expected between crews living in confined environments on Earth versus in microgravity (e.g. pungency [25]) yet, the remote and confined environment of the Neumayer Antarctic stations and their crews represented a very close analogue to an early manned space mission. The conduct of this initial survey also brought about a number of improvements that should be brought into future fruit and vegetable preferences surveys for extreme environments. It was realized that additional data on crew member gender, nationality, age and more specific information about the number of times and duration of each Antarctic stay would significantly enhance the utility of the results and these and other aspects will be built into future surveys.

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