# **Profiles of Malaria Research in Portugal:** Organizing, Doing and Thinking in Science Under Capitalism

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## Abstract

Synergies between globalization and knowledge economy were suggested to direct biomedical research towards economically-interested activities. In this context, research in malaria, a disease endemic to poverty, may be at a paradoxical stance. This study addresses this issue assessing whether malaria research is driven by the accumulation of economic and/or other forms of capital. Drawing upon academic and epistemic capitalism, malaria research is characterized through the analysis of all Web of science-indexed publications involving Portuguese organizations (1900-2014; n=467). First, data was systematized by content and bibliometric analyses. Subsequently, multiple correspondence analysis revealed a bi-dimensional landscape (who's publishing; what's published) and cluster analysis identified three profiles (beginners; local appropriations; global science). This study reveals the construction of Portugal's scientific system and unveils the assimilation of dominant modes of organizing, doing and thinking despite malaria's research low profit potential. Extending this approach to other biomedical fields can unravel the dimensions underlying science's (re)construction.

**Keywords:** capitalism, scientific practices, malaria

## Introduction

In 2015, there were approximately 212 million new cases of malaria, 429 thousand deaths, and almost half of the world's population was at risk of developing this pathology (World Health Organization, 2016). As such, malaria is a major threat for public health, particularly in geographies where it is endemic, mostly poor countries and populations, including regions of all former Portuguese territories. Despite these numbers, only 0.4% of all biomedical research focused on malaria research in 2004, with most studies being conducted in North America and Europe (Lewison and Srivastava, 2008)[2]. In Portugal, science has long contributed to the understanding of malaria. This has been attributed to the fact that malaria was endemic in continental Portugal until 1973, the year when malaria was considered to be eradicated by the World Health Organization (Bruce-Chwatt and Zulueta, 1977), and to the long-standing relations with Portugal's former territories, where malaria remains endemic. Indeed, the relevance of the scientific contribution of malaria research in Portugal can be revealed by the presence of Portuguese scientists in major international scientific grants and publication outlets (Ferreira, 2016). However, the social foundations of malaria research remain, for the most part, to be ascertained.

Aiming to address this knowledge gap, the present study is driven by the following research question: how has malaria research changed since the beginning of the 20$^{th}$ century in Portugal? This is a period characterized by deep transformations in science that have been described under academic and epistemic capitalism, and other theoretical backgrounds (see Hessels and van Lente, 2008 for a review). According to academic capitalism, capitalist dynamics are revealed in the increasing presence of economically-oriented practices in academic institutions. More specifically, the authors point to the participation of academic actors in market activities (e.g., patenting, spin-off companies) or development of market-like activities (e.g., competition for external grants, partnerships with industry) (Slaughter and Leslie, 1999; Slaughter and Rhoades, 2004). Epistemic capitalism extends this rationale to propose capitalism as a cultural way of producing, attributing and accumulating specific forms of worth, which are not necessarily monetary (e.g., symbolic capital associated with publications and grants) and that can be currently found both in academia and enterprises (Fochler, 2016). According to both traditions, pressures towards the embodiment of capitalist dynamics (conceptualized in strictly economic terms or going beyond these terms) are revealed in transformations of scientific organizations, practices, and culture (Fochler, 2016; Hackett, 1990; Slaughter and Leslie, 1999; Slaughter and Rhoades, 2004). During this period of time, other studies have also shown that pressures to pluralise science and address public interest issues have been brought up by civil society groups, for instance through new forms of participatory research, such as community-based research, science shops or consensus conferences (Brown et al., 2006; Epstein, 1996; Hess, 2016; Moore et al., 2011). As such, science will result from on-going struggles, coalitions, and repositioning of academic, corporate, governmental, and civil society actors.

In this scenario, the focus on malaria research is particularly pertinent. On the one hand, it addresses an acute infectious disease that has major impacts in global public health, and thus, could be an arena of both corporate and public interest. On the other, it focuses on a pathology that affects mainly poor countries and populations, and thus is not particularly attractive for investment by the pharmaceutical and/or biotechnology industry (Daems et al., 2014; Lezaun and Montgomery, 2015). Concomitantly, scientists, including malaria researchers, operate in a global, highly competitive scientific arena, that is mostly characterized by dominant modes of organizing, modes of doing, and modes of thinking. According to academic and epistemic capitalism, the organization of academic and scientific institutions tends to replicate private corporations; scientists are pushed into the production of both traditional academic yields (e.g. grants; papers), and the fulfilment of market opportunities, and other economic and social outputs, and the ethos of science is increasingly driven by competition and performance. Still, civil society groups have been contesting these dominant forms, with their action being more visible in environmental issues, but being also present in other areas, including the biomedical arena (Brown et al., 2006; Epstein, 1996; Hess, 2016; Moore et al., 2011). Within the field of malaria research, how these processes have been developing is, to the best of our knowledge, unstudied.

For this purpose, this study will scrutinize malaria research outputs, i.e., indexed scientific publications published between 1900 and 2014, to characterize the following layers: organizational (evaluating authorships and organizational affiliations); scientific practices (characterizing the types of papers; methodological approach and publication subject area); and culture of the scientific field (assessing performance indicators and the order of authors and co-authors). The mentioned indicators have been previously associated with the transformations of science and allow assessing for the presence of market-like activities (as revealed for instance in the presence or absence of partnerships with companies) and to characterize the significance of other forms of capital (as revealed for instance by performance indicators associated with publications). All mobilized variables are listed in Table 1. This characterization will allow us to address the following specific questions. 1) Which dimensions are underlying malaria research performed by Portuguese organizations? And, 2) do the profiles of malaria research reveal the previously reported transformations of science?

This paper will start by exploring these issues in malaria research outputs. This approach allows addressing the process of scientific construction through the imprinting of what is perceived as legitimate science developed by legitimate actors. For this purpose, we will carry out bibliometric and content analyses of research outputs. However, many before us have analysed changes in individual indicators in other contexts and drawing upon diverse theoretical traditions (see Hessels and van Lente, 2008 for a review). Nevertheless, within the study of malaria research, these analyses are limited to few, strictly descriptive, bibliometric studies (Fu et al., 2015; Garg et al., 2009; Gupta and Balaji, 2011; Lewison et al., 2002; Lewison and Srivastava, 2008; Rodrigues et al., 2000). Most importantly, previous studies focus on the independent analysis of individual indicators, and thus preclude an assessment of the multidimensional nature of knowledge production. In addition, the research design of these studies did not allow assessing whether and how the different layers and corresponding indicators interact with one another. The present study will overcome this knowledge gap via an integrative analysis of a wide variety of variables that draw upon previously reported indicators of science's transformations without establishing *a priori* which the most relevant dimensions for scientific production are. Going beyond simply analysing what changed in the specific context of malaria research (as previous studies did), we will carry out multiple correspondence analysis to specify, among all studied variables, which contribute to the most critical dimensions of malaria's scientific landscape (specific question 1). This analytical procedure is followed by a cluster analysis that will identify malaria research profiles and reveal whether the previously described transformations of science are also present in malaria research (specific question 2).

Altogether, our approach to the study of malaria research is particularly relevant since it proceeds with a relational multidimensional analysis to characterize the evolution of knowledge production in malaria in light of the above-described transformations of science. Thus, this approach allows addressing how knowledge production reflects the institutional conditions governing biomedical sciences in general and, malaria research, in particular. In addition, the counters of the Portuguese example, which remain unstudied, render it to be particularly pertinent. This is the case since Portuguese organizations link organizations from more developed S&T systems and their associated modes of scientific production (ways of organizing; ways of doing, and ways of thinking), with organizations from poor countries and regions where malaria remains endemic, such as regions of all former Portuguese territories.

The following sections systematize previous studies addressing the transformations of science and, more specifically, transformations at the organizational level; scientific practices' level; and cultural level. Whenever possible, this discussion focuses on modifications in life sciences, and, particularly, malaria research. The following section addresses the processual nature of science and its articulation with the chosen methodological approach. This opens up to the methodological section and, subsequently, to the results. A discussion immediately follows, in which the shortcomings of our research and future lines of study are outlined. Also, the major scientific inputs of this research as well as its social and scientific relevance are presented in the concluding remarks.

## The changing patterns of science

Presently, science is recognized, among many theoretical traditions, as an heterogeneous endeavour (see Hessels and van Lente, 2008 for a review), framed by on-going struggles, coalitions, and repositioning of academic, corporate, governmental, and civil society actors. Within academic and epistemic capitalism, the transformations of the scientific landscape have been argued to result from synergies between globalization and knowledge economy that directed science towards economically–interested market and market-like activities (academic capitalism) and/or to the attainment of other forms of capital such as the symbolic capital associated with performance indicators (epistemic capitalism) (Fochler, 2016; Hackett, 1990; Slaughter and Leslie, 1999; Slaughter and Rhoades, 2004). This is not to say that the interconnections between the markets and academia are a recent phenomenon, quite the contrary, they have been present for a long time (Blumenthal et al., 1986; Etzkowitz, 1983; Weiner, 1987). However, their prevalence and relevance have significantly increased since the 1970s-1980s. It is precisely in these years that the commercialization of life sciences becomes more recognizable. In the wake of the discovery and application of recombinant DNA molecule techniques, academic, corporate, and political actors were confronted with the immense possibilities associated with new sources of funding, faster technology transfer to industry, incentives for innovation, and competitive advantage in (inter) national markets. However, they were simultaneously faced up against the potential detrimental impacts of such connections, including a redirection of research agendas, the presence of conflicts of interest on the research being developed, and the erosion of the open science model (Krimsky et al., 1991; Krimsky and Nader, 2004). Most noticeably in areas such as environmental issues, but also in biomedical research and others, participatory research and diverse forms of demonstration and direct action have challenged the dominant modes of scientific production (Brown et al., 2006; Epstein, 1996; Hess, 2016; Moore et al., 2011). As such, the science that is produced at particular times and spaces results from the interactions of this multitude of actors.

The period this paper addresses has witnessed transformations of scientific and academic organizations and in the relationships these organizations establish with the contexts in which they operate (ways of organizing). Additionally, the epistemological principles guiding scientific practices have been changing. Presently, an increasing demand for contributions to national, corporate or public goals has led to an intensification of multi-, inter-, and/or transdisciplinary scientific practices as well as to research primarily guided by its application (applied research) or, at least inspired, by knowledge's future application (use-inspired research)[3] (Martin, 2011; Stokes, 2011) (ways of doing). Interestingly, between 1995 and 2009, big pharma increased R&D investment while presenting small decreases in total publication numbers. However, the same companies steadily increased the publication rate in disciplines more oriented to clinical application or health services, a pattern that is present in infectious diseases. Also increasing, was the number of external collaborations in publications (Rafols et al., 2014). What these data suggest is a transformation of the research that is developed by big pharma. Rafols and colleagues describe it as a shift from basic science to clinical fields, from research in-house to increasing outsourced development. These results are consistent with the increasing relevance of public-private partnerships in drug development for neglected tropical diseases, such as malaria (Lezaun and Montgomery, 2015).

Finally, the codes, norms and values that underlie scientific practices, have also been under relevant transformations (ways of thinking). Some authors have argued that these changes, revealed for instance in the relation between scientists and their work or the relation among scientists (Hackett, 1990; Hackett, 2005; Krimsky and Nader, 2004), reflect the assimilation of a capitalist ethos that also pervades non-profit driven scientific practices (Fochler, 2016; Kleinman, 2010) and can be illustrated by the significance given by scientists and their organizations to performance-oriented models of research (Fochler, 2016).

In the following sub-sections, this paper presents studies focusing on specific indicators of science's transformations at the organizational, practices, and cultural level. These will be discussed in the context of life sciences and, whenever possible, malaria research.

### *Scientific organizations*

As described by the academic capitalism literature and others (see Hessels and van Lente, 2008 for a review), the growth of international partnerships is a common example of organizational transformations. This is a long standing trend that was severely strengthened in the last decades (Coccia and Wang, 2016; Frame and Carpenter, 1979; Glänzel, 2001; Hicks and Katz, 1996; Luukkonen et al., 1992).

As for the Portuguese case, its research presents one of the largest rates of international collaborations in scientific articles since 1980s, with the life sciences presenting a relevant role in this growth (Patrício, 2011; Santos Pereira, 2002). Several factors have been suggested to contribute for these numbers. First, Portugal is a small European country with a small, but growing, scientific community, with still reduced scientific outputs. Also, the collaborations of Portuguese organizations follow the overall patterns of Portugal's geographic, linguistic, historical, cultural, economic or political affinities (Frame and Carpenter, 1979; Luukkonen et al., 1992). In addition to the United Kingdom and Spain, Portugal also maintains strong scientific collaborations with its former territories, particularly Brazil (Patrício and Santos Pereira, 2015). In these settings, this study will go beyond simply addressing internationalization patterns, to characterize the specific countries with which Portuguese organizations have been collaborating with, and how these collaborations have been developing.

The increasing participation of diverse organizations in scientific production is yet another organizational transformation that is important to tackle. In fact, an increasing heterogeneity in papers' authorships has been shown in diverse geographies and scientific fields (Godin and Gingras, 2000; Hicks and Katz, 1996; Martin, 2011), with biomedical organizations (Godin and Gingras, 2000; Hicks and Katz, 1996) and industry (Godin and Gingras, 2000) increasing their relevance. In spite of these data, to the best of our knowledge, no studies have mapped the interconnections between academia and other organizations in Portugal in any area of scientific research. Nonetheless, several studies confirm the presence of diverse organizational types in malaria research outside Portugal (Daems et al., 2014; Lezaun and Montgomery, 2015; Pollock, 2014; Trouiller et al., 2002).

Most importantly, the impacts of these diversified country and organizational profiles on the scientific practices *per se* have not been previously assessed.

### *Scientific practices*

Within the framework of academic capitalism, a trend towards increasing application of scientific production has also been discussed (Hackett, 1990; Hackett, 2001; Slaughter and Leslie, 1999; Slaughter and Rhoades, 2004). However, if this trend seems to be present when focusing on a specific area of research (Martin, 2011), studies reveal some lack of consistency (Hicks and Katz, 1996)[4]. This is possibly resulting from conceptualization and/or methodological differences. Since our study focuses exclusively on a specific sub-field of biomedical sciences, i.e. malaria research, the papers to be analysed will always be at least inspired by a potential application (Stokes, 2011). This being said, we will go one step forward in this characterization to address the studies' methodological design. More specifically, within experimental papers, we can ascertain whether publications are solely focused on describing pathophysiological mechanisms of disease without any translation to cellular or animal models (the quest here, though use-inspired, is focused on the understanding of specific phenomena or processes). We will also ascertain whether the research also involves any type of translation to cellular or animal models, but not to human subjects; or, finally, whether it involves human subjects (the quest here is the translation of the understanding of specific phenomena or processes to human subjects). This categorization, intending to recapitulate the multiple steps of the translational process of biomedical research, should allow us to understand whether malaria research focuses on the understanding of its pathophysiological mechanisms or the translation and potential application of this knowledge to the inhibition or blockage of pathophysiological progression. To the best of our knowledge, this has not been previously evaluated. Still, previous studies have suggested relevant characteristics of malaria research that we will consider in our study. Among these is the presence of a broad range of publication types (from non-experimental types such as reviews or editorials; to empirical studies reported as conference papers and scientific articles) (Meena and Nagarajan, 2013) and publication areas (from medicine, to epidemiology or pharmacology, to subfields of malaria vaccine research) (Garg et al., 2009; Garg et al., 2006; Gupta and Balaji, 2011). However, as these studies aimed at describing the characteristics of malaria research, and not to address whether and how these characteristics reveal the on-going transformations of science, their inputs, important as they are, cannot answer the questions guiding the present study.

***The culture of science***

Finally, regarding the scientific ethos, we will focus on the presence of performance-oriented models of research as revealed by the increasing significance attributed to journals' impact factors and articles' number of citations[5]. If, within the biomedical community, these indicators are perceived as proxies of journals' quality (Adam, 2002; Saha et al., 2003) or, at least, reliable sources of legitimization of one's work (Rushforth and de Rijcke, 2015), in fact, they were reported to present a number of limitations and biases[6] and, thus, can only give a partial assessment of scientific production (Gläser and Laudel, 2007; Weingart, 2010).

Nevertheless, citation-based performance indicators have become highly pervasive and this was suggested to result from the market-like structuration of academic and scientific organizations that instigated project-oriented research and an ever increasing relevance of what is understood as highly performative science (Kleinman and Vallas, 2001; Krimsky and Nader, 2004; Luukkonen et al., 1992; Sigl, 2015; Ylijoki, 2003). This happens in a context of an increasing number of graduates and, as previously said, decreasing long-term senior positions and increasing short-term positions, generally associated with third-party funded projects. This means that scientists, today, need to balance the participation in research projects that are collaborative endeavours, under a highly competitive environment that requires them to be the single most performant researcher (Muller, 2012). In biomedical sciences, this means not only publishing the highest amount of papers, in the highest ranked journals, receiving the highest number of citations, but also being either the first or the last author of such publications. To note that while these authorship positions and authors contributions are not a formalized system that is transversal to all fields of science, it was recently shown that some characteristics of authorships are shared among diverse scientific areas of expertise: first and last authors typically contribute to more tasks than middle authors (Larivière et al., 2016). Within the biomedical field, the scientist that performed the most central work is the first author; the head of the laboratory (the "funder" of the research, and the one responsible for critical mentoring) is the last author; and the other co-authors performed smaller parts of the research or gave some intellectual input (Dance, 2012; Muller, 2012). With these indicators, we do not intend to characterize the best/most performant research but rather to evaluate what type of research is published in journals perceived to be the most relevant, and thus, that mostly contribute to establish perceptions on what the most pertinent type of research is.

In what concerns previous studies in malaria research, it was shown that chemical and pharmacology studies were the most cited, while public health research was the least cited[7] (Gupta and Balaji, 2011). However, the relations between perceived performance (impact factors; citations, and authorship positions) and application patterns, internationalization or actors heterogeneity were never assessed. This study will cover these issues, analysing whether malaria profiles are associated with the above-mentioned performance indicators.

## The process of (re)constructing malaria research landscape: linking theory to methodology

It is our understanding that science results from on-going struggles, coalitions, and repositioning of academic, corporate, governmental, and civil society actors. If this is the case, the transformations of scientific organizations, practices and culture, cannot be assumed as central tendencies. In other words, the transformations of science should not be studied as static notions that result from specific contexts or actions, but rather as being part of an interdependence system of relations. As such, malaria's scientific landscape will be characterized not through the evaluation of any specific indicator or the independent characterization of several indicators (Hicks and Katz, 1996; Martin, 2011), but rather, through the integrative characterization of indicators of the organization, practices and culture of science (see Table 1). This characterization will allow for the identification of the most relevant dimensions of malaria research and of the variables that underlie them. The dimensions that compose this scientific landscape will be described as axes of variation presenting opposing poles with contrasting features. At any given point in time, actors' struggles, coalitions, and repositioning can alter the balance between the opposing poles and favour a specific pole over the other. Consequently, a diversified set of research profiles will be located across the spectrum of the axes that structure the research plan. This framework, previously mobilized to address modifications in the culture of academic science (Hackett, 1990), is rooted in the processual nature of the (re)construction of the scientific landscape. Also, it allows to go beyond simply describing the individual transformations of science, to identify and characterize the most relevant dimensions (axes of variation), and, subsequently, to work towards a deeper understanding of what compelled these changes.

As such, understanding science as a multilayer relational process imposes that its analysis 1) concomitantly addresses indicators of the diverse levels at stake, 2) assesses whether and how the identified variables relate to one another (i.e., assesses the underlying relational structure among the different variables), and 3) identifies diverse profiles of research on that structure. This is not possible to achieve via uni- or bivariate statistics but can be achieved via specific multivariate techniques that address the multidimensionality and relational characteristics of the observed processes.

Going beyond previous studies analysing how specific indicators change, our methodological approach draws upon the influential work of the French sociologist Pierre Bourdieu, and many others (Benzécri, 1992; Bourdieu, 1979; Bourdieu, 1984; Bourdieu, 1989; Bourdieu, 1999; Greenacre and Blasius, 2006; Roux and Rouanet, 2004; Roux and Rouanet, 2010). As such, this paper combines multiple correspondence analysis (to unravel the structure of malaria's scientific landscape - specific question 1), with cluster analysis (to identify specific profiles of research and whether they replicate or diverge from the dominant modes of organizing; practising and thinking in science - specific question 2).

## Methodology

This study starts by identifying the scientific publications that fulfil the following criteria: 1) are indexed in Web of Science (Thomson Reuters), a private database that gathers scientific publications since 1900, and is perceived within the biomedical community as one of the *loci* of maximum legitimization of research (Adam, 2002; Saha et al., 2003); 2) include the words "Malaria" and/or "Plasmodium", the causative agent of malaria[8], either in the title or summary; 3) were published between 1900 and 2014; and 4) are (co-)authored by researchers working at Portuguese organizations. These publications reveal the participation of Portuguese organizations in the international scientific community. This task was performed between January and March 2015 at the platform http://apps.webofknowledge.com/. A total of 472 publications fulfilled the above-mentioned criteria. After a careful analysis of the publications' content, 5 papers were removed from our corpus of analysis. This was the case since 1 of these publications did not focus on malaria research, and the other 4 did not present authors affiliated with Portuguese organizations.

In the second stage of research, we combined the use of bibliometric indicators, a commonly used strategy to empirically address the transformations of the scientific landscape (Hicks and Katz, 1996; Martin, 2011), with content analysis of the same publications (n=467), a strategy aiming for a deeper understanding of the publications at stake (Weber, 1990). This approach provides us a detailed characterization of papers' date of publication; participating organizations; developed scientific practices; and underlying culture of science. The specific variables and categories within each layer of analysis can be found in Table 1.

Following, the configuration of the scientific landscape of malaria research was established

**Table 1.** Layers of analysis, variables, and categories

| Layers of Analysis | Variables | Categories |
|---|---|---|
| **Date of publication** | **Year of publication** | Before 1995<br>1995-1999<br>2000-2004<br>2005-2009<br>2010-2014 |
| **Organization** | **Number of authors** | 1<br>2-4<br>5-9<br>10 or more |
| | **Country of organizational affiliations** | Portugal*<br>International** |
| | **Collaboration with former Portuguese territories** | Yes<br>No |
| | **Collaboration with Europe, North America and Oceania** | Yes<br>No |
| | **Collaboration with countries with endemic malaria and not former Portuguese territories** | Yes<br>No |
| | **Number of different types of organizational affiliation** | 1<br>2<br>3 or more |
| | **Affiliation: academic or research organization** | Yes<br>No |
| | **Affiliation: hospital** | Yes<br>No |
| | **Affiliation: state departments/governmental organization** | Yes<br>No |
| | **Affiliation: non-governmental organizations or non-profit corporations** | Yes<br>No |
| | **Affiliation: industry** | Yes<br>No |
| | **Affiliation: museum** | Yes<br>No |
| **Practices** | **Publication subject area** | Infectious diseases and Tropical Medicine<br>Molecular & Cellular Biology and Immunology<br>(Bio)chemistry;<br>Pharmacology and Biotechnology<br>Medicine and Public Health<br>Multidisciplinary<br>Others |
| | **Paper type** | Meeting abstracts<br>Research articles<br>Reviews/discussions<br>Others |

**Table 1 cont.**

| | | |
|---|---|---|
| | **Methodology** | Non-experimental<br>No live models[§]<br>Cellular & animal models[§§]<br>Translational research[§§§] |
| **Culture** | **Impact factor**[&] | Under 2<br>Between 2 and 10<br>Above 10 |
| | **Citations**[$] | Top 10% (most cited papers)<br>]10-25%]<br>]25-50%]<br>]50-100%] (least cited papers) |
| | **First authorship: Portuguese**[#] | Yes<br>No |
| | **Last authorship: Portuguese**[##] | Yes<br>No |

Note: [*]: publications authored by researchers working exclusively in Portuguese organizations; [**]: publications authored by researchers working in Portugal and elsewhere; [§]: chemical and/or mathematical studies; [§§]: Non-human live models of research including cellular and/or animal models; [§§§]: studies with human subjects; [&]: Journal citation reports (JCR) impact factor in 2014; [$]: number of citations until 2014; [#]: the first author is affiliated with a Portuguese organization; [##]: the last author is affiliated with a Portuguese organization.

through the simultaneous analysis of its different components (variables) and of the relations established between them. Multiple correspondence analysis (MCA), a technique that uncovers the underlying structure of a multivariate space, through geometric data modelling (Roux and Rouanet, 2004; Roux and Rouanet, 2010), was used to establish the underlying dimensions of the scientific landscape without imposing any previous structure. As any multivariate technique, the MCA aims at clarifying a complex data structure, and it does so through the identification and characterization of the main dimensions (i.e., axes of variation with opposing poles) supporting that structure. The identified dimensions are those that account for the most variance, thus explaining the most relevant relations between subjects (i.e., papers) and categories of the variables. This is the case since the purpose of MCA is to reduce the multidimensionality of the data while unravelling its underlying relational structure. As such, “Each dimension added to the solution increases the explained variance of the solution, but at a decreasing amount (i.e., the first dimension explains the most variance, the second dimension the second greatest, etc.)” (Hair et al., 2013: 528).

Next, we proceeded with a first identification of research profiles (interpreted from the geometry of the interrelations between the subjects and categories) and, subsequently, operationalized these profiles via a cluster analysis based on the MCA’s object scores for each identified dimension. The further characterization of the identified clusters (groups of subjects that share certain characteristics) was accomplished by the cross tabulation with the initial variables that represent the scientific landscape of malaria research and other relevant dimensions, such as the times and spaces of science production. Pearson chi-square tests assessed the independence between nominal variables, and adjusted standardized residuals assessed associations between categories of nominal variables.

Statistical analysis was performed with IBM SPSS Statistics, version 20, statistical package.

## Results

### *Researching malaria in Portugal: who is researching malaria and what is being produced in malaria research*

We started by performing a MCA in order to reduce the complexity of the data, and establish

**Table 2.** Discriminatory dimensions of the scientific landscape of malaria research.

| Variables | Discrimination measures | |
|---|---|---|
| | Dimension 1 | Dimension 2 |
| Country of organizational affiliation | 0.646 | 0.006 |
| Collaboration with Europe, North America, and/or Oceania | 0.556 | 0.107 |
| Number of authors | 0.496 | 0.170 |
| First authorship: Portuguese | 0.350 | 0.027 |
| Last authorship: Portuguese | 0.330 | 0.049 |
| Number of different types of organizational affiliations | 0.303 | 0.004 |
| Methodology | 0.156 | 0.673 |
| Paper type | 0.183 | 0.643 |
| Collaboration with former Portuguese territories | 0.013 | 0.204 |
| Impact factor | 0.074 | 0.175 |
| Citations | 0.167 | 0.084 |
| Publication subject area | 0.120 | 0.051 |
| Collaboration with countries with endemic malaria which are not former Portuguese territories | 0.238 | 0.018 |
| Active total | 3.033 | 2.210 |

Note: Shaded cells correspond to an above average contribution to the definition of the dimension. For dimension 1, the average contribution of the variables is 0.279, and for the second dimension the average contribution is 0.170 (dimension's active total/number of active variables). Variables that are not significantly contributing to the discrimination of either dimension (i.e., that do not present any shaded cells) are still kept in the analysis due to their categories' significant contribution (see Figure 1, Supplementary Table 1).

the dimensions that mostly structure the space of malaria research. The following variables discriminated the observations into two main dimensions (Table 2).

This analysis reveals that the variables contributing the most for the structure of the first dimension are: country of organizational affiliation; collaboration with Europe, North America, and/or Oceania; number of authors; first and last authorships: Portuguese; and number of different types of organizational affiliations. These variables indicate that dimension 1 is mainly focusing on who produces malaria research. As for dimension 2, the variables contributing the most are: methodology; paper type; collaboration with former Portuguese territories; impact factor; and number of authors. In this case, the variables underlying dimension 2 are mostly concerned with the types of publications being published.

Once having recognized what the two dimensions mostly refer to, and since we understand these dimensions as axis of variation, we will now specifically assess what the opposite poles of each dimension are. This will allow us, in the following analytical stage, to interpret more clearly the meaning of the profiles according to their positioning on the scientific landscape. For this purpose, we will proceed with the analysis of the variables' categories and their relative positioning in the identified research plane (see Supplementary Table 1 for this analysis).

The combined evaluation of the contribution of both variables and categories is depicted in Figure 1. This analysis led us to label dimension 1 as "Who's publishing", ranging from small (negative coordinates) to high heterogeneity of contributors (positive coordinates), and dimension 2 as "What's being published", ranging from translational science (negative coordinates) to non-experimental science (positive coordinates). This analysis addresses specific question 1, i.e., which dimensions are underlying malaria research performed by Portuguese organizations?

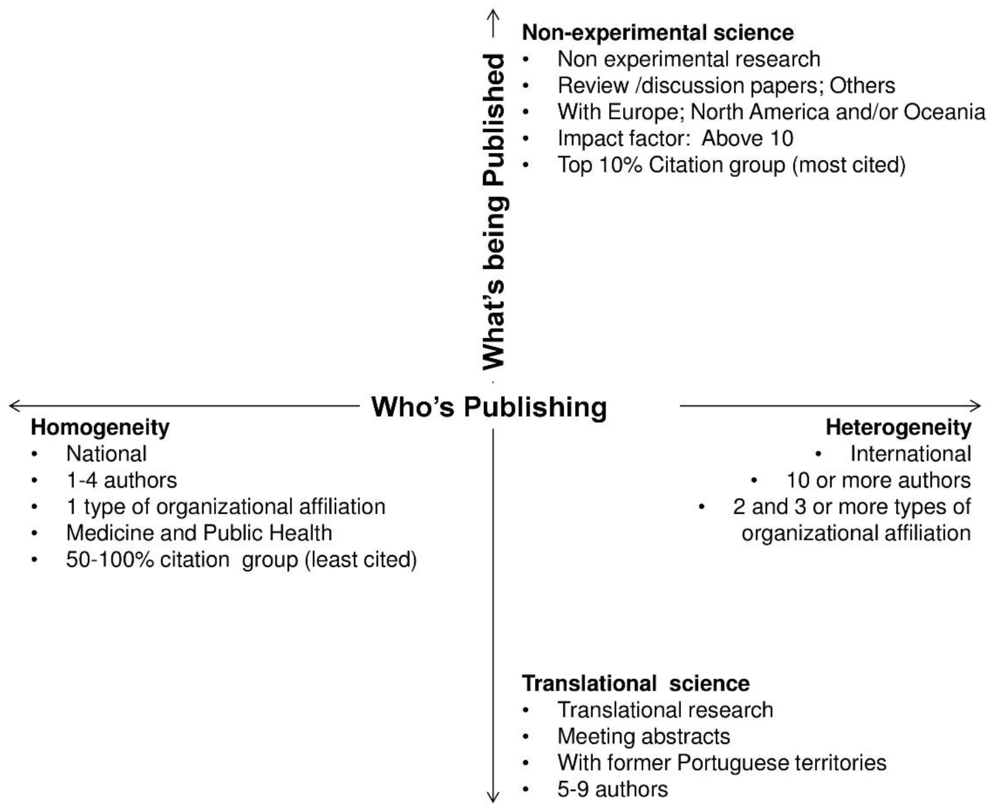


**Figure 1.** Bi-dimensional representation of the scientific landscape of malaria research.
Dimension 1 depicts "Who's publishing", with its negative coordinates being characterized by a profile of homogeneity, while its positive coordinates present a profile of heterogeneity. Dimension 2 depicts "What's being published", with its negative coordinates being characterized by a profile of translational research, while its positive coordinates present a profile of non-experimental science.

Once having characterized the bi-dimensional structure of malaria research, in the next section we will identify and characterize the specific profiles of malaria research via a cluster analysis.

### *Profiles of malaria research in Portugal*

The characterization of malaria research profiles was accomplished through a hierarchical cluster analysis based on the multiple correspondence analysis' object scores. This allowed operationalizing and characterizing more clearly the revealed profiles. More specifically, and given the methodological options undertaken and previously described, this analysis suggests the presence of three profiles of malaria research located along a bi-dimensional landscape[9].

As shown in Table 3 and depicted in Figure 2, there is a high probability of publications grouped in cluster 1 being 1) review or discussion papers (and other types of papers), and thus papers without any empirical data. Also, there is a high probability that these publications 2) present high impact factors (10 or above); 3) are written by a relatively small number of authors for the context of biomedicine (4 or less). Also, there is a high probability that these authors are 4) mainly affiliated with Portuguese organizations; and 5) present no more than one type of organizational affiliation (Table 3). Overall, there is a high probability that this cluster includes non-experimental publications in journals with high impact factors and in which the contributors are highly homogeneous (as perceived by its placement on the second quadrant of Figure 2). A quick note to say that this cluster is associated with publications in journals specifically dedicated to reviews and discussion papers, which publish papers that are highly cited, and, thus, present higher than average impact factors. In spite of these journals' high impact factors, no associations were found with any of the categories of citation numbers. This is indicative that the specific publications that were analysed did not have such a high pervasiveness in the malaria field.

Publications in Cluster 2 have a high probability of 1) being written by 2 to 4 authors, 2) presenting contributors affiliated in Portuguese organizations that are first and last authors, and 3) have additional contributors from former Portuguese territories, but neither from European, North American and/or Oceanian countries, nor from countries where malaria is endemic and which are not former Portuguese territories (Table 3). These publications are associated with 4) only one type of organizational affiliation, 5) Medicine and Public Health, 6) translational methodological approaches (i.e., with the participation of human subjects), and 7) meeting abstracts (not full publications). Also, these papers are associated with smaller impacts, as they show a high probability of belonging to 8) the least cited group of papers (50%-100%), and of 9) being published in journals with low impact factors (less than 2). These "performance profiles" seem to be consistent

**Table 3.** Characterization of malaria research outputs per scientific profile.

| | | Cluster 1 (n=60) | Cluster 2 (n=131) | Cluster 3 (n=276) | Total |
|---|---|---|---|---|---|
| **Number of authors** | 1 | **5.8*** (15.0%) | 0.6 (3.8%) | -4.6* (0.0%) | 3.0% |
| | 2-4 | **7.4*** (63.3%) | **5.4*** (42.0%) | -9.9* (8.3%) | 24.8% |
| | 5-9 | -4.7*(18.3%) | 0.9 (49.6%) | **2.4*** (51.1%) | 46.5% |
| | 10 or more | -4.2 (3.3%) | -6.5* (4.6%) | **8.8*** (40.6%) | 25.7% |
| **Country of Affiliation** | Portugal | **3.2*** (40.0%) | **13.3*** (65.6%) | -14.3* (0.4%) | 23.8% |
| | International | -3.2* (60.0%) | -13.3* (34.4%) | **14.3*** (99.6%) | 76.2% |
| **Col. with former PT territories** | Yes | -3.6* (3.3%) | **3.5*** (31.3%) | -0.8 (19.6%) | 20.8% |
| | No | **3.6*** (96.7%) | -3.5* (68.7%) | 0.8 (80.4%) | 79.2% |
| **Col. with Europe, North America and Oceania** | Yes | -1.5 (55.0%) | -16.6* (4.6%) | **16.1*** (93.5%) | 63.6% |
| | No | 1.5 (45.0%) | **16.6*** (95.4%) | -16.1* (6.5%) | 36.4% |
| **Col. with countries with endemic malaria and not former PT territories** | Yes | -1.8 (11.7%) | -6.6* (0.8%) | **7.2*** (31.5%) | 20.3% |
| | No | 1.8 (88.3%) | **6.6*** (99.2%) | -7.2* (68.5%) | 79.7% |
| **Number of types of organizational affiliation** | 1 | **3.7*** (73.3%) | **6.8*** (76.3%) | -8.8* (34.1%) | 51.0% |
| | 2 | -2.5* (25.0%) | -5.5* (19.8%) | **6.7*** (52.2%) | 39.6% |
| | 3 or more | -2.2* (1.7%) | -2.6* (3.8%) | **3.9*** (13.8%) | 9.4% |
| **Publication subject area** | Infect diseases/Trop Med | -0.3 (55.0%) | 0.3 (58.0%) | -0.1 (56.5%) | 56.7% |
| | Mol & Cell Biol/Immunol | 0.1 (8.3%) | -1.7 (4.6%) | 1.4 (9.4%) | 7.9% |
| | (Bio)chem/Pharm/Biotech | 1.0 (15.0%) | -2.2* (6.1%) | 1.4 (13.0%) | 11.3% |
| | Medicine and Public Health | 0.2 (6.7%) | **4.8*** (14.5%) | -4.6* (1.8%) | 6.0% |
| | Multidisciplinary | -1.1 (10.0%) | -1.2 (11.5%) | 1.8 (17.0%) | 14.6% |
| | Others | 0.7 (5.0%) | 1.4 (5.3%) | -1.8 (2.2%) | 3.4% |
| **Paper type** | Meeting abstracts | -3.0* (0.0%) | **6.5*** (26.7%) | -4.0* (6.5%) | 11.3% |
| | Research articles | -13.6* (1.7%) | -0.2 (73.3%) | **9.4*** (89.9%) | 73.9% |
| | Reviews/discussions | **16.3*** (60.0%) | -3.9* (0.0%) | -7.5* (0.0%) | 7.7% |
| | Others | **10.1*** (38.3%) | -3.7* (0.0%) | -3.5* (3.6%) | 7.1% |
| **Methodology** | Non-experimental | **21.0*** (98.3%) | -4.9* (0.8%) | -9.8* (0.4%) | 13.1% |
| | No live models | -0.7 (0.0%) | 0.2 (0-8%) | 0.3 (0.7%) | 0.6% |
| | Cellular & animal models | -6.7* (1.7%) | 0.7 (44.3%) | **3.9*** (48.9%) | 41.5% |
| | Translational | -7.5* (0.0%) | **2.6*** (54.2%) | **2.7*** (50.0%) | 44.8% |
| **Impact Factor** | Under 2 | -0.8 (13.8%) | **5.7*** (34.5%) | -4.6* (10.9%) | 17.5% |
| | 2-10 | -1.8 (67.2%) | -3.3* (65.5%) | **4.2*** (83.2%) | 76.5% |
| | Above 10 | **4.5*** (19.0%) | -3.2* (0.0%) | -0.2 (5.8%) | 6.0% |
| **Citations** | Top 10% (most cited) | 0.1 (10.0%) | -3.7* (1.5%) | **3.3*** (13.4%) | 9.6% |
| | ]10-25%] | 0.0 (15.0%) | -3.1 (6.9%) | **2.8*** (18.8%) | 15.0% |
| | ]25-50%] | -0.6 (21.7%) | -2.8* (16.0%) | **3.0*** (30.1%) | 25.1% |
| | ]50-100%] (least cited) | 0.5 (53.3%) | **6.8*** (75.6%) | -6.6* (37.7%) | 50.3% |
| **First authorship: Portuguese** | Yes | 1.0 (73.3%) | **8.4*** (96.9%) | -8.4* (52.5%) | 67.7% |
| | No | -1.0 (26.7%) | -8.4* (3.1%) | **8.4*** (47.5%) | 32.3% |
| **Last authorship: Portuguese** | Yes | 0.7 (66.7%) | **9.4*** (96.2%) | -9.1* (45.7%) | 62.5% |
| | No | -0.7 (33.3%) | -9.4* (3.8%) | **9.1*** (54.3%) | 37.5% |

Note: Values are expressed as adjusted standardized residuals and percentage within specific clusters. * Denotes statistical significance (|Z| > 1.96; level of significance of 0.05); bold indicates positive significant probability of association. Col.: Collaboration; PT: Portuguese; Infect diseases/Trop Med: Infectious diseases and Tropical Medicine; Mol & Cell Biol/Immunol: Molecular and Cellular Biology and Immunology; (Bio)chem/Pharm/Biotech: Biochemistry; Chemistry, Pharmacology; and Biotechnology.

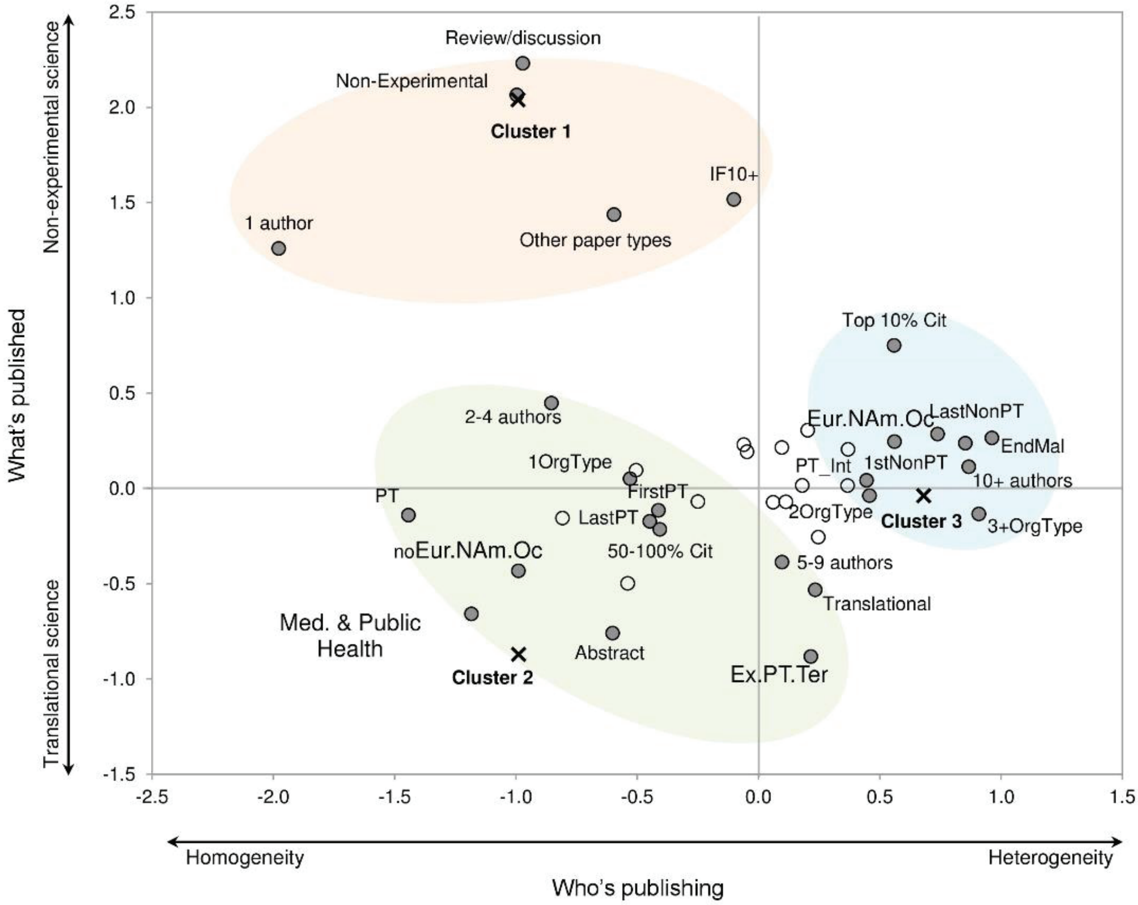


**Figure 2.** The scientific landscape of malaria research.
The first dimension illustrates who's publishing (ranging from homogenous to heterogeneous publications); the second dimension illustrates what's being published (from translational science to non-experimental publications). Shadings correspond to Cluster 1 (top, left) (n=60); Cluster 2 (bottom, center) (n=131) and Cluster 3 (middle, right) (n=276). IF10+: Impact factor above 10; Top 10% Cit: Top 10% citation group (most cited); 50%-100% Cit: ]50-100%] citation group (least cited); PT: Country of affiliation Portugal; PT_Int: Country of affiliation Portugal and others; FirstPT: First author from Portuguese organization; LastPT: Last author from Portuguese organization; 1stNonPT: First author from non-Portuguese organization; LastNonPT: Last author from non-Portuguese organization; 1OrgType: 1 type of organizational affiliation; 2OrgType: 2 types of organizational affiliation; 3+OrgType: 3 or more types of organizational affiliation; Ex.PT.Ter: collaboration with former Portuguese territories; Eur.NAm.Oc: Collaboration with Europe, North America and Oceania; noEur.NAm.Oc: No collaboration with Europe, North America and Oceania; EndMal: Collaboration with countries with endemic malaria and not former Portuguese territories; Med. & Public Health: publication on Medicine and Public Health area.

with the fact that this cluster has a high probability of presenting meeting abstracts and full papers in Medicine and Public Health, an area of research that was previously associated with low citations in malaria research (Gupta and Balaji, 2011). Overall, this cluster is characterized by its contributors' homogeneity and translational low impact research (placement on the third quadrant (Figure 2).

Lastly, papers in cluster 3 have a high probability of being co-authored by diversified profiles of authors and organizations. More specifically, these papers present a high probability of 1) being written by 5 or more authors; 2) presenting 2 or more types of organizational affiliations, that are based not only in Europe, and of North America and/or Oceania, but also in countries where malaria is endemic (and which are not former Portuguese territories) (Table 3). Methodologically, these publications have a high probability of 3) encompassing human subjects and/or cellular and animal models, and thus represent a use-inspired research which stands either very close (translational research) or relatively close (cellular and animal models) to a strict applied model of scientific research. Additionally, this cluster has a high probability of 4) including papers whose first and/or last authors are not working in Portuguese organizations, 5) being published in journals with moderate to high impact factors, and 6) being among the 50% most cited papers, which includes the top 10% most cited publications (Table 3). These results denote that papers in Cluster 3 do not tend to present major inputs from Portuguese organizations, but rather that Portuguese organizations and authors had, for the most part, less important contributions. Altogether, this profile is associated with relatively high impact and heterogeneity regarding the papers' contributors (as perceived by this cluster's placement on the intersection of the first and fourth quadrants (Figure 2)).

Overall, these results allow us to identify the presence of three profiles of malaria research located along a bi-dimensional landscape that opposes homogeneous to heterogeneous contributions (Cluster 3), and translational (Cluster 2) to non-experimental science (Cluster 1). In addition, the analysis of these data starts to address specific question 2 (i.e., do the specific profiles of malaria research reveal the previously reported transformations of science?).

In the next section, we will further characterize these practices to evaluate whether the profiles now identified are associated with the date of publication or the organizational types where scientific production took place.

### *Times and spaces of scientific production*

We started by testing whether the previously identified scientific profiles of malaria research were associated with the publication date, and types of organizational affiliations.

On the one hand, we found statistically significant differences among the clusters regarding the time frame in which the papers were published ($X^2_{(8)}$=18.146; p=0.020). Publications in Cluster 1 are associated with earlier dates (before 1995)[10]; Cluster 3 with more recent ones (from 2010 to 2014)[10], and Cluster 2 with papers published in the meantime (between 2005 and 2009)[10]. These data show that malaria research profiles are not independent of the date of scientific production.

On the other hand, we found statistically significant differences among the clusters regarding the organizational types participating in these publications ($X^2_{(2)}$=14.309; p=0.001; $X^2_{(2)}$=28.463; p<0.001, for the participation of universities and research institutions, and of hospitals and governmental organizations or departments, respectively). Moreover, as identified earlier, the papers grouped in Cluster 3 are associated with collaborations that are more diverse. As such, it does not come as a surprise that a significant relation was found between Cluster 3 and several organizational types, namely university and research institutions[11]; hospitals[11]; governmental organizations or departments[10]; and industry[11]. In addition, this cluster is not associated with the participation of non-governmental organizations or non-profit corporations, whose presence is residual in our corpus of analysis (1.7% of all papers). Knowing that research articles mostly characterize this specific cluster, this cluster more concretely adheres to the patterns of empirical malaria research recognized by peers. Confirming its location in the scientific landscape, these are practices that are highly heterogeneous in terms of contributions, including not only the more traditional spaces of scientific production, but also revealing that even in malaria research, the participation of biotechnological and pharmacological industry is emerging. Altogether, these data show that malaria research profiles are not independent of the spaces of scientific production.

## Discussion

### *Looking through the scientific landscape of malaria research*

This study reveals that the scientific landscape of malaria research is structured along two major dimensions (Figure 1). The first dimension explains the most relevant relations found in our data. This dimension concerns the actors of malaria research and ranges from a homogeneous to a heterogeneous composition. At a second level, presenting a lower but significant explanatory power, we found the papers that were published, with opposing non-experimental and translational poles. It is in this bi-dimensional plane that we have identified three scientific profiles of research. These profiles result from actors' struggles, coalitions, and repositioning taking place between 1900 and 2014. Noticeably, these profiles reflect very consistently the specificities of the Portuguese context, which we will now discuss.

Firstly, 98.5% of all Web of science-indexed malaria papers were published after 1995, which is very consistent with the development of Portuguese scientific system. In fact, if the most known scientific organizations that develop malaria research in Portugal were founded before the Portuguese revolution in 1974, it was only in the 1990s that Portugal presented significant growth of its major indicators of science and technology, significantly reducing the distance to the European Union levels (Rodrigues, 2015). It was also in this decade that Portugal had its first Ministry of Science (1995) and that the current national funding agency for science, technology, and innovation, the Foundation for Science and Technology, was founded (succeeding, in 1997, the earlier Junta Nacional de Investigação Científica e Tecnológica (1967)). It was also during the 1990s that public policies specifically targeting internationalization of science revealed a significant growth, and that policies targeting links between academia and industry were implemented (Rodrigues, 2015). In summary, the major international developments revealed by the analysed Web of science-indexed publications seem to be framed, at least partially, by the national context.

Secondly, the types of papers that were published, as well as the role that Portuguese-affiliated scientists have in them, are very revealing of the context of scientific production in Portugal. The first profile ("Beginners", Cluster 1), is associated with less recent reviews and discussion papers, mostly written by scientists affiliated with Portuguese organizations. This can be interpreted as an indication of an incipient internationalization of science. This implies that, in the earlier years of indexed-outputs of malaria research, publications were mostly characterized by an "experimental void" and rather discussed and reviewed others work.

The second profile, "Local appropriations", is associated with indexed outputs in which there is a high probability of Portuguese scientists assuming the most relevant positions in terms of authorships (first and last), and collaborations with scientists affiliated in organizations of former Portuguese territories. These studies are also associated with "Medicine and Public Health" and with the participation of human subjects with and without malaria, whose samples were most probably accessed through the collaborations with former Portuguese territories where malaria remains endemic. Importantly, these empirical studies are associated with "Meeting abstracts". This reveals that there is a high probability of studies included in the second profile to be not quite finalized, but rather on-going projects that could be "translated" into full papers, on a later point in time. Even though other factors could also play a role, it is our understanding that features such as the association of Cluster 2 with "Meeting abstracts" and with publications in "Medicine and Public Health" could contribute to the high probability of low impact factors and citation numbers that also characterize the papers included in "Local Appropriations". Finally, in spite of the authors affiliated in Portuguese organizations having a high probability of assuming the most relevant positions in the publications at stake (i.e., first and last authorships), both the specific type of publications and other associated performance indicators are revealing of a not so developed structure of Portugal's scientific system.

Lastly, we will focus on the specific profile of malaria research that includes 59.1% of all publications (Cluster 3). As suggested by the designation "Global science", this scientific profile is associated with research collaborations throughout the world. In addition, it is also associated with organizational, practices and cultural features previously reported under academic and epistemic capitalism. Some of the features were previously reported in studies focusing on biomedical sciences, including malaria research. To be more specific, our data show that papers in Cluster 3 are associated with an international pattern (Gupta and Balaji, 2011; Hicks and Katz, 1996; Patrício, 2011; Santos Pereira, 1996; Santos Pereira, 2002) and with heterogeneous actors (Godin and Gingras, 2000; Hicks and Katz, 1996), including the industry. Since no associations were found with civil society organizations, at this point, we have to conclude that the role of public science in malaria research developed by Portuguese organizations and revealed by indexed scientific publications seems to be minor. In what concerns the industry participation, it always took place through public-private partnerships, a feature that is revealing of the development of market-like activities by academic institutions, as described under academic capitalism (Slaughter and Leslie, 1999; Slaughter and Rhoades, 2004). These cooperative efforts confirm the current patterns of R&D developed by pharmaceutical companies (Daems et al., 2014; Rafols et al., 2014). In addition, particularly considering that malaria distribution is spatially limited, and mainly affects very poor regions and populations, it was not to be expected that malaria research would be a major target for pharmaceutical and biotechnological companies. Two lines of reasoning can be put forward for the small but significant participation of industry in these studies. On the one hand, the increasing global travelling expose people who can afford medical treatment to diseases to which they would not be otherwise exposed to (Cullen et al., 2016). On the other hand, the spatial limitation of malaria distribution and its seasonal activity are impacted upon climate factors; local capacity to control the disease; and other socio-economic factors such as the level of land use, urbanization, population growth, and mobility (including human; mosquito vector - *Anopheles*; and parasite - *Plasmodium*). This being the case, if today we have almost half of the world population already at risk of developing malaria (World Health Organization, 2016), the 21st century could witness further increases (Caminade et al., 2014). This scenario can create new market opportunities that are being anticipated by industrial actors.

Very much related to what we have been discussing is that this "Global science" profile groups papers that, methodologically speaking, are associated with either translational research practices (the closest level to an applied model of research), or practices that mobilize cellular and animal models of research (the second closest level). These methodological designs reveal a proximity to an applied model of research that has been shown to be more prevalent in more recent times (Hicks and Katz, 1996) and to characterize research performed within academic capitalism. This was not previously studied in the context of malaria research.

Finally, we analysed performance indicators that were suggested to be increasingly relevant for researchers' careers and that could reveal the presence of more pervasive capitalist dynamics, as described under epistemic capitalism (Fochler, 2016). Since most recent malaria research is associated with top cited papers (despite the lower amount of time that these publications had to be cited), one can infer the increasing importance of performance for research in malaria. One additional feature is further revealing of the dependence of Portuguese science on the countries with a longer institutionalized scientific system: the dependence position of Portugal's affiliated researchers (generally assuming middle positions in authorships) on these publications. These features were not previously addressed in biomedical research including malaria research.

We are thus in the presence of three research profiles that range from a "Beginners" stage, in which authors reviewed others work, to a profile that maximizes on Portugal's links to its former territories where malaria is still endemic, to a more recent profile where fully legitimatized empirical studies are developed, but in which Portugal assumes a secondary role.

Taken together, both "Global science" and "Local appropriations" profiles are characterized by features that have been associated with academic and epistemic capitalism. While public-private partnerships reveal the presence of market-like activities, a crucial feature of academic capitalism, the production, attribution, and accumulation of non-monetary forms of capital, a central characteristic of epistemic capitalism, is shown by the authors' positioning and differential impacts of published indexed research. As such, our data allowed us to establish the presence of features of both academic and epistemic capitalism. Nevertheless, the relative importance of these features to the actors that develop malaria research can not be inferred from the present study and would require the application of a diverse methodological approach. This would involve for instance, interviews to the authors of these studies. Only then, could we assess, as Fochler (2016), the actors perceptions on the influence of these diverse forms of capital in knowledge production.

Altogether, our data suggest that Portuguese malaria research follows dominant modes of production present countries with more developed S&T systems and imposes these modes in countries with less developed S&T systems, such as former Portuguese territories.

### *Limitations and opportunities for future research*

One first limitation of this study results from the use of the platform *Web of Science*, and its associated bibliometric indicators. This type of data bank and indicators are understood, within the biomedical community, as important tools for the assessment of scientific practices (Adam, 2002; Saha et al., 2003) or as reliable sources of scientific legitimization, with high impact factors and citations allowing for future success in applications for grants and jobs (Rushforth and de Rijcke, 2015). However, their known insufficiencies and bias impose some limitations that require further discussion. As previously said, journals' impact factors measure the average number of citations of papers published in a specific journal in a specific year. As such, they do not specifically mirror the impact of any specific paper. Actually, it has been previously reported that journals' impact factors are mostly determined by citations received by a small portion of all publications (10-30%) (Slegen, 1997). In fact, our data reflect this bias – while publications in the "Beginners" profile are associated with high impact factors, the number of citations for the specific publications in our sample are low. Another concern regarding the use of the so-called performance indicators relates to the use of citations counts as a direct measure of the relevance of a specific paper. However, acknowledging the influence of a particular paper is one among many reasons a paper is cited. Authors cite others' work to refer to a specific methodology or work within the same thematic focus; to support a specific idea developed in their work; to acknowledge the work of their mentors or leaders in the field; or even to rebut others methods, results or conclusions. As such, citations counts *per se* are not indicative of research influence but rather indicate a paper's usefulness for writing other papers (Belter, 2015). Therefore, citation-based indicators only allow for a partial evaluation of scientific practices (Gläser and Laudel, 2007; Weingart, 2010). A further caution note to state that impact factors and number of citations are very much dependent on the journal's area(s) of research. This means that an high impact factor in social sciences (such as an impact factor of 2) would be considered to be a relatively low impact factor in biomedicine (an area of research where top journals, such as Science, Nature or Cell, have impact factors above 20). Considering that 1) most journals included in our corpus of analysis belong to more than one Web of Science research area and category, and 2) the above-mentioned limitations of performance indicators, we did not mobilize impact factors or citation numbers to characterize performance *per se*. Rather, we complemented these quantitative performance indicators with other bibliometric indicators and qualitative indicators resulting from the content analysis of the full publications. As such, our aim was to characterize performance patterns in what it relates to other characteristics of malaria research profiles. This being said, a deeper understanding of these patterns would require a more comprehensive qualitative analysis of the papers that cite the original work to understand the context and terms in which the reported citations occur. Even though we do recognize the limitations of this platform and of its bibliometric indicators, and, additionally, that by using it, we are legitimizing the quantitative outputs it produces, we did not mobilize these indicators as crude measures of research performance. Rather, these were mobilized in combination with other indicators of scientific practices that result from content analysis of the papers in our sample. Despite the above-mentioned limitations, this approach allowed for the development of a first broad characterization of malaria research in Portugal, including some inputs on what is perceived by the scientific actors working on malaria to be significant or useful malaria research.

Another concern still arises from the usage of *Web of Science*. This type of database is today understood, within the biomedical community, as an important tool of analysis of scientific practices (Saha et al., 2003). However, that does not seem to be the case for publications arising from Portuguese organizations in the beginning of the twentieth century. At that time, malaria research developed in Portugal was rather published in non-indexed scientific *fora* (Ferreira, 2016). If the analysis now developed give us some relevant inputs as to the internationalization of peer-recognized research developed in Portuguese organizations since the beginning of the 20th century, it does not integrate all malaria research performed within these organizations. Only an analysis that addresses non-indexed scientific publications could reveal a more complete scenario of malaria research in Portugal.

A third limitation of this study relates to the fact that we are focusing on research on one particular pathology, i.e., malaria, a disease that presents a number of specificities (short term infectious disease, mainly affecting poor countries and populations, and thus, not particularly attractive for industry's investments) (Daems et al., 2014; World Health Organization, 2016). This implies, from the go-ahead, that some of the patterns of today's science, such as the industry's participation, might not be so prevalent in our sample. In any case, we were still able to show their small but significant presence in the most recent publications (Global science). In addition, one should keep in mind that in spite of the mobilized methodology being able to capture some connections between science's actors, it does not exhaust all concrete interactions that, in the case of public-private partnerships, can include the funding of projects; patents; financing of teams; departments; or research institutions (Krimsky and Nader, 2004). The same limitation can be pointed out as for the analysis of public science, which has been described to take other forms of collaboration and action that are precluded from scientific publications (see Moore et al., 2011 for a review). These interactions will be addressed in a future project mobilizing a qualitative analysis that thoroughly characterizes the scientific process, the actors participating in it, and their positions throughout research development.

A fourth limitation to be pointed out regards the characterization of the methodology of the different articles. If our approach has allowed to directly address whether an application dynamics is present in malaria research, it does not detail for instance, within translational research, the specific subgroups of malaria treatments that could be at stake. Such a categorization is highly relevant for establishing a research agenda to eradicate malaria, and has been previously proposed by Alonso and colleagues (Alonso et al., 2011). Future studies on malaria translational research should mobilize it.

Finally, the fact that we have chosen to focus on malaria research performed within Portuguese organizations means that we are in face of a case study. If this approach allowed us, on the one hand, to assess the full universe of publications, giving access to extremely valuable information, on the other, it does not allow us to address these contributions in a broader context, a study that remains to be done. It does give us, however, import hints into the potential features of malaria research in general and of biomedical research in Portugal. Future studies should cover both suggested directions, studying malaria research in a broader international context (assessing whether similar research profiles are also present), and addressing other pathologies in the Portuguese context (checking whether the contextual specificities now revealed are also present in the research patterns of other pathologies). These contingencies, though situating our study, do not jeopardize the social and scientific relevance of this research, in which we will now focus.

### Concluding remarks

This study revealed the main dimensions of malaria research. These involve, at a first level, the actors that actively participated in the publication effort. Along this dimension of our plane, we can observe transformations at the organizational level. The second dimension reflects the types, methodological approaches, and performance levels of the analysed publications. As such, this dimension gives us the transformations of scientific practices and culture. Altogether, our results show that the dimension characterizing who is developing malaria research has a higher explanatory power of the structure of the scientific landscape, than the dimension addressing the practices that are being developed and their underlying culture. As such, the present study suggests that malaria research is indeed the result of on-going struggles, coalitions, and repositioning of academic, corporate, governmental, and civil society actors.

Our results further show that the most recent profile of malaria research in Portugal is associated with international and heterogeneous actors (including associations with industrial but not civil society actors), and application- and performance-driven research. Since this profile is consistent with the theoretical backgrounds of academic and epistemic capitalism, it suggests that despite pressures to pluralize science, even non-profit driven research profiles are framed by the dominant modes of organizing, modes of doing, and modes of thinking. In these settings, Portugal seems to be embodying the scientific modes of production from countries with more developed S&T systems and reinforcing them, by imposing some of its features in former Portuguese territories.

Finally, the mobilized methodology allowed establishing three profiles that portray the recent evolution of the Portuguese scientific system and the implemented policies and measures. This being the case, we suggest that this approach can be used as a tool to assess the latest trends of the scientific market and, particularly, of biomedical research.

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## Notes

1. Postal address: Avenida de Berna, 26 C, 1069-061, Lisboa, Portugal.
2. To the best of our knowledge, this is the most recent data addressing the prevalence of malaria research within all biomedical studies.
3. Stokes developed a quadrant model of scientific research in which basic and applied research are not opposite modes of research but rather modes with different goals. According to this model, "Basic research" (Bohr's quadrant) aims to deepen the understanding of particular phenomena or processes without considering knowledge's potential application. "Applied research" (Edison's quadrant) is uniquely guided by applied goals while "Use-inspired research" (Pasteur's quadrant) includes all research that aiming for further understanding of phenomena or processes, is inspired by its potential applications. The last quadrant includes research that is driven by researchers' curiosity on specific phenomena or processes, neither aiming for a general understanding (Bohr's quadrant), nor application (Edison's quadrant).
4. Quite illustrative of this point is the study of Hicks and Katz focusing on United Kingdom publications in all scientific fields between 1981 and 1991. In this study, the authors addressed the "application of science" through the analysis of variations in the number of publications 1) from organizational types that are closer to an applied model of research (such as hospitals and industry) and those that are not, and 2) in fields of science closer (including medicine) and further from application. While, in the first case, the authors report an increase in applied research, the same trend is absent in the analysis of all fields of science. Still, medicine is the fastest growing field of science.

5. The impact factor refers to the average number of citations *per* paper published in a specific journal (i.e., it divides the total number of citations of all papers published in a journal on a specific year by the total number of papers published in the same journal during the two preceding years). Thus, impact factors are not specific to the paper being analysed. On the contrary, the number of citations specifically reveals how many times a specific paper was cited. In both cases the citations are counted within a specific database of scientific journals (e.g., Web of science; Scopus).
6. A discussion on the limitations of impact factors and number of citations can be found in the section "Limitations and opportunities for future research".
7. This study is focused on publications between 1988 and 2009 with Indian organizations.
8. Malaria is triggered by the bite of a female *Anopholes* mosquito leading to the passage of the parasite *Plasmodium* into the host's bloodstream (Ferreira, 2011).
9. The hierarchical cluster analysis used the squared Euclidean distance as the measure of similarity between the subjects (i.e., indexed malaria papers). Several clustering methods were tested and the increase of the agglomeration coefficients suggested the presence of three clusters. For the same number of clusters a 66% to 100% degree of convergence between tested clustering methods was found (Within-groups Average linkage; Between-groups Average linkage; Single linkage; Complete linkage; Centroid linkage; Median linkage; and Ward linkage). The final cluster membership of each subject was performed with the non-hierarchical method k-Means (Marôco, 2014) and then analysed in relation to the original variables in order to proceed to the cluster characterization.
10. Adjusted standardized residual>1.96; 95% confidence level: $|Z|>1.96$.
11. Adjusted standardized residual=1.9; 90% confidence level: $|Z|>1.645$.

## Appendix 1

**Supplementary Table 1.** Contributions of the categories to the inertia of the dimensions and centroid coordinates of the considered variables' categories.

| | | Contribution of the category to the inertia of the dimension | | Centroid Coordinates | |
|---|---|---|---|---|---|
| | | Dim. 1 | Dim. 2 | Dim. 1 | Dim. 2 |
| Number of authors | 1 | **0,032*** | 0,021 | -1,977 | 1,259 |
| | 2-4 | **0,050*** | **0,023**** | -0,853 | 0,448 |
| | 5-9 | 0,001 | **0,031*** | 0,097 | -0,386 |
| | 10 or more | **0,053*** | 0,002 | 0,868 | 0,114 |
| First authorship: Portuguese | Yes | **0,032*** | 0,004 | -0,412 | -0,115 |
| | No | **0,065*** | 0,008 | 0,853 | 0,238 |
| Last authorship: Portuguese | Yes | **0,034*** | 0,008 | -0,447 | -0,173 |
| | No | **0,056*** | 0,014 | 0,739 | 0,285 |
| Methodology | Translational | 0,007 | **0,057*** | 0,234 | -0,532 |
| | Cellular & animal models | 0,000 | 0,001 | 0,060 | -0,072 |
| | No live models | 0,000 | 0,000 | -0,505 | 0,096 |
| | Non-experimental | **0,035*** | **0,246*** | -0,991 | 2,040 |
| Paper type | Research articles | 0,012 | 0,022 | 0,246 | -0,255 |
| | Reviews/discussions | 0,020 | **0,174*** | -0,971 | 2,231 |
| | Meeting abstracts | 0,011 | **0,030*** | -0,601 | -0,760 |
| | Others | 0,007 | **0,066*** | -0,595 | 1,437 |
| Number of types of organizational affiliation | 1 | **0,039*** | 0,001 | -0,529 | 0,051 |
| | 2 | **0,023**** | 0,000 | 0,457 | -0,038 |
| | 3 or more | **0,021**** | 0,001 | 0,908 | -0,133 |
| Country of Affiliation | Portugal | **0,136*** | 0,002 | -1,442 | -0,141 |
| | International | **0,042*** | 0,001 | 0,446 | 0,042 |
| Collaboration with former Portuguese territories | Yes | 0,003 | **0,073*** | 0,217 | -0,883 |
| | No | 0,001 | 0,019 | -0,061 | 0,230 |
| Collaboration with Europe, North America and Oceania | Yes | **0,055*** | 0,017 | 0,561 | 0,246 |
| | No | **0,098*** | **0,031*** | -0,989 | -0,433 |
| Collaboration with countries with endemic malaria and not former Portuguese territories | Yes | **0,052*** | 0,006 | 0,963 | 0,264 |
| | No | 0,014 | 0,002 | -0,250 | -0,069 |
| Publication subject area | Infect diseases/Trop Med | 0,002 | 0,001 | 0,113 | -0,070 |
| | Multidisciplinary | 0,002 | 0,006 | 0,202 | 0,306 |
| | Mol & Cell Biol/Immunol | 0,000 | 0,002 | 0,096 | 0,215 |
| | (Bio)chem/Pharm/Biotech | 0,000 | 0,002 | -0,047 | 0,193 |
| | Medicine and Public Health | **0,023**** | 0,012 | -1,182 | -0,658 |
| | Others | 0,006 | 0,000 | -0,808 | -0,155 |
| Impact Factor | Under 2 | 0,014 | 0,019 | -0,539 | -0,498 |
| | Between 2 and 10 | 0,007 | 0,000 | 0,180 | 0,016 |
| | Above 10 | 0,000 | **0,060*** | -0,101 | 1,517 |

**Supplementary Table 1 cont.**

| | | Contribution of the category to the inertia of the dimension | | Centroid Coordinates | |
|---|---|---|---|---|---|
| | | Dim. 1 | Dim. 2 | Dim. 1 | Dim. 2 |
| Citations | Top 10% (most cited) | 0,008 | **0,025*** | 0,560 | 0,750 |
| | ]10-25%] | 0,006 | 0,003 | 0,369 | 0,205 |
| | ]25-50%] | 0,009 | 0,000 | 0,367 | 0,016 |
| | ]50-100%] (least cited) | **0,023**** | 0,011 | -0,406 | -0,215 |

Note: Dim.: Dimension Infect diseases/Trop Med: Infectious diseases and Tropical Medicine; Mol & Cell Biol/Immunol: Molecular and Cellular Biology and Immunology; (Bio)chem/Pharm/Biotech: Biochemistry; Chemistry, Pharmacology; and Biotechnology.

The contribution of the category to the inertia of the dimension represents the amount of a dimension's inertia (variance) that is explained by a point (category). One should privilege the categories that have an above average contribution: since the sum of the contributions of all categories in each dimension equals 1, the reference cut point is given by 1/p (where p is the total number of active categories). In this case, the cut point is 0.025 (=1/40). Therefore, the categories with a contribution above 0.025 are the ones, for each dimension, that produce higher discrimination between the objects. * represents categories with an above the average contribution to the inertia of the dimension; ** represents categories with a very close to the average contribution to the inertia of the dimension.

The centroid coordinates depict the position of each category in the perceptual map, aiding its interpretation and visualisation of the found profiles. Since not all categories have a significant discriminant contribution, one should only consider the projection of those that have an above average contribution (or close to the average). This is why those categories with smaller contributions are represented as hollow circles with no labels and those with significant contributions are represented as filled circles with labels (see Figure 2).