1 **Opportunities and challenges for improving a Colombian public research program in plant breeding**

2 **and plant genetic resources lead by AGROSAVIA**

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21 **Author contributions**

22 Carlos H. Galeano, Hugo Jiménez, and Carolina González designed the study. Carlos H. Galeano,

23 Katherine Tehelen, and Ivania Cerón-Souza performed the data analyses and interpretation. All authors

24 wrote the manuscript and approved the final version of the manuscript for publication.

25

26   **Abstract**

27   AGROSAVIA (Corporación Colombiana de Investigación Agropecuaria) is the Colombian state institution in

28   charge of the agricultural research at the national level, including plant breeding. Since 2014, AGROSAVIA

29   started to increase its research staff and has reset the leadership of public research to solve the needs of the

30   agricultural sector population, focusing on small producers. However, the current team working on plant

31   breeding and plant genetic resources are facing some challenges associated with generation gaps and the

32   lack of a collaborative working plan for the next years. To identify the opportunities and actions in this

33   research area, we surveyed all the 52 researchers working in AGROSAVIA in this area in 2017. We analyzed

34   the opinions of researchers to detect the strengths and weaknesses of the program using a sentiment score.

35   We also examined the networking to test both how consolidated the group is and if among top leaders are

36   gender parity and also have a higher academic degree. Results showed that there is a mixed community of

37   old and new researchers with clear gender bias in the proportion of male-female. Within the network, the

38   interactions are weak, with several subgroups where the top-ten of both central leaders and the most

39   influencer are frequently males with mostly an M.Sc. degree but with significant experience in the area.

40   Researchers have an interest in 31 crops. From them, 26 are in the national germplasm bank, but this bank

41   is not the primary source for their breeding programs. The top-five of plants with increasing interest are

42   corn, cocoa tree, golden berries, oil palm, and sugarcane. Researchers also want to establish collaborations

43   with 54 different institutions, where the *Universidad Nacional de Colombia,* which is the top public

44   university in the country, is on the head. Researchers also perceived weaknesses in the marker-assisted

45   selection, experimental design, and participatory plant breeding, but those criticisms have a positive

46   sentiment score average of 1.55 (0.3 SE) across 31 texts analyzed. Based on all results, we identified five

47   critical strategic principles to improve the plant-breeding research program. They include a gender diversity

48   policy to hire new researchers strategically to reduce the gender gap and strength the generational shift.

49   Better collaboration between the national germplasm bank and plant breeding research. A coordinate plan

50   where the studies focus on food security crops that the government supports independently of market

51   trends. And finally, adequate spaces for the project's design and training programs. Hence, we recommend

52   the creation of a consultant group to implement these policies progressively in the next years.

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54   **Keywords:** diagnosis, gender gap, germplasm banks, social networks.

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Introduction

Plant breeding is a field where many complementary disciplines converge to generate more productive and better-adapted cultivars that respond to the challenges of world agriculture. Traditionally, plant breeding depends significantly on the selection of plants based on the evaluation of target agronomic traits, increasing the frequency of favorable alleles. The primary outcome of a plant breeding program is to increase crop productivity (i.e., yield, resistance to diseases and pests) and specific crop adaptation (i.e., tolerance to heat, frost, drought or salinity). Moreover, other desirable traits for plant breeding are the development of new processing alternatives (i.e., culinary quality, milling, fermentation, biofuel production, postharvest storage, and shelf life) and consumer acceptance (i.e., flavor, protein content, oil profile, fiber quality, nutritional value) [1].

Currently, the world requires more productive cultivars to provide enough food for the constantly growing human population, which will reach an extraordinary number of 9,000 million people by 2050. Therefore, world food production must increase from 25% to 70% compared with 2014 [2]. Moreover, due to global warming, there is an urgent need to develop varieties with high nutritional value and adaptation to stresses such as droughts, floods, frosts, and certain soils, but also to pests and diseases ([3,4]. In this context, new methodologies and tools based on genomics are helping in the generation of more accurate data for better characterization of the genetic diversity of crops and the association of critical phenotypic traits with genome regions [1,5].

In Colombia, research on plant breeding began in the 50s, directed by DIA (*Departamento de Investigaciones Agrarias*). At that time, a large group of experts developed the first successful plant varieties in different crops such as corn and potato (i.e., Diacol H104 and Diacol Capiro, respectively). During this period, DIA becomes ICA (*Instituto Colombiano Agropecuario*), starting an essential collaboration with the Rockefeller Foundation. In this period, research was focused actively in areas such as plant breeding, plant pathology, and plant physiology. A large group of researchers from ICA was granted with fellowships to carry out M.Sc. and Ph.D. studies, as well as research training outside the country. Besides, ICA led the creation and consolidation of the National Germplasm Bank of Colombia for agricultural purposes and also several genetic improvement programs with a multidisciplinary research scope [6]. Both government initiatives contributed to establishing the first national master's degree program in genetics and the first breeding program in collaboration between ICA and *Universidad Nacional de Colombia*. During the next 30 years, ICA produced and released a large number of plant varieties, mainly corn, wheat, barley, oat, rice, and potato, which generated high impact and benefits for producers in the country. In the early 90s, the government created AGROSAVIA (previously known as Corpoica) as a national research institution in agriculture, leaving ICA only in charge of the phytosanitary control, inspection, and surveillance functions. Unfortunately, at the end of the 90s, government priorities changed, and the research

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95   budget for agricultural research, including plant breeding programs, was severely affected. Due to these

96   unfortunate decisions, the national plant breeding research goal shifted to carry out field assessment of

97   plant varieties developed by International Centers such as CIAT (International Center for Tropical

98   Agriculture), CIMMYT (International Maize and Wheat Improvement Center) and CIP (International

99   Potato Center).

100

101   From 2014, the national government, through Law Project No. 1731, approved by the Colombian Congress,

102   promised to assign an annual budget to support and promote the agricultural research programs in

103   AGROSAVIA. Since then, AGROSAVIA has increased its research capacity progressively through the

104   incorporation of new research staff as well as new infrastructure. Currently, the central core of researchers

105   working in plant breeding and plant genetic areas are young Ph.D. researchers trained in the use of both

106   conventional and cutting-edge methodologies and tools for the selection and development of new plant

107   varieties. However, AGROSAVIA is still working on different strategies to accomplish its objectives. From

108   2014 until 2016, the main focus was the creation of research networks based on national agricultural

109   production chains. Then, from 2017 until today, AGROSAVIA has been working to consolidate disciplinary

110   groups [7]. As part of this strategy, this study aims at characterizing the challenges and future opportunities

111   for the current plant breeding and plant genetic resources (PB&PGR) group established in AGROSAVIA.

112   Based on the results of this study, we identified the most important crops to future projects, the external

113   institutions better to collaborate, and five critical strategic principles to strengthen a public plant breeding

114   research program in Colombia lead by AGROSAVIA.

115

116   **Materials and methods**

117

118   In February 2017, we surveyed the total of the 52 researchers from AGROSAVIA that, in that year, were

119   working on PB&PRG projects. We designed an online Google questionnaire divided into three sections: (1)

120   The group description, (2) Challenges and opportunities in the PB&PGR area, and (3) the construction of a

121   social network based on the links within the PB&PRG group and externals (i.e., from other disciplines in

122   AGROSAVIA and outside institutions) in six different scientific activities during the last ten years.

123

124   We performed all the statistical analyses and visualization using different R-packages under R Studio

125   1.2.5001. For section (1) and (2), we used PLOTRIX 3.7-4 [8] and GGPLOT2 3.3.1 [9] to compare age, gender

126   identity, highest academic degree, years of experience, and rank category among the 52 researchers from

127   the PB&PGR group in AGROSAVIA. Moreover, we identified and counted the crops that researchers worked

128   in the last ten years and compared them with the list of plants that researchers want to continue working in

129   the future and separate them into three categories, such as increasing, equal or decreasing interest among

130   the 52 researchers. Furthermore, we counted how many times the researches have been using the National

131   Germplasm Bank in their projects and the name of the external institutions that researchers consider key to

132 working collaboratively in the future. Also, we asked the 52 researchers to agree or disagree with ten

133 questions associated with identifying the strengths and weaknesses across different activities and skills in

134 the area. The questions were: (1) Should PB&PGR group participates in advising and training students and

135 young professionals?, (2) should PB&PGR group open spaces for journal clubs and research discussion?

136 (3) Have students and young professionals a good knowledge of quantitative genetics? (4) Have students

137 and young professionals a good understanding of fieldwork? (5) Have PB&PGR researchers a good

138 understanding of MAS (Marker-Assisted Selection)? (6) Have PB&PGR researchers a good knowledge of

139 experimental design? (7) Have PB&PGR researchers a good understanding of G (Genetic) x E

140 (Environment) models? (8) Have PB&PGR researchers a good understanding of quantitative genetics? (9)

141 Have PB&PGR researchers a good knowledge of molecular plant breeding? And (10) have PB&PGR

142 researchers a good understanding of participatory plant breeding?

143

144 Finally, section (2) had an open question asking for comments or suggestions to improve the PB&PGR

145 group in the future. Because we got 31 different answers, we made a corpus text mining analysis that

146 included a sentiment analysis and a word cloud. The first step was to translate the 31 texts from Spanish to

147 English using the free software DEEPL (https://www.deepl.com/translator) and reviewed by hand securing

148 the automatic translation was the closest possible to the original meaning. Then, we cleaned the corpus

149 under the R-function GSUB and the R-package TM 0.7-7 to remove punctuations, numbers, empty spaces,

150 stopwords, and a list of words associated with the workplace and research area (i.e., AGROSAVIA, plant

151 breeding, plant genetic resources, etc.). Finally, using the R-package STRINGR 1.4.0, we broke each text into

152 its characters to compare them with a positive and a negative list of words [10,11]. Both the positive and

153 negative words identified weight one. Thus, we generated a sentiment score for each text subtracting the

154 number of negative words from the number of positive words count. If the score was positive, the opinion

155 has a positive sentiment. But, if the score was negative, the sense of the text is negative. We calculated the

156 average and the standard error of the sentiment score across the 31 opinions. Moreover, we generated a

157 word cloud based on the 30 most frequent words across the corpus under the R-package WORDCLOUD 2.6.

158

159 For section (3), we used the R-package IGRAPH 1.0.1 [12] to construct a two-way social network for

160 analysis that consist in 48/52 researchers from the PB&PGR group that specified 812 interactions within

161 the group but also with 116 external researchers (i.e., either with other disciplines within AGROSAVIA and

162 outside institutions). We asked for six class of interactions among researchers, such as collaboration on

163 projects in the PB&PGR area, discussion about new advances in the PB&PGR area, germplasm interchange

164 or request, preparation of scientific papers and grey literature, registration of new varieties and technical

165 advising. For each class, we compared the number of interactions within researchers from the PB&PGR

166 group vs. between PB&PGR researchers and external.

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168   In the network, we calculated and ranked the degree and the influence for each one of the researchers (i.e.,

169   vertex). The degree is a measurement of the number of adjacent interactions (i.e., edges). We associated the

170   top-ten of the degree score, with the highest academic degree of the PB&PGR researchers to test the

171   hypothesis that as a higher educational degree, higher interactions. Moreover, we measured the influence of

172   each researcher based on two related statistics, the hub, and the authority scores. The hub score measures

173   the interactions that a researcher has with different relevant influential researchers (i.e., authorities). Thus,

174   the hub researchers are those that work together with trustworthy researchers on a common topic.

175

176   In comparison, the authority score measures the number of links of interactions that a researcher earned.

177   Therefore, an authority researcher is one that should have relevant information on the field and, thus,

178   received more links from other researchers. These two scores reinforce mutually because a good hub hint at

179   many competent authorities; and, a proper authority is pointed to by many good hubs [13]. We associated

180   the top-ten of both hub and authority scores with the gender information of PB&PGR researchers to test the

181   hypothesis that researchers' influence is independent of gender.

182

183   For the overall network, we calculated four descriptive statistics (i.e., the width, the edge density, the

184   average distance, and the transitivity) to diagnose how researchers are working together within and outside

185   the PB&PGR group. The diameter, the density, and the mean distance indicate together how connected the

186   network is. In other words, they measure the ability of information to run through the system. Thus, for a

187   tied network (i.e., with fewer intermediates across interactions and higher direct connection), we should

188   expect lower diameter, higher density, and smaller mean distance. Likewise, the transitivity measures the

189   local-scale-structure of the network. Thus, weak transitivity suggests that interactions occur in clusters

190   loosely connected. In comparison, high transitivity indicates a well-consolidated system without a chance

191   to identify discrete internal subgroups [14].

192

193   The methodology of this study was revised and approved by the biotetichs committee of AGROSAVIA. All

194   researchers surveyed were verbally notified about the purpose of the study and voluntarily accepted to

195   participate. Moreover, all the surveyed researchers knew and discussed the results during the second

196   workshop of plant breeding and plant genetic resources celebrated in The Tibaitata Researc Center of

197   AGROSAVIA during March 22-24, 2017.

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199

200   **Results**

201

202   **The group description.** We found an apparent gender disparity among researchers working on PB&PGR

203   within AGROSAVIA. The 71% (n=37) are male, and 29% (n=15) are female, and none declared a gender

204   identity outside the binary male-female. The 40% (n=21) of both male and female researchers are between

6

205   31-40 years old. Male researchers are present in all age ranges, but female researchers are more frequent at

206   younger intervals of age. There are only two female researchers in the age group of 51-70, and none are

207   older than 60 years (Fig.1A).

208

209   Moreover, male researchers are present in all AGROSAVIA'S rank and all ranges of ages of experience

210   within the PB&PGR group. In comparison, female researchers are only distributed in five of the eight

211   categories, and with mostly 1-10 years of experience. However, no female researcher has more than 30

212   years of experience (Fig. 1B). Concerning the education background, the 52% (n=27) are M.Sc. researchers

213   (20 male and seven female), and 27% (n=14) are Ph.D. researchers (seven male and seven female) (Fig.

214   1B). Considering lower academic degrees, both men and women studied only in Colombia. Nevertheless,

215   there is a gender imbalance associated with studies abroad. From 37 male researchers, 14 (nine M.Sc. and

216   five Ph.D.) studied abroad. In contrast, from 15 female researchers, four obtained their Ph.D. degree abroad

217   (Fig. 1C).

218

219   **Challenges and opportunities in the PB&PGR area**. Researchers from AGROSAVIA have a broad

220   spectrum of investigation experience in at least 31 crops. From this list, 19 species showed an increased

221   research interest (i.e., more researchers interested in future projects than currently working on them), three

222   species with equal importance between past and future research plans and nine species with decreased

223   interest (i.e., few researchers interested in future projects than currently working on them) (Fig. 2).

224   Although the National Germplasm bank conserves 26 of the 31 species from the list, the survey showed

225   that this germplasm bank, also administered by AGROSAVIA, is not the primary focus of pre-breeding and

226   breeding programs. The 37% (N=19) of the researchers have never used the germplasm bank, and 40%

227   (N=21) have used once or twice in the last ten years (Fig. 3). Finally, researchers working on PB&PGR are

228   interested in establishing collaborations with different 54 universities and research institutions inside and

229   outside of Colombia in the next years. The most relevant was the *Universidad Nacional de Colombia*, with

230   23 researchers interested in collaborating. Moreover, 29 researchers want to establish partnerships with

231   three of the CGIAR (Consultative Group for International Agricultural Research) bases within and outside

232   of Colombia, such as CIAT (Colombia), CYMMIT (Mexico), and CIP (Peru). Finally, other research

233   institutions with at least six researchers looking for collaborations are Embrapa (Brazil), CIRAD (France),

234   and Cenicaña (Colombia) (Fig. 4).

235

236   We found that researchers perceived weaknesses in fieldwork, Marker Assisted Selection (MAS),

237   experimental design, and participatory plant breeding skills. Moreover, the researchers feel that they should

238   contribute more actively to advise and train students and young professionals, as well as leading in journal

239   clubs and research discussion spaces (Fig. 5). The opinion of 31 researchers about how to improve the

240   group agreed in three main points: (1) work as a network where the different PB&PGR researchers benefit

241   from the knowledge of others members of the group in several areas and disciplines, (2) work jointly with

242   other researchers that are strong in other subjects such as plant physiology and plant phytopathology and

243   (3) improve our impact by focusing on very few strategic crops but developing a multidisciplinary long-

244   term research program. The top-five of the most used words include "programs, network, knowledge,

245   improvement, and researchers" (Fig.6). The opinions and the most frequent words enclosed were

246   purposeful, with a positive sentiment score average of 1.55 (0.3 SE) across 31 texts analyzed.

247

248   **Social network.** The network had 166 researchers, 48 from the PB&PGR group (with metadata

249   associated) and 118 external, either from AGROSAVIA or other institutions. The 166 researchers had 812

250   two-ways interactions among them. We found apparent differences in the number of interactions depending

251   on the types analyzed. The registration of new varieties had the lowest number interaction (N=50), whereas

252   the collaboration in projects in the area had the highest number of interactions (N=242) within the network.

253   Moreover, only two types of links among researchers (i.e., germplasm interchange or request and

254   discussion about new advances in the area) showed more interactions within the PB&PGR group than

255   between PB&PGR and external researchers (Fig. 7).

256

257   Across the network, the diameter was 8, the edge density was 0.03, and the mean distance was 3.07. These

258   values suggest a loose network with many intermediate researchers across interactions among researchers.

259   Likewise, the transitivity was 0.17. This low value indicates a weak system characterized by several

260   discrete and identifiable subgroups.

261

262   In the center of the network are the researchers with more influence (i.e., more interactions with other

263   researchers). In contrast, in the periphery are mostly external researchers (Fig. 8A). The top-ten researchers

264   with more interactions (i.e., more degrees in the network) are all from the PG&PGR group, mostly males

265   (N=8) with an M.Sc. degree (N=6) with most of 20 years of experience in the field (N=7) who are currently

266   in the process of retirement during the next two years (Fig. 8B). From them, seven and six researchers are

267   also in the list of the top-ten of hubs and authorities, respectively.

268

269   The top-ten of influencer researchers are more diverse (i.e., a broader range of years of experience in the

270   area, and three external researchers in the authorities list). However, similar to the degree score, they are

271   mostly men (i.e., N=8 in both groups) typically with an M.Sc degree (i.e., eigh and six for hubs and

272   authorities, respectively). Spite of females are a minority as influencers; a female researcher got the top

273   score in both hubs and authorities top-ten researchers (Fig. 8C and 8D).

274

275   **Discussion**

276

277   The growing world population, climate challenges, and the loss of agrobiodiversity are the main focus of

278   plant breeders and plant genetic resources managers nowadays. These challenges require that researchers

8

279   work together using a trans-disciplinary approach to produce results that finally generate an impact in our

280   societies. This study represents the challenges and opportunities that AGROSAVIA should focus on

281   improving in the next years.

282

283   **The population of researchers and their background and collaboration networks**

284

285   AGROSAVIA researchers that work in PB&PGR have a high level of scholarly with broad expertise in plant

286   breeding, plant physiology, and plant production, among others. Although this experience is essential for

287   helping move forward the development of a productive research program over the next years in

288   AGROSAVIA, this study shows the value of decreasing gender gaps, strengthening the generational shift, and

289   improving internal collaboration among different age groups.

290

291   Our results showed strong gender bias in the composition of researchers working on plant breeding and

292   plant genetic resources. Although in AGROSAVIA, the global proportion of male/female researchers was

293   1.63 in both 2017 and 2018, in our survey, the ratio of 2.45 is worst [15]. Several studies focused on gender

294   equality support that the agricultural sciences are a male dominate research area [16,17]. Consequently,

295   crop sciences, horticulture, and agricultural engineering worldwide describe a female/male global ratio of

296   0.435, 0.449, and 0.241, respectively [18]. Moreover, according to UNESCO, females working in

297   agricultural and veterinary sciences are just 37.6% of the research population [19].

298

299   This gender disparity also agrees with the proportion of male/female ratio graduates in the Agronomy and

300   Veterinary sciences in Colombia. Currently, the ratio is 1.30 for bachelors, 1.27 for M.Sc., and 1.44 for

301   Ph.D. [20]. Moreover, the Agronomy Faculty from the *Universidad Nacional de Colombia* in Bogotá,

302   which represents the largest public university in the country, has a proportion of male/female students of

303   1.76 and 2.57 among professors staff [21]. For this reason, although this faculty represents only 2.7% of all

304   the student population, it is the third most male-biased across all faculties in the university [22].

305

306   Also, our results showed that fewer women researchers in AGROSAVIA obtained their M.Sc. and Ph.D.

307   degrees abroad compared to men. This result suggests that in Colombia, it is still socially more challenging

308   for women to study overseas compared to men. Unpaid care and housework are strongly biased toward

309   female population in Colombia in two indicators, the total number (i.e., 89.5% of females vs. 62% of males

310   assuming those responsibilities) and time (i.e., 7:03 h for females vs. 3:30 h for male spend for those unpaid

311   tasks in 24h). Thus 12.7% of females declared no free time compared with 8.1% of males [23]. Moreover,

312   female Colombian scientists reported a robust androcentric environment at all levels. Therefore, the

313   combination of unpaid care and housework strongly biased toward women, a patriarchal academic

314   background, and vertical and horizontal segregation pursuing a scientific career may be hindering the

315   mobility of women researchers abroad ([20,22].

316

317   On the other hand, the network analysis allowed us to identify that the top-ten of influencer researchers in

318   the area of plant breeding and plant genetic resources within AGROSAVIA are not evenly distributed neither

319   by the highest degree or the gender, as we hypothesized [24]. The survey showed that the current

320   proportion of researchers with M.Sc. and Ph.D. degrees has a ratio of 2:1. Nine of the M.Sc. researchers

321   have outstanding productivity that has to lead them to reach the category of Associate or Senior.

322   Accordingly, the network showed a concentration of interactions (i.e., degree score) based mainly on male

323   researchers with an M.Sc. degree and with plenty of experience in the area. Likewise, these researchers are

324   the ones who show the highest number of connections with other external actors, probably because their

325   investigative journey has allowed them to expand the number of colleagues with whom they interact.

326   Despite this, the research community is not well consolidated yet. Direct collaboration is scarce, and

327   therefore, it was evident the existence of loosely connected clusters with rare collaborations outside of these

328   subgroups. (Fig. 8). Although AGROSAVIA needs to focus on these key actors (nodes) as the best way to

329   communicate and transfer innovation within the entire PB&PGR network, the main obstacle is that these

330   identified leaders are close to their retirement age in the next four years.

331

332   The network analysis also showed that AGROSAVIA researchers maintain strong links with many external

333   researchers not included in the survey. This result suggests that those foreign actors are influential

334   consultants for the design of a breeding program strategy. Therefore, the collaborative agreements that

335   AGROSAVIA is constructing with several institutions inside and outside the country must encourage the

336   formulation of projects that allow them to maintain and strengthen these known external collaborations.

337   Finally, this analysis allowed us to identify productive isolated groups of young researchers that are in the

338   periphery of the network, but that in the future should be in the center of the system, leading projects.

339

340   The data collected in this study strongly support the urgency to construct a gender diversity policy

341   combined with a generation shift program in the PB&PGR area. Currently, AGROSAVIA is a flourishing

342   national institution for agronomic research. Therefore, it is essential that within a gender diversity policy,

343   encourage more interactions among older researchers, characterized by their leadership and commitment,

344   with the creativity and dynamism of younger researchers. This strategy that supports diversity and inclusion

345   would increase AGROSAVIA'S reputation, making this an attractive working place, especially for women

346   and gender-diverse researchers within the agronomic area.

347

348   Currently, AGROSAVIA is progressively growing the number of Ph.D. researchers formed in Colombia or

349   abroad in the scientific staff [25]. Moreover, AGROSAVIA has an equal pay policy for females and males

350   across different research rank categories. Therefore, new hiring calls in the area should emphasize this

351   favorable policy to attract more women and gender-diverse researchers in future work calls to replace the

352   current leaders that are close to retirement. Moreover, a gender policy that starts and grows internally

353   could provide an excellent opportunity to promote agricultural development with a gender perspective

354   across different projects lead by AGROSAVIA [26,27].

355

356   Finally, the analysis of improvement networks in corn and wheat in Mexico showed similar patterns that

357   we found in this study [28]. Therefore, this approach could be used in the future for the plant breeding

358   group to manage resistance genes in different crops [29], to understand the dynamics of seed distributions

359   [30] and to determine strategies in grain production [31]. Furthermore, additional analysis using a national

360   survey and publication databases will provide a broad picture of how plant scientists in Colombia are

361   collaborating and what can be improved on institution governance to increase and support these

362   collaborative relationships [32].

363

364   **Research experience and skills in the discipline**

365

366   Researchers working on plant breeding and plant genetic resources in AGROSAVIA have two noticeable

367   interests for current and future research: 1) tropical fruits for international markets and 2) food sovereignty

368   and food security (Fig. 2). However, results also show that there is not a direct relationship between

369   experience and interest on a specific crop with the impact of new varieties released. For instance, maize

370   was the first crop in the list with a high number of researchers involved in breeding and genetics, but also,

371   with increasing interest to work with in the future. This result makes sense because Colombia consumes 6.2

372   million tons of maize per year, and this crop is of critical importance for food security and the economy of

373   small farmers. However, Colombia imports more than 70% of the maize mainly from the United States and

374   Argentina, and there is not a public maize breeding program focused on open-pollinated varieties or hybrids

375   to fill the needs of small farmers [33]. Although Mexico faced the same problem as Colombia today, where

376   imports jeopardized the local maize production, they found a solution. In 2010, the CIMMYT (International

377   Maize and Wheat Improvement Center) and SAGARPA (*Secretaría de Agricultura, Ganadería, Desarrollo*

378   *Rural, Pesca y Alimentación*) of the Mexican Government, successfully started MasAgro. This joint

379   initiative goal is to increase maize productivity, profitability, and sustainability [34]. The MasAgro effort

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380 achieved a significant increase in maize production and food self-sufficiency within the country by

381 implementing programs for specific management practices, hybrid seeds, and direct sale in maize markets

382 [35]. Based on this effective result, we suggest constructing similar long-term initiatives and synergies with

383 the Colombian government that support the local production for food security crops, such as maize, beans,

384 quinoa, cassava, and potato, independent of the market trends.

385

386 Successful breeding programs worldwide usually start with the use of the broad genetic germplasm base.

387 Thus, collecting, conserving, and characterizing genetic resources are mandatory to introgress novel alleles

388 into elite materials. Colombia has a large National Plant Germplasm Bank with an extensive collection of

389 native and introduced crops [36]. Three current factors are helping improve this situation in the future.

390 First, since 2015, the National Plant Germplasm Bank is working on an ambitious five-year project that

391 aims at implementing a user-friendly GrinGlobal platform for curators and users [37]. Second, as part of the

392 same project, new approaches such as genomics for a robust characterization of collections are beginning to

393 be used [38]. Currently, results for two critical crop collections, such as potato [39]and cacao [40], are

394 available for the public. Soon, we expected to publish similar results for avocado and other native crops.

395 Third, starting in 2018, AGROSAVIA was officially delegated by the Ministry of Agriculture to manage the

396 Germplasm Banks for food and agriculture [7]. Therefore, we expect that in the next future, a combination

397 of active management, genomic characterization, high-throughput phenotyping, and genomic selection will

398 increase the introgression accuracy of novel germplasm into a breeding program [41,42].

399

400 This study also revealed that the base of strategic alliances that are being constructed by AGROSAVIA with

401 national or regional institutions focused on conventional crops (Fig. 4). For instance, Colombia is

402 validating technologies or varieties generated on other institutions, such as cassava, beans, forages, and rice

403 from CIAT, maize from CIMMYT, and potato from CIP. Further, a new collaboration with high ranked

404 research institutions and universities such as Wageningen University, CIRAD, and USDA are opening new

405 possibilities to co-lead international research initiatives using cutting-edge technologies and novel breeding

406 approaches to switch from being technology adopters to generators of our knowledge and technology.

407 Besides, the current context of a knowledge-based economy in which experience plays a vital role in

408 economic growth, the growing relationship with universities as a critical player in the national innovation

409 system, becomes essential. An example of this is South Korea that has evolved from being a developing

410 state to a developed country [43]. Thus, the synergistic and collaborative work of AGROSAVIA with public

411 and private universities has to be a priority. However, the innovation model also involves the industry into

412 the triple helix paradigm where university, industry, and government try to understand and then facilitate

413 and enable collaboration and cooperation between these components to boost national innovation

414 performance [44].

415

12

416   Researchers surveyed expressed worrying issues, such as generational inclusion, powerlessness, capacities,

417   and training opportunities in new areas (Fig. 6 and 7). Our results suggest that researchers are facing a

418   change influenced by the new networking model and the entrance of at least seven new researchers in the

419   area of genetics and plant breeding in the last four years. This situation can explain individual resistance

420   attitudes, usually governed by the anxiety that causes sudden changes in what is conventional or traditional,

421   but also by the broad differences in ages, experiences, scientific productivities, and abilities of the current

422   plant breeding group in AGROSAVIA [45,46]. Although these results require more detailed analyses, the first

423   approximation suggests that AGROSAVIA needs to quickly address this assortment of concerns to structure

424   and consolidate a robust PB&PGR group, especially in all those areas that are demanding more time or

425   better training.

426

427   **Conclusions**

428

429   This study is a pivotal input to understand the challenges and opportunities for researchers in the areas of

430   PB&PGR in a state institution as AGROSAVIA. Based on our analysis, we propose five principles to start

431   working within the next years: 1) The urgent implementation of a gender diversity policy in AGROSAVIA,

432   combined with a generation shift program that allows contracting a new generation of women and gender-

433   diverse researchers. 2) The construction of long-term initiatives and synergies with the Colombian

434   government to support the local production of food security crops independent of market trends. 3) Better

435   collaboration between the National Plant Germplasm Bank and plant breeding researchers. 4) A concerted

436   priority list of species and external institutions to focus the collaborative efforts in plant-breeding research.

437   5) Better spaces for the ideation and design of projects among researchers, as well as training programs in

438   border areas associated with plant breeding and plant genetic resources management. Furthermore, we also

439   suggest creating a consultative group to include these five principles across the high-impact research

440   proposals in the generation of new cultivars that respond to biotic and abiotic challenges of national

441   agriculture.

442

443   **Acknowledgments**

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570

571   **Figures**

572

573   **Figure 1.** The characterization of a population of 52 researchers working in Agrosavia that participated in
574   this study counting the number of researchers by (A) age range, (B) rank category in AGROSAVIA, and (C)
575   the highest academic degree obtained in Colombia and abroad separated by gender. The horizontal scales
576   represent the number of researchers, males at the left, and females at the right.

577

578   **Figure 2**. List of crops indicating in each line, the number of researchers in AGROSAVIA that work or have
579   worked with these in the last ten years (blue dots), and the number of researchers that consider relevant to
580   continue working with these in the future (yellow dots). There are three groups according to the patterns
581   between past and future research interest, thus: crops with increasing interest, crops with similar interest in
582   the historic vs. the future, and crops with decreasing interest in the future.

583

584   **Figure 3**. The frequency that researchers working on plant breeding and plant genetic resources from
585   AGROSAVIA have requested germplasm from the National Plant Germplasm Bank of Colombia in the last
586   ten years. The color of the bars is increasing from the five categories analyzed, from never to higher than
587   five times.

588

589   **Figure 4.** The number of researchers working on plant breeding and plant genetic resources from
590   AGROSAVIA interested in starting collaborative breeding initiatives with national and international research
591   institutions and universities. In parenthesis is the country of origin of each institution.

592

593   **Figure 5.** List of ten questions on challenges and opportunities associated with research in plant breeding
594   and plant genetic resources within AGROSAVIA. The color bars represent the opinion of the 52 researchers
595   surveyed, indicating in percentage the level of agreement for each question. The categories from left to
596   right: strongly disagree, disagree, neutral, agree, strongly agree.

597

598   **Figure 6.** Graphic representation of a word cloud analysis of the 52 opinions about how to improve the
599   plant breeding and plant genetic resources group in AGROSAVIA.

600

17

601   **Figure 7**. The six types of interactions among 48 researchers from the plant breeding and plant genetic

602   resources (PB&PGR) group in black and 116 external (E), including other disciplines within AGROSAVIA

603   and outside institutions, in grey. The six types of interactions appear from the lower to the highest number

604   of total connections. Within the parenthesis is specified the number of interactions for both within the

605   PB&PGR group and between the PB&PGR and externals. The dots represent the researchers (i.e., vertex in

606   the network), and the lines represent the interactions (i.e., edges in the system). The dots are in different

607   colors by type from the lower to the highest number of total connections.

608

609   **Figure 8.** Graphic representation of the network analysis of 48 researchers working in plant breeding and

610   plant genetic resources in AGROSAVIA and 118 externals, including researchers from other disciplines

611   within AGROSAVIA and outside institutions. (A) Distribution of researchers (nodes) and their interactions

612   (edges) separating the 48 researchers from the PB&PGR group and 118 external. (B) Characterization of

613   researchers (nodes) by the degree score (i.e., size of the circle) and highest academic degree (i.e., color).

614   The degree score indicates the number of adjacent direct interactions with other researchers. (C)

615   Characterization of nodes by the hub score (i.e., size of the circle) and gender (i.e., color). The hub score

616   indicates the number of outward links that have each researcher with others. (D) Characterization of nodes

617   by the authorities score (i.e., size of the circle) and gender (color). The authority score indicates the number

618   of interactions that receive each researcher from others.
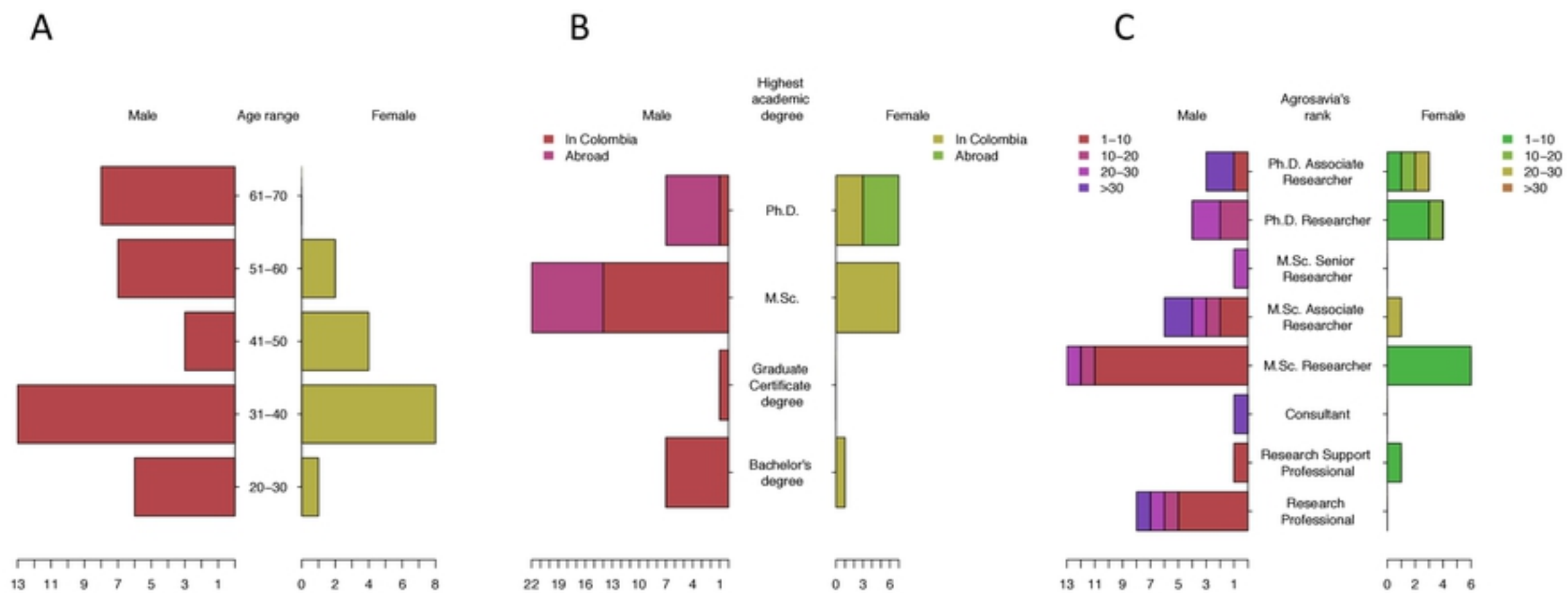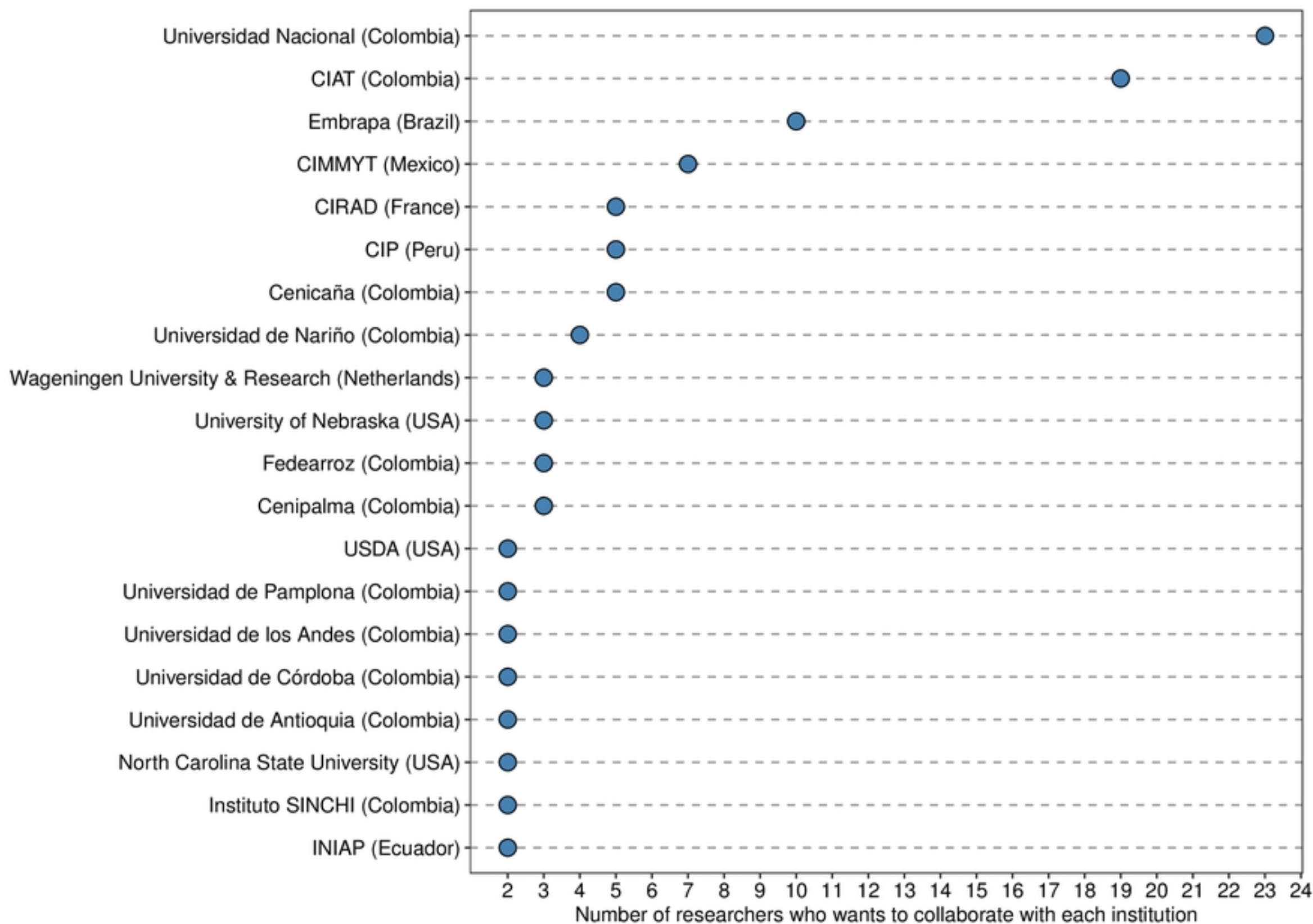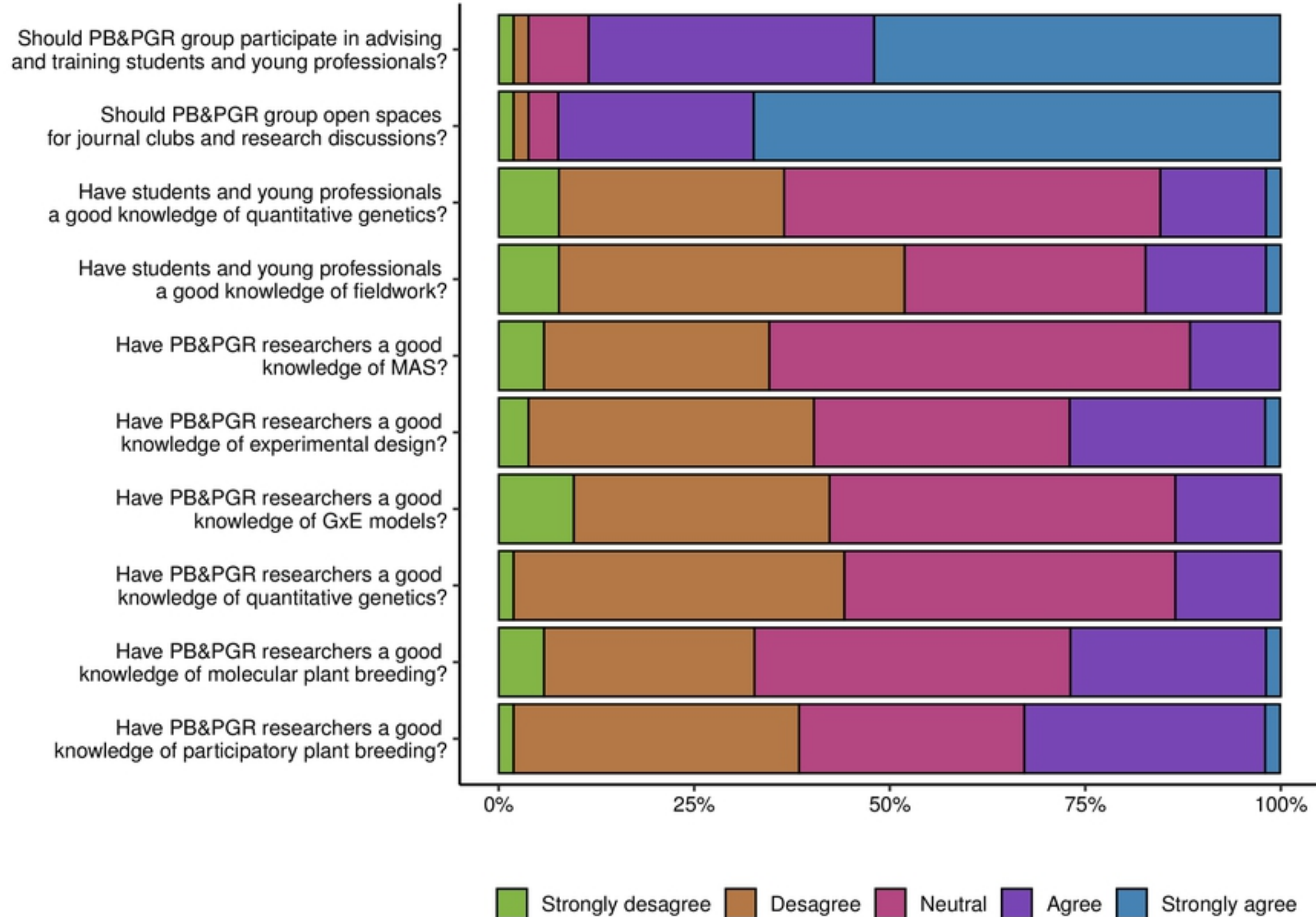
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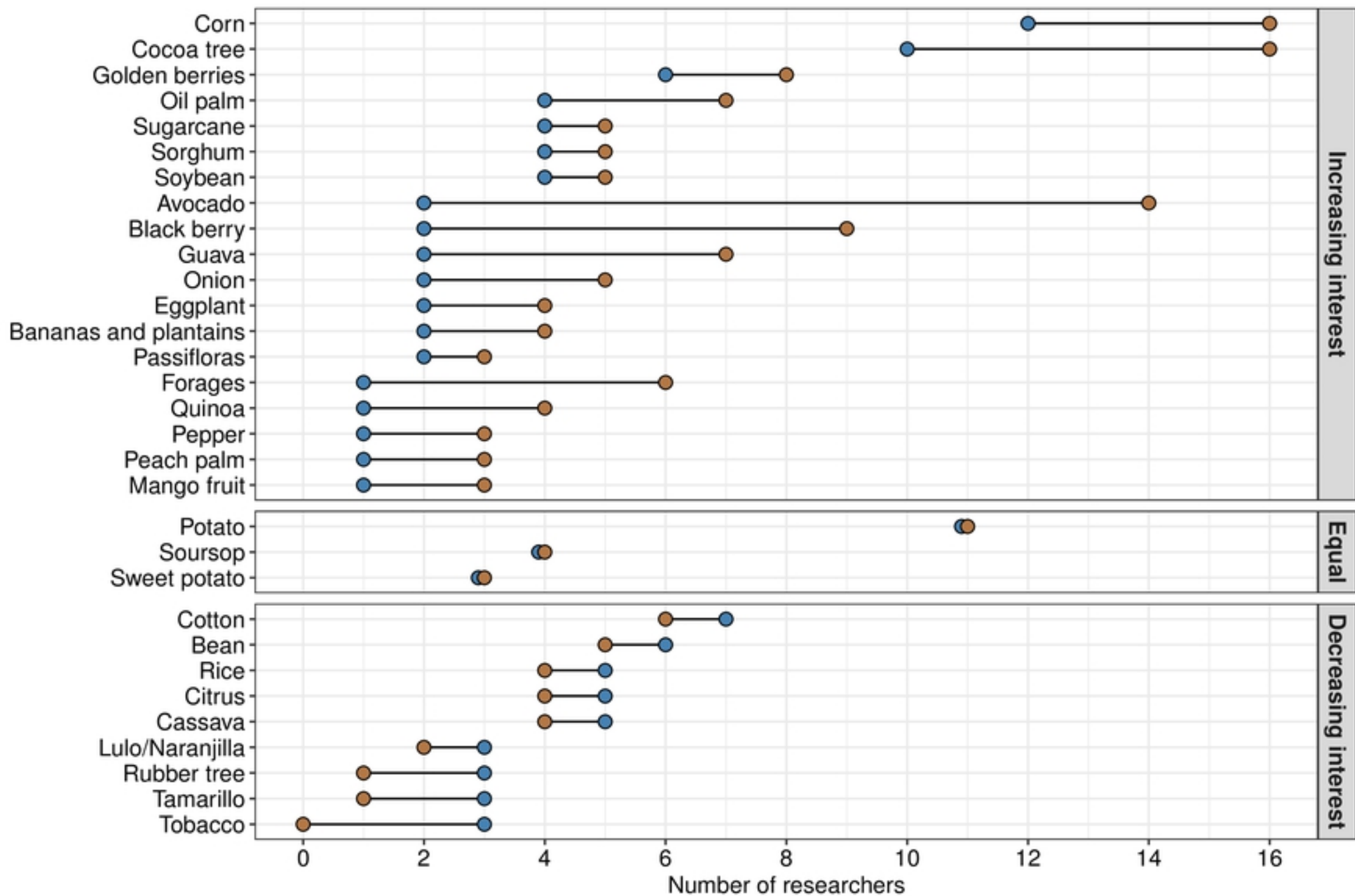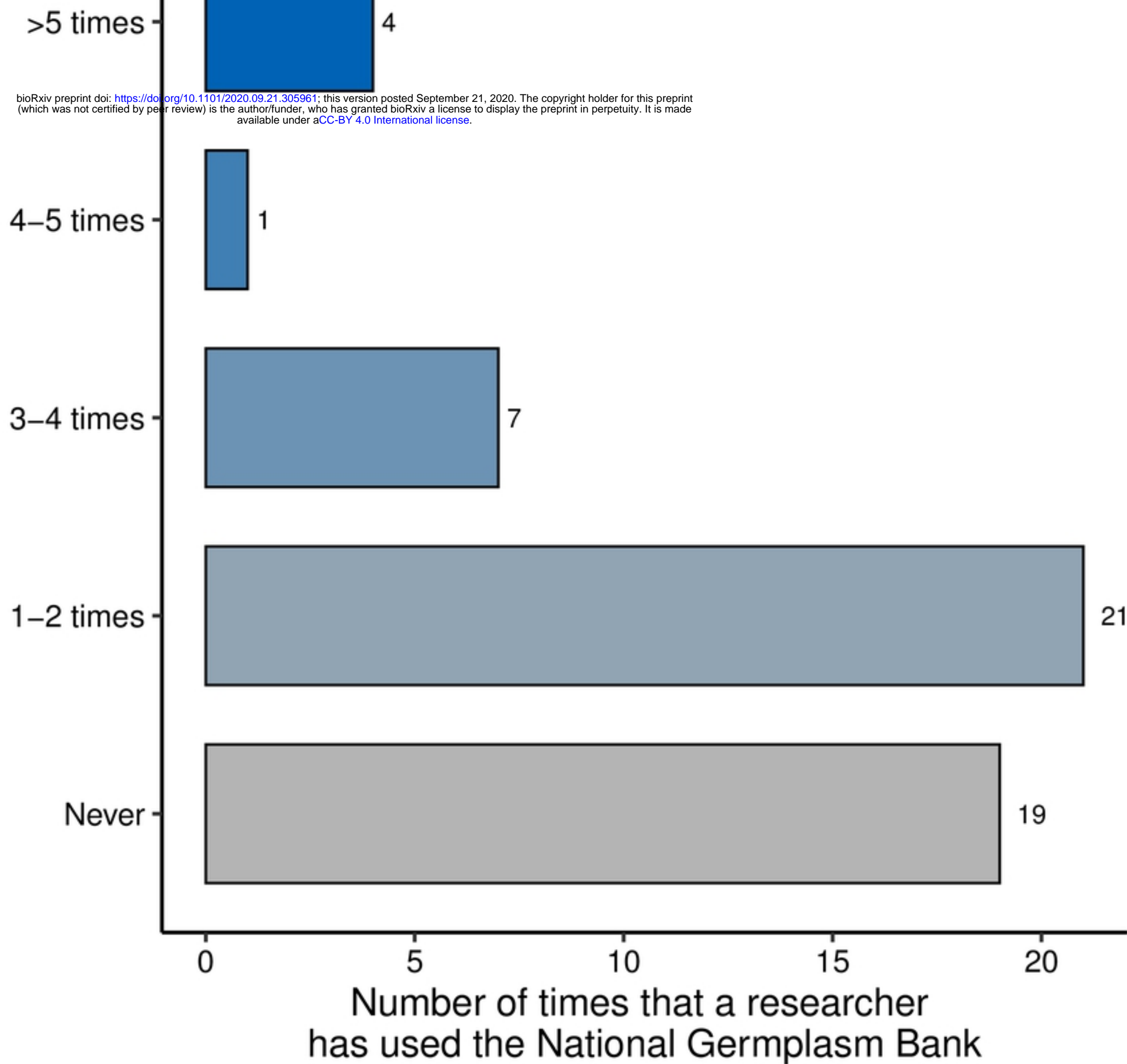
Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

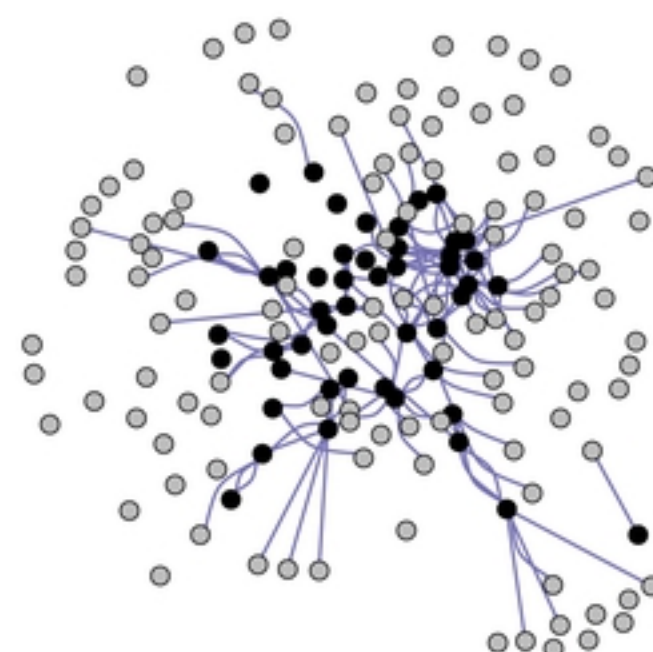Registration of new varieties – N=50
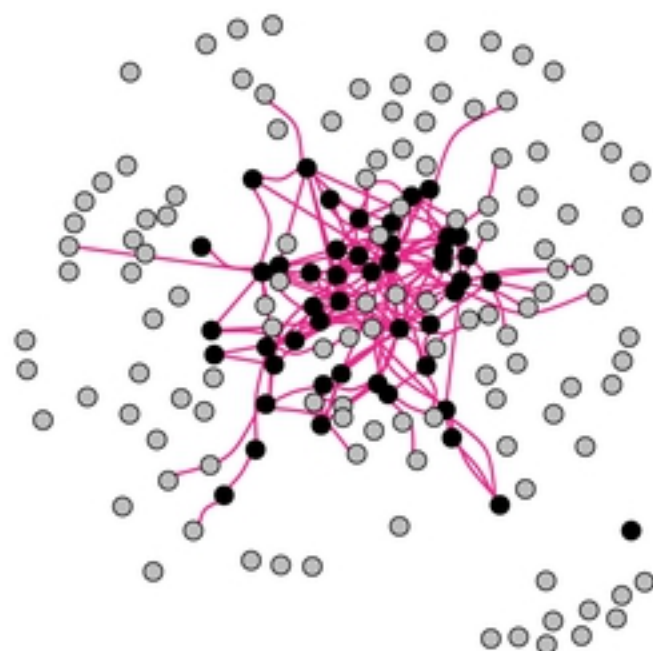(21 within PB&PGR and 29 among PB&PGR–E)

Germplasm interchange or request – N=76
(41 within PB&PGR and 71 among PB&PGR–E)
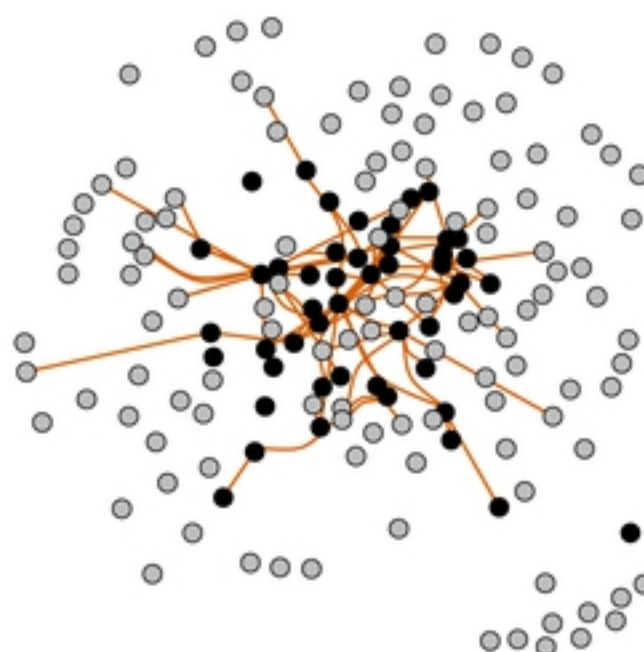
Preparation of scientific papers and grey literature – N=112
(41 within PB&PGR and 71 among PB&PGR–E)

● Plant breeding & plant genetic resources group (PB&PGR)
◯ External (E)

Discussion about new advances in the area – N=156
(101 within PB&PGR and 55 among PB&PGR–E)

Technical advising – N=176
(83 within PB&PGR and 93 among PB&PGR–E)
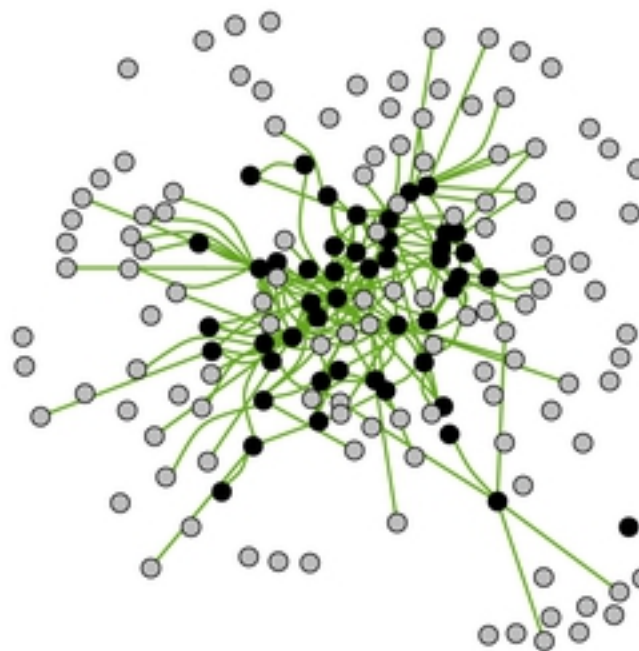
Collaboration on projects in the area – N=242
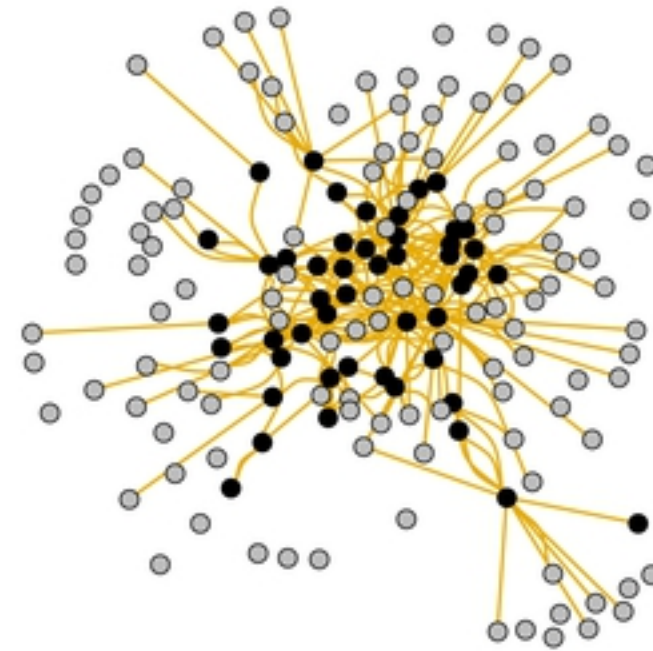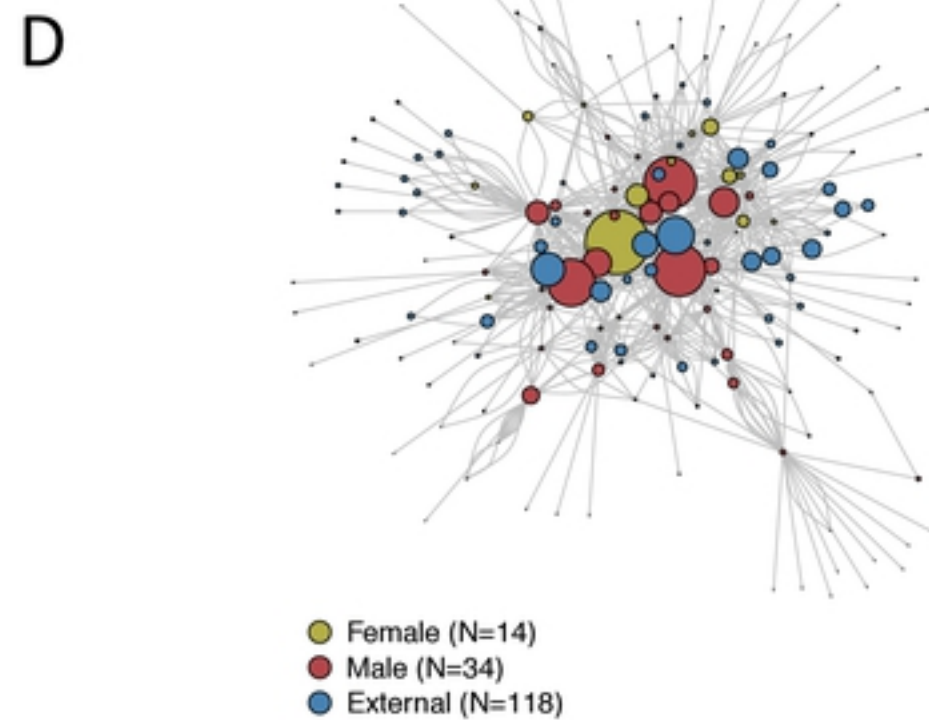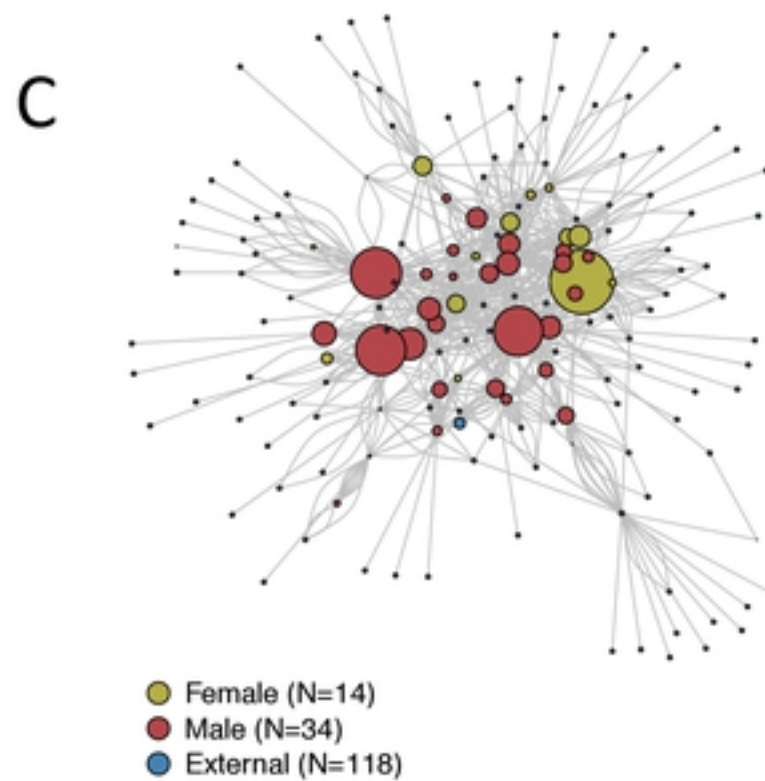(101 within PB&PGP and 141 among PB&PGP–E)
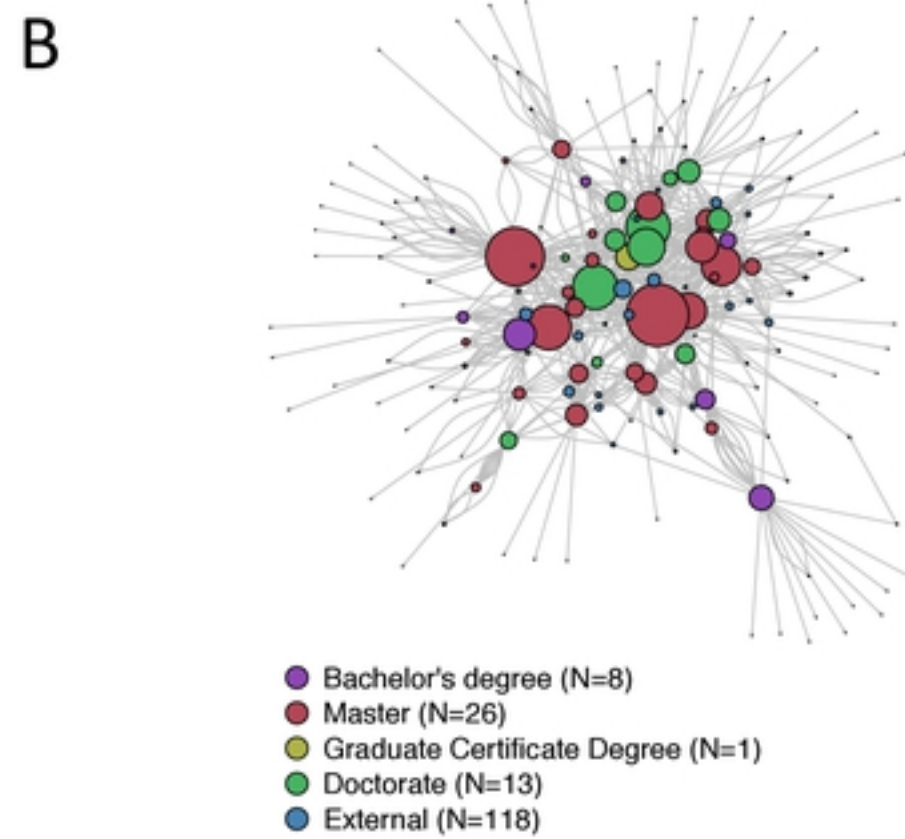
Figure 7

A

Plant breeding & plant genetic resources group (N=48)
External (N=118)

B

Bachelor's degree (N=8)
Master (N=26)
Graduate Certificate Degree (N=1)
Doctorate (N=13)
External (N=118)

C

Female (N=14)
Male (N=34)
External (N=118)

D

Female (N=14)
Male (N=34)
External (N=118)

Figure 8