

A critical analysis of plant science literature reveals ongoing inequities

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1 **ABSTRACT**

2 The field of plant science has grown dramatically in the past two decades, but global
3 disparities and systemic inequalities persist. Here, we analyzed ~300,000 papers published
4 over the past two decades to quantify disparities across nations, genders, and taxonomy in the
5 plant science literature. Our analyses reveal striking geographical biases—affluent nations
6 dominate the publishing landscape and vast areas of the globe having virtually no footprint in
7 the literature. Authors in Northern America are cited nearly twice as many times as authors
8 based in Sub-Saharan Africa and Latin America, despite publishing in journals with similar
9 impact factors. Gender imbalances are similarly stark and show remarkably little improvement
10 over time. Some of the most affluent nations have extremely male biased publication records,
11 despite supposed improvements in gender equality. In addition, we find that most studies focus
12 on economically important crop and model species and a wealth of biodiversity is under-
13 represented in the literature. Taken together, our analyses reveal a problematic system of
14 publication, with persistent imbalances that poorly captures the global wealth of scientific
15 knowledge and biological diversity. We conclude by highlighting disparities that can be
16 addressed immediately and offer suggestions for long-term solutions to improve equity in the
17 plant sciences.

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20 **SIGNIFICANCE STATEMENT**

21 We analyzed ~300,000 papers published over the past two decades to quantify global,
22 gender, and taxonomic disparities in plant science. Our analyses reveal striking geographical
23 biases that are correlated with national affluence. Gender imbalances were also evident, with far
24 more papers led by authors with masculine names than authors with feminine names. Lastly, we
25 identified substantial taxonomic sampling gaps. The vast majority of surveyed studies focused
26 on major crop and model species and the remaining biodiversity accounted for only a fraction of
27 publications. Taken together, our analyses represent an important addition to the growing
28 conversation about diversifying and decolonizing science.

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31 **INTRODUCTION**

32 Plant science research is accelerating at a rapid pace. New technologies and expanding
33 infrastructure have opened the door for cutting-edge research to be conducted at monumental
34 scales. Despite this noteworthy growth, access to resources is not evenly distributed across the
35 globe and recent studies have revealed striking participation gaps and longstanding disparities
36 tied to colonialism, economic inequality, and systemic biases (1-6). Plant science, which, for the
37 context of this study, we define broadly as *any research investigating an organism that performs*
38 *photosynthesis*, suffers from acute historical exclusion and ongoing underrepresentation of
39 marginalized identities (7). In Northern America, associations between plant science and
40 agriculture with colonialism, slavery, and the exploitation of migrant workers (8) have
41 contributed to a notable lack of diversity in the discipline. Global economic disparities,
42 established under imperial colonialism and perpetuated through modern eurocentric
43 frameworks, further exacerbate underrepresentation of diverse perspectives in plant science (9,
44 10, 3). Researchers working in low-income countries and under-resourced institutions face

45 multiple barriers to participating in plant science research, including limited funding
46 opportunities, reduced access to cutting-edge technologies and infrastructure, and exclusion
47 from collaboration networks (5,11). In the field of plant genomics for instance, few projects have
48 been led by researchers in the Global South, despite the striking biodiversity and extensive local
49 botanical knowledge within these regions (3). These dynamics are reinforced by a eurocentric
50 framework that centers English language standards, Latin binomial naming conventions, and
51 reductionist thinking. Coupled with historical and ongoing expropriation of plant germplasm from
52 the Global South, this has resulted in a system that unjustly benefits certain individuals and
53 excludes others. A first step of addressing these inequalities is to quantify patterns of
54 participation in plant science.

55 Both race and gender compound with global economic disparities to generate emergent
56 barriers for people of color and individuals with marginalized gender identities (2, 12). For
57 example, women of color are uniquely oppressed across multiple axes in ways that amount to
58 more than the sum of their racial and gender identities (12). Although our analyses do not
59 address race directly, we explore global patterns with links to imperial colonialism that cannot be
60 understood without an acknowledgement of race and the persistent oppression faced by people
61 of color, especially Black and Indigenous communities. Our analyses address patriarchy,
62 sexism, and gender dynamics more directly. Patriarchy can be described as a way of living that
63 privileges all men over women and some men over other men, and the politics of patriarchy can
64 be understood as “the politics of domination – a politics that rationalizes inequality” (13).
65 Systems of patriarchy vary in their manifestation and severity across the globe, but are
66 pervasive and have infiltrated all levels of society including scientific research (14–17). While
67 self-identified women are not excluded from the field of biology as a whole, they are often
68 excluded from prestigious tenured and editorial positions as well as collaboration networks (7,
69 18–20). Studies suggest that gender biases also exist in hiring, publication, and funding
70 decisions (6, 19, 21–25). These inequities impact academic currency on job and funding
71 markets and further exacerbate imbalances in academia. Quantifying the extent and patterns of
72 gender bias in plant science is an important step in creating a more equitable discipline.

73 Despite noteworthy efforts made towards cataloging all life, research attention has not
74 been equally distributed across study systems and many species remain underexplored. In
75 plant genomics, for example, there are substantial taxonomic gaps—multiple clades lack a
76 reference genome assembly while other clades have dozens of sequenced species (3, 26, 27).
77 These findings suggest that research attention has been disproportionately directed towards a
78 few select species with agricultural and economic relevance to modern society. Focusing on
79 these elite crop and model species has enabled noteworthy scientific breakthroughs and
80 agricultural innovations, but it has come at the cost of exploring the rich biodiversity of wild
81 plants and regionally important crops. With species extinction rates at an all-time high (28, 29),
82 much of this biodiversity could be lost before it is understood scientifically. Participation gaps
83 likely contribute to taxonomic sampling gaps in complex and context dependent ways. For
84 example, the exclusion of Indigenous perspectives from science has removed valuable
85 knowledge of local biodiversity and diverted resources away from regionally important plants
86 (30). Together, these factors exacerbate the patriarchal and eurocentric system of publication,
87 and result in a body of literature that poorly represents the global wealth of biological diversity
88 and knowledge.

89 To better understand the changing global landscape of plant science research and
90 quantify patterns of underrepresentation, we conducted a large-scale bibliometric analysis of
91 nearly 300,000 papers published across the past two decades of plant science research. Our
92 analyses are framed from the perspective of the first axiom of Ardila-Mantilla which states that
93 scientific potential is “distributed equally among different groups, irrespective of geographic,
94 demographic, and economic boundaries” (31). If we take such a statement to be the null
95 hypothesis, then disparities in educational advancement and promotions, funding, or publication
96 and citation rates indicate that other factors, like oppression, have created historical and
97 contemporary biases in science. To test this hypothesis, we identified the demographic features
98 (e.g., nationality and gender) associated with high publication and citation rates and quantified
99 taxonomic sampling gaps and regional differences in focal organism choice to explore
100 associations between participation gaps and study organisms. We examined how these
101 dynamics change over time and space to identify areas that are improving, stagnant, or
102 regressive. We close by discussing the need to dismantle oppressive systems in the plant
103 sciences, improve equity, and how such changes will ultimately advance the field in the coming
104 decades.

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107 **RESULTS**

108 We compiled a database of 296,447 plant science papers published between 2000 to
109 2021. Papers were sourced from a representative set of 127 plant science journals based in 26
110 different nations across 5 continents, covering 21 different subspecialties. We included both
111 society and for-profit journals in our analyses, with open access, hybrid, and subscription
112 publishing models (see Supplementary Dataset S1 for journal information). The database we
113 assembled does not capture the entire breadth of plant science and related fields as many
114 regional and subject specific journals are not included here. As such, these analyses represent
115 an important but non-exhaustive step towards quantifying inequities in plant science.

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117 ***Geographic disparities in publication and citation rates***

118 To gain insight into the global landscape of plant science research, we summarized
119 geographic differences in publication and citation numbers. Vast areas of the world have
120 virtually no footprint in the plant science literature over the past two decades (Figure 1A) and
121 publication rate is tightly correlated with national affluence. On a continental level
122 (Supplementary Figure 1A), nearly one third (27%) of all papers were led by authors based in
123 Europe, another 18% were led by authors in Northern America, and 37% by authors in Asia.
124 The remaining 17% of publications were led by authors distributed across Africa, Latin America,
125 and Oceania. Within each continent, authors were further consolidated into distinct hubs of
126 research activity, with the USA, China, and Western Europe dominating the plant science
127 landscape (Figure 1A). National publication rates were highly correlated with Gross Domestic
128 Product (GDP) ($R^2=0.75$, $F_{1,140}=213$, $p=3.18e-43$) (Figure 1B) and investment in research and
129 development ($R^2=0.83$, $F_{2,117}=295$, $p=2.08e-46$) (Figure 1C and Supplementary Figure 2A). Both
130 relationships follow a power law, as reflected by a linear relationship in logarithmic plots.
131 However, some individual nations performed better (or worse) than expected. Many emerging
132 economies such as India, South Africa, Mexico, Pakistan, Nigeria, Trinidad and Tobago, Iraq,

133 and Madagascar produced far more publications than expected relative to the money invested
134 in research and development. In contrast, some high income nations, particularly in
135 Scandinavia, Northern Europe, and the Middle East produced far fewer publications than
136 expected relative to the money invested in research and development (Figure 1C and
137 Supplementary Figure 2A). There was very little correlation between publication rate and per
138 capita income ($R^2=0.23$, $F_{2,136}=20$, $p=1.68e-08$) (Supplementary Figure 2B). Based on the
139 United Nations' income classifications of high, upper-middle, lower-middle, and low income
140 (Supplementary Figure 1B), we found that 61% of all papers published in the last 20 years were
141 led by authors in high income nations. Another 32% were led by authors in upper-middle income
142 nations, and the remaining ~7% of publications were distributed among lower-middle nations.
143 Less than 1% of papers were led by authors in low income nations.

144 The plant science landscape has changed over the past 20 years. While research output
145 in high income countries has remained relatively stable, there has been a 10-fold increase in the
146 number of papers from upper-middle income nations in the past two decades. In fact, by 2021,
147 there were more papers published by authors in upper-middle income nations than by authors in
148 high income nations (Figure 2A and B). However, this increase was driven primarily by China,
149 which accounted for more than 60% of the publication output from upper-middle income nations
150 in 2020. Other emerging economies such as India, Brazil, Iran, South Africa, Mexico, and
151 Argentina have also made noteworthy contributions to the increased research output of upper-
152 middle income nations (Figure 2C). Publication rates in lower-middle and low income nations
153 have also increased in the past two decades, but still lag far behind those of high and upper-
154 middle income nations (Supplementary Figure 3). In some cases, noticeable decreases in
155 research activity appear to correlate with national disasters and war (e.g. Syria's annual
156 publications declined sharply in the past 10 years (Supplementary Figure 3A)). Despite
157 noteworthy growth in plant science research, many countries remain underrepresented in the
158 literature.

159 In general, productivity is expected to scale with population size following a power law,
160 such that larger cities produce more research output than smaller ones (32–34), and this is what
161 we observed in the plant science literature (Supplementary Figure 4). However, this scaling was
162 variable across the globe. In general, cities in Northern America, Northern Europe, and Oceania
163 had above average research output relative to population size. In contrast, cities in Asia, Africa,
164 and Latin America had below average research output relative to their population size (Figure
165 2A). Taken together we find that high income nations produced a higher proportion of their
166 research in rural areas, whereas lower income nations concentrated research activity in high-
167 density, urban areas. This is noteworthy because high income nations in Northern America,
168 Europe and Oceania account for less than 10% of the rural population globally (Supplementary
169 Figure 5) but produce more than 64% of the plant science research.

170 International and intercontinental collaborations were strikingly uncommon in the past
171 two decades of plant science research (Figure 4 and Supplementary Figure 6). More than two
172 thirds (71%) of the publications in our database were written by authors based in a single
173 nation. Just 22% of studies involved a collaboration between two nations, and only 5% of
174 studies included three nations. Less than 1% of studies involved four nations even though 71%
175 of papers have four or more authors, and just 0.04% included five nations despite the fact that
176 54% of papers had five or more authors. When international collaborations did occur, they

177 tended to be across continents rather than within continents. Only Europe-based authors
 178 showed a high frequency of within-continent collaboration (Supplementary Figure 6).
 179 Collaborations across continents did occur but were not evenly distributed. Most nations
 180 preferred to collaborate with researchers in Europe, Northern America, or China (Figure 3), and
 181 were less likely to collaborate with authors in Latin America, Africa, or West Asia. A similar
 182 pattern is evident when considering income groupings—only the most affluent nations
 183 participated in within-group collaborations, and all other nations preferred to collaborate with
 184 high income nations (Supplementary Figure 6).

185 Despite striking differences in research output, the mean impact factor of the journals
 186 that papers were published in spanned just over one point across continents—ranging from 2.92
 187 ± 0.017 for papers led by authors in Sub-Saharan Africa to 4.06 ± 0.011 in Northern America
 188 (Table 1). In contrast, citation rates were substantially more variable across continents. In
 189 general, papers from the Global South received dramatically fewer citations than those from the
 190 Global North, despite publishing in journals with similar impact factors. For example, mean
 191 cumulative citations ranged from 17.82 ± 0.304 for papers led by authors working in Sub-
 192 Saharan Africa to 36.75 ± 0.298 in Northern America (Table 1)—a twofold difference. This
 193 dynamic has remained relatively stable over the past 20 years, with persistent differences in
 194 annual citation rates between continents (Supplementary Figure 7). Some individual nations
 195 (e.g., China) have seen improvements in citation rates over time, but most have not.

196
 197 **Table 1.** Continental averages and standard error for the impact factor of journals that authors published in and mean
 198 number of citations that papers received.

<i>Continent</i>	<i>Mean impact factor</i>	<i>Mean cumulative citations</i>
<i>Northern America</i>	4.06 ± 0.011	36.75 ± 0.298
<i>Oceania</i>	3.67 ± 0.022	31.99 ± 0.621
<i>Europe</i>	3.94 ± 0.008	31.21 ± 0.193
<i>Asia (minus China and West Asia)</i>	3.53 ± 0.008	26.32 ± 0.210
<i>North Africa and West Asia</i>	3.05 ± 0.017	23.00 ± 0.409
<i>China</i>	4.13 ± 0.009	21.69 ± 0.159
<i>Latin America and the Caribbean</i>	3.13 ± 0.011	18.57 ± 0.240
<i>Sub-Saharan Africa</i>	2.92 ± 0.017	17.82 ± 0.304

199
 200 We also investigated how journal policies such as open access fee and society
 201 membership related to participation rates for authors with different identities. Of the 296,447
 202 papers examined, only 14% were published Gold open access. Authors in Northern America
 203 and Asia published the highest proportion of open access papers (23% and 18% respectively).
 204 In contrast, only 10-15% of papers led by authors based in Africa, Latin America, and West Asia
 205 were published open access. Of the 16,641 papers published in “elite” journals (with impact
 206 factors above seven), 68% were led by authors in high income nations, compared to 61%

207 overall, and another 15% were led by authors based in China. The remaining 17% were
208 distributed across authors in lower income nations. Citation rates were extremely skewed within
209 these journals. For example, papers led by authors in high income nations were cited 82 ± 0.23
210 times whereas papers from low income nations were cited only 24 ± 0.86 times—a fourfold
211 difference. In general, society journals did not exhibit any more geographic equality in
212 publication and citation rates than the overall trend. Of the 158,711 papers published in society
213 journals 63% were led by authors in high income nations and these received almost double the
214 number of citations (38.9 ± 0.217) compared to papers led by authors in low income nations
215 (20.3 ± 1.767).

216

217 ***Persistent gender inequalities in the plant sciences***

218 We quantified the effects of patriarchy and gender discrimination in plant science
219 publishing by associating author names with masculinity or femininity. We acknowledge that a
220 binary gender division is an oppressive concept in itself and that true gender is self-identified
221 (35), and we recognize the proximity of our approach to the harmful practice of gender
222 inference. However, we find that we cannot discuss patriarchy and gender discrimination
223 without employing the concept of gender. We purposefully seek to avoid inferring the gender
224 identity of individuals and instead measure the oppressive effects of patriarchy associated with
225 the names themselves. We focus on the normative association of names with masculinity or
226 femininity to measure these effects, and do not presume to know the true gender identity of
227 authors. We further acknowledge that biases in name-based gender inference can arise from
228 the global diversity of cultural naming systems (36). The accuracy of name-based gender
229 prediction varies considerably across ethnicities and is notably poor for East Asian names (37,
230 38). This is indicative of yet another layer of bias that has resulted in a eurocentric set of tools
231 and analytical frameworks. Improved algorithms that can handle a diversity of naming
232 conventions and accommodate non-binary gender classifications are needed (39). We have
233 tried to adhere to the five principles for ethical gender inference articulated by (38) still, we
234 struggled with the ethics of algorithmic gender inference within our working group and must
235 acknowledge that in conducting such analyses, we too are culpable in propagating the gender
236 binary anew. Given the caveats and obvious shortcomings of name-based gender inference, we
237 urge all readers to interpret these findings with caution.

238 We hypothesized that individuals with marginalized gender identities (including women,
239 non-binary, gender non-conforming, trans, and people of multiple sexes/genders) would face
240 barriers to participation in plant science and that these would compound with socioeconomic
241 disadvantages and/or historical oppression to further limit participation by intersectional
242 individuals. We cannot test this hypothesis directly without knowing the gender identities of the
243 authors in the paper, so we aimed to instead measure perceptive discrimination based on
244 sexism, that disadvantages individuals with names normatively associated with femininity (40,
245 41). To test this prediction, names of corresponding authors for each paper were isolated and
246 classified as either 1) names normatively associated with masculinity (NNMs) or 2) names
247 normatively associated with femininity (NNFs) and used as a proxy for gender.

248 Globally, there were far more papers led by authors with NNMs than authors with NNFs
249 (Figure 4A and B). However, the degree of gender imbalance varied considerably across
250 continents and nations. Among the 20 nations with the highest publication rates, the most NNM

251 biased nations were Japan (14% NNF), India (21% NNF), Netherlands (23% NNF), Switzerland
252 (24% NNF), and Israel (25% NNF). In contrast, the least NNM biased nations were Poland (61%
253 NNF), Argentina (57% NNF), Italy (41% NNF), Brazil (41% NNF), and Spain (38% NNF). On a
254 continental level, Latin America and Europe had the highest proportions of papers led by
255 authors with NNFs whereas Northern America, Asia, and Oceania had the lowest proportion of
256 NNFs. There has been a modest increase in participation by individuals with NNFs over time,
257 but gender ratios remain far from equal across much of the globe (Figure 5).

258 There was no correlation between national GDP and the proportion of papers led by
259 NNFs ($R^2=0.013$, $F_{2,116}=0.78$, $p=0.46$) (Supplementary Figure 7A). In fact, some of the highest
260 GDP nations had the lowest proportion of NNF authors. There was a similar lack of relationship
261 between per capita income and the proportion of NNF authors ($R^2=0.099$, $F_{2,113}=6.22$,
262 $p=0.0027$) (Supplementary Figure 8B).

263 There was no significant difference in the impact factor of the journals that authors with
264 NNFs versus NNMs published in. However, there were noteworthy differences in the number of
265 citations these papers received. Papers led by authors with NNMs were cited on average 5
266 more times than those led by authors with NNFs. This pattern has not improved over time and, if
267 anything, the difference in annual citations for authors with NNFs versus NNMs has expanded
268 (Supplementary Figure 8).

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270 ***Taxonomic gaps in focal species studied in the plant sciences***

271 Funding priorities and research activities have historically focused on a narrow subset of
272 described plant species (3, 42, 43) and we expected to find notable taxonomic sampling gaps in
273 the current dataset. To test this prediction, we identified all taxonomic entities mentioned in
274 abstracts via natural language processing. We then summarized overall patterns and
275 geographic differences in the choice of focal species to identify taxonomic sampling gaps and
276 regional patterns.

277 There were 73,527 unique taxonomic entities represented in our publication database.
278 While the majority of studies focused on plants, we also identified numerous non-plant species
279 including pathogens, symbionts, and other interactors across animalia, fungi, and bacterial
280 groups (Figure 6B). All the top 20 most studied plants represent economically important crop
281 species or models developed by the plant research community (Figure 6A). The model plant
282 *Arabidopsis thaliana* was by far the most studied plant in the past two decades, appearing in
283 four times as many studies as the next most common species wheat (*Triticum aestivum*) (Figure
284 6A). Poales was the most studied order with over 50,000 mentions, followed by Brassicales,
285 Fabales, and Solanales (Supplementary Figure 10). Many orders were statistically over- or
286 under-represented in the dataset relative to their species richness. The most over-represented
287 orders were Brassicales, Poales, Solanales, Fabales, and Cucurbitales. In contrast, the most
288 under-represented clades were Asterales, Asparagales, Gentianales, Polypodiales, and
289 Lamiales (Figure 6C).

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292 We also identified regional differences in the choice of focal organisms. Most high
293 income nations with high publication rates tended to focus on *A. thaliana*, grain crops,
294 vegetables, fruits, and model species (Figure 7). In contrast, many of the nations

295 underrepresented in publishing, tended to focus on lesser-known species and minor or
296 regionally important crops. This finding exemplifies how underrepresentation at the human level
297 impacts the diversity and breadth of focal organisms and research directions.

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300 **DISCUSSION**

301 Our analyses reveal striking geographical biases in plant science research that are
302 associated with national affluence. Global patterns of wealth distribution cannot be understood
303 without an acknowledgement of the impact of imperial colonialism and the resulting
304 consolidation of resources within select nations of the Global North (3, 9, 44). Not only was
305 wealth redistributed during this process, but diverse perspectives and peoples were effectively
306 erased from science as a eurocentric worldview was exported across the globe. Christian
307 missionaries, European traders, and inquisitive researchers all helped to spread frameworks of
308 capitalism, patriarchy, and white supremacy. In biology, these value systems are coupled with a
309 precedence for the English language, reductionist thinking, Latin naming conventions, and
310 biased standards of academic excellence that further exclude individuals from non-European
311 backgrounds. We identified strong correlations between publication rates, GDP, and research
312 and development expenditure. In general, high income nations spent a higher proportion of their
313 GDP on research and development and this led to higher publication output. This finding
314 highlights the privilege of being able to invest in research and development at all, and most
315 lower income nations do not have the necessary funds to support a robust research sector.
316 However, many lower income nations published far more papers than expected relative to their
317 research and development expenditure, while many higher income nations published less than
318 expected. Admittedly, some research output is not captured here because it does not flow into
319 traditional plant science publishing channels and may, instead, be represented by growth in
320 other academic, private, or governmental sectors. Still, this finding gives us reason to pause and
321 recognize the noteworthy accomplishments of scientists from less affluent nations who are
322 doing more with less—an impressive testament to the resourcefulness, creativity, and ingenuity
323 in these regions.

324 Research output is also associated with increased population density. However, we
325 detected regional differences in this pattern. High income nations (especially in Northern
326 America and Oceania) generated a substantial proportion of their research in rural areas, which
327 makes intuitive sense since plant science is inherently linked to agriculture and natural spaces,
328 and numerous research centers and Land-grant Universities have been built in rural regions.
329 However, lower income nations did not produce many papers in rural areas and instead
330 concentrated research activity in urban centers. We suspect that this pattern is driven by the
331 fact that rural areas are often the last places to be developed and still lack basic infrastructure
332 across much of the globe (45). The differences in rural development impact where research is
333 conducted and contribute to the exclusion of rural peoples and agricultural communities in less
334 affluent nations from the scientific discussion. Only 8% of the world's rural population lives in
335 Europe, Northern America, and Oceania, but these areas produce more than 64% of the plant
336 science papers. The remaining nations have a disproportionately small publication footprint and
337 the knowledge of ecology, ethnobotany, and agriculture from local and indigenous communities
338 within these areas is largely absent from the literature. These voices and perspectives are often

339 co-opted by researchers from affluent nations through parachute science and other colonialist
340 practices, with no acknowledgment, consultation, or compensation for the discoveries (46).
341 Such gaps in participation undoubtedly translate into gaps in understanding and represent a lost
342 opportunity. These harmful practices have perpetuated persistent inequity in the field.

343 International and intercontinental collaborations were notably uncommon in the past two
344 decades of plant science research. Of the few international collaborations that we identified, the
345 majority involved a collaborator from Europe, Northern America, and to a lesser degree, China.
346 We suspect that differences in resources (both financial and infrastructural) contribute to these
347 dynamics. Researchers working in high income nations have access to more funding for
348 research, engaging collaborators, and traveling to conferences. Researchers in less affluent
349 nations do not have the same funding opportunities and are therefore limited in the number and
350 type of collaborations they can participate in, as well as the research activities they can
351 undertake. There may also be more subtle and problematic factors driving the skewed
352 collaborative networks we observed. Differences in institutional prestige, born out of eurocentric
353 mindsets, have led some to believe that the best science is done in select institutions in the
354 Global North and that working at or collaborating with those institutions is most desirable. We
355 believe that this rationale is fundamentally flawed and should be dismantled. Affluent nations
356 could do more to engage collaborators in less represented regions of the globe instead of
357 following the well-established global network. Not only would this help to equalize the plant
358 science landscape, but it would enrich our science by bringing in the wisdom of different
359 perspectives.

360 We identified striking and persistent gender biases in plant science publishing. Given the
361 caveats and shortcomings of name-based gender inference, making specific claims about the
362 gender of individuals or small groups should be avoided, but the overarching patterns identified
363 here are representative. Over 70% of publications in the past two decades were led by authors
364 with masculine names. The extent of gender imbalance was variable across nations and
365 continents but showed remarkably little change over time. In most regions, we detected only
366 modest increases in the number of papers led by authors with feminine names over the past two
367 decades. Interestingly, some of the most affluent nations (e.g., USA, Japan, Netherlands,
368 Switzerland, Germany, Canada, and New Zealand) had extremely male biased publication
369 records despite supposed improvements in women's rights in many of these nations. In
370 contrast, some less affluent nations in the Global South (e.g., Argentina, Brazil, and Mexico)
371 had among the highest proportions of authors with NNFs. This finding is similar to the “gender-
372 equity paradox” detected in mathematics (47), and contradicts our prediction that individuals
373 facing the intersecting barriers of economic constraints and marginalized gender identity would
374 be more excluded from academic publishing. It suggests that other factors, like cultural
375 differences, could be playing a role in gender inequity. For example, in regions where farming
376 and agriculture are traditionally women's work, more women may choose to enter the plant
377 sciences. In addition, differences in available support systems can drive career choice, with
378 women sometimes pursuing higher paying jobs (often in STEM fields) when social support
379 systems are limited (48). We looked at a variety of economic development indicators to try to
380 understand what could be driving gender biases in plant science publishing. In contrast to
381 geographical patterns, there was no association between national GDP, research and
382 development expenditure, or per capita income with gender ratio. These findings suggest that

383 the footprint of patriarchy in plant science is deeper than we acknowledge and does not align
384 neatly with narratives about cultural differences in sexism. We also identified gender biases in
385 citation rates that were independent of time, suggesting persistent and ongoing gender
386 discrimination. Because individuals, not institutions drive citation rates, this suggests a deep and
387 pervasive bias running through the discipline. It also means that we, as individuals, have the
388 power to shift these patterns through our actions and choices.

389 In the past two decades, plant scientists have studied thousands of species spanning
390 plants, animals, bacteria, and fungi. Despite the noteworthy diversity and volume of research,
391 sampling effort has not been equally distributed across clades and taxa. The vast majority of
392 studies have investigated major crop and model species, and the remaining biodiversity
393 accounts for only a fraction of the research on plants. Our analyses identified a number of
394 statistically overrepresented groups of plants, all of which included agriculturally and
395 economically important plants. We also identified numerous underrepresented taxonomic
396 groups, which were ecologically diverse, speciose, and generally of less economic relevance to
397 modern society. These underexplored lineages could provide untold value to humans and
398 ecosystems but have been largely overlooked by modern plant scientists (3, 30, 49). We found
399 some evidence to indicate that taxonomic gaps are related to geographic and gender gaps and
400 we suspect that limited diversity of authors is exacerbating biases in study organism choice. In
401 general, affluent nations in Europe, Northern America, and Asia tended to focus on major crops
402 associated with industrialized agriculture (e.g., wheat, rice, soybean, tobacco, tomato, etc.). In
403 comparison, many of the nations with a smaller footprint in plant science focused their research
404 on regionally important and underutilized crops such as cassava, yam, and millets or local
405 plants with medicinal or historical importance. The disproportionate focus on major crops in the
406 mainstream literature reinforces a homogenization of plant science and limits our ability to
407 conserve and utilize biodiverse plants. It is possible that work on biodiverse species is
408 disproportionately published in regional and subject-specific journals that are not included here,
409 and future studies investigating parallel patterns in these sectors of plant science publishing
410 would be worthwhile extensions of this work. We suspect that if more researchers from across
411 the world were actively engaged in plant science research, there would be a natural
412 diversification of study systems and a broadening of cumulative knowledge.

413 414 **Conclusions**

415 Our analyses provide evidence of deep disparities in plant science with links to
416 colonialism, eurocentrism, and patriarchy. Despite the proliferation of statements, committees,
417 workshops, and trainings aimed at increasing diversity, equity, and inclusion, little progress has
418 been made towards actually diversifying plant science in the past two decades (51). These
419 findings can be used as evidence in advocating for change at institutional and policy levels,
420 while also motivating individuals to make positive change in their own research activities and
421 philosophy. While many recognize that the current system is unfair, there are contrasting views
422 on what changes should be made. Some advocate for reformation while others favor abolition,
423 but both agree that there is a need to broaden science and embrace the diversity of knowledge
424 acquisition systems that exist globally. We suggest that first steps towards improving the
425 discipline should consist of a fundamental broadening of our definition of what science is and
426 who can do it. By embracing a more nuanced and context dependent view of data,

427 acknowledging that novelty is not the only source of scientific merit, and recognizing the value of
428 qualitative research, we can begin to minimize colonial biases in academic culture, language,
429 and institutions (30). Funding is another important component, and wealthy nations should take
430 the lead in making efforts to equalize disparities in national affluence established through
431 colonialism. Grants that specifically promote intercontinental collaborations coupled with direct
432 funding to lower income nations could play an important role. Formal policies that provide
433 guidelines and regulations for data ownership and benefit sharing can also help to ensure
434 equitable research practices. The Nagoya protocol represents one such effort, but many nations
435 lack the necessary infrastructure and institutional support to implement the policy effectively.
436 Given the longstanding disparities that exist in plant science, it may be useful to employ
437 concepts of restorative justice, truth and reconciliations practices (50, 51), and a more general
438 shift away from gatekeeping policies and towards inclusive groundskeeping concepts (52). By
439 expanding our definition of what constitutes scientific inquiry and who can take part in it, we
440 begin to open the door to new sources of knowledge. After centuries of centering patriarchal
441 ideals and eurocentric ways of knowing, it is time to make space for other systems of knowledge
442 to rise to the forefront. We hope our analyses can be used to support these positive changes.

443
444

445 **METHODS**

446

447 ***Data acquisition and filtering***

448 We assembled a large-scale database of plant science papers from 127 journals
449 spanning a range of impact factors, nationalities, and sub-specialties (see Supplementary
450 Dataset S1). We cross referenced plant science journals listed in the Journal Citation Reports
451 Database (<https://jcr.clarivate.com>) with a list of plant science journals compiled by the
452 American Society of Plant Biology (<https://plantae.org/plant-biology-journal-database/>). We then
453 filtered journals on the following criteria: (1) the journal must have an impact factor, (2) it must
454 be plant specific, and (3) it must include research articles. Metadata associated with all research
455 papers from the resulting 127 journals across the last 20 years were included in the current
456 study. Other metadata were incorporated by referencing JCR and journal webpages, the World
457 Bank 2019 database, the UN Statistics Division, and the UN Department of Economic and
458 Social Affairs (see Supplementary Appendix 1 for methodological details).

459

460 ***Geography based analyses***

461 The location of authors was inferred from the addresses listed in the papers using an ad-
462 hoc text processing script. Geographic coordinates (geocoordinates) for all these locations were
463 obtained using the Google Maps Geocoding API
464 (<https://developers.google.com/maps/documentation/geocoding>) with Python via GeoPy. We
465 computed national summary stats, global patterns of author location, and associations with
466 national development indicators using Python (v3.8.8) packages Pandas (v1.5.0) and Numpy
467 (v1.22.4) and visualized data in Seaborn (v0.11.1) and Matplotlib (v3.6.1).

468 We quantified patterns of collaboration by identifying the location of the corresponding
469 author relative to all other authors for each paper. We then determined if authors were from

470 different countries, continents, or income brackets and summarized global patterns (see
471 Supplementary Appendix 1 for methodological details).

472

473 ***Gender analyses***

474 We quantified the effects of patriarchy and gender discrimination in plant science by
475 associating author names with masculinity or femininity. The analyses presented here do not
476 identify the true gender of authors. Rather, they show the assumed gender based on the
477 association of first name with either masculinity or femininity. These analyses also likely mis-
478 identify and fail to account for non-binary, gender neutral, and trans individuals, among others.
479 Geographic biases in the performance of gender inference algorithms have also been
480 documented, with most tools performing poorly on East Asian names. This is noteworthy since
481 many of the papers in our dataset are led by individuals with East Asian heritage. Given these
482 caveats, we selected the most robust tool available for this type of analysis (GenderAPI) based
483 on the extensive benchmarking and comparative analyses presented in (36, 37). Summary
484 stats, regional patterns, and changes over time in gender ratios were computed using Python
485 (v3.8.8) packages Pandas (v1.5.0) and Numpy (v1.22.4) and visualized in Seaborn (v0.11.1)
486 and Matplotlib (v3.6.1) (see Supplementary Appendix 1 for methodological details).

487

488 ***Study Species analyses***

489 The species studied in each paper were identified from abstracts using the Python
490 package TaxoNERD (53). Each biological entity was assigned to a NCBI taxonomy ID and
491 higher-level taxonomic classifications were extracted with ETE Toolkit (54). We summarized the
492 number of mentions for each species, genus, family, and order of land plants to identify
493 sampling gaps in focal organisms and test for statistically over- and under-representation of
494 focal organisms relative to the species richness of the order (see Supplementary Appendix 1 for
495 methodological details).

496

497

498 **DATA AVAILABILITY**

499 Data associated with this study and a description of data acquisition and curation are
500 deposited in Dryad at <https://doi.org/10.5061/dryad.pg4f4qrb>.

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502

503 **AUTHOR CONTRIBUTIONS**

504 RAM, EJA, SP, ARC, CCR, SMT, JMF, DHC and RV conceived of the study. RAM, EJA,
505 SP, ARC, SMT, contributed to data acquisition and curation. RAM, EJA, and SP conducted data
506 analyses. RAM, EJA, SP, ARC, CCR, SMT, JMF, DHC and RV contributed to data
507 interpretation and conceptual framing of the manuscript. RAM, EJA, and SP drew the figures.
508 RAM wrote the manuscript. All authors edited and reviewed the manuscript.

509

510

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646

647 **FIGURE LEGENDS**

648 **Figure 1. Global patterns of plant science publishing.** A) The global distribution of where authors are
649 based, scaled by the number of publications from each location. B) The number of studies published by
650 each nation relative to national Gross Domestic Product (GDP). C) The number of studies published by
651 each nation relative to their research and development expenditure.

652

653 **Figure 2. Publication output relative to national affluence and population size.** A) The number of
654 studies published each year by authors in high income nations. B) The number of studies published each
655 year by authors in upper-middle income nations. C) Map of publication output relative to population size
656 for locations with more than 300,000 inhabitants or with more than 100 papers produced during the period
657 of 2000-2021. Locations are scaled and colored according to their research output relative to the global
658 trend. Large green points correspond to locations that produce more research than expected based on
659 the global population trend, while large pink circles represent regions that publish less than expected for a
660 city of their size.

661

662 **Figure 3. Disparities in global collaborations within plant science research.** Circles represent
663 publications that did not involve an intercontinental collaboration. Arrows represent cross-continental
664 collaborations and are directed from corresponding author to co-author. Circles and arrows are scaled by
665 the number of publications.

666

667 **Figure 4. Disparities in the global distribution of corresponding authors by gender.** A) Map showing
668 the distribution of name-based gender ratio. All regions where accuracy of name-based gender prediction
669 is less than 90% are faded out. There were many more papers led by authors who had names
670 normatively associated with masculinity (NNMs) than by authors with names normatively associated with
671 femininity (NNFs), but the extent of the imbalance was variable across the globe. B) The total number of
672 publications led by authors with NNMs and NNFs, C) the impact factor of the journals that NNMs and
673 NNFs published in, and D) the citation rates for papers led by authors with NNMs and NNFs.

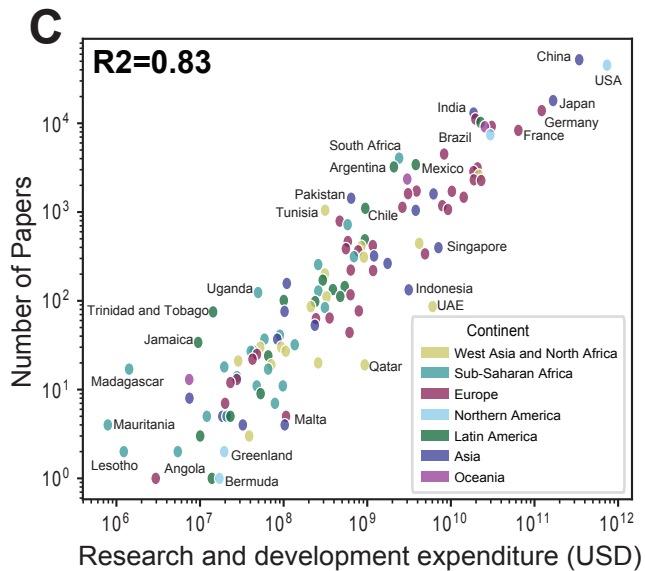
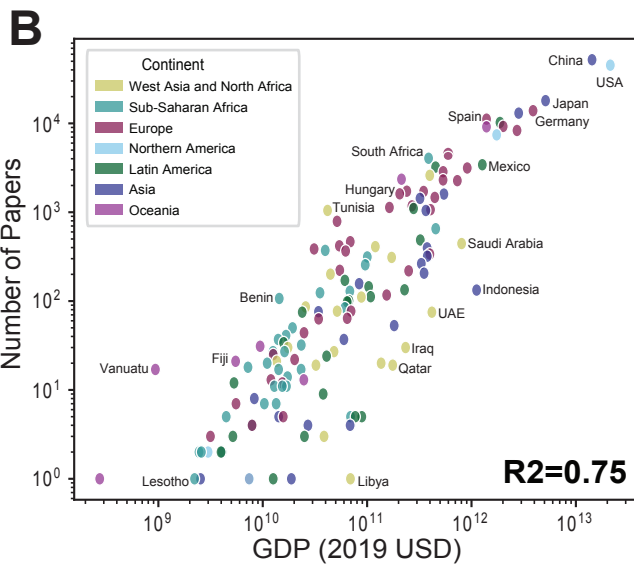
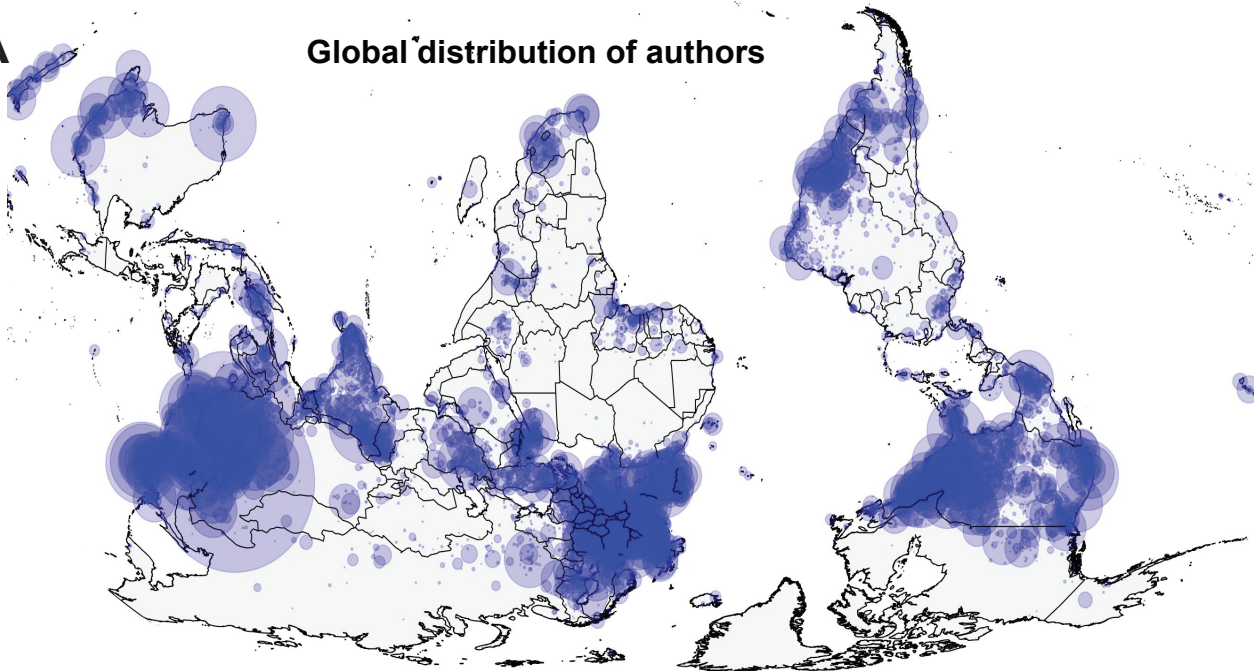
674 **Figure 5. Stagnant gender bias over the past two decades.** The proportion of authors with NNFs over
675 the last 20 years is plotted for each of the eight geographical regions investigated.

676
677
678 **Figure 6.** A) The top 20 most studied plant species across all studies. B) The top 9 most studied orders
679 for non-plant groups (animalia, fungi, and bacteria). C) The observed number of studies investigating
680 each order or land plants minus the number expected if sampling effort had been evenly distributed
681 relative to species richness.

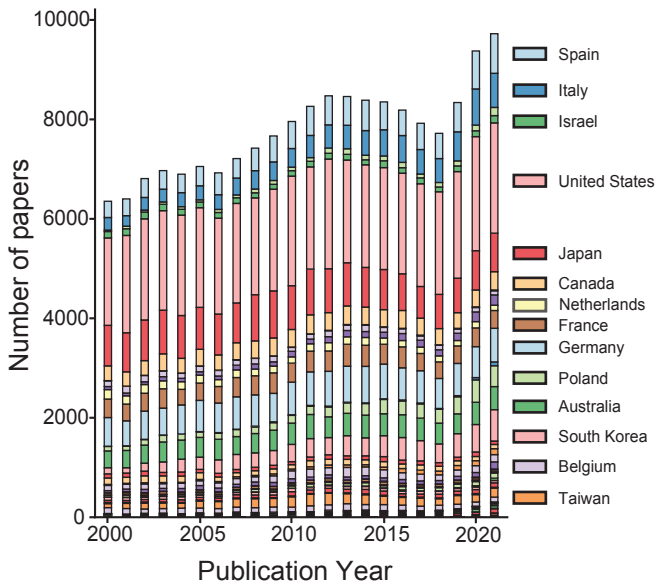
682
683 **Figure 7. National differences in focal organism choice.** The top 10 most studied species from the
684 literature in select nations is plotted. Nations are organized from most prolific to least, and focal
685 organisms are colored by generalized groupings of organism type. The x-axis shows the number of
686 papers that focus on each focal organism.

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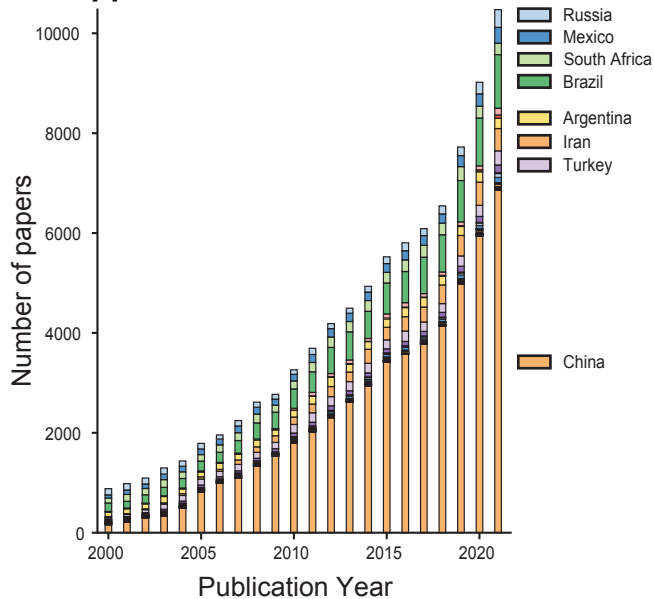
A Global distribution of authors



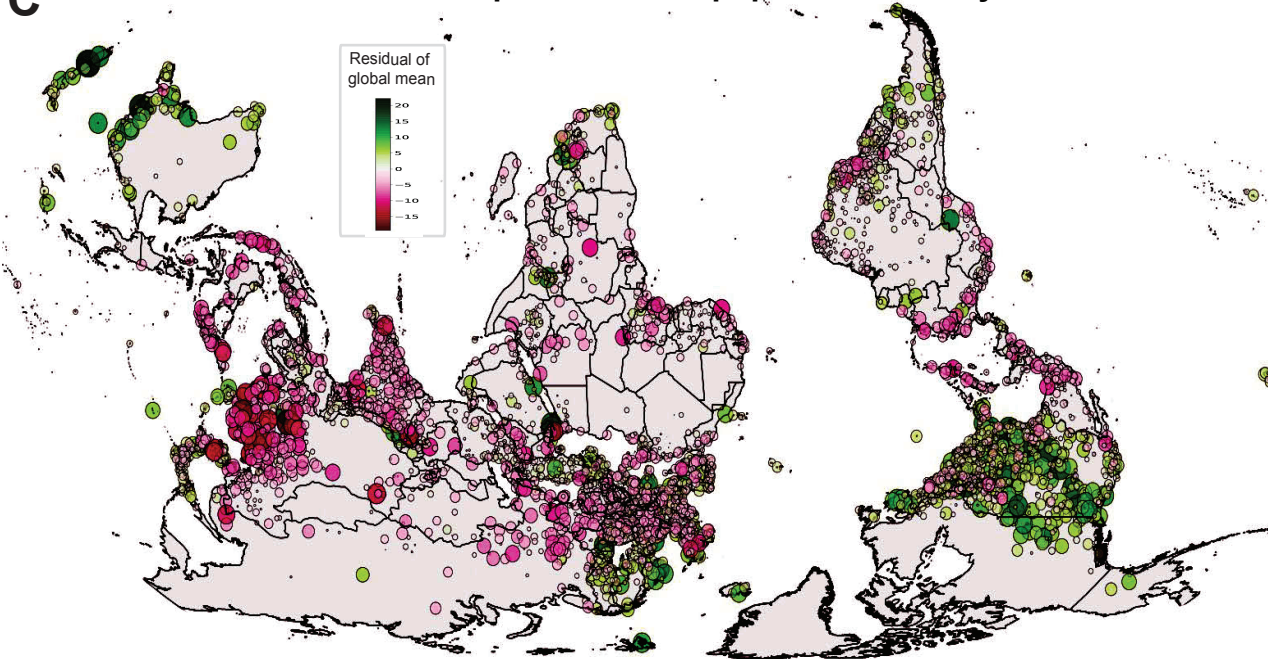
A High income nations

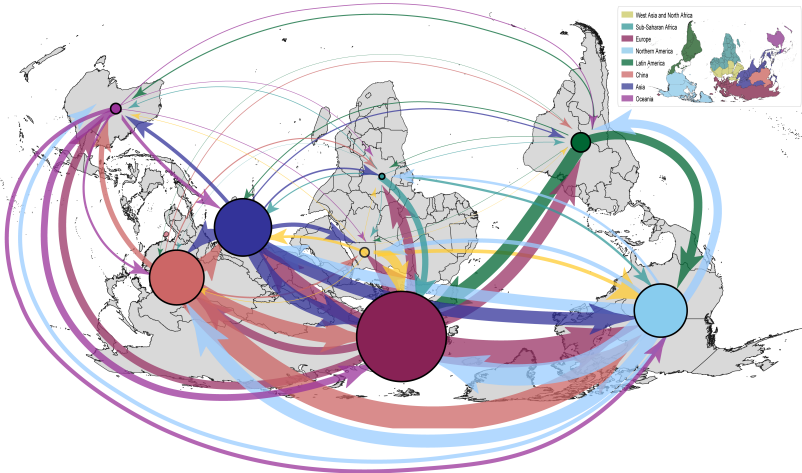


B Upper-middle income nations



C Publication output relative to population density





A Gender ratio of corresponding authors' names

