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Consumer Attitudes towards Microalgae Production and Microalgae-Based Agricultural Products: The Cases of Almería (Spain) and Livorno (Italy)

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Abstract: The production of microalgal biomass and products derived thereof for a wide variety of applications is a hot research topic, with the number of facilities being built and products and biologically active molecules launched into the market increasing every year. The aim of the current study was to identify the attitudes of citizens in Almería (Spain) and Livorno (Italy) towards the construction of a microalgae production plant and a biorefinery in their cities and also their opinions about the microalgae-based products that could be produced. Overall, in Almería (Spain), a NIMBY (not in my back yard) attitude towards the construction of a microalgal production facility and especially towards a microalgal biorefinery was observed, despite the strong microalgal industry in the region and the higher knowledge of citizens about microalgae. In both locations, but especially in Livorno (Italy), microalgae-based biostimulants, biofertilisers, and aquafeeds were well accepted. Proximity was the main factor affecting the acceptance of a microalgae producing facility. Consumer knowledge about microalgal biotechnology and the health and environmental benefits of this valuable raw material are scarce, and opinions are based on drivers other than knowledge. After gaining more knowledge about microalgal biorefineries, most of the responses in Almería (47%) and Livorno (61%) were more positive.

Keywords: consumer studies; biotechnology; cyanobacteria; agricultural products; aquafeed; biorefinery; photobioreactor; biomass; survey

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1. Introduction

Microalgal biotechnology is a relatively new research area that has increased exponentially during the last two decades in parallel with the development of facilities and microalgae-derived products [1]. The term microalgae generally includes both eukaryotic microalgae and cyanoprokaryotes/cyanobacteria, as the fundamentals of their production are similar. Microalgae have emerged as an innovative feedstock with potential applications as food [2,3], animal feed [4,5], cosmetics [6], agricultural products [7,8], and other applications such as waste and wastewater treatment [9,10] or production of biodiesel [11,12]. Because of their small size, microalgae cannot be harvested from the environment and must be produced in controlled industrial facilities [13]. Most common production systems are open ponds and closed photobioreactors. Both strategies, but specially closed systems, are energy intensive: the maximum exploitation of the produced biomass while minimizing the energy requirements remains key to render the process economically viable [14]. In this context, the concept of a "microalgal biorefinery" emerged as a promising strategy to maximize the benefits obtained from microalgal biomass. Microalgae contain

high amounts of proteins, lipids, carbohydrates, and other valuable biomolecules that could be used as feedstock for various products [15]. Different products have been produced following the biorefinery approach, for example, microalgae produced in dairy wastewater have been used as feedstock for the production of bioethanol [16], or microalgae produced in wastewater have been used as a source of biofertilizers [17]. Pilot- and large-scale validations are currently being conducted including the ALLGAS project, in which a 10 ha facility is used to process wastewater and produce energy, and the SABANA project, where pilot-scale photobioreactors are being used to produce biofertilizers and aquafeed from wastewater and seawater [18]. The combination of microalgae production with wastewater treatment and CO_2 capture from flue gases could reduce production costs to under 1 €·kg^{-1}, making the produced biomass useful for different applications such as the production of agricultural products [14].

Microalgae-derived products for food and agricultural applications are already available in the market. However, little is known about the perception that consumers have about these products. A recent study conducted in Spain revealed that consumer knowledge about microalgae, what they are, how they are produced, and the benefits associated with their production and utilization were unknown to the vast majority of the population [19]. Still, microalgae-containing foods were considered safe, nutritious, and sustainable, and the purchase intention of microalgal products was found to be highly influenced by the knowledge that consumers had about this valuable raw material [19]. Microalgae-containing products such as breadsticks [20], soups [3], bread [21], pasta [22], and powdered milk-shakes [23] showed a comparable acceptance to that of the same products formulated without microalgae. Other non-conventional foods showed high acceptance in other European countries previously [24]. However, consumer attitudes towards non-food microalgae-based products are unknown. Knowledge about microalgal production systems and their attitudes towards the construction of a microalgal biorefinery are important, as these will largely influence the final acceptance of the products developed. Moreover, opposition to new uses of land, once defined as NIMBY (not in my back yard) syndrome [25] or LULU (locally unwanted land uses) [26] describes the specific opposition on site to new projects due to their spatial proximity. This phenomenon causes local residents to oppose the construction of industries, such as microalgal production facilities and biorefineries, because they are close to them. As microalgae, their environmental benefits, and their potential applications are unknown to most of the population, it is important to assess the attitudes of consumers towards microalgal production facilities, as this would help facilitate the commercialization of the products produced and the construction of the production plants.

The main goal of the current study was to assess the attitudes of consumers in Almería (Spain) and Livorno (Italy) towards the construction of a large-scale microalgal production plant in their city, and to identify potential strategies for improving the acceptance of microalgal production plants and the products derived therefrom.

2. Materials and Methods

2.1. Questionnaire Design and Data Collection

A specific questionnaire was designed for this study, including eight close-ended questions and two open questions provided as Supplementary Figure S1. Responses given to the open questions will be used as a starting point to design a more in-depth analysis in the future. Coded options were provided as responses, and consumers were asked to choose the option that best reflected their opinion [19]. The demographic characteristics of the respondents is provided as Supplementary Figure S2. Personal data included age group, gender, and educational level, and the questionnaire was anonymous.

The questionnaires were conducted by interviewing citizens in the street in Almería, Spain (n = 200) and Livorno, Italy (n = 200). The interviews were conducted in the main

shopping streets of both cities. Half of the respondents in each city were told that a microalgal production plant and a microalgal biorefinery were going to be built in their city, while the other half were told that a microalgal production plant and a microalgal biorefinery were going to be built faraway (in Almería or Livorno). In Almería, citizens have been in contact with news about microalgae and there are currently several microalgal production facilities operating and producing microalgal biomass and products derived from microalgae, most of them for agricultural applications. Moreover, Almería has the largest concentration of greenhouses in the world, which represent approximately 4% of the total provincial surface and are managed by approximately 15,000 family farmers [27]. The production of organic crops, as well as the utilization of microalgae-derived biofertilizers and biostimulants, is increasing in the region. In turn, the majority of the population in Livorno has never been exposed to news about microalgae and industrial activities related to microalgae are scarce in the region.

2.2. Statistical Analysis

Data were analyzed using SPSS v.24 (IBM Corp., Armonk, NY, US). All variables were analysed by cross-tabulation and differences were considered statistically significant at $p < 0.05$ using the Chi-square test.

3. Results

Briefly, approximately 50% of the respondents were female with a similar distribution in terms of age group in both cities, but with the percentage of respondents aged 30–49 years old being higher in Almería (Supplementary Figure S2). In terms of educational level, the percentage of respondents with a university degree was higher in Spain (31%), while in Italy the majority of the respondents had a secondary education level (63%). Consumers were first asked if they knew what microalgae are. Overall, 81.5% of the respondents in Almería affirmed that they had heard the term microalgae before while only 41.5% of respondents in Livorno were aware of microalgae. When asked about their awareness about a microalgal production facility being built close to their city, which was a true statement for Almería and False for Livorno, affirmative responses in Almería were 22% against 10% in Livorno.

3.1. Attitudes towards Microalgal Production Facilities

Respondents were asked to assess their opinion about the construction of a microalgal production plant in their city using a 5-point hedonic scale, from "strongly disagree" to "strongly agree". The results are shown in Figure 1. Significant differences were observed between the two cities, as approximately 40% of the respondents in Almería did not agree with the construction of the microalgal production facility in their city and in Livorno, only 1% of the respondents disagreed. The percentage of respondents who replied "neither agree nor disagree" was higher in Livorno (75%) than in Almería (44%). Responses were influenced by location ($p < 0.05$) and age group ($p < 0.01$). Overall, in both locations, respondents aged between 30 and 49 years old were more aware about microalgae, followed by those aged between 18 and 29 years old ($p < 0.05$). Surprisingly, respondents over 49 years old (who were theoretically less aware of the benefits of microalgae production and utilization) were more in favour of the construction of a microalgae production plant. Responses given in Almería to disagree with microalgal production facilities (open question) included high emissions of CO_2 (2.5%), unknown side-effects on health (2.0%), and negative effects on the environment, especially on water (3.0%). In turn, when consumers were asked to give their opinion about the construction of a microalgal production plant far away, responses in Almería were more positive, mainly because of the positive impact on the economy (3.5%). In this case, approximately 25% of respondents agreed with the construction of the facilities while the number of consumers who replied

"strongly disagree" decreased from 25% to 5%. In Livorno, the construction of the microalgal production plant far away also led to a larger number of consumers agreeing with the construction, although the number of consumers who answered "neither agree nor disagree" was still very high (67%).

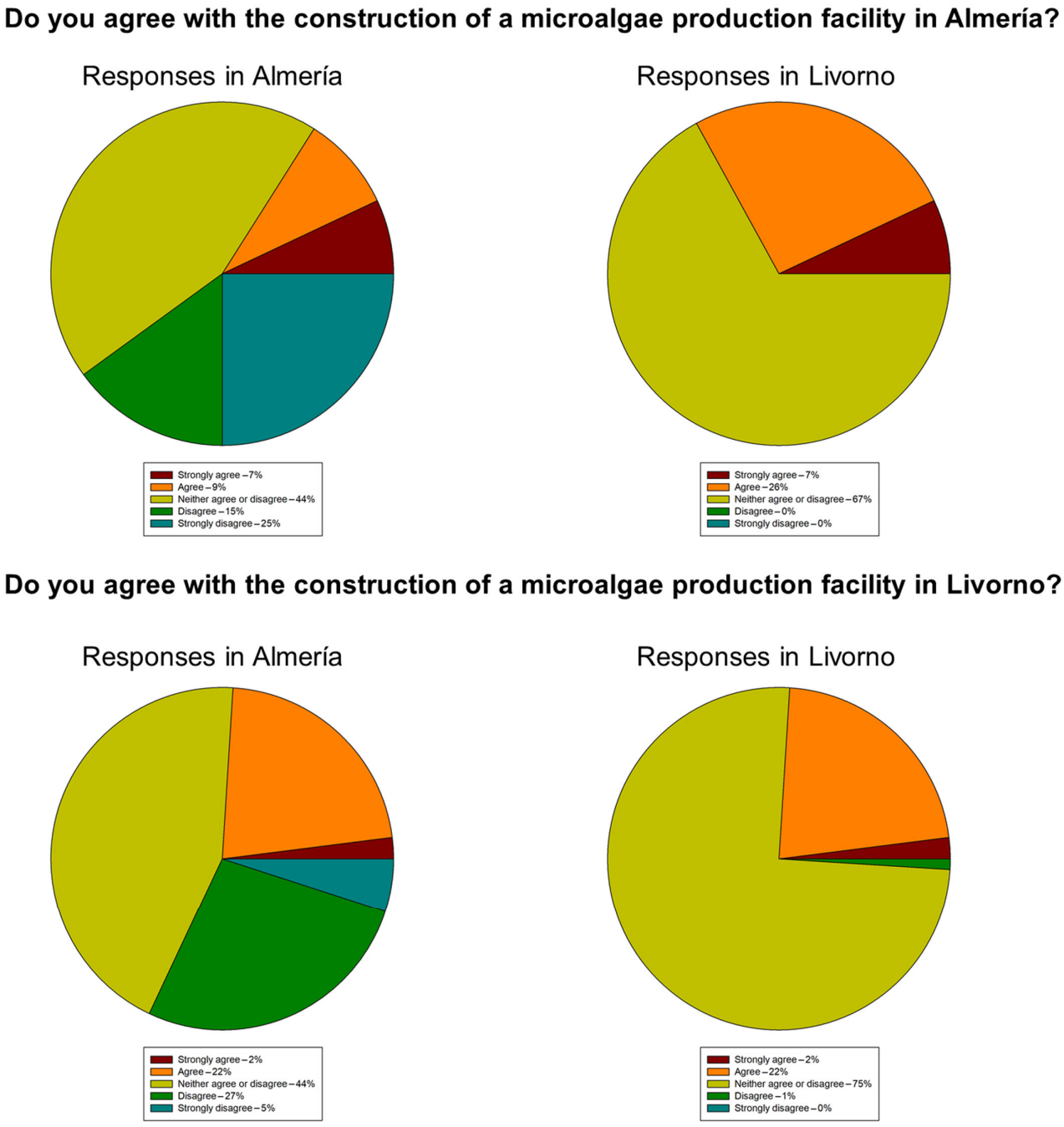

Figure 1. Attitudes towards the construction of a microalgae production facility.

Figure 2 lists the main reasons given by respondents in Almería for agreeing or disagreeing with the construction of a microalgal production plant. The main reasons for being in favour of the production of microalgae in their city were the economy, health,

and safety (over 20%), while environmental reasons were also considered important (15–20%). In turn, proximity was the main reason to disagree with the construction of the microalgal production plant followed by legality, health, and safety. The response "legality" meant that the respondent was concerned about the legality of the construction of such industrial facilities close to his/her city. When asked about the construction of the plant in Livorno, the main reasons given to agree in Almería were safety and health, while legality and safety were still the main reasons for disagreement. In Livorno, the most common reason for agreeing or disagreeing with the construction of a microalgal production plant was, in both cases, the environment, while "no opinion" was the most common answer.

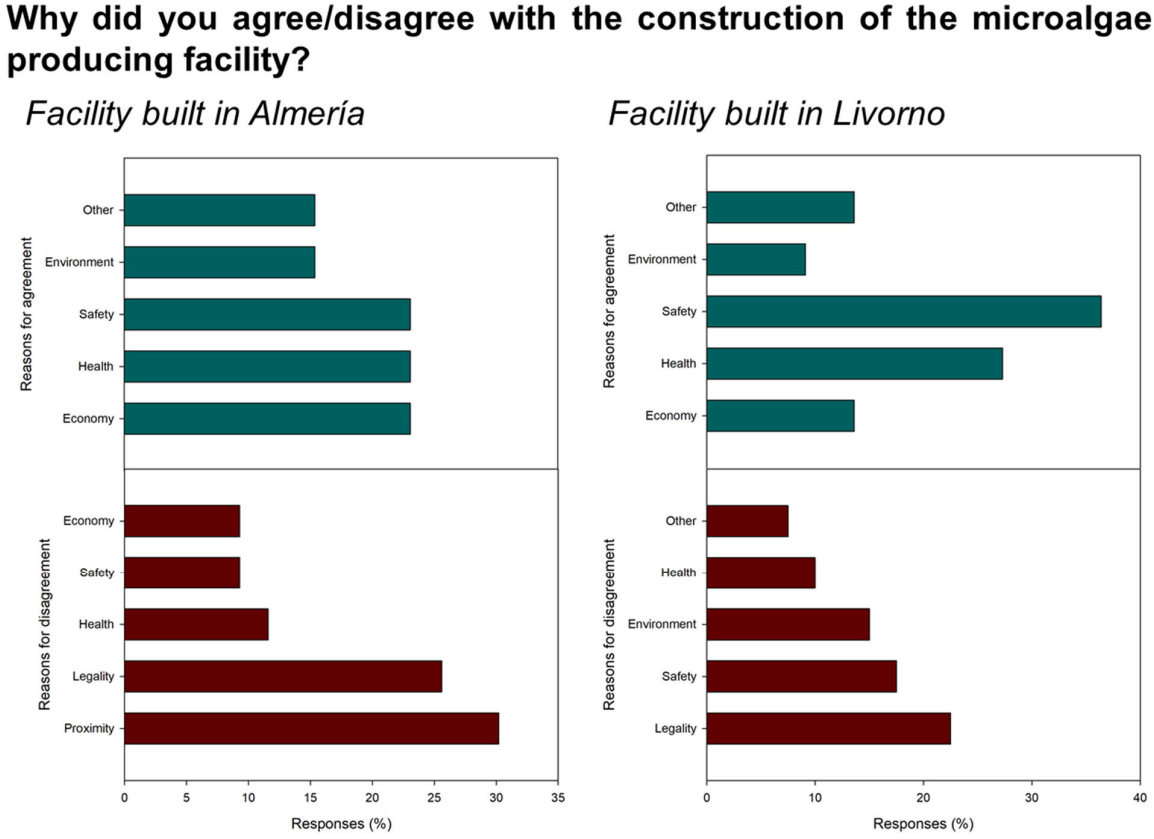

Figure 2. Main reasons given in Almería to agree or disagree with the construction of a microalgal production facility.

3.2. Attitudes towards a Microalgal Biorefinery

In the same way, consumers were asked to assess their opinion towards the construction of a microalgal biorefinery together with the production plant, again using a 5-point hedonic scale from "strongly disagree" to "strongly agree". Responses were affected by location ($p < 0.05$), age group ($p < 0.05$), and educational level ($p < 0.01$), and are summarized in Figure 3. In Almería, when respondents were told that the biorefinery was going to be built in their city, the number of respondents who disagreed was over 50%, while only 20% agreed or strongly agreed. The most common answers to the open question (why did you agree/disagree?) were the negative environmental impact (5.5%) and unknown effects of biorefineries to the environment (5.5%). In turn, when they were told that the biorefinery was going to be built in Livorno, the number of responses against the initiative decreased to 25% and over 50% of respondents neither agreed nor disagreed. In this case, the number of consumers that believed that microalgal biorefineries have a positive environmental impact increased from 0 to 5.5%, while only two respondents (1%) believed that a microalgal biorefinery could negatively affect the environment. In Livorno,

almost 30% of respondents agreed with the construction of a biorefinery in Almería, while only 19% agreed when the biorefinery was going to be built in their city.

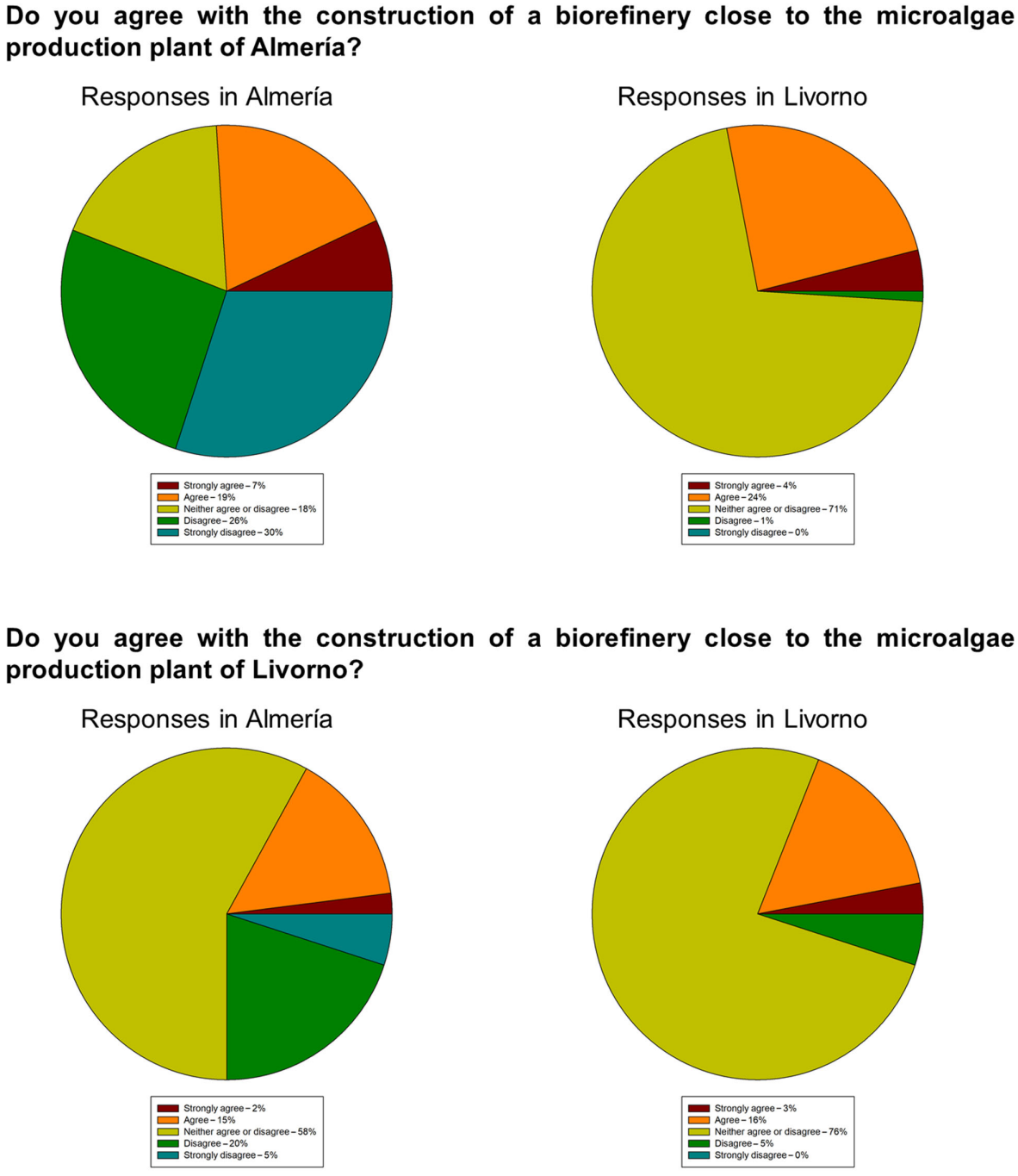

Figure 3. Attitudes towards the construction of a microalgal biorefinery.

The percentage of Italian consumers who disagreed with the construction of a biorefinery increased when they were told that it was going to be built in their own city (from 1% to 5%). Several Italian respondents showed no interest in microalgae production, as 10.5% of respondents replied "I don't care about microalgae" to the open questions. When consumers in Almería were told that a biorefinery was going to be built close to their own

city, the main reasons given for disagreeing were proximity and legality (50–60%), while environmental and safety issues were also significant reasons (20–30%). In turn, the main reasons to agree with the construction were health, safety, economic, and environmental benefits. The main reasons given in Almería to agree or disagree with the construction of a microalgal biorefinery are listed in Figure 4. For those who answered "other reason", the most common reasons for disagreeing were "unknown negative effects" and "adverse environmental impact". In Livorno, the main reason for agreeing or disagreeing with the construction of a microalgal biorefinery was environmental issues, although again the most common response was "no opinion", both when they were told that the biorefinery was going to be built in Livorno and when they were told that the biorefinery was going to be built in Almería.

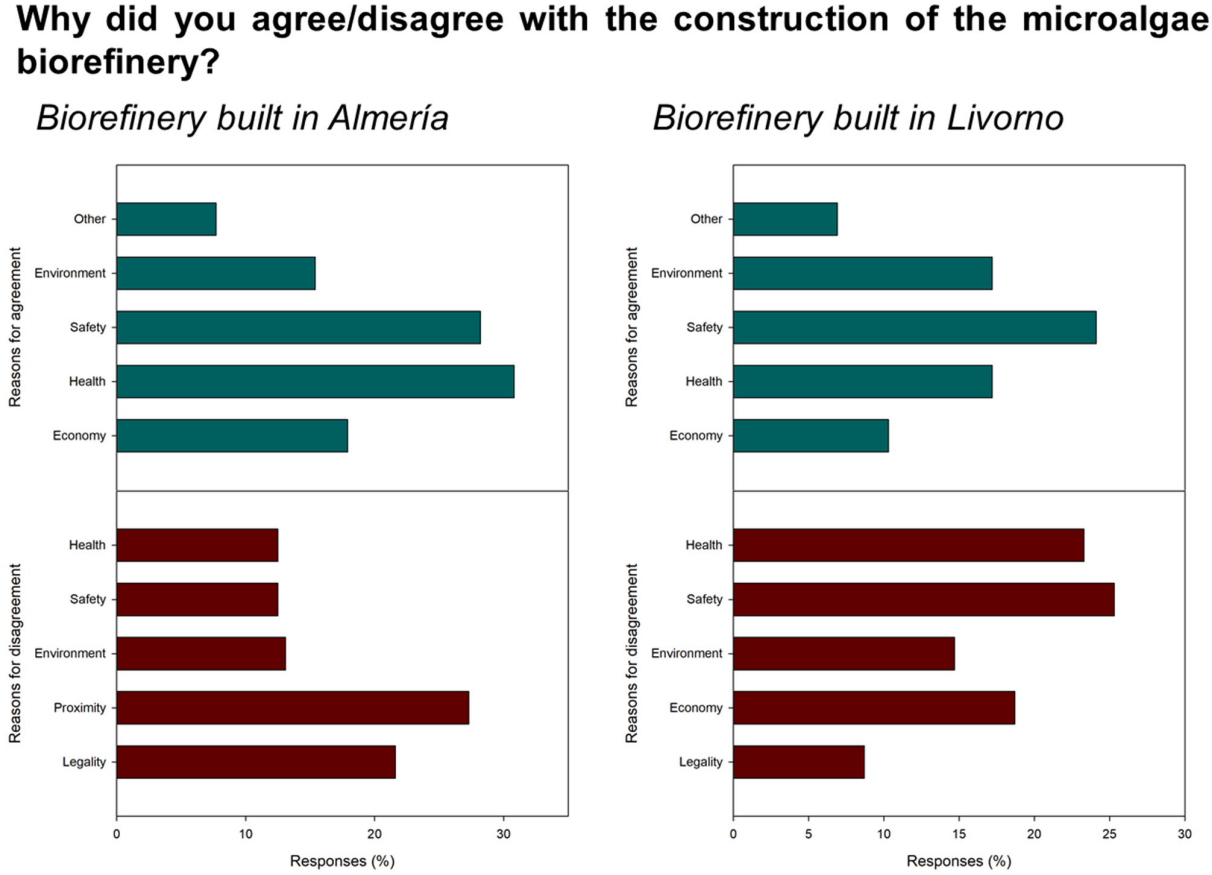

Figure 4. Main reasons given in Almería for agreeing or disagreeing with the construction of a microalgal biorefinery.

3.3. Attitudes towards Microalgae-Derived Products

Agricultural products derived from microalgae are currently commercially available, and respondents were asked about their attitudes towards such products. The results, shown in Figure 5, demonstrated that in Livorno, most of the respondents (approximately 60%) agreed with the production of biofertilizers, biopesticides, biostimulants, aquafeeds, and aquafeed additives. The number of respondents that disagreed with the production of microalgae-derived products was lower than 5% in all cases. In turn, in Almería, although most of the respondents agreed with the production of these products, approximately 40% of the respondents disagreed with producing agricultural products and aq-

uafeed ingredients from microalgae. Finally, two questions were asked to identify the effect of proximity on the perception of microalgal processing plants, as well as to assess the effect of knowledge about microalgae on their acceptance.

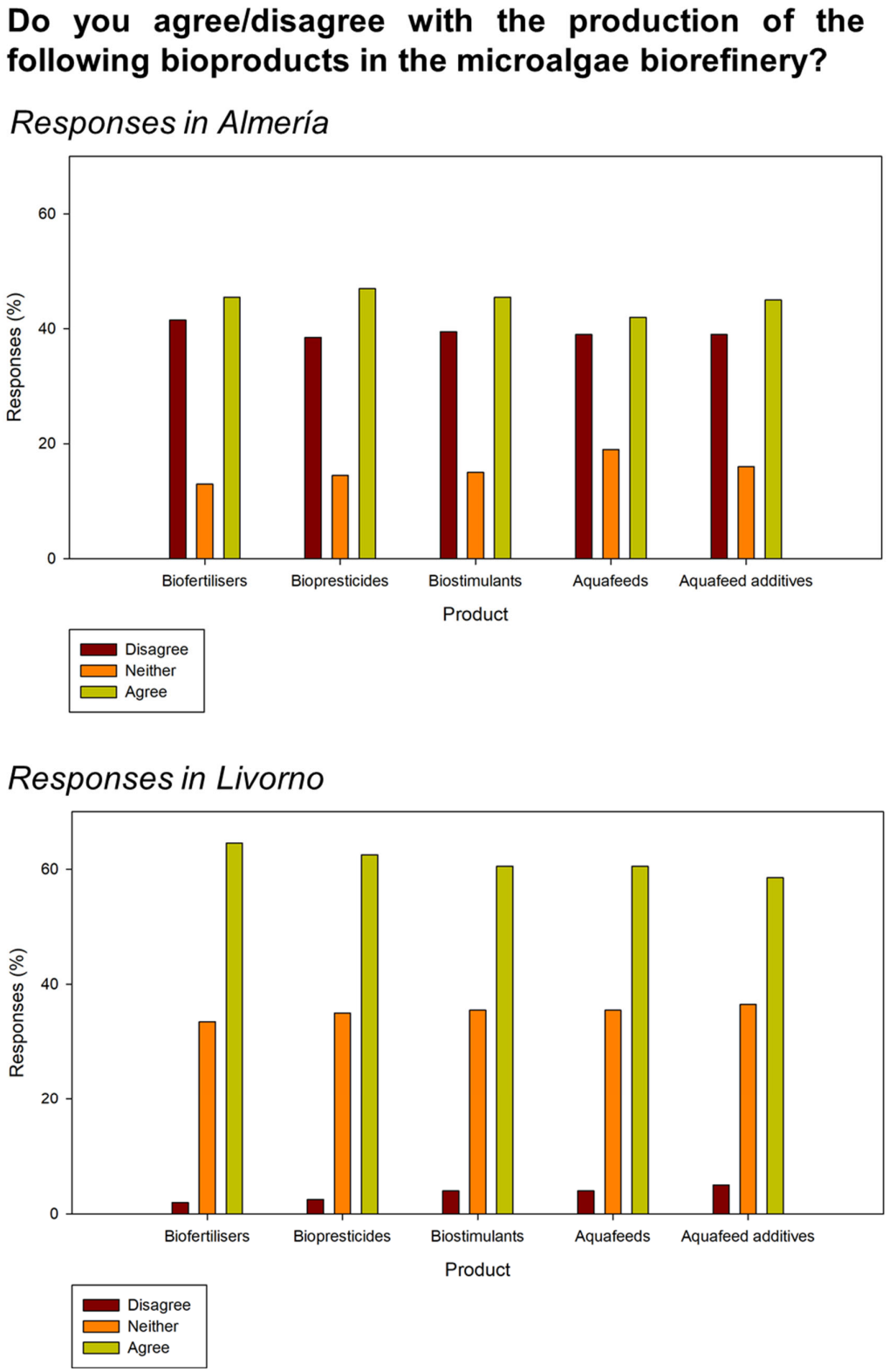

Figure 5. Attitudes towards microalgae-derived commercial products.

In Almería, consumers who thought that a microalgal biorefinery was going to be built in their own city were asked about their opinion in the case that the plant was built in Italy. Approximately 40% of the respondents said that their opinion wouldn't change, while 22% said that it probably wouldn't (Figure 6). Approximately 35% of respondents affirmed that their opinion would change, or would probably change, if the microalgal processing plant was built in Italy. In turn, more than 60% of those who were told that the processing plants were going to be built in Italy affirmed that they would probably change their opinion if the plant was built in their city. In addition, respondents were told what microalgae are and what the goal was of building a microalgal biorefinery and the main benefits and problems associated with the microalgal industry. Overall, after being made more aware of microalgae, most of the respondents in Almería (47%) and in Livorno (61%) affirmed that their opinion towards microalgae-containing products and microalgal processing industries were much more or more positive (Figure 7). This shift was statistically influenced by location ($p < 0.05$), gender ($p < 0.05$), and educational level ($p < 0.05$). Overall, female respondents improved their opinion to a larger extent, and the same trend was observed for those with a higher educational level, independently of the location.

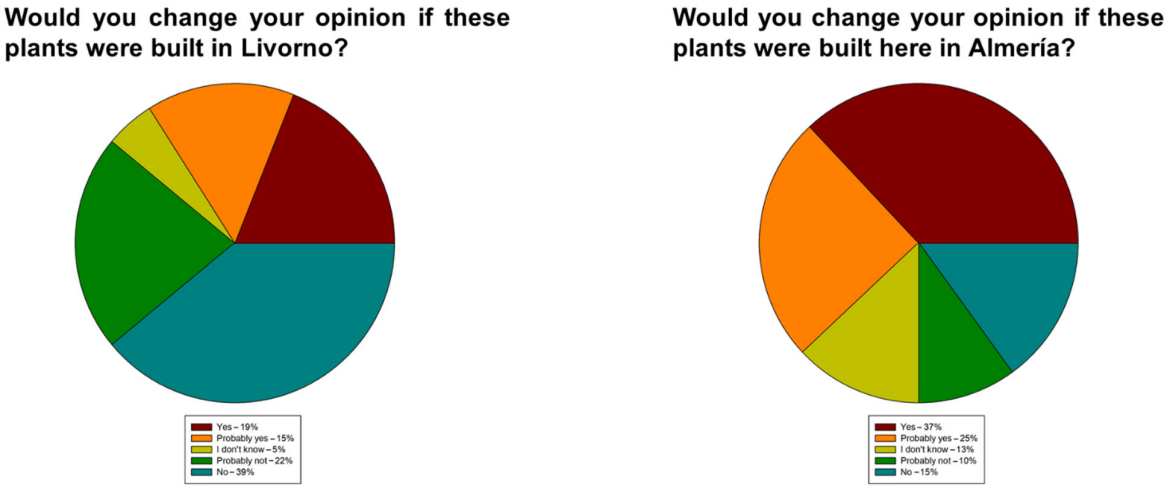

Figure 6. Effect of location on the perception of microalgae processing facilities in Almería.

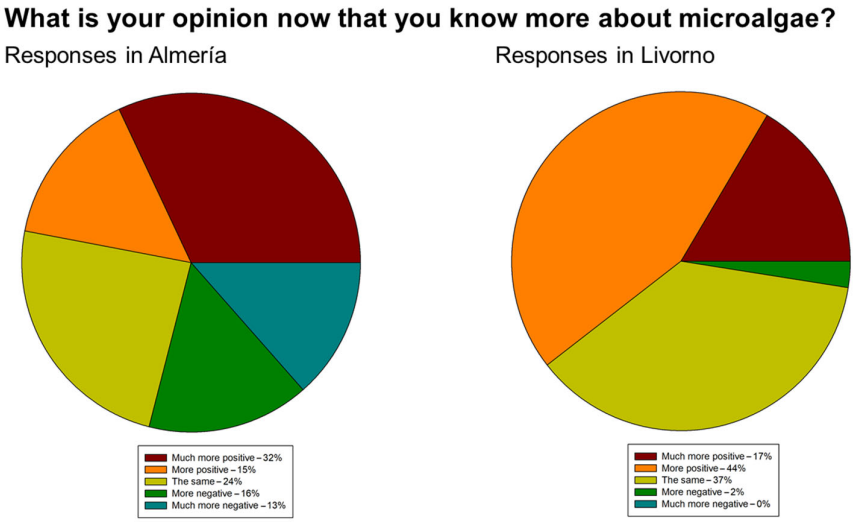

Figure 7. Effect of knowledge about microalgae production on the perception of microalgae processing facilities and products.

4. Discussion

In Almería, 22% of the respondents were aware that a microalgal production plant was going to be built in their city, which was expected because of the strong microalgal production industry in the region and the strong background of the University of Almería on this topic [1]. Most of the respondents in Livorno did not know that a microalgal production plant was going to be built in Almería and some of them (4%) believed that a microalgal production plant was going to be built in Livorno, which was not true. Microalgae are produced in controlled industrial facilities. When used for low value purposes, such as the production of agricultural products or animal feed, microalgae are produced in open reactors such as raceways, although, more recently, thin-layer cascade photobioreactors have been studied because of their higher areal productivity [28,29]. One of the main advantages of producing photosynthetic organisms, including microalgae is that they use sunlight as a source of energy and fix carbon dioxide to produce biomass and oxygen. Despite the (theoretical) higher awareness about microalgae in Almería, Spanish consumers were more hesitant about the production of microalgae than consumers in Livorno, especially when they were told that the production plant was going to be built in their city, suggesting a NIMBY effect. Based on comments made by the respondents, it is likely that the potential economic benefit and the creation of jobs had a stronger effect on the responses of those aged over 49 years old. Indeed, the percentage of respondents over 49 years old that agreed with the construction of a microalgae production plant and a microalgal biorefinery was higher in both cities, independently of the location. However, a more in-depth study would be needed to confirm this hypothesis. In terms of educational level, those respondents with higher education were keener to the production of a microalgal biorefinery. The educational level of the respondents did not affect their attitudes towards a microalgae production plant, which suggests a bad perception of the term biorefinery, especially amongst those with lower educational levels.

Because of the lower (theoretical) awareness of citizens in Livorno about microalgae, approximately 60–70% of respondents there neither agreed nor disagreed with the production of microalgae independently of the location of the facility. The high percentage of undecided responses in Spain, but especially in Italy, can also be attributed to the fact that algae are not commonly consumed in these two countries except for some areas such as Galicia, where seaweeds are common. Results suggested that increasing consumer knowledge about the environmental and health benefits of microalgae, as well as about the safety and legality of this industry, could lead to a higher interest in the topic and, in turn, to a higher acceptance of microalgae-based processes and products. Previous studies demonstrated that increasing knowledge about microalgae can make those consumers who do not have a clear opinion keener to purchase and use microalgal products [19]. Moreover, an efficient and informative communication of the benefits of a novel technology or process has been shown to be a success factor when it comes to consumer acceptance, as it can reduce consumer uncertainty [30].

The main reasons given in Almería for agreeing or not agreeing with the production of microalgae are shown in Figure 2. Overall, respondents who agreed with the production of microalgae both in their own city and in Italy mentioned safety, health, and the economy as the main reasons for their decision. This is in line with previous reports that suggested that consumers consider microalgae as nutritious and safe [19]. However, risk perception is key as it is the most important factor influencing consumer interest in production technologies [30]. Consumers pay more attention to risks and losses than to benefits and gains [31]. Many microalgal strains have achieved GRAS status in the US, can be commercialized as novel foods in the EU, and are safe for human consumption. However, harmful algal blooms such as those caused by the dinoflagellate *Pyrodinium bahamense* are common and known by many consumers [32]. Moreover, responses to a previous survey conducted in Almería [31] suggested that several consumers were aware of the ability of algae to accumulate toxic and carcinogenic heavy metals [33], and this could also have

contributed to the safety concerns of consumers. Similar results were observed when consumers were asked about the production of a microalgal biorefinery, as the majority of the respondents in Almería were against its construction, especially when they thought it was going to be built in their city (Figure 3). The term "biorefinery" could have raised concerns within respondents as the acceptability of a microalgal production plant was higher than that of a biorefinery.

Proximity was the main reason given in both cities to disagree with the production of microalgae in their own city. The NIMBY syndrome is used to explain public opposition to new developments near homes and communities—NIMBY stands for "not in my back yard" [34]. The NIMBY effect has been reported against hazardous chemical factories [26] and nuclear power plants [35], although this is the first time, to the best of the authors' knowledge, that it is reported for microalgal production facilities. Previous reports demonstrated that the expected benefits of a NIMBY facility including social benefits and job opportunities can promote public acceptance, although expectations about potential risks such as pollution, or an impact on health or safety can generate public opposition [36]. Thus, based on the responses received herein, it is of key importance to inform citizens about the many benefits of microalgae and microalgal production, as the trade-off between perceived benefits and risks is a critical determinant of the acceptance of NIMBY facilities. For example, local economic benefits can reduce public opposition to nuclear power plants in Japan [36]. Because of the many positive aspects of microalgal production, it is likely that a marketing strategy highlighting the benefits of microalgal production to the region would promote the acceptance of existing and novel production plants in the region.

The goal of a microalgal biorefinery is to produce commercial products derived from microalgae. Agricultural products derived from microalgae are currently commercially available, and their market share is expected to grow. When asked about microalgae-derived agricultural products and ingredients for aquafeed, most of the respondents in Livorno agreed with their production. The acceptability of microalgae-based products was higher than that of their production and processing technologies. A large percentage of respondents in Almería did not agree with the production of agricultural products based on microalgae. These results are consistent with those observed in previous questionnaires, where a negative attitude towards microalgae was observed for a high percentage of the population. Currently, microalgae-based agricultural products are being produced and commercialized in Almería.

Overall, the main factors affecting the acceptance of microalgal production facilities were proximity and awareness about the positive aspects of microalgae and microalgal production. These were in line with previous reports that demonstrated that increasing consumer knowledge about microalgae could promote their purchase intention and consumption [19]. Initial responses in Almería suggest that many consumers had clear ideas about microalgae production while consumers in Livorno were undecided, mainly because of a lack of awareness about microalgae. In both locations, increasing knowledge about microalgae and microalgae-derived products led to a shift from undecided respondents to positive answers. Consumers' knowledge about microalgal biotechnology and the health and environmental benefits of this valuable raw material are scarce, and opinions are based on drivers other than knowledge.

5. Conclusions

Citizens in Almería (Spain) and Livorno (Italy) were asked about their attitudes towards the construction of a microalgae production plant and a microalgal biorefinery in their cities. In Almería, results suggest that citizens could potentially adopt a NIMBY attitude towards microalgae production in their city, despite there currently being microalgal production plants in place and the University of Almería being very active at disseminating information about microalgae. In Livorno, consumers did not show a clear opin-

ion, and this was attributed to a lack of awareness about microalgae and microalgal industrial applications. Microalgae-based products were well accepted within consumers in both cities, but especially in Livorno. Proximity and age group were the main factors affecting the acceptance of microalgae (both production and products). Respondents over 50 years old were keener towards the construction of a microalgae production plant, independently of location. However, their attitudes towards a microalgae biorefinery were not so positive. A negative perception towards the term biorefinery was observed independently of gender, age group, or educational level. A more in-depth study is needed to assess the main reasons for accepting or rejecting microalgal processes and products. Their safety, sustainability, and economic impact were the main reasons given for accepting the construction of microalgal production plants and microalgae-based products. Proximity, safety, and environmental impact were the main reasons given for rejecting the construction of microalgae processing facilities. Increasing consumer knowledge about microalgae, as well as microalgal processes and products, is key to achieving high acceptance rates and increasing market shares. Marketing campaigns to increase consumer awareness of the health and environmental benefits of microalgae and to guide them towards the utilization of microalgal products are necessary. Further consumer studies are needed, as little is known about the perception that consumers have about microalgal processes.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/chemengineering5020027/s1: Figure S1—Questionnaire; Figure S2—Demographic characteristics.

Author Contributions: Conceptualization, G.A. and G.D.; methodology, G.A., G.D., C.P., L.M., and F.A.; formal analysis, T.L., C.P., and G.D.; investigation, C.P., L.M., and F.A.; writing—original draft preparation, T.L.; writing—review and editing, G.D. and G.A.; visualization, T.L.; project administration, G.A.; funding acquisition, G.A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the University of Almería (*Código de buenas prácticas de investigación*, 2011) and the University of Milan (*Codice etico e per l'integrità nella ricerca*, 2011).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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