Science journalism in pandemic times: perspectives on the science-media relationship from COVID-19 researchers in Southern Europe

Esther Marín-González[1]*, Inês Navalhas[2], Anne M. Dijkstra[3], Anouk De Jong[3] and Cristina Luís[2]

[1]cE3c - Centre for Ecology, Evolution and Environmental Changes & CHANGE - Global Change and Sustainability Institute, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal, [2]CIUHCT - Centro Interuniversitário de História das Ciências e da Tecnologia, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal, [3]University of Twente, Faculty of Behavioural, Management and Social Sciences, Enschede, Netherlands

Several studies have investigated the relationship between scientists and journalists. However, Southern Europe has been less studied when it comes to understanding the nature and effectiveness of collaborations between these two groups of professionals. To address this gap, this study focused on researchers (i.e., academics and scientists from different fields, including clinical researchers and medical doctors) who conducted research activities on COVID-19-related topics in three Southern European countries (Italy, Portugal, and Spain). Using an approach that combined survey data ($n = 317$) with semi-structured interviews ($n = 40$), we explored researchers' personal beliefs, opinions, and experiences regarding their encounters with the media during the pandemic. Our results show that researchers' motivations, concerns, and benefits in their interactions with the media remained largely unchanged during the pandemic. Despite the additional challenges posed by the health emergency, most researchers in Italy, Portugal, and Spain rated their interactions with journalists positively. Several practices to promote and maintain trustful and fruitful cooperation with journalists were also identified. Additionally, lessons learned were extracted from the interactions between researchers and journalists during the pandemic. They hold particular relevance in a context of uncertainty, fake news, high demand for information and high expectations in science and technology. These findings aim to support both the scientific community and media professionals to deal with current and future communicative challenges such as health, environmental and social crises that require joint efforts from multiple societal actors.

KEYWORDS

COVID-19, Southern Europe, health communication, science-media relationship, science journalism, scientists-journalists' interactions

1. Introduction

The COVID-19 pandemic posed multiple social and political challenges worldwide. In a moment of high uncertainty where information was scarce, the scientific community and media professionals were confronted with the common goal of communicating accurate and trustworthy scientific information and recommendations to guide society in facing

the pandemic. As a result of growing demands for information, public communication of COVID-19 issues thrived in both traditional and social media. The information overload increased the risk of misinformation (i.e., false or inaccurate claims not intended to deceive) and disinformation (i.e., deliberate dissemination of false information intended to deceive; Wardle and Singerman, 2021) that threatened the ability of media professionals to ensure accountability on behalf of the public. Soon it became evident that disseminating accurate and truthful information was crucial in tackling the spreading of false information (Zarocostas, 2020). Even before the World Health Organization (WHO) declared SARS-CoV-2 a pandemic, the organization alerted to the risks of "a massive *infodemic*" (World Health Organization, 2020, p. 2). The race to combat the spread of the virus triggered scientific production related to this novel disease (Oliveira et al., 2021), which was also reflected in the global mass media coverage of COVID-19-related research (Hart et al., 2020; Sousa-Pinto et al., 2020). As such, frequent interactions between scientists and journalists reporting on COVID-19 were necessary and inevitable.

Facing the spreading of misinformation and disinformation (or fake news) associated with the pandemic represented a challenge for media professionals, health professionals and scientists (Mesquita et al., 2020; Naeem et al., 2021), but it was not the only one. Recent works have investigated how some practices of these professionals have been shaped in the context of the pandemic. These include dealing with the growing use of pre-print data in media outlets (Fleerackers et al., 2021, 2022; Fraser et al., 2021), the increasing coverage of science topics in the media and their impact on the cultural authority of science and scientists (Metcalfe et al., 2020), the intense workload and associated anxiety and stress problems reported by journalists (Massarani et al., 2021), the stress and pessimism associated to the pressure to publish reported by academic researchers (Suart et al., 2022), or a shift in the selection of sources in the news coverage of COVID-19 (Catalan-Matamoros and Elías, 2020; Leidecker-Sandmann et al., 2022). However, how the relationship between scientists and journalists was impacted by the pandemic has received less attention. To our knowledge, no study has yet investigated this aspect. Therefore, we aim to fill this gap in knowledge about the prevailing relationships between scientists and journalists by providing novel insights into how these interactions developed during the pandemic, with a focus on Southern Europe.

A large body of literature has explored the nature and quality of the interactions between journalists and scientists working in different research fields and countries (for an overview of the topic see, e.g., Dudo, 2015; Yeo and Brossard, 2017). With a few exceptions (Kaye et al., 2011; Lo and Peters, 2015; Appiah et al., 2020; Koso, 2021), research on the science-media relationship has largely focused on the USA and other English-speaking countries, as well as on Northern and Western Europe (e.g., Peters, 2007, 2013; Peters et al., 2008a; Dijkstra et al., 2015). In consequence, regions such as Southern European countries have been less studied when it comes to understanding the science-media relationship. In a recent study on the European science communication landscape (Davies et al., 2021), authors acknowledged the need to go beyond the anglophone context when thinking and discussing science communication practices.

Our focus on three Southern European countries (Italy, Portugal, and Spain) responds to this demand and explores three countries that share many historical and structural characteristics of their media ecosystems (Hallin and Mancini, 2004; Brüggemann et al., 2014). A recent report identified commonalities between Greece, Italy, Portugal, and Spain, such as a certain degree of state interference compared to the EU average, lower media plurality and social inclusiveness, lower freedom of expression, and financial sustainability of the media sector at risk (PromethEUs, 2022). In addition, declining resources to invest in using innovative formats and supporting in-depth investigations, as well as scarce capacity to deal with crucial issues such as content verification, which can lead to a potential acceleration of misinformation, pose multiple challenges to media professionals in the region.

The research questions guiding our study are the following: (i) How (and why) did interactions between researchers and journalists develop during the COVID-19 pandemic? (ii) What practices helped researchers to overcome their hesitance to interact with the media during the COVID-19 pandemic, which could also facilitate future collaboration between researchers and journalists? and (iii) What lessons can be learned from the COVID-19 pandemic that may help address current and future communication challenges?

The combination of survey data with semi-structured interviews allowed us to understand how researchers in three Southern European countries experienced their interactions with journalists and to address practical insights on opportunities to advance the building and strengthening of fruitful collaborations between researchers and journalists. We argue that these findings can help both the scientific community and media professionals in other EU countries.

2. Literature review

In the last decade, a growing body of literature has discussed scientists' motivations to participate in public engagement and communication activities. See Weingart et al. (2021) for a systematic analysis of academic literature on the topic. Additionally, barriers and facilitators for co-production activities involving the interaction between researchers and journalists have been identified (MacGregor et al., 2020). Focusing on science-media interactions, scholars have identified multiple predictors of scientists' willingness to engage with media professionals, namely professional status or seniority (Dunwoody et al., 2009; Bauer and Jensen, 2011; Besley and Nisbet, 2013; Dudo, 2013; Leidecker-Sandmann et al., 2022), learning opportunities (Dunwoody et al., 2009), personal rewards such as research funding, public accountability, increased legitimacy of their research (Gascoigne and Metcalfe, 1997; Allgaier et al., 2013; Dijkstra et al., 2015), perception of moral or professional duty (Allgaier et al., 2013; Peters, 2013), positive intrinsic rewards that include raising positive attitudes toward science, promotion of science literacy, influencing public understanding of science, self-growth, personal enjoyment, or the feeling of being valued or having made a difference (Gascoigne and Metcalfe, 1997; Peters et al., 2008a,b; Dunwoody et al., 2009; Besley and Nisbet, 2013; Dudo, 2013; Besley et al.,

2018; Larsson et al., 2019), and normative expectations of scientific organizations and research institutions (Peters, 2013).

Disincentives, concerns, challenges and conflicts associated with these interactions have also been identified in the literature (Peters, 1995; Gascoigne and Metcalfe, 1997; Peters et al., 2008a; Larsson et al., 2019). For example, the different expectations of researchers' and journalists' goals and their control over the communication process (Peters, 1995), or the risk of misquotes, the unpredictability of journalists, and the possibility of negative publicity (Peters et al., 2008a). Medical experts reported short and exaggerated headlines, the media's choice of topics, and lack of medical knowledge as some of the difficulties encountered in their relationships with journalists (Larsson et al., 2019). Considering their shortcomings, scientists and health professionals have also reported the lack of communication skills and media training as critical factors in their encounters with the media and, in general, with the public (Gascoigne and Metcalfe, 1997; Kaye et al., 2011; Allgaier et al., 2013; Dudo, 2013; Larsson et al., 2019; Weingart et al., 2021).

Even though some reluctance exists, scientists are increasingly oriented toward the mass media and the media logic, that is, understanding processes, routines, and formats that frame the production of media content and its effects. This phenomenon, named "medialization of science," and discussed by several authors (Peters, 2012; Allgaier et al., 2013; Lo and Peters, 2015; Koso, 2021; Olesk, 2021) stresses the increasing need for public visibility that scientists and scientific organizations perceive as a way to legitimize their research toward society. In addition, the medialization of science provides an opportunity to bridge existing knowledge gaps between scientists and journalists (Allgaier et al., 2013).

When considering the number and quality of interactions between scientists and journalists, the works by Peters et al. (2008a,b) have challenged the perception of conflicting and difficult encounters between them. Based on the scientists' views, the authors concluded that interactions between these two actors were more frequent, pleasant and beneficial for researchers than previously expected. Interestingly, modest differences were observed across the five countries examined (France, Germany, the UK, the USA, and Japan), reporting similar global trends. Other studies have proven similar findings in other countries and research fields (Allgaier et al., 2013; Peters, 2013; Dudo et al., 2014; Lo and Peters, 2015) indicating that the interactions between scientists and journalists are, overall, considered positive and fruitful in terms of their impact. Despite this trend, research has also shown more cautious approaches and negative outcomes of these interactions have been observed, such as poor-quality coverage, sensationalized research findings, disruption of scientists' work routines, or increased distrust in science due to media coverage (Gascoigne and Metcalfe, 1997; Allgaier et al., 2013; Koh et al., 2016; Metcalfe et al., 2020). Notwithstanding, the effect that the intensive and exhaustive contact may have had on the interactions between journalists and scientists during the pandemic is still unclear.

Previous studies have explored cooperative practices between journalists and scientists such as co-authored science journalism articles (Canan and Hartman, 2007). In the context of the pandemic and the current post-pandemic, closer collaborations between scientists, physicians, journalists, and the public to fight online misinformation on public health issues (Swire-Thompson and Lazer, 2020) seem nowadays more relevant than before.

Several authors pledged the cooperation of the scientific community and journalists to halt the spreading of misinformation (e.g., vaccination rumors; Harper and Attwell, 2022) and help society to identify COVID-19 fake news stories (Naeem et al., 2021). Similarly, the collaboration between science communication professionals and scholars to develop evidence-based approaches can support responsible science communication by reflecting on the value, quality and effectiveness of its practice and research (Jensen and Gerber, 2020).

3. Data and methods

3.1. Study design

To investigate the interactions between researchers and journalists in the context of the COVID-19 pandemic in Southern Europe (Italy, Portugal, and Spain), we used a mixed-methods approach (Teddlie and Tashakkori, 2009) that combined survey research with semi-structured interviews. Our study specifically addresses researchers (academics and scientists from different fields, including clinical researchers and medical doctors) who were involved in COVID-19 research activities during the pandemic. Survey data portrayed general trends about the interactions between researchers and journalists in Italy, Portugal, and Spain. Specifically, it explored some motivations that could influence researchers' willingness to interact with the media (Gascoigne and Metcalfe, 1997; Allgaier et al., 2013; Peters, 2013), perceived benefits and concerns regarding their media contacts (Peters et al., 2008a), the medialization effect of the pandemic (Massarani et al., 2021) or the nature and assessment of the encounters between these actors (Peters et al., 2008a). This information was complemented with more in-depth insights collected through semi-structured interviews with researchers in the three countries. The design of the interview questionnaire was mainly informed by the results of the survey, previous works that explored scientists-journalists relations (e.g., Gascoigne and Metcalfe, 1997; Peters et al., 2008a; Kolandai-Matchett et al., 2021) and recent works on the impacts of the pandemic (e.g., Mesquita et al., 2020; López-García et al., 2021; Massarani et al., 2021). Interview questions aimed at gathering more in-depth insights into researchers' experience with journalists during the pandemic, which helped us to reply to our first research question, as well as their views on how to advance in the construction and strengthening of fruitful science-media relationships by identifying some of the practices that can support collaborations between these actors (second research question) and address future communication challenges beyond the COVID-19 pandemic (third research question).

3.2. Participants

Survey participants were recruited following two approaches. First, we conducted an online search on Scopus and Web of Science to identify published research work on COVID-19 in the three

studied countries (March 2022). Corresponding authors and co-authors (when contact information was available) were invited to participate in the study. Next, we contacted scientific and medical societies, professional associations, research institutions and universities in Italy, Portugal, and Spain to request the distribution of the survey among their employees and/or associates. A total of 465 people accessed the survey link. Of these, 148 questionnaires were excluded because respondents did not meet the study criteria, i.e., did not participate in COVID-19 research or had not worked in the studied countries; 44 responses), or questionnaires were incomplete (104 responses). The remaining 317 respondents completed the questionnaire and represent the final sample (with 140 valid responses from Italy, 70 from Portugal, and 107 from Spain). Overall, the sample was mainly composed of respondents with Ph.D. degrees, with primary responsibilities in research, clinical services, or teaching, who mainly worked in universities (59.6%) or hospitals (21.1%). Almost two-thirds of the respondents had an indefinite-term contract. Divided by research field, most respondents worked in medical and health sciences or social sciences. Gender distribution shows that 46.4% of the sample identified as female, 51.1% as male, and 0.6% as non-binary. Most respondents were between 35 and 44 years old (31%). Out of the 317 researchers, 147 individuals interacted with the media during the COVID-19 pandemic (46.4%). Specifically, 53 respondents from Italy, 31 from Portugal, and 63 from Spain had media contacts (Supplementary Table 1 shows a description of demographic and background variables).

Interview participants were identified through purposive sampling. Inclusion criteria for participation were (i) to have been involved in research on the COVID-19 pandemic (any topic or perspective), and (ii) to have interacted with journalists covering COVID-19 issues. Gender and research fields were also considered to ensure the diversity of profiles. Additionally, survey respondents who interacted with journalists and expressed their willingness to give more in-depth replies were also contacted to participate in the interviews. In total, 40 participants (13 in Italy, 15 in Portugal, and 12 in Spain) were interviewed. Supplementary Table 2 shows the interviewees' country, areas of expertise, and codes used for data anonymization.

3.3. Data collection and analysis

To collect the quantitative data, an online survey was created on the platform Qualtrics XM (a web-based software) in four languages (Italian, Portuguese, Spanish, and English) and was distributed through an anonymous link from May to July 2022. It addressed researchers who conducted research on COVID-19 in Italy, Portugal, and Spain. The questionnaire was constructed mainly based on the studies of Peters et al. (2008a) and Massarani et al. (2021) to allow comparability with previous studies exploring interactions between scientists and journalists (Peters et al., 2008a), and the impact of COVID-19 on journalists practices (Massarani et al., 2021). It consisted of four questions addressing respondents who indicated contacts with the media during the pandemic. These questions aimed at understanding the nature and quality of these interactions (i.e., their origin and number, and researchers' assessment of these encounters). One of these questions (personal assessment of the interactions) was constructed on a Likert scale in which respondents indicated their level of agreement with several statements on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Cronbach's alpha showed high reliability (0.87). Moreover, three questions explored the motivations, benefits, and concerns of the overall sample of researchers to interact with the media. Lastly, one question aimed at collecting the perception of researchers regarding the impact of the pandemic on science and media relations. This last question was also constructed on a 5-point Likert scale. Cronbach's alpha (0.68) showed moderate but sufficient reliability and internal consistency (Pallant, 2020). At the end of the survey, seven questions collected information about respondents' demographics. The entire questionnaire is provided in Supplementary File 1. Statistical analysis of survey data was performed using IBM SPSS statistical software (v.28.0). Descriptive statistics are presented for categorical variables as percentages. Data is presented in percentages per country.

Semi-structured interviews were conducted between September and November 2022 via an online video conferencing platform (Zoom). A guideline with seven questions was developed and used. The questions explored the personal experiences of researchers in interacting with journalists during the pandemic, their motivations and concerns, and ways to improve these collaborations and deal with infodemic and other communication challenges (Supplementary File 2). The interviews were conducted in the participant's native language (Italian, Portuguese, or Spanish). Interviews were audio-recorded and transcribed and had an average duration of 25.5 min (SD = 5.9) in Italy; 44.7 min (SD = 13.6) in Portugal, and 46.6 min (SD = 12.6) in Spain. Interview data from Portugal and Spain were analyzed in their original language while the interviews in Italian were translated into English before analysis.

To analyze the interview data, we employed a reflexive approach to thematic analysis supported by Atlas.ti v22. Thematic analysis is a flexible method that enables the identification of patterns of meaning (themes) across data sets by interrogating both semantic and latent meanings (i.e., content, ideas, assumptions) below the surface (Braun and Clarke, 2006, 2012). Initially, the transcripts were coded using a combination of inductive and deductive approaches. Next, themes were developed for each country by reviewing the coded data and identifying patterns (i.e., similarities and overlaps among the codes), which were then grouped into potential themes. Themes and subthemes were carefully reviewed against the coded data extracts, the entire data set, and the themes themselves to ensure meaningful capture of the most essential elements of the data. Whenever necessary, themes and subthemes were refined. Lastly, a cross-national comparison was conducted to identify commonalities. Relevant quotes were selected to provide vivid and compelling examples that support and illustrate the meaning of each theme. To ensure the validity of this analysis, codes, and themes underwent iterative review and discussion among the three coders involved in all steps of data analysis until a consensus was reached. Although inter-coder reliability was not calculated, there was a high level of agreement between the coders, and regular peer debriefing were

held throughout the analysis to uphold reliability. Moreover, we adopted a reflexive approach to data analysis, recognizing that the backgrounds and positions of researchers can influence the perceptions and interpretations of the data.

3.4. Ethical approval

The Ethics Committee of the Faculdade de Ciências da Universidade de Lisboa (CEC/1/2022) gave ethical approval to conduct this research. All study participants were informed about the voluntary, confidential, and anonymous nature of their participation and consent was given freely.

4. Results

4.1. Survey data

Survey data helped to outline general trends in the reasons that move researchers to interact or had some hesitance to interact with journalists, the perceived benefits of these encounters, the nature of these interactions, and the impacts of the pandemic on the medialization of science and scientists. The following sub-sections present the results emerging from the three studied countries are present.

4.1.1. Motivations, benefits, and concerns to interact with the media

Most respondents deemed three main reasons to be in contact with the media, namely, improve the scientific culture of society (79.2%), contribute to fighting misinformation related to the COVID-19 pandemic (74.4%), and promote science in the media (70.3%). Relative importance was also given to the fact that researchers considered it a professional duty, particularly in Portugal and Spain (Figure 1). This trend is observed in the three analyzed countries. Supplementary Table 3 provides the distribution of responses per country.

Interactions with the media were also seen as potentially beneficial at different levels. Survey respondents were asked to identify possible benefits that may increase their confidence in interacting with journalists. Results indicate that promoting a more positive public attitude toward research is one of their main incentives (75.7%), together with a better-educated public (66.9%), and the possibility of influencing public debate (57.1%; Figure 2). Although all three countries showed very similar trends (Supplementary Table 4), it is noteworthy that 8 in 10 respondents from Portugal considered educating the public as the main perceived benefit of interacting with journalists.

Yet, some concerns increase researchers' reluctance to interact with the media. Researchers in the three countries shared common concerns regarding the risk of incorrect quotation (69.7%) and the unpredictability of journalists (66.6%; Figure 3). Respondents from Portugal and Spain pointed to the possibility of negative publicity as the third reason for refusing to interact with the media (44.3 and 39.3%, respectively) while for their Italian colleagues, critical reactions coming from their heads of departments or

organizations were also a concern. Supplementary Table 5 provides the distribution of responses per country.

4.1.2. Changes in medialization due to the COVID-19 pandemic

Survey respondents were asked to agree or disagree with six positive statements about the medialization (i.e., media presence) of science and scientists during the COVID-19 pandemic compared to the media attention received before. Overall, researchers of the three countries shared similar thoughts, agreeing with all the statements (Figure 4), and indicating greater agreement with the following two: "researchers are more frequently accessed and cited as sources of information in the media than before the pandemic" (57.4 and 15.1% reported their agreement and strong agreement, respectively) and "there is a higher presence of scientific topics in the general media than before the pandemic" (51.7 and 13.2% reported their agreement and strong agreement, respectively). Across countries, similar trends were observed in four of the six statements with the highest consent (Supplementary Table 6).

4.1.3. Nature and assessment of personal interactions with the media

To gain further insights into the researchers' experiences with the media on issues related to COVID-19, we directed specific questions exclusively to respondents who reported such interactions (147 respondents; Figure 5A shows their distribution per country).

First, when asked how many interactions they had with the media on issues related to COVID-19, over 60% of respondents indicated that they interacted between one and five times, while almost 20% stated that the number of interactions with journalists exceeded 10 times (Figure 5B). The latter is particularly prominent for respondents from Spain, where almost three out of 10 researchers interacted with journalists more than 10 times during the pandemic (28.6%). Despite some variation, the number of interactions reported is similar across countries, indicating that researchers in the three countries were comparably contacted, in most cases up to five times.

Regarding the origin of the interactions, 72.8% of respondents were contacted due to their area of expertise, whereas 21.1% were contacted after a press release. In a small number of cases (2.7%), both reasons were given for the origin of the interaction. Other reasons mentioned (3.4%) included, among others, previous interactions with journalists or contacts initiated by researchers (Figure 5C). This distribution is similar across countries.

Considering how researchers assessed these interactions, results show that almost 70% of the respondents rated their media contacts positively (53.1% were considered "good" and 16.3% "excellent"). By contrast, 10.2% were negatively assessed (1.4% "terrible" and 8.8% "poor") and about 20% were considered neutral ("neither good nor bad"; Figure 5D). This trend is observed across countries. Results indicate that a large proportion of researchers in Italy, Portugal, and Spain coincide in rating positively their interactions

FIGURE 1
Reasons that motivate researchers to interact with the media. Distribution of responses to the question "Regardless of whether you have interacted with the media or not, your reasons to interact with journalists would be/are…" in percentages per country.
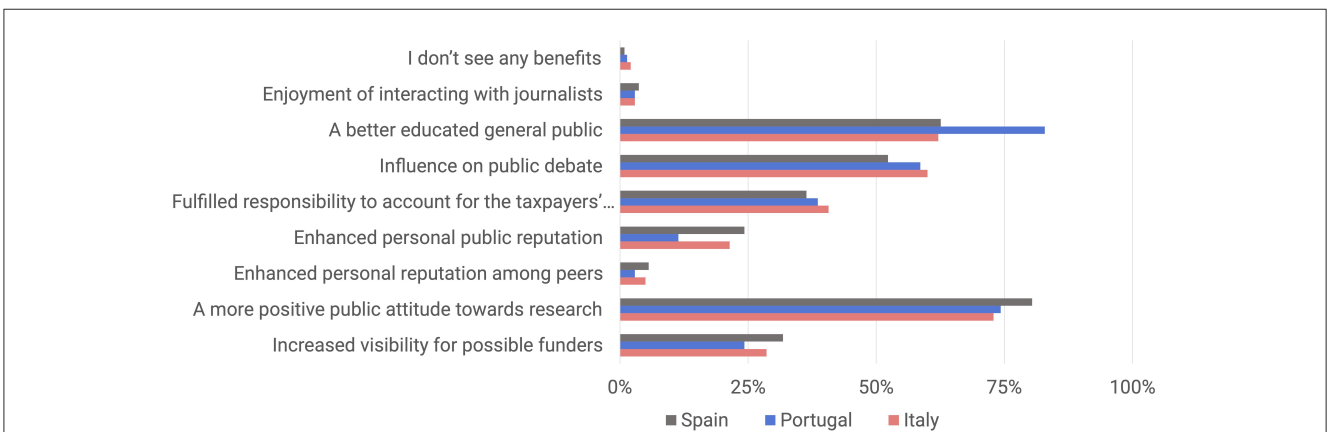

FIGURE 2
Benefits that increase researchers' confidence to interact with the media. Distribution of responses to the question "Regardless of whether you have interacted with the media or not, how important to you are the following possible benefits that increase researchers' confidence to interact with the media?" in percentages per country.
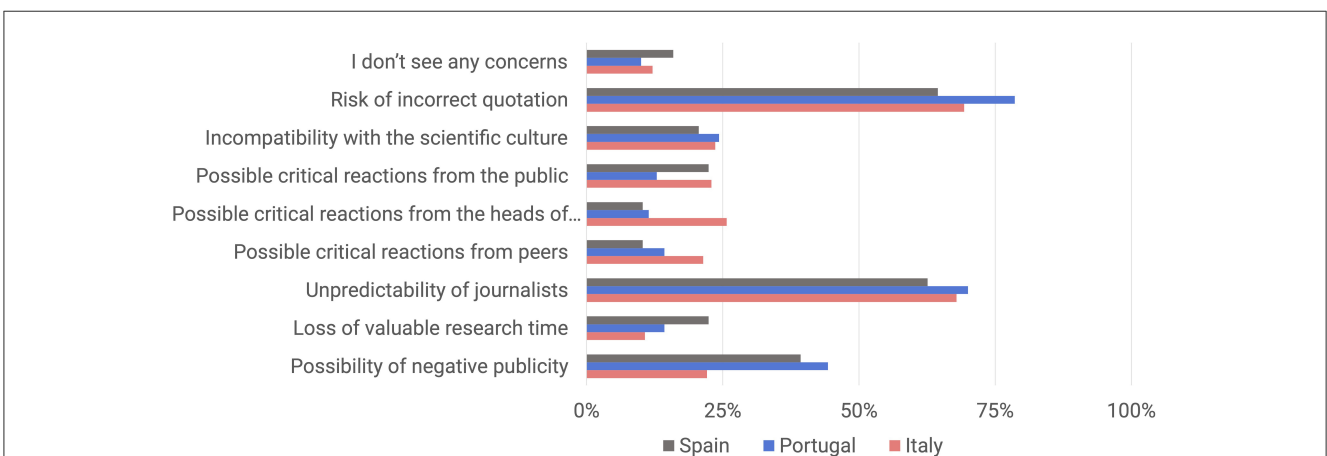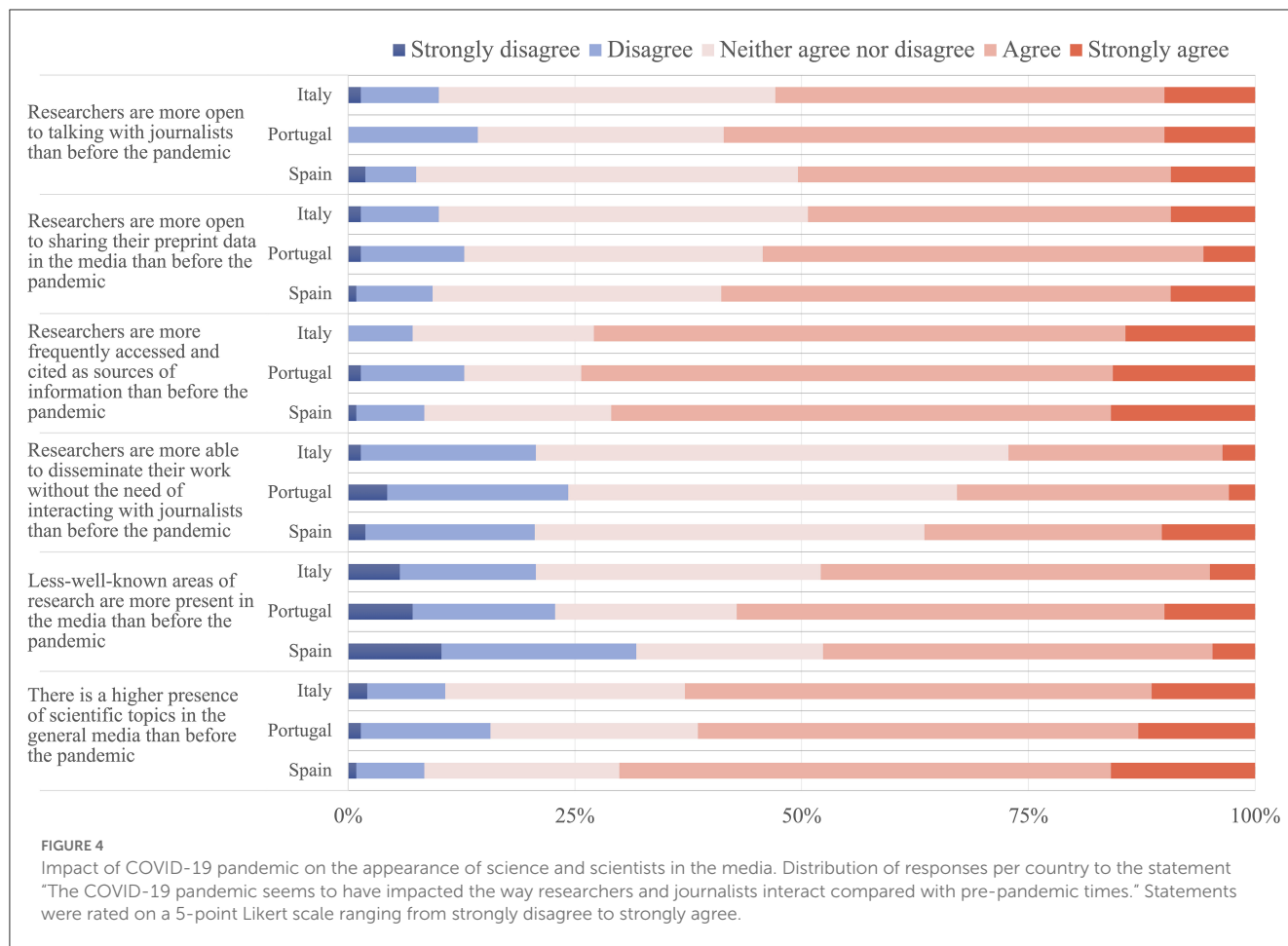

FIGURE 3
Concerns that increase researchers' reluctance to interact with the media. Distribution of responses to the question "Regardless of whether you have interacted with the media or not, how important to you are the following possible concerns that increase researchers' reluctance to interact with the media?" in percentages per country.
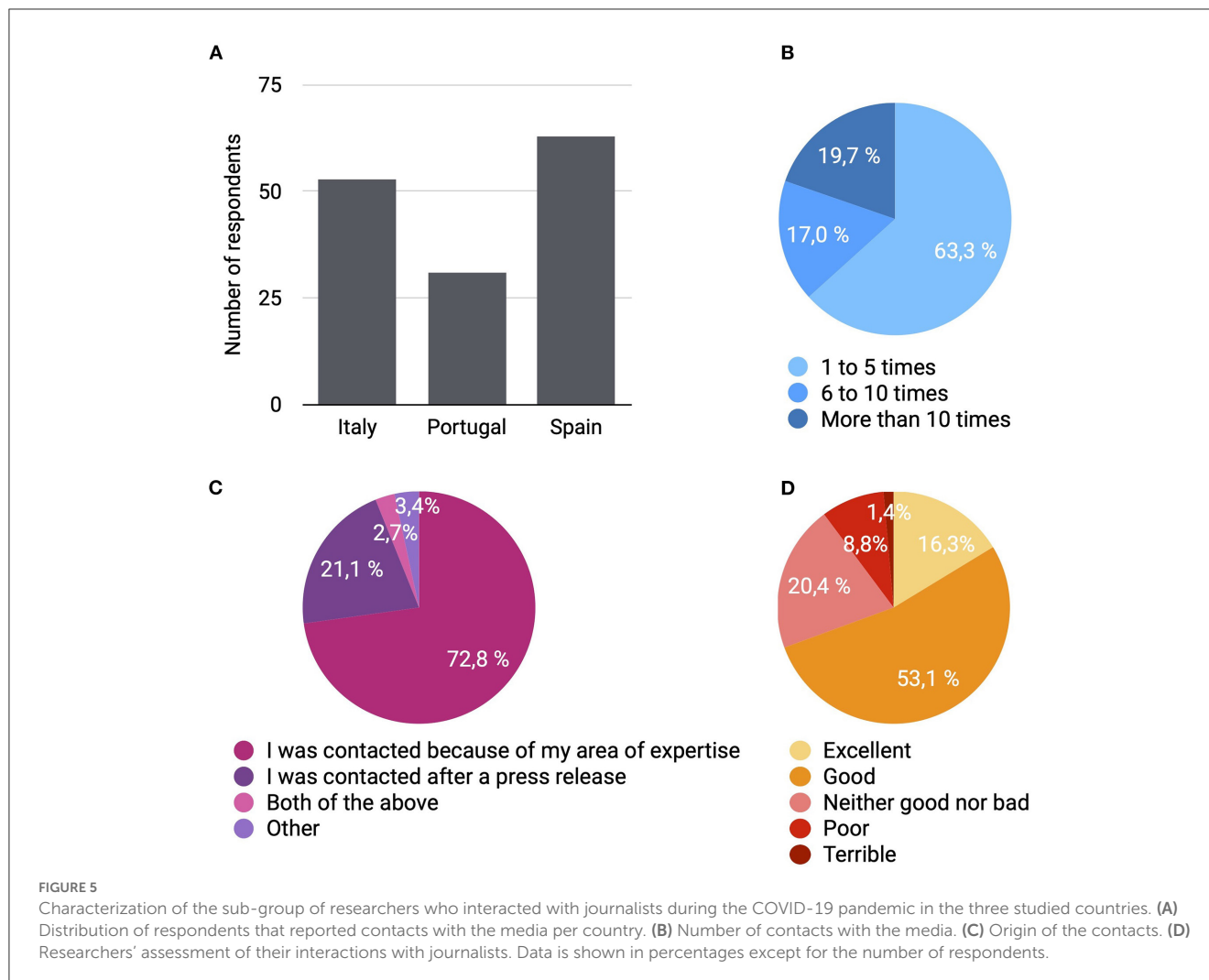
FIGURE 4
Impact of COVID-19 pandemic on the appearance of science and scientists in the media. Distribution of responses per country to the statement "The COVID-19 pandemic seems to have impacted the way researchers and journalists interact compared with pre-pandemic times." Statements were rated on a 5-point Likert scale ranging from strongly disagree to strongly agree.

with the media. Supplementary Table 7 provides the distribution of responses per country.

Next, researchers' interactions with journalists were explored in more detail through a series of positive and negative statements. Respondents who reported contacts with the media were asked to show their level of disagreement or agreement with 11 plausible situations they could have experienced during their encounters with journalists covering COVID-19 topics. Echoing previous studies (Peters et al., 2008a), respondents in all three countries agreed with the positive statements and disagreed with the negative ones (Figure 6). In general, respondents from Portugal were overall more positive in their assessment of media contacts. On average, the three positive statements that obtained higher levels of agreement were "I was able to get my message out to the public" (59.7 and 17.9% reported their agreement and strong agreement, respectively), "Talking to the journalists was pleasant" (49.8 and 20.5% reported their agreement and strong agreement, respectively) and "The journalists really listened to what I had to say" (48.2 and 21.1% reported their agreement and strong agreement, respectively). Conversely, the negative statements that reach higher levels of disagreement were "The journalists treated me with little respect" (47.6 and 39.5% reported their strong disagreement and disagreement, respectively), "My statements were distorted" (32.7 and 42.9% reported their strong disagreement

and disagreement, respectively), "I felt unsure when talking to journalists" (35.4 and 38.8% reported their strong disagreement and disagreement, respectively), and "The most important information I gave was omitted" (25.9 and 45.6% reported their strong disagreement and disagreement, respectively). These results show that researchers were pleased with the interactions they had with the media and with the outcomes derived from these encounters. Supplementary Table 8 provides the distribution of responses per country.

In summary, these findings show that, as a whole, researchers' interactions with the media were motivated by their desire to improve society's scientific culture, promote more favorable public attitudes toward research, and contribute to a better-educated public. Conversely, concerns arise due to the risk of being misquoted and the unpredictability of journalists. Despite these reservations, researchers agreed that they were approached and cited more frequently as sources of information, with a higher presence of scientific topics in the media than in pre-pandemic times. Overall, researchers who encountered journalists to cover COVID-19-related topics expressed favorable views of their interactions across all three countries. Researchers acknowledged that, in general, they conveyed their message to the public and found their conversations with journalists pleasant and attentive.

FIGURE 5
Characterization of the sub-group of researchers who interacted with journalists during the COVID-19 pandemic in the three studied countries. **(A)** Distribution of respondents that reported contacts with the media per country. **(B)** Number of contacts with the media. **(C)** Origin of the contacts. **(D)** Researchers' assessment of their interactions with journalists. Data is shown in percentages except for the number of respondents.

4.2. Semi-structured interviews

Through thematic analysis of the interview transcripts, a series of themes and subthemes were identified per country and compared cross-nationally to distill commonalities among them. In this section, common themes and subthemes are presented, organized into four main topics (Figure 7). Supplementary Table 9 shows themes, subthemes, codes used and some extracts that illustrate these findings.
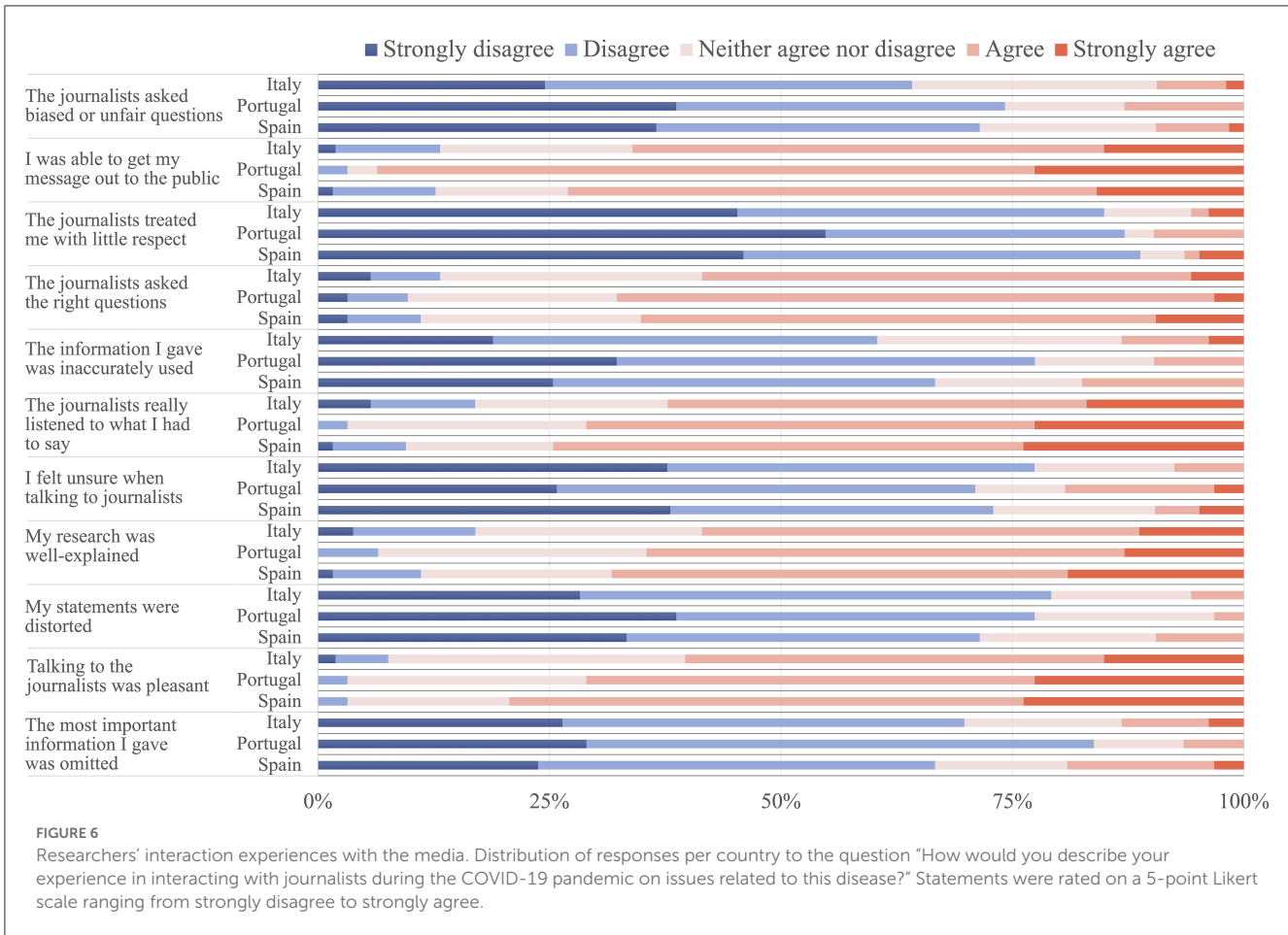
4.2.1. Reasons to interact with the media

It was possible to distill one common driver (theme) across countries that moved researchers to interact with the media in the context of the COVID-19 pandemic: a sense of commitment to meet the need for information related to the appearance and spreading of the virus during early stages of the pandemic, and later, the development of the vaccines. Intrinsic motivations to interact with the media also emerged (e.g., rewarding at the personal level, having had previous positive interactions with journalists, or their

willingness to promote scientific culture and interest in science), although these were less prevalent and not common in all countries.

The commitment to understand and respond to societal information needs can be divided into two normative motivations (subthemes), i.e., the consideration of communication practices as part of researchers' work and the willingness to ensure citizens' right to be informed. These common motivations were guided by the rationale of keeping society updated about evidence-based recommendations and novel scientific findings on COVID-19 research (as stated by one-third of the participants interviewed), the responsibility of giving back their knowledge to society as part of their duties (one-third) and understanding and meeting societal needs and interests related to COVID-19 related-information (one-fourth, approx.). One participant expressed their motivations as follows:

> *"We understood that we had to be available to help clarify things and try to somehow alert people to the need for means, policies, and solutions to a problem that was obviously very serious, and we had this availability"* (PT3)

FIGURE 6
Researchers' interaction experiences with the media. Distribution of responses per country to the question "How would you describe your experience in interacting with journalists during the COVID-19 pandemic on issues related to this disease?" Statements were rated on a 5-point Likert scale ranging from strongly disagree to strongly agree.

4.2.2. Assessment of personal interactions with the media

During the first 2 years of the COVID-19 pandemic, researchers had positive and negative experiences in their contact with the media. Although most participants described pleasant interactions with the media, negative contacts were also identified. Thus, two common themes ("positive assessment of interactions" and "negative assessment of interactions") emerged across countries.

Overall, more than half of the researchers described satisfactory interactions related to the specialization of some journalists in covering science topics. Some participants also acknowledged positive interactions associated with the good preparation or previous knowledge of journalists on the topic covered (almost one in four), and respectful attitudes (approximately, 1 in 10). Positive interactions associated with the good preparation of the topic and the interview process are illustrated in the following quote:

> "I was contacted by journalists that I knew were already more or less into the subject because the questions were specific (...) there was always a preparation, I was always informed about the topic and the questions that they were going to ask me" (PT7)

Conversely, poor interactions with the media were divided into two subthemes based on researchers' critical assessment of their practices, attitudes, or skills ("researchers' role") and the practices,

attitudes and skills displayed by journalists ("journalists' role"). Thus, when reflecting on their capacities, half of the researchers identified the lack of training to deal with the media as an element that hindered their interpersonal relations with journalists. Also, some researchers felt out of their comfort zone when interacting with the media (one out of 10 participants). One participant described the pandemic as a learning-by-doing-period due to a lack of previous media training:

> "It has been a (learning) process throughout these two and a half years. The first half year was especially difficult because the novelty was combined with the seriousness of the situation (…) little by little we began to understand how we had to do it (interact with journalists)" (ES8)

On the other side, participants identified journalists' practices or attitudes that reduced the quality of their interactions, such as the use of sensationalist headlines (and clickbait tactics), alarmism or false expectations when covering the topic (stated by almost half of the participants), the risk of being incorrectly cited (which in some cases was associated with a negative impact on researchers' reputation, but in most cases, with a negative effect on the accuracy of news coverage; one third), the lack of preparation or knowledge of journalists on the topic (one in four), and less frequently, a politicization of the scientific knowledge (one out

FIGURE 7
Common themes and sub-themes identified across the three studied countries organized by topic. Topics cover reasons that moved researchers to interact with the media during the COVID-19 pandemic, assessment of their interactions, practices that researchers considered helpful to overcome concerns and facilitated (or could facilitate) collaborations with the media, and lessons learned from the COVID-19 pandemic that can contribute to deal with current and future communication challenges.

of five). Regarding sensationalism and raising false expectations, researchers highlighted the existence of practices that seek to attract audiences by providing immediate, superficial or inaccurate information. In some case, researchers justified these practices on the basis that generalist journalists have limited knowledge, time, and resources to cover highly specialized areas, whereas others, associated these practices to commercial interests (e.g., click bait tactics or the creation of conflicts and controversies to increase audience impact). As illustrated by one participant:

> "I had the feeling that the journalist was constantly waiting for me to say something controversial and tried to force me to say a sentence that went against what was being done by other colleagues or by the General Directorate of Health. The intervention was relatively short, but the feeling I had was that I was always trying not to say anything that would be used as a headline (…) our objective was to contribute to the control of the pandemic and not to enter unnecessary controversies" (PT6)

In general, these negative features increased researchers' worries about the interview process (feeling unprepared, out

of their comfort zone, and misused) and the communication outcomes (misinterpretation of their statements) and might increase researchers' reluctance to interact with the media in the future.

4.2.3. Practices to overcome concerns and facilitate collaborations with the media

When asked about possible ways to overcome some of their concerns to interact with the media and to enhance further collaborations with journalists, researchers across the analyzed countries suggested three common ways of action. Participants referred to journalists' practices that helped (or could help) them to smooth the way for the establishment of fruitful interactions with the media. This theme, named "improving science coverage in the media," relates to the researchers' expectations of journalists' work in the process of news production. Moreover, participants also critically reflected on their practices and competencies (and their limitations) as well as journalists' limitations to develop their work and identified some factors that could pave the way for fostering

mutual learning and understanding (theme "acknowledgment of limitations"). The third emerging theme was directed at the ways researchers can support and facilitate journalists' work. Additionally, in Portugal and Spain, some participants identified a fourth way of action that involved building science-media relationships based on mutual trust and respectful attitudes and avoiding personal interests to serve society's needs. This set of practices was aimed at both groups of actors, in a joint effort, to facilitate collaborations.

Within the theme that addresses how journalists cover scientific topics in the news, four subthemes associated with the process of news production emerged, i.e., topic approach, interview preparation, piece production, and their review before publication. From the point of view of most researchers interviewed (around two-thirds), the way journalists approach science topics, also COVID-19 research, should be based on a good understanding of scientific practices. This involves knowledge of the scientific method, the timings of science and, more importantly, the fact that science is open to change thus not providing immutable facts. These features are exemplified in the following quote:

> *"Sometimes it is difficult to convey which things are proven and which are not (...) that must be transmitted better, what is the scientific method (...) and that science always doubts, that science is not the truth. Science is continually trying to get closer to the truth (...) nuances must also be explained to journalists (...) more than explaining the details, it is important to transmit concepts"* (ES5)

Moreover, within this subtheme more than half of the participants also recognized that there is a need for journalists specialized in science issues, or at least, to have the basis to be able to understand and prepare news about scientific topics. This would help, according to many of the interviewed participants, to overcome some reluctance to interact with the media, improve science coverage, and ultimately, foster mutual trust relationships.

To facilitate the interview process, almost one out of five researchers considered that having the questions in advance (or, at least, some information) would make their interactions with the media easier. This request was commonly associated with the responsibility participants felt toward the message sent in the context of the COVID-19 pandemic when data was limited, and new findings appeared regularly.

Regarding the coverage of the topic (i.e., COVID-19-related issues), almost half of the participants highlighted the importance of avoiding sensationalist headlines, alarmism or the creation of false expectations associated with novel scientific findings, such as the effectiveness and/or risk of the vaccines. Some participants (more than one-third) also appealed to journalists' responsibility toward the information published or broadcasted or remarked on the need to make nuances and uncertainty apparent in the news produced, particularly in a context of high uncertainty such as the early stages of the pandemic (one out of five). For some participants, contextualizing research findings, especially when pre-print data was used, as was often the case in pandemic coverage, was also considered an important practice to overcome concerns and foster collaborations with the media.

The openness to review and the possibility of making corrections before publication was a common requirement that almost half of the researchers interviewed pointed out to avoid or reduce the risk of incorrect quotations and to allow content checking for the accuracy of reports and news.

Within the theme that identified the limitations, two subthemes about researchers' and journalists' limitations emerged. Here, almost half of the participants were aware of their shortcomings in communicating effectively with the media due to a lack of training in dealing with journalists and, in general, with the public.

At the same time, participants recognized the limitations of journalists in doing their job, such as structural problems of journalism (e.g., limited time and resources to cover their stories, and for some, the existence of agendas and private interests behind them that reduce their independence) and the lack of knowledge to cover science topics when they are generalist journalists that cover several topics.

> *"… journalists are often forced to write a piece in a microsecond because they must beat the news immediately and they don't have a lot of time to look at it, report it and maybe send it back to the interlocutor for him/her to correct it before it goes to print. I am not sure that in a period of emergency like the one we have experienced, there was time to make these steps..."* (IT9)

Finally, more than half of the participants identified the need of sending clear messages (using accessible language) to facilitate journalists' work, as well as showing their availability and willingness to respond to journalists' demands for clarifications to solve any doubts they could have for the benefit of accuracy (one-third). These two practices aimed at supporting journalists' work could also facilitate more fruitful collaborations between researchers and journalists.

Altogether, these practices were identified as facilitators that helped participants (or could help them in the future) to overcome concerns to collaborate with the media and/or to enhance further collaborations with the media.

4.2.4. Dealing with current and future communication challenges

Researchers in all three countries discussed how the infodemic, misinformation and fake news arose during the pandemic and how uncertainty and scarcity of accurate information, especially in the first weeks, was also a struggle for both producers and consumers of information. Additionally, participants proposed practices to improve the effectiveness of science communication activities and foster scientific culture. These three themes summarized several ways of action that researchers, journalists, and other publics can undertake to face current and future socio-technical scenarios (e.g., new pandemics, climate emergency, or the energy transition) and their associated communication challenges.

One of the main problems that information producers and consumers suffered during the COVID-19 pandemic was the need to deal with the excess of information, particularly, regarding mis/disinformation and fake news. In this regard, participants identified some practices associated with their own role that could help to tackle these problems. Specifically, half of the

participants recognized that it is necessary to be aware of the lack of knowledge or capacities when talking about topics that are not directly related to their scientific areas or research topics, thus, claiming responsibility toward the message sent. For one-third of the researchers, making clear distinctions between opinions and facts when talking to the media was crucial to avoid sending wrong messages to the audience, especially in moments of high uncertainty. To avoid some of these issues, more than one-third of the participants proposed increasing researchers' availability and willingness to respond to journalists' needs (e.g., clarify any unclear aspects after an interview).

On the journalists' side, participants identified practices that can help communication professionals to tackle infodemic and far-reaching spreading of inaccurate or false information, such as looking for relevant and reliable sources (almost half of the participants). Other practices mentioned were the need to make reliable and verified information accessible (two in five), to assume responsibility toward the information published or broadcasted (one-third), to make use of fact-checking to ensure that information is accurate, reliable, and truthful (almost one-third), and clearly identify opinions and facts in a report or news (more than one-quarter of participants).

> *"Journalists must contrast the information, look for more than two sources. And if there is a mistake or misreporting, they have a moral duty and a professional duty to restore the information"* (ES7)

Several groups of stakeholders can play a role in tackling misinformation and fake news. Communication departments of research institutions, governmental agencies, professional associations, and policymakers were pointed out as key players in centralizing information and identifying good spokespeople to avoid sending contradictory information to the media and, more generally, to the public (one-third). Moreover, according to one-quarter of researchers, the public is expected to play a key role in fighting fake news spreading through the development of media literacy and critical thinking skills.

The second major issue identified by the participants was dealing with uncertainty and some problems associated with limited knowledge available, especially during the first months of the COVID-19 pandemic. For many participants, some ways of facing this problem included understanding and presenting how science works (e.g., the scientific method, the timings of science, and science as a process open to change), acknowledging the lack of existing knowledge, and making nuances and uncertainty apparent.

> *"Journalists need to be aware of the complexity and uncertainty associated with the communication of science, in particular with the communication of a pandemic and do not expect definitive answers from scientists"* (IT2)

Finally, a set of practices emerged to improve the effectiveness of science communication and to foster scientific culture, preparing society to deal with future health crises or socio-technical challenges. Concretely, participants acknowledged the benefits of promoting interdisciplinary practices to face complex societal (and communication) challenges. As such, more active and regular

(but never forced) collaborations between scientists and journalists were envisaged. This cooperation was expected to be based on mutual recognition and respect of each other's expertise and complementary roles (i.e., journalists as communication experts, and researchers as scientific/health experts; as stated by almost half of the participants). One-third of the participants also identified the need to create the necessary tools or environments to meet and interact to overcome shortcomings of their interactions and foster collaborations.

> *"If journalists and researchers collaborated (…) the result would probably be better. The journalist is the communication professional and, therefore, s/he is the one who has the know-how to propose certain information in the best way, on the other hand, the researcher is who knows the subject and who can provide a better idea of what aspect of a given topic may be more important and more interesting (...) collaboration would be desirable..."* (IT3)

Maintaining a sustained presence of science and scientists in the media giving visibility to science and technology in problem-solving and, contributing to promote scientific culture and interest in science were also identified as helpful practices. Furthermore, paying attention to risk management communication strategies during a crisis, but more importantly, working in the prevention (pre-crisis) and the analysis of the post-crisis were also identified as important practices to deal with future challenges by some interviewed. Finally, using emotional content was also mentioned by some participants (one in ten), although it was mentioned as a resource to be carefully used when covering topics such as a global pandemic.

In summary, our interviews have revealed that researchers who were in contact with journalists to cover COVID-19-related topics were primarily driven by a sense of commitment to fulfilling society's information needs. Researchers viewed this interaction with journalists as part of their professional responsibilities but also as a way to ensure that citizens were well-informed about evidence-based recommendations and novel findings related to the virus and vaccines. Overall, researchers reported satisfactory experiences with the media, largely attributed to the preparedness of journalists. Unsatisfactory interactions stemmed from various factors, with researchers (lack of media training) and journalists (inaccurate, superficial, or sensationalist coverage) sharing responsibility. To overcome these issues, researchers identified several practices that could facilitate productive science-media interactions. These include enhancing science coverage in the media, providing media training for researchers, and improving journalists' working conditions. Lessons learned from the pandemic highlight the importance of combating mis/disinformation and uncertainty. Researchers can play a significant role in reducing the spreading of inaccurate or false information by taking responsibility for the messages they convey and clearly distinguishing between facts and opinions; on the other hand, journalists can use reliable sources and engage in fact-checking. To address uncertainty and knowledge limitations in reporting, researchers emphasized the need to demonstrate how science works, including its limitations, timelines, and methodologies. They also stressed the importance of conveying nuances and uncertainties to prevent

false expectations. Active and frequent collaborations between researchers and journalists, with mutual recognition and respect in their respective roles, are envisioned as a means to enhance the effectiveness of science communication and effectively tackle future communication challenges.

5. Discussion

Our results show that, in the context of the COVID-19 pandemic, researchers in three Southern European countries were driven by normative expectations and professional responsibility. For most participants, ensuring citizens' right to be informed about the novel COVID-19 research and/or the action plans to fight the disease were their main motivations to encounter the media. Additionally, educational motivations, instrumental arguments, and intrinsic rewards were also stated as main motivations. Overall, these results resemble findings obtained pre-COVID-19 in Northern Europe, North America, and Australia with scientists from several research fields (Gascoigne and Metcalfe, 1997; Dunwoody et al., 2009; Besley and Nisbet, 2013; Dudo, 2013; Besley et al., 2018).

Perceived benefits and concerns derived from these interactions with the media also emerged. Survey respondents emphasized having a better-educated public, more positive public attitudes toward research, and influencing public debate as benefits regarding media contacts; conversely, the risk of incorrect quotations, the unpredictability of journalists, and the possibility of negative publicity were assessed as important factors reducing scientists' willingness to interact with journalists. These findings resonate with pre-COVID-19 results obtained by Peters et al. (2008a,b) in France, Germany, the US, the UK, and Japan with stem cell researchers and epidemiologists. The similarity suggests that regardless of external factors (e.g., research field, country, or the urgency of the situation) scientists manifest consistent reasons and incentives driving their interactions with the media also stressing the persistent nature of the worries and barriers stated by scientists when interacting with the media.

Similar to the journalists' perception of the availability of scientists to interact with the media during the COVID-19 crisis (Massarani et al., 2021), our study also shows that researchers in Italy, Portugal, and Spain believe that scientists were more frequently accessed and cited as sources of information in the media than before the pandemic. Most participants also considered that there was a higher presence of scientific topics in the general media, and a higher openness to talk with journalists and share their pre-print data in the media. These findings stress the increasing medialization of science and scientists (Olesk, 2021), particularly during the pandemic.

Even in a period of high uncertainty, pressures and tensions to respond to the COVID-19 emergency, the relationship between researchers and journalists was positively assessed. Thus, this relationship proved to be resilient to the challenges, tensions, and pressures that both parties underwent during the COVID-19 crisis.

Some of the reasons reported for these satisfactory interactions were associated with the good preparation or previous knowledge of journalists. Several authors have reported similar findings

regarding the favorable appraisal of science-media interactions in other contexts (Peters et al., 2008a,b; Besley and Nisbet, 2013; Peters, 2013; Dudo et al., 2014; Lo and Peters, 2015). This suggests that the exceptionality of the pandemic did not have a significant negative impact on scientists' perceptions of their interactions with the media in the analyzed Southern European countries. Yet, negative encounters were also reported. Practices that promoted poor interactions with the media are associated with a lack of confidence and communication skills and media training to deal with journalists (in agreement with previous works, e.g., Gascoigne and Metcalfe, 1997; Kaye et al., 2011; Dudo, 2013; Dijkstra et al., 2015; Larsson et al., 2019) and with the lack of accuracy, preparation on the topic, and sensationalism that some journalists and media perform (in particular, those not specialized in science coverage; as discussed in Peters et al., 2008b; Petersen et al., 2009).

Regardless of the existence of uneasy interactions, participants recognized the importance of joining forces with media professionals to respond to societal needs for accurate and trustworthy information to confront the COVID-19 crisis. Some of these identified collaborative actions are not novel (Nikunen et al., 2019), although the COVID-19 crisis might have evidenced the urgent need to enhance science-media cooperation based on mutual trust and mutual learning relationships. Other (pre-COVID-19) studies stated that mutual trust contributes to positive science-media relations, e.g., in the form of fruitful interviews (Geller et al., 2005; Kolandai-Matchett et al., 2021).

As shown in this work, practices to overcome some of these concerns and enlarge the mutual benefits of the science-media interactions include a necessary self-reflection of own practices (both for researchers and journalists) as well as the cooperation of both types of actors. A better understanding and reporting of scientific practices and their outcomes (e.g., presenting science as a process open to change, with uncertainties and nuances, rather than an immutable truth) and awareness of scientists' limitations (e.g., lack of formal media training) and structural problems of journalism (e.g., lack of time and resources, or lack of specialization in science coverage) can settle the ground for fruitful and trustful collaborations.

Although more collaborative practices between these actors are desirable, it is also important to consider that challenges can arise. Some of the difficulties have been already identified in literature (e.g., disappointed expectations or misunderstandings related to science news outcomes and each other's roles; Maillé et al., 2010; Kolandai-Matchett et al., 2021) together with some suggestions to overcome them, such as considering the necessary time to build mutual trust and respect as well as common views on news media coverage (Kolandai-Matchett et al., 2021).

The COVID-19 emergency has also posed specific challenges and evidenced communication pitfalls, such as the growing use of preliminary research data (i.e., pre-prints, in many cases not contextualized or identified) in media reporting (Fleerackers et al., 2021; Fraser et al., 2021), difficulties in managing increasing uncertainty (Dunwoody, 2020; Fernandes, 2021; López-García et al., 2021), and the fight of dis/misinformation and global fake news spreading (Mesquita et al., 2020; López-García et al., 2021; Naeem et al., 2021; Muresan and Salcudean, 2023). From the point of view of the participants interviewed, researchers, journalists,

but also other stakeholders (e.g., policymakers, national agencies, and the public) are co-responsible for tackling the infodemic and fighting the far-reaching spreading of inaccurate and false information. This shared responsibility to help the public identify fake news has been also suggested by other authors (e.g., Naeem et al., 2021).

Researchers consider that their contribution to dealing with the problem of misinformation and fake news lies in their responsibility toward the message sent. Participants stated that making a clear distinction between facts and opinions and acknowledging their lack of knowledge and/or capacities on the topic are crucial to avoid sending confusing messages or causing misunderstandings. Showing availability and willingness to respond and clarify any doubts that could emerge when covering COVID-19 research and the possibility of making corrections were also reported as practices that could tackle the dissemination of inaccurate information. These results align with some of the recommendations by Swire-Thompson and Lazer (2020) who proposed that all health communicators (including scientists, the media, governmental bodies, and health practitioners) should actively spread truthful information and increase the correction of misinformation to dispel fake news.

Participants also referred to practices that are indispensable in any journalistic work and that conform the basis of journalists' deontological code, i.e., the distinction between facts and opinions, ensuring reliable and verified information, the inclusion of relevant and reliable sources, and the responsibility of the media toward the information published or broadcasted. As discussed by Mauri-Ríos et al. (2021), following some of these practices was indeed recommended by several international organizations at the beginning of the pandemic. Additionally, fact-checking practices in traditional and new media were also acknowledged as crucial to fight the spreading of rumors and hoaxes and reduce uncertainty related to this novel disease, which aligns with the recommendations of several authors (e.g., Dunwoody, 2020; López-García et al., 2021).

6. Limitations

One of the limitations of our study is its limited scope to the perspective of researchers, thus disregarding the views of journalists. However, although focusing only on one of the actors may narrow our view of these interactions, this allowed us to deepen the analysis of the beliefs, opinions, and experiences of researchers directly involved in COVID-19 research. Second, the group of researchers addressed by our study (i.e., academics and scientists from different fields, including clinical researchers and medical doctors) represents a small (although specific) sample of respondents, allowing us to draw general and specific conclusions about the science-media relationship in three Southern European countries in the context of COVID-19 communication. Future work can address some of these limitations by exploring the perspective of journalists in these three countries, complementing previous work published on this topic (Massarani et al., 2021). Also, enlarging the sample to other scientific fields or emerging research topics, such as artificial intelligence, human-machine interfaces, or renewable energy generation and storage, can also provide insights

into fruitful ways to address the communication of some of these present and future challenges.

7. Final remarks

Taking the perspective of researchers involved in COVID-19 research in Italy, Portugal, and Spain, our findings provide valuable insight into how their interactions with the media developed and into ways to facilitate their consolidation in the future. This study shows that, in comparison with previous studies, the motivations, concerns, and benefits perceived by the scientific community from their encounters with journalists have not substantially changed as an effect of the pandemic. On the contrary, researchers in Southern Europe rated their interactions with the media positively and revealed their openness to maintain a trustful and fruitful cooperation with journalists to ensure citizens' rights to be informed. In the interviews, researchers also provided relevant reflections about their role and the role of journalists, suggesting individual and common practices (addressed to scientists, journalists, or both actors) that could facilitate mutual learning and support their cooperation. Finally, in a context of uncertainty, spreading of fake news, high demand for information and great expectations in science and technology, researchers recognized the opportunities that collaborating with the media can offer to tackle current and future communication challenges. Overall, these results help to advance the understanding of how critical moments, in this case, the COVID-19 pandemic, may affect the science-media relationship and suggest ways to advance in the construction and strengthening of fruitful relationships between scientists and journalists. Moreover, these findings aim to support current and future communicative challenges such as health, environmental and social crises that require joint efforts from multiple societal actors.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Committee of the Faculdade de Ciências da Universidade de Lisboa (CEC/1/2022). The patients/participants provided their written informed consent to participate in this study.

Author contributions

EM-G, AMD, and CL contributed to the conceptualization of the study. EM-G, AMD, ADJ, and CL contributed to the methodology. EM-G and IN collected data. EM-G, IN, and CL conducted data analysis. EM-G wrote the first draft of the manuscript. All authors contributed to the manuscript revision and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm. 2023.1231301/full#supplementary-material

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