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Interpopulational differences in the frequency and distribution of delta types

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Corresponding Author:	Noemí Rivaldería, Ph.D Universidad de Alcala Alcalá de Henares, Madrid SPAIN
First Author:	Noemí Rivaldería, Ph.D
Order of Authors:	Noemí Rivaldería, Ph.D
	Esperanza Gutiérrez-Redomero, Ph.D
Abstract:	The classification of the main pattern types, arch, loop and whorls, is based on the number and location of deltas or triradii, which are areas defined by the confluence of three ridge systems carrying different directions on the fingerprint. Despite being areas that give place to an important morphological variability, their study has only been approached from the quantitative point of view, in relation to the number with which they appear per finger, hand, or individual (intensity pattern), and their sexual and population differences; while the qualitative aspects have not been evaluated so far. The following paper aims to study and analyze the qualitative variability, both intra and interpopulation, of the frequency of occurrence of the different types of deltas or triradii, in four fingerprint samples from males of different population origin: 100 individuals from China, 100 individuals from Colombia, 100 individuals from Nigeria and 100 individuals from Romania, which has meant the analysis of 4000 fingerprints. For this purpose, the classification of 24 types used by the Scientific Police and Criminalist Departments of the Guardia Civil of Spain has been employed. The results obtained showed the non-equiprobability of the frequency distribution of the different delta types in the four populations. In all cases, sunk open total deltas (Hat), sunk open total with point (Hat(p)) and tripod long (Tl) were the most frequent types, while the sunk closed total with point (Hct(p)) had the lowest frequency. Furthermore, for the first time, interpopulation differences in the frequency distribution of different types of deltas have become noticeable. The data provided in this paper are a pioneer in the field of dactyloscopy and can be used as a reference by the departments of criminalistics of the different countries for the estimation of the scientific value of the evidence in dactyloscopy.

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Interpopulational differences in the frequency and distribution of delta types

Noemí Rivaldería[1,2], Esperanza Gutiérrez-Redomero [1,2]

[1] Departamento de Ciencias de la Vida, Facultad de Ciencias, Universidad de Alcalá, Alcalá de Henares, Madrid, Spain

[2] Instituto Universitario de Investigación en Ciencias Policiales (IUICP), Universidad de Alcalá, Alcalá de Henares, Madrid, Spain.

Corresponding author(s) name and contact address:

Noemí Rivaldería Moreno
Dpto. Ciencias de la Vida
Facultad de Ciencias
Campus Universitario, Crta. Madrid-Barcelona, km 33,6
28802 Alcalá de Henares (Madrid) España
Telef: +34 918855090
noemi.rivalderia@uah.es

Highlights files:

For the first time, the non-equiprobability of the different types of deltas has been revealed.

Population differences in frequency distribution of different delta types have been demonstrated.

There is a significant association between the different types of pattern and the fingers.

The frequency presented by the different types of deltas has been shown to be associated with the main pattern type in the samples from Romania and Colombia.

Abstract

The classification of the main pattern types, arch, loop and whorls, is based on the number and location of deltas or triradii, which are areas defined by the confluence of three ridge systems carrying different directions on the fingerprint. Despite being areas that give place to an important morphological variability, their study has only been approached from the quantitative point of view, in relation to the number with which they appear per finger, hand, or individual (intensity pattern), and their sexual and population differences; while the qualitative aspects have not been evaluated so far.

The following paper aims to study and analyze the qualitative variability, both intra and interpopulation, of the frequency of occurrence of the different types of deltas or triradii, in four fingerprint samples from males of different population origin: 100 individuals from China, 100 individuals from Colombia, 100 individuals from Nigeria and 100 individuals from Romania, which has meant the analysis of 4000 fingerprints. For this purpose, the classification of 24 types used by the Scientific Police and Criminalist Departments of the Guardia Civil of Spain has been employed.

The results obtained showed the non-equiprobability of the frequency distribution of the different delta types in the four populations. In all cases, sunk open total deltas (Hat), sunk open total with point (Hat(p)) and tripod long (Tl) were the most frequent types, while the sunk closed total with point (Hct(p)) had the lowest frequency. Furthermore, for the first time, interpopulation differences in the frequency distribution of different types of deltas have become noticeable.

The data provided in this paper are a pioneer in the field of dactyloscopy and can be used as a reference by the departments of criminalistics of the different countries for the estimation of the scientific value of the evidence in dactyloscopy.

Keywords: delta, triradius, triradii, fingerprints, dermatoglyphics, population variability.

Introduction

Identification through the comparison of a latent print, collected at the scene of a crime, and thus of unknown or dubious origin, with another taken with the assurance of legal certainty in order to know its identity reliably and therefore indubitably, has been one of the most used techniques in the forensic field for more than a century. Since the first dactyloscopic identification was conducted by a police force, in 1905 by Juan Vucetich, belonging to the Central Police Department in La Plata in Argentina [1], this technique was gradually incorporated by all countries, being accepted as incriminating evidence by all courts of justice around the world. Since its beginning, the uniqueness of fingerprints, determined by the variability of dermopapillary ridges, both in their individual trajectory and in the designs that form the ridges on the epidermal surfaces of hands and feet, along with their permanence throughout life, with hardly any substantial changes, has given this type of evidence a high discriminatory power to establish identity in both legal and civil spheres [2, 3].

The variability presented by dermopapillary ridges is determined by multifactorial and polygenic inheritance, with the influence of the environment limited to the first months of intrauterine life during which their formation occurs. Thus, after 20 weeks of gestation, the morphological characteristics of the ridges will not vary except in their size, remaining constant throughout life, unless there is damage that affects the base layer of the epidermis (3,4).

Studies of variability in dermopapillary ridges, also known as dermatoglyphs (from Greek, *derma*, skin, and *glyphs*, engraving), have focused on the analysis of bimanual and sexual variability in many different human populations of the main pattern types (arch, loop and whorls), ridge counting (between triradius and core), pattern intensity (as the sum of all triradii) [4]. Hence, there is a wide knowledge of the intra- and interpopulation variability of these features, while others such as minutiae, despite being the basis in the process of identification by fingerprint, are significantly less known [5]. However, in recent decades, the interest in these characteristics has been increasing [3, 4, 6-12]; although, undoubtedly, many more studies are still required to reach a similar level of knowledge about them to that of other dermatoglyphic particularities such as those mentioned above. Also, the variability presented by deltas or triradii, areas formed by the confluence of three ridge systems whose flows take different directions, has not been assessed as far as we know. In these areas, specific configurations are formed, which present a great variability, but which can also be classified and analyzed.

The classification already made by Galton [13] in the three main pattern types (arch, loop and whorls) was based on the presence and number of deltas on the fingerprint. Thus, the arches were characterized for not having any delta configurations, loops for having one and whorls for having two or more. In loops and whorls, triradius or delta starts from the meeting of three defined topographic zones within the fingerprint, which delimit the area of the pattern (or core system), the distal transverse system (or marginal system) and the proximal transverse system (or basilar system) [14, 15].

The Latin term of *triradius* (singular) *triradii* (plural) has been used to define the model that creates the confluence of the three ridge flows of different direction, in whose central point can be located the origin of three radiants that separate the three systems [14]. Similarly, the term delta is used to refer to this configuration. The concept of delta is an analogy to the island formed in front of the divergent sides of the banks where the river flows, whose correspondence in the fingerprints would be that of the first obstruction of any nature located in front of or near the center of the point of divergence of the type lines. Delta is the name of the fourth letter of the Greek alphabet (capital letter Δ, lowercase letter δ), equivalent to the letter D. The Greeks called the alluvial deposit at the mouth of the Nile, because of its shape, the Nile Delta. Thus, the delta point or focal point is that point on a ridge that's at or ahead of; it is also the closest to the center of the divergence of type lines [16].

The publication in 2009 of the report "Strengthening Forensic Science in the United States: A Path Forward" issued by the National Research Council of the U.S. National Academies of Science. [17], has led to the review of some features by relevant institutions in the forensic field such as the International Association of the identification (IAI) and European Network of Forensic Science Institutes (ENFSI). In 2010 the IAI and in 2011 ENSFI, advocated the development of statistical models through research to improve the methods employed to calculate the scientific value of fingerprint evidence, provided that these were accepted by the scientific community [18, 19]. This means that there is a need to promote research in all areas of identification, including fingerprints [20, 21].

Thus, it is important to point out that, to date, there is no work that analyses the frequency and distribution of the different types of deltas, data that could be of interest in the statistical evaluation of the evidence in the comparison of fingerprints. Hence, the main aim of this paper has been to analyze the bimanual and population variability of the different types of deltas based on the distribution of their frequencies, in order to know if there are differences between their types, and if they show interpopulation differences.

Material and methods

The analyzed samples were obtained from the files of the General Scientific Police Station and from the Criminalistics Service of the Guardia Civil of Spain. The sample was composed of the ten-print files of a total of 400 male individuals, of which 100 individuals were of Chinese origin, 100 individuals of Colombian origin, 100 individuals of Nigerian origin and 100 individuals of Romanian origin. Thus, a total of 4,000 fingerprints have been analyzed and studied for this research.

The criterion used for the selection of the cards was that the ten fingerprints were correctly rolled and not pasted (a fingerprint is pasted when it is of very poor quality and contains a lot of noise). The population origin, in relation to the country of origin that appears in the cards, is that referred to by the individual at the time of taking the fingerprints.

In the ten-print files, the fingers are numbered from 1 to 10, starting with the right thumb, identified as finger 1 (F1), and ending with the left little finger, identified as finger 10 (F10).

Fingerprints were classified into four main pattern types depending on the number and location of the triradius or delta, defined as arches (without delta), ulnar loops (with a delta in the radial area), radial loops (with a delta in the ulnar area) or whorls (with two or more deltas) [14].

The analysis of the variability of the different delta types, was conducted by the study authors following the classification given by the Spanish Scientific Police based on the suggestion made by Federico Oloriz [15], formed by 24 types of deltas, which can be divided into four main categories: Sunk white, sunk with point, tripod short and tripod long (Figure 2).

Sunk white open

- Open total: those deltas whose three vertices are open (Hat).
- Open in: those deltas whose vertex, formed by the nuclear and basilar type lines, is not closed, while the other two vertices remain closed (Hai).
- Open out: those deltas whose vertex formed by the marginal and basilar type lines is not closed, while the other two vertices remain closed (Hae).
- Open up: those deltas whose upper vertex, formed by the nuclear and marginal type lines, is open, while the other two, remain closed (Has).

Sunk white closed

- Closed total: those deltas whose three vertices are closed (Hct).
- Closed in: Those deltas with two open vertices and one closed vertex; this last one formed by the union of the nuclear and basilar type lines. The closed vertex is oriented towards the nuclear system of the fingerprint, (Hci).
- Closed out: those deltas with two open vertices and one closed vertex; this last one formed by the union of the marginal and basilar type lines. The closed vertex is oriented towards the external part of the fingerprint or the marginal system, (Hce).
- Closed up: those deltas whose upper vertex, formed by the nuclear and marginal type lines, is closed, while the other two, facing the basilar system, remain open (Hcs).

Sunk open with point

In these deltas, it should be stressed that their uniqueness is that the delta point is formed by a ridge point. The configuration adopted by the ridges regarding the vertices that appear closed or open is the same as the one already described for the sunk open and closed, with the exception that, in this case, the delta point corresponds to a ridge point. Open total with point: (Hat (p)).

- Open in with point: (Hai (p))
- Open out with point: (Hae (p)).
- Open up with point: (Has (p)).

Sunk closed with point

In the same way, these deltas form similar shapes to the ones described in the sunk closed, except that the delta point is above the ridge point, which is located inside the triradius. Classified as follows

- Closed total with point: (Hct (p)).
- Closed in with point: (Hci (p)).
- Closed out with point: (Hce (p)).
- Closed up with point: (Hcs (p)).

Tripods

On the other hand, tripods are characterized because the delta or triradial center is formed by the union of the three ridges that form the limits of each of the systems (basilar, marginal and nuclear). They also have different morphologies depending on the length of their branches. A branch is considered to be long when its length exceeds five times the width of the ridge. If it does not exceed this length, we consider the branch to be short and will classify it as such.

Tripod short

- Tripod short: it has three short-length branches (Tc).
- Tripod short up: its upper branch (marginal) is short, while the two remaining branches (nuclear and basilar) are long (Tcs).
- Tripod short in: its branch oriented towards the core or nuclear system is short, while the other two (marginal and basilar) are long (Tci).
- Tripod short out: its branch oriented towards the basilar system is short, while the other two (nuclear and marginal) are long (Tce).

Tripod long

- Tripod long: it has three long-length branches (Tl).
- Tripod long up:its upper branch (marginal) is long, while the two remaining branches (nuclear and basilar) are short (Tls).
- Tripod long in: its branch oriented towards the nuclear system is long, while the other two (marginal and basilar) are short (Tli).
- Tripod long out: its branch oriented towards the basilar system is long, while the other two (nuclear and marginal) are short (Tle).

Statistical analysis

The location of the type of delta was carried out in the 4,000 fingerprints that, along with other variables, such as the area where the delta appeared (radial or ulnar), the number of deltas in each print, the type of pattern or nationality, allowed the construction of a database for subsequent analysis. Thus, the frequency of occurrence of each type of delta per finger, hand, area and type of main pattern, for each of the population samples, was established, and the results compared between them.

The data obtained were statistically analyzed by correspondence analysis (CA) and Chi² test with 95% confidence, using SPPS 22.0 and Statistica 12.5 software.

The interpretation of the correspondence analysis shows that when the angle between the two analyzed variables is acute, the relationship between them is more noticeable. A summarized description of this method can be seen in the paper about variability of the minutiae in the fingerprint of Spanish population [9]. Concerning the correspondence analysis, it is important to point out that those types of deltas that have shown a very low frequency of occurrence, thus being far from the coordinate axis for a better visualization in the analysis, have been represented in the periphery of the graph (included in a circle).

Results

Main pattern type

Table 1 shows the relative frequencies obtained, per finger and population, for each of the four main pattern types assessed, arch, radial and ulnar loop and whorls. As expected, the most frequent pattern types in the four populations analyzed were ulnar loops and whorls, with significant lower frequencies for radial loops and arches. The association between fingers and main pattern types by population was assessed through a correspondence analysis (Figure 3). In all four populations an important dependence was found between the main pattern type and the fingers, with whorls being associated with the thumbs (F1 and F6) and ring fingers (F4 and F9), ulnar loops with the middle fingers (F3 and F8) and little fingers (F5 and F10), while arches and radial loops were associated with the index fingers (F2 and F7).

The total relative frequencies obtained for each type of main pattern per population are shown in Figure 4. The most frequent type of main pattern was the ulnar loop in all populations, except in the sample of Chinese population, where the most frequent type of main pattern was the whorl, with a frequency of occurrence of 51%. The association between the main pattern types and population was assessed through a correspondence analysis shown in Figure 4B. The total inertia of the analysis was 98.99%, separating the first dimension with 88.19% of the inertia, the population of Nigeria (associated to arches) and the population of Colombia and Romania (both associated to the ulnar and radial loops), from the sample population of China (associated to whorls). Results of the Chi^2 analysis revealed a statistically significant dependence between the main pattern types and populations.

Variability of the different types of deltas and triradii

Based on the classification used by the Spanish Scientific Police of 24 types of deltas, already detailed in material and methods, frequencies were calculated for each population per finger (Supplementary material 1). To appraise the association, within each population, between the different types of delta and fingers, a correspondence analysis was carried out; results are shown in Figure 5. The only population sample that showed a statistically significant dependency was that of Romania (Figure 5D).

Variability of delta types per hand and area

The variability of the different types of delta was also analyzed per hand (right and left) and area (radial and ulnar). The results showed a statistical dependence on the distribution of different delta types per hand in the samples from China (Chi^2=39,184 df=23 p=0,019) and Romania (Chi^2=39,711 df=21 p=0,008). While, for the radial and ulnar areas, the statistically significant dependence of distribution of delta types was found for the Nigerian (Chi^2=39,562 df=23 p=0,017) and Romanian (Chi^2=33,777 df=21 p=0,038) samples.

Variability of delta types per pattern type and area

The variability of the different delta types was evaluated per area (radial and ulnar) for the most frequent pattern types, whorls and ulnar loops (Supplementary material 2). In the case of the whorls, whose patterns show two deltas, the radial and ulnar areas were assessed separately, while in the ulnar loops, which only show one delta, the area where it appears, which is the radial, was taken into account. Thus, the association between delta types and area types, for the four populations, was assessed by correspondence analysis, and the results are shown in Figure 6. The results showed that the first dimension separates the types of deltas associated with whorls, both in the radial and ulnar area, from the deltas associated with ulnar loops. The associations showed a statistically significant dependence in all samples, except in Colombia.

Interpopulation comparison of delta types

The total relative frequency for the different types of deltas was obtained for each population sample (Figure 7). The results for the sample of the Chinese population show that the most frequent type of delta was the open total (Hat) with a frequency of occurrence of 14.93%, followed by the open total with point (Hat(p)), which had a frequency of 13.72% and the tripod long (Tl), with a frequency of 11.08%. The following types of deltas had frequencies ranging from 6.26% to 0.24%; the three less frequent deltas were the open in (Hai), open out (Hae) and the closed total with point (Hct(p)), which were found with a frequency of 0.64%, 0.40% and 0.24%, respectively.

In the sample of the Colombian population, the most frequent type of delta was also the open total (Hat) with a frequency of 24.12%, followed in this case by the tripod long (Tl) with a frequency of 15.62% and the open total with point (Hat(p)) with a frequency of 13.91%. The frequency of occurrence of the rest of deltas ranges from 6.87% to 0.17%; the three less frequent deltas were the open in (Hai), open up with point (Has(p)) and closed total with point (Hct(p)), which appeared with a frequency of 0.34%, 0.26% and 0.17%, respectively.

In the sample of Nigeria, the most frequent delta was the tripod long (Tl), with a frequency of 14.88%, followed by the open total (Hat) with a frequency of 14.61% and the open total with point (Hat(p)) with a frequency of 11.36%; the remaining types have considerably lower frequencies, which vary between 6.25% and 0.35%. The three less common deltas were the open out (Hae), open up with point (Has(p)) and closed total with point (Hct(p)), with a frequency of occurrence of 0.70%, 0.53% and 0.35%, respectively.

Finally, for Romania's sample, the most frequent type of delta was the open total (Hat) with a frequency of 27.57%, the tripod long (Tl) with a frequency of 16.57 and the open total with point (Hat(p)) with a frequency of 11.31% and, as in the rest of the populations, the rest of the types had considerably lower frequencies, with values between 5.34% and 0.08%. In contrast to the other three analyzed populations, where the 24 types of deltas were found, although with different frequency, in the case of the Romanian sample, the open out with point (Hae(p)) and closed total with point (Hct(p)), were not found in any of the analyzed prints. Among the types, those that had the lowest frequencies are: closed in with point (Hci(p)) (0.40%), closed up with point (Hcs(p)) (0.24%) and open up with point (Has(p)) (0,16%).

Therefore, these data show the non-equiprobability of the frequency distribution of the different types of delta in all the samples, finding statistically significant differences (always with p_values < 0.001) in the distribution of the different types of deltas in the four samples.

An interpopulation comparison has also been carried out by evaluating the association between the 24 types of deltas and the four population samples through a correspondence analysis, whose two dimensions represent 92.89% of inertia Figure 8. The analysis shows that the distribution of delta types differs in the frequency with which they appear in the populations, leaving the four samples separated in the graph. The first dimension (74.05% of inertia), separates the deltas associated with the population of Colombia and Romania, from the deltas associated with the population of Nigeria and China. In the correspondence analysis can be noticed that China and Nigeria are associated with more different types of deltas than Romania and Colombia. Furthermore, only two types of tripods are associated with the samples from Colombia and Romania; tripod short up (Tcs) is the only tripod-shaped delta associated with the population of Colombia, and the tripod long (Tl) is the only tripod-shaped delta associated with the Romanian population.

To assess possible differences in the variability of the delta types found over the radial and ulnar area, a new correspondence analysis was performed. The results are shown in Figure 9 (Supplementary material 3). Similarly, the analysis shows that the distribution of delta types, regardless of the area in which they appear, differs in the frequency with which they appear in the populations, leaving the four population samples separated in the graph. The analysis, with 73.56% of inertia, showed a statistically significant dependence between both variables.

Finally, to assess the possible influence of the main pattern type on the distribution of the different delta types in the four populations, a new correspondence analysis was carried out (Figure 10 and Supplementary material 4). For this analysis, the radial and ulnar loops were evaluated together within the loop pattern type (L). The results show, with an inertia of 71.64%, that the distribution of delta types separates the populations of Nigeria and China, regardless of the type of pattern (loop or Whorl), which seems to have less effect than that printed by the origin of the population. Nevertheless, in the samples from Romania and Colombia, the analysis shows that the variability of the deltas is more determined by the type of pattern than by the origin of the population, separating the samples from Romania and Colombia with loops from the samples with whorls. The correspondence analysis separated in its first dimension, with an inertia of 58.70%, the deltas associated with the populations of Romania and Colombia, for both types of main pattern (whorls and loops) from those associated with the populations of Nigeria and China, which show a higher variability of delta types.

Discussion

The data provided in this paper are completely new, since they are the first results about the frequency of occurrence of the different types of delta and their distribution in different populations.

Before studying the variability of the delta types, the distribution of both inter and intrapopulations frequencies presented by the different types of patterns, per finger and globally, was evaluated. A common pattern of distribution per finger was found in the four populations, coinciding with the results of other samples from Spain [22], Argentina [10; 11] and various countries in the Sub-Saharan zone [23], as well as from many other populations [24], which would be demonstrating a universal association pattern.

In terms of the variability of the deltas or triradii, the studies that have been conducted to date have only assessed quantitative aspects of them, such as the average number of deltas and their bimanual, sexual and population association, which has allowed a detailed understanding of the variability of this characteristic in human populations [25]. However, from a qualitative point of view, the variability introduced by the different morphological types of deltas has not been studied, so the results obtained in this paper are of special interest.

It should be stressed that the results obtained show, in the four samples, the unequal probability of the frequency of occurrence of the different types of deltas, thus giving each type of delta a different probative value in the quantification of the evidence. It has also been shown that there are three most frequent types of deltas that coincide in the four populations, two of them being sunk deltas (open total, Hat, and open total with point Hat(p)), and the tripod (tripod long, Tl). While the less frequent type of delta in all samples was the closed total with point (Hct(p)). These results would be revealing a similar distribution pattern in all four populations, although with frequencies for each type of delta that are different from each other.

Concerning intrapopulation variability, the frequency distribution of the different delta types in each population has not been demonstrated to be similar in the four samples. Although the analyses show associations between different types of deltas and different types of fingers, only a statistically significant dependence between them has been found for the Romanian sample. While statistically significant associations for the distribution of deltas per hand were found in the sample from China and Romania, and per area (radial and ulnar) in those from Nigeria and Romania. Consequently, although there is some basis for considering that the presence of some types of deltas or others on fingers, hands, or areas, may be conditioned by some biological factors; there is no clear pattern in all populations that allows this to be asserted, so further studies are needed. However, when assessing whether the presence of some types of deltas is more frequent than others over the different types of patterns (whorl and loop) a stronger association has been observed in each of the four samples and statistically significant in all samples except the one from Colombia, indicating that different types of deltas are associated with whorls and loop.

As for the interpopulation comparison, since the results of this work are the first related to the variability of the different types of delta on four samples of very distant geographical origin, at a continental level, and since they have been analyzed following the same methodology, a comparison can be made, although only between them, because in the bibliography no studies have been found to analyze these dermatoglyphic characteristics. The results obtained show, for the first time, interpopulation differences in the frequency distribution of the different types of deltas. The fact that inter-populational differences between the chosen samples have been found, with the sample size selected for this study of 4000 fingerprints (one thousand for each sample), would indicate that this has been enough to show these differences, since, if they had not been found, its absence could have been attributed to the sample size, which has not been the case. Choosing a representative sample of a population is complex and always subject to interpretations, depending on the method chosen, so it remains an unsolved problem. Therefore, it must be considered that this paper is an exploratory study on the variability of the types of deltas in diverse human populations, without pretending that the chosen sample size is considered representative of the population of the chosen country of origin.

Undoubtedly, more studies on these and other dermatoglyphic characteristics used in the identification process are necessary.

Therefore, the population comparison has been performed firstly taking into account the distributions of the different types of deltas, secondly taking into account the distribution of the delta types over the areas (radial and ulnar) and, thirdly, evaluating their distribution over the types of main patterns (whorl and loop). Thus, the results on the distribution of delta types separate the four samples, showing that there are differences in the variability of the types associated with each population. Furthermore, it has been shown that the Nigerian and Chinese samples show a greater variability in the types of deltas appearing in their fingerprints, which contrasts with the low number of delta types associated with the Romanian and Colombian samples. The same results were obtained when the distribution of delta types was compared between the four populations per area (radial and ulnar), indicating that the types of deltas associated with each population are kept in both areas, being more determinant the population origin.

Lastly, the population comparison for the frequency of the different types of delta was also carried out taking into account the type of main pattern. The results show that the association of delta types with the type of pattern only affects the samples from Romania and Colombia, showing that the types of delta associated with loops, on the one hand, and with whorls, on the other, are the same in both populations, suggesting that the variability of deltas is more determined by the type of pattern, than by the origin of the population. In contrast, the Nigerian and Chinese samples are more different by population origin than by type of pattern, since each population, in both patterns, is associated with different types of deltas.

The greatest similarity found both in the distribution of the main pattern types and in the types of deltas associated with the loops and whorls in the samples from Colombia and Romania could be due to the fact that the individuals that are part of the Colombian sample have a high percentage of miscegenation, with a high European component in it [26, 27]. Although this aspect cannot be evaluated since the only data available is the individual's place of birth, without additional data on the origin of the parents and grandparents.

It is important to emphasize that, within fingerprint matching, and especially in those countries that follow a holistic method, the frequency with which the different analyzed characteristics appear in the fingerprints is of particular relevance, as it involves not only quantitative but also qualitative aspects. In this sense, those features that are less frequent will be the most identifying and, therefore, the most useful when it comes to giving importance to the evidence in the process of personal identification.

In addition, relevant research is being conducted within the probabilistic context, and some important contributions within this field are those made on statistical modeling of variability in minutiae [28, 29]; along with others that address the calculation of likelihood ratios (LR), with the aim of assigning a different weight to the evidence in each dactyloscopic comparison [30]; or by studying the scores obtained by the Automated Fingerprint Identification System (AFIS) [31,32].

In this sense, the variability presented by the different types of deltas, valued and quantified in this research, on different samples of fingerprints from human populations of geographical and thus biologically different origins, besides contributing to the general knowledge about these characteristics in human populations, until now unknown, could be used for the assessment of the scientific value of the evidence in dactyloscopy. It must be taken into account that the evaluation of the weight of evidence, whether done by means of frequentist statistics (holistic method depending on the frequency of the trait) or Bayesian (LR), needs for its calculation and application of the data provided by the feature variability study. These values can only be obtained from the systematic study of the variability with which the different dermatographic traits occur in different human populations, as is the case in the present study. On the other hand, automatic search or identification systems, although they may seem endowed with their own life and magic, are not such, and they need data to shape search algorithms that improve and optimize their performance. For all these reasons, it is necessary to increase basic research on the variability of the morphological features used in human identification in general and in fingerprint identification in particular.

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Footnotes and figures:

Table 1: Relative frequencies obtained for each type of main pattern by finger and population. A: arch; UL: ulnar loop; RL: radial loop; W: whorl; F1,…,F10: finger.

Figure 1: Location of deltas or triradii and ridge systems in a fingerprint.

Figure 2: a) Classification used for the identification of the different types of deltas, b) Some examples of the different types of deltas located on fingerprints.

Figure 3: Correspondence analysis between the fingers and the main pattern type for each population: A) China; B) Colombia, C) Nigeria; D) Romania. Finger: F1,…,F10.

Figure 4: Relative frequency of main pattern types per population (A) and correspondence analysis between both variables (B). A: arch; UL: ulnar loop; RL: radial loop; W: whorl

Figure 5: Correspondence analysis between the fingers and the delta type for each population: A) China; B) Colombia, C) Nigeria; D) Romania. F1 ,…,F10: fingers).

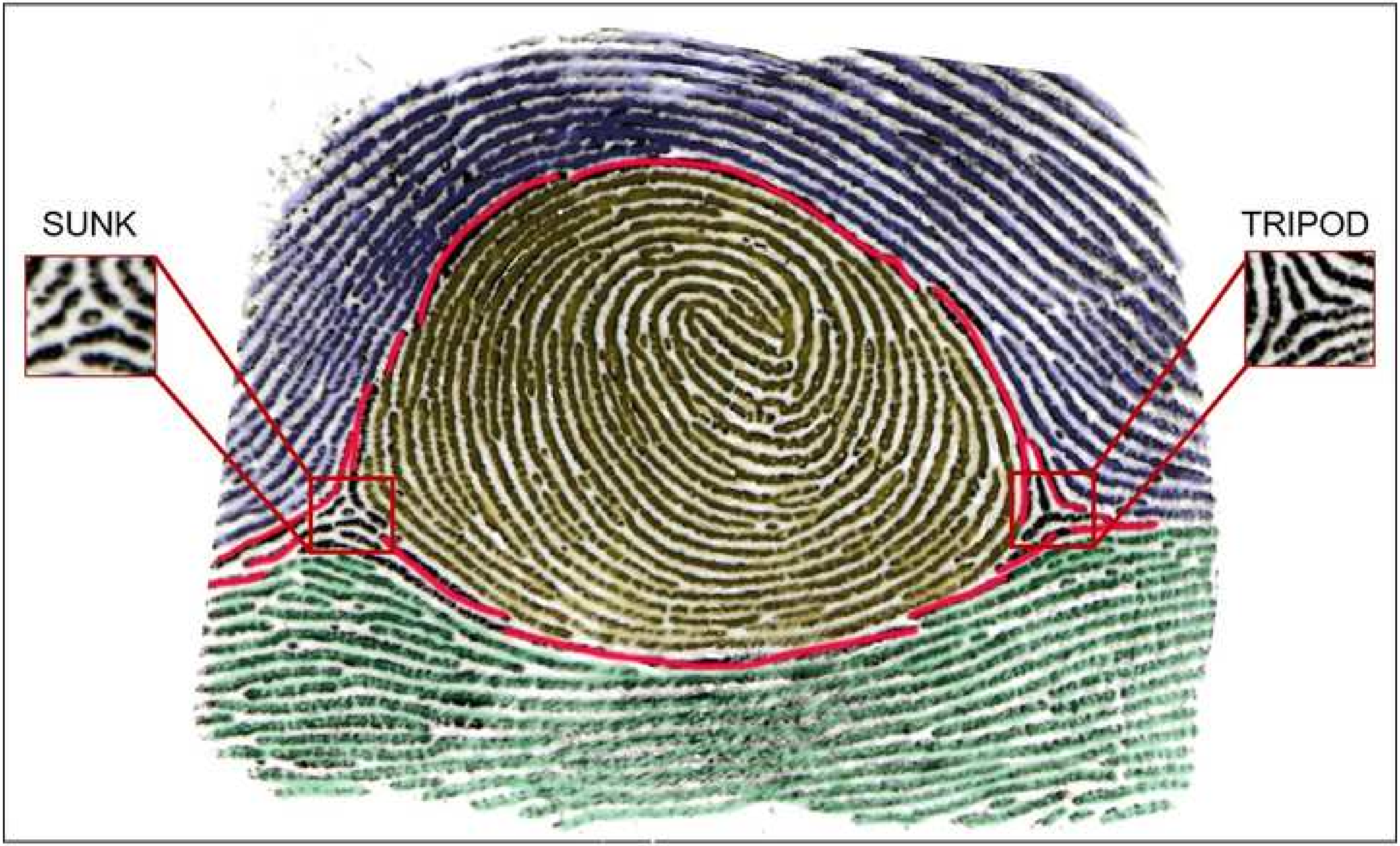
Figure 6: Correspondence analysis between the different delta types and the main pattern and area for each population. A) China; B) Colombia, C) Nigeria; D) Romania. W: whorl; UL: Ulnar loop.

Figure 7: Relative frequencies of occurrence of the different types of delta for each population:

Figure 8: Correspondence analysis between the types of delta and the four analyzed populations

Figure 9: Correspondence analysis between the types of delta and fingerprint per population. U: ulnar; R: radial.

Figure 10: Correspondence analysis between the different delta types and the four population samples according to main pattern type. U: loop; W: whorl.


SUNK
TRIPOD

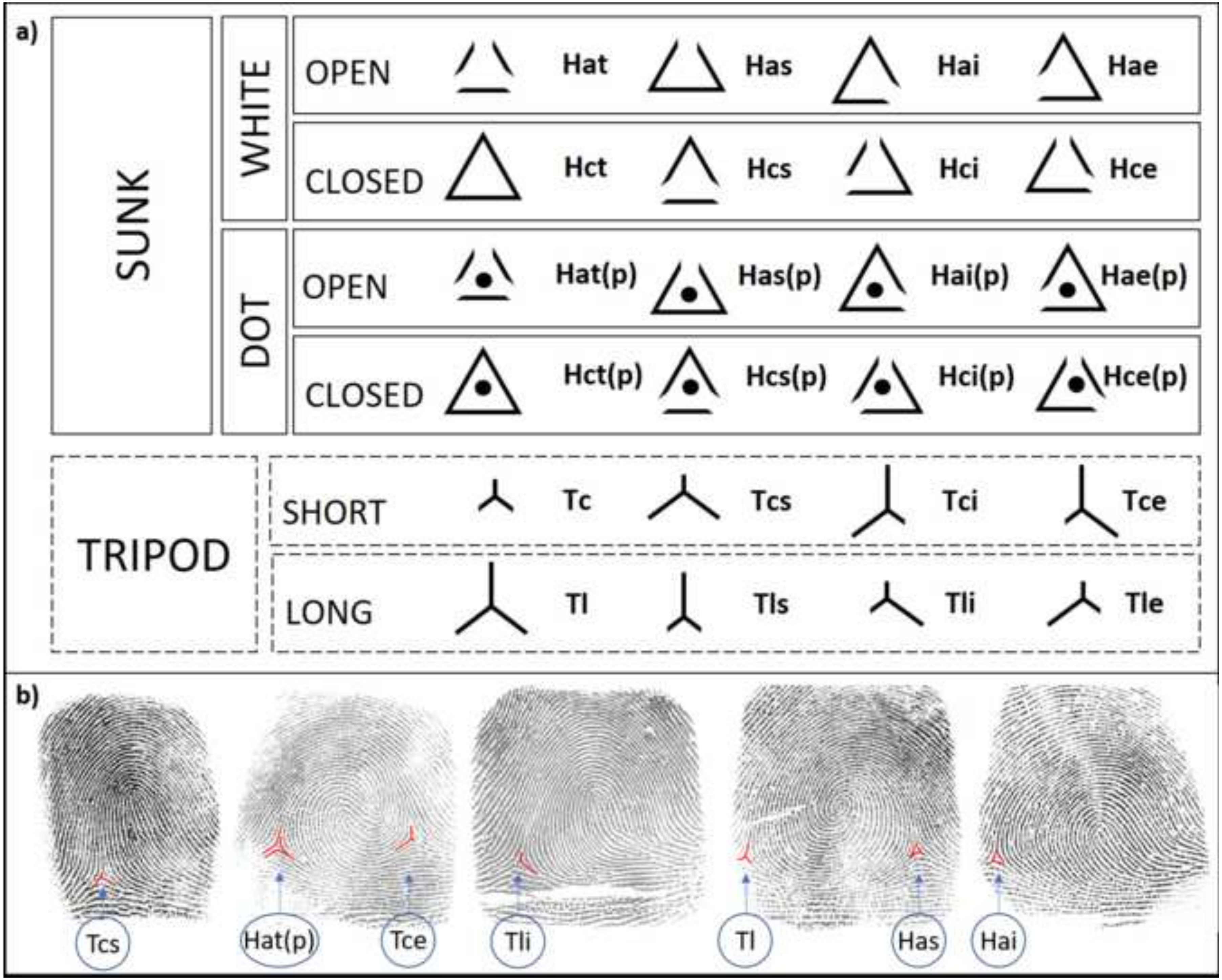

a)
SUNK
WHITE
OPEN
Hat
Has
Hai
Hae
CLOSED
Hct
Hcs
Hci
Hce
DOT
OPEN
Hat(p)
Has(p)
Hai(p)
Hae(p)
CLOSED
Hct(p)
Hcs(p)
Hci(p)
Hce(p)
TRIPOD
SHORT
Tc
Tcs
Tci
Tce
LONG
Tl
Tls
Tli
Tle
b)
Tcs
Hat(p)
Tce
Tli
Tl
Has
Hai

Figure3

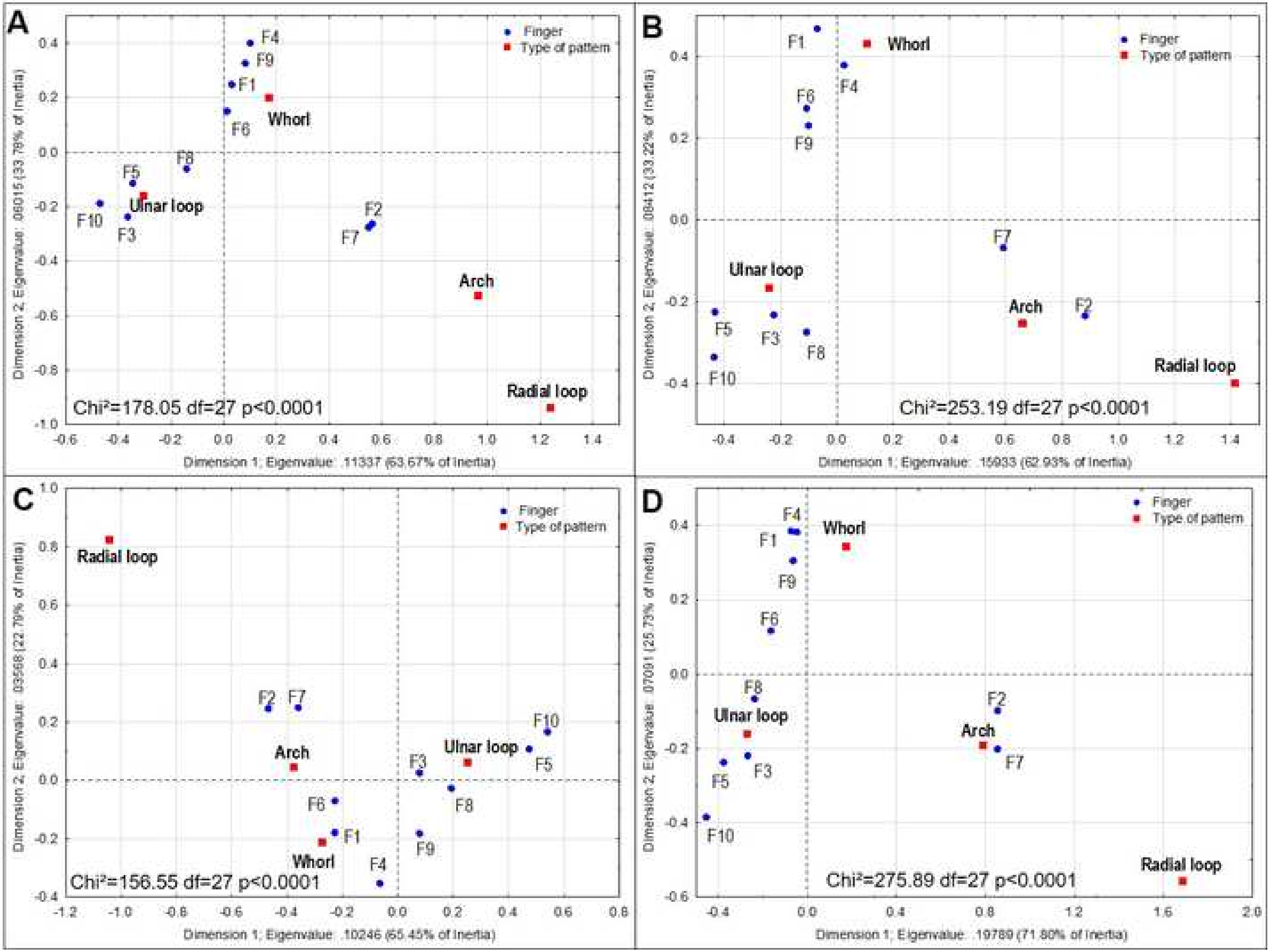

A
Finger
Type of pattern
F4
F9
F1
Whorl
F6
F8
F5
Ulnar loop
F10
F3
F2
F7
Arch
Radial loop
Chi²=178.05 df=27 p<0.0001
Dimension 1; Eigenvalue: .11337 (63.67% of Inertia)
Dimension 2; Eigenvalue: .06015 (33.78% of Inertia)
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
B
Finger
Type of pattern
F1
Whorl
F4
F6
F9
F7
Ulnar loop
Arch
F2
F5
F3
F8
F10
Radial loop
Chi²=253.19 df=27 p<0.0001
Dimension 1; Eigenvalue: .15933 (62.93% of Inertia)
Dimension 2; Eigenvalue: .08412 (33.22% of Inertia)
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
-0.4
-0.2
0.0
0.2
0.4
C
Finger
Type of pattern
Radial loop
F2
F7
F10
Arch
Ulnar loop
F3
F5
F8
F6
F1
Whorl
F9
F4
Chi²=156.55 df=27 p<0.0001
Dimension 1; Eigenvalue: .10246 (65.45% of Inertia)
Dimension 2; Eigenvalue: .03568 (22.79% of Inertia)
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
D
Finger
Type of pattern
F4
F1
Whorl
F9
F6
F8
Ulnar loop
F2
Arch
F7
F3
F5
F10
Radial loop
Chi²=275.89 df=27 p<0.0001
Dimension 1; Eigenvalue: .19789 (71.80% of Inertia)
Dimension 2; Eigenvalue: .07091 (25.73% of Inertia)
-0.4
0.0
0.4
0.8
1.2
1.6
2.0
-0.6
-0.4
-0.2
0.0
0.2
0.4

Figure4

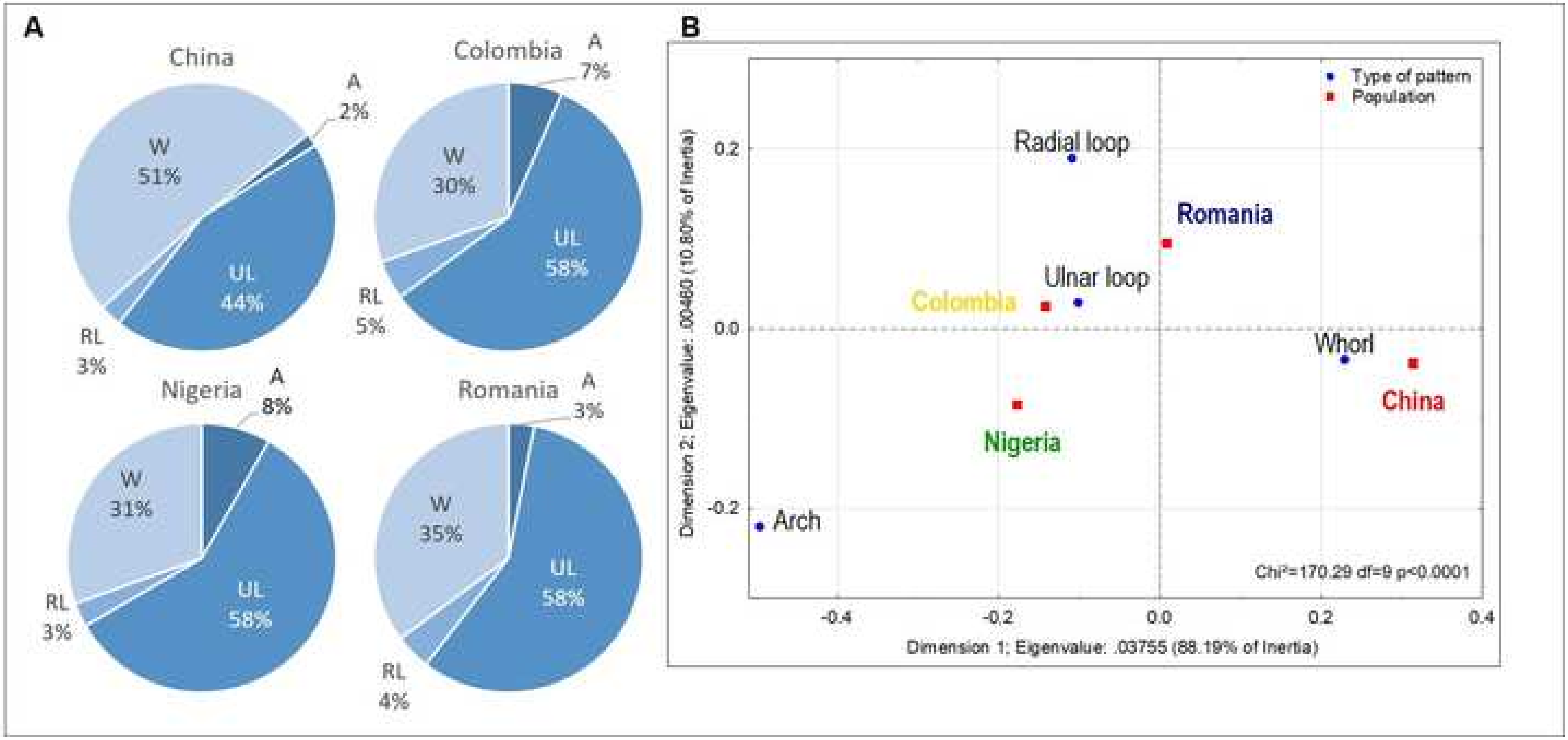

A
China
W 51%
UL 44%
RL 3%
A 2%
Colombia
W 30%
UL 58%
RL 5%
A 7%
Nigeria
W 31%
UL 58%
RL 3%
A 8%
Romania
W 35%
UL 58%
RL 4%
A 3%
B
● Type of pattern
■ Population
Radial loop
Romania
Ulnar loop
Colombia
Whorl
China
Nigeria
Arch
Chi²=170.29 df=9 p<0.0001
0.2
0.0
-0.2
-0.4
-0.2
0.0
0.2
0.4
Dimension 1; Eigenvalue: .03755 (88.19% of Inertia)
Dimension 2; Eigenvalue: .00480 (10.80% of Inertia)

Figure5

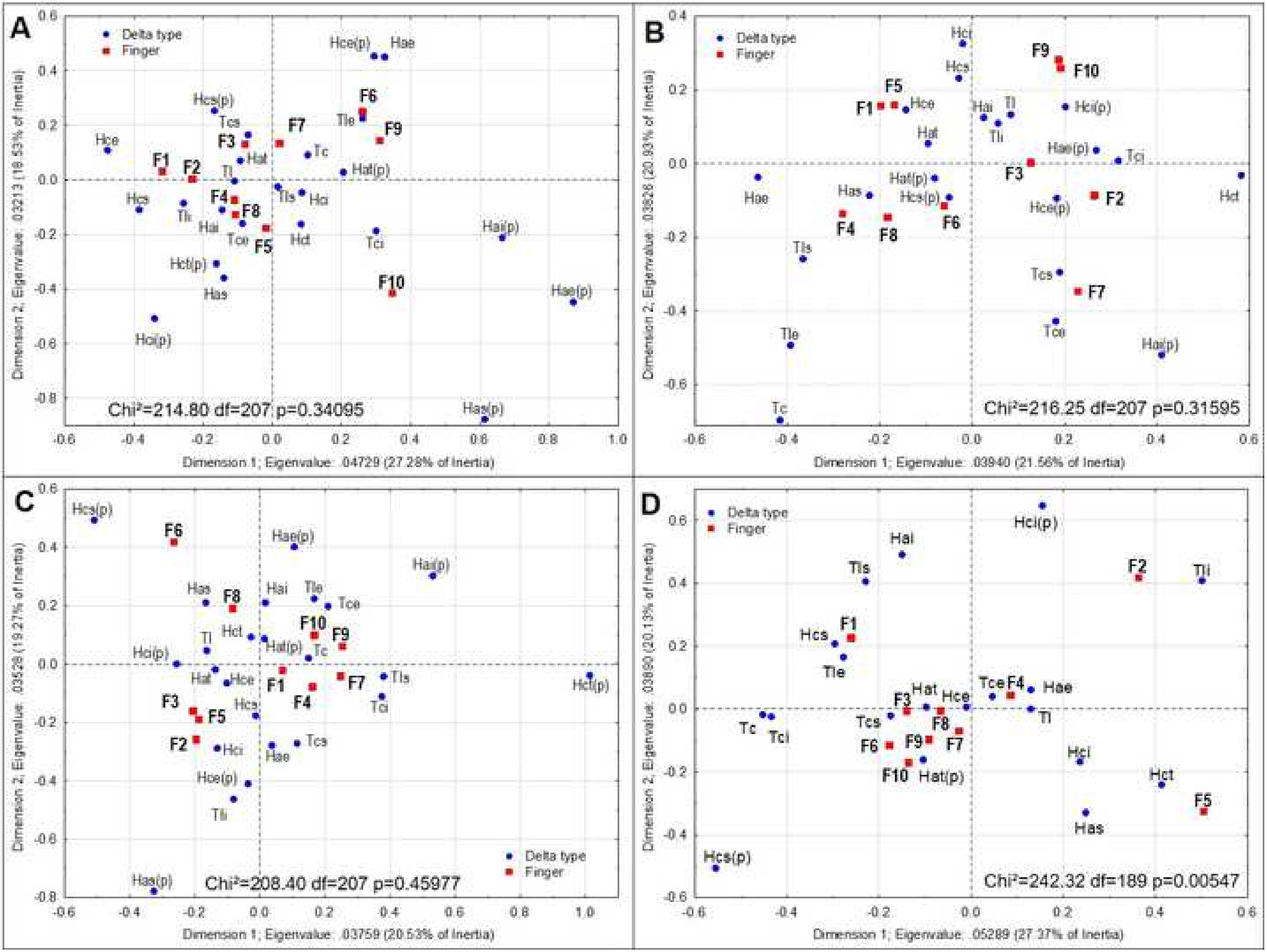
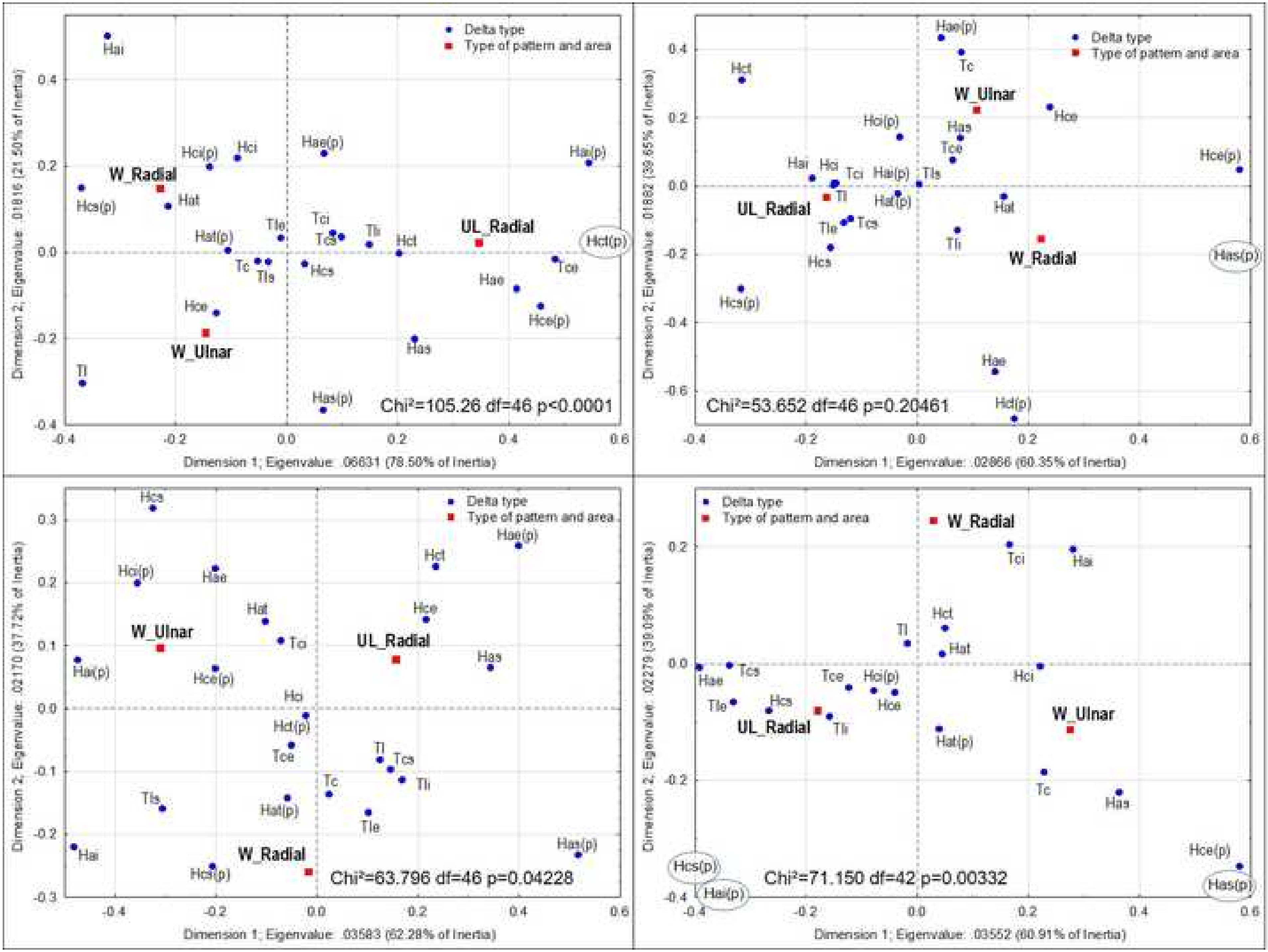
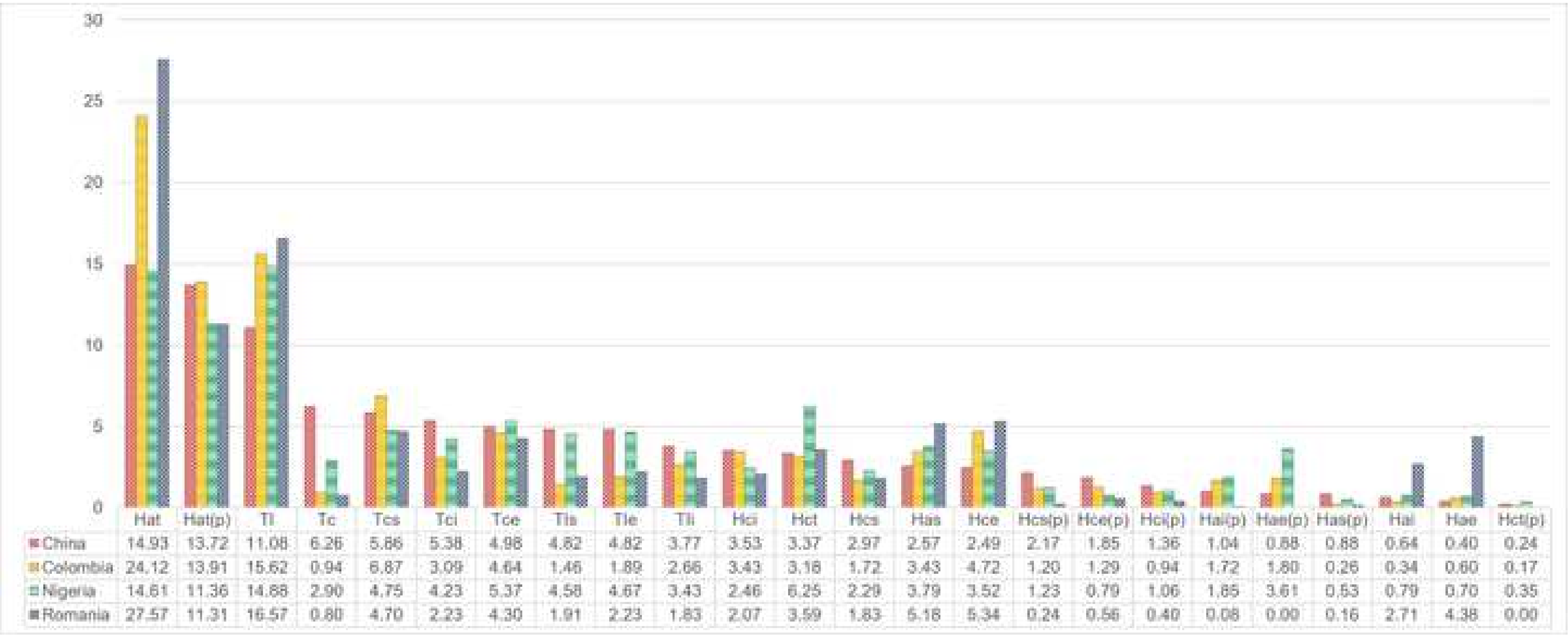

A
Delta type
Finger
Hce(p)
Hae
Hcs(p)
Tcs
F6
Tle
F7
F9
Hce
F3
Hat
Tc
F1
F2
Tl
Hat(p)
Hcs
Tli
F4
Tls
Hci
F8
Hai
Tce
F5
Hct
Tci
Hai(p)
Hct(p)
Has
F10
Hae(p)
Hci(p)
Has(p)
Chi²=214.80 df=207 p=0.34095
Dimension 1; Eigenvalue: .04729 (27.28% of Inertia)
Dimension 2; Eigenvalue: .03213 (18.53% of Inertia)
B
Delta type
Finger
Hct
Hcs
F9
F10
F5
F1
Hce
Hai
Tl
Hci(p)
Tli
Hat
Hae(p)
Tci
F3
Hae
Hat(p)
Has
Hcs(p)
Hct
Hce(p)
F2
F4
F8
F6
Tls
Tcs
F7
Tle
Tce
Hai(p)
Tc
Chi²=216.25 df=207 p=0.31595
Dimension 1; Eigenvalue: .03940 (21.56% of Inertia)
Dimension 2; Eigenvalue: .03828 (20.93% of Inertia)
C
Hcs(p)
F6
Hae(p)
Hai(p)
Has
F8
Hai
Tle
Tce
F10
Tl
Hct
F9
Hci(p)
Hat(p)
Tc
Hat
Hce
F1
F7
Tls
Hct(p)
F3
F4
Tci
F5
Hcs
F2
Hci
Tcs
Hae
Hce(p)
Tli
Has(p)
Delta type
Finger
Chi²=208.40 df=207 p=0.45977
Dimension 1; Eigenvalue: .03759 (20.53% of Inertia)
Dimension 2; Eigenvalue: .03528 (19.27% of Inertia)
D
Delta type
Finger
Hci(p)
Hai
F2
Tli
Tls
F1
Hcs
Tle
Tce
F4
Hae
Hat
Hce
F3
Tl
Tcs
F8
Tc
Tci
F6
F9
F7
F10
Hat(p)
Hci
Hct
F5
Has
Hcs(p)
Chi²=242.32 df=189 p=0.00547
Dimension 1; Eigenvalue: .05289 (27.37% of Inertia)
Dimension 2; Eigenvalue: .03890 (20.13% of Inertia)
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
-0.8

Figure6



● Delta type
■ Type of pattern and area
Dimension 1; Eigenvalue: .06631 (78.50% of Inertia)
Dimension 2; Eigenvalue: .01816 (21.50% of Inertia)
Chi²=105.26 df=46 p<0.0001
Hai
Hci(p)
Hci
Hae(p)
Hai(p)
W_Radial
Hcs(p)
Hat
Tle
Tci
Tcs
Tli
Hct
UL_Radial
Hct(p)
Hat(p)
Tc
Tls
Hcs
Tce
Hae
Hce
Hce(p)
W_Ulnar
Has
Tl
Has(p)
Dimension 1; Eigenvalue: .02866 (60.35% of Inertia)
Dimension 2; Eigenvalue: .01882 (39.65% of Inertia)
Chi²=53.652 df=46 p=0.20461
Hae(p)
Tc
Hct
W_Ulnar
Hce
Hci(p)
Has
Tce
Hce(p)
Hai
Hci
Tci
Hai(p)
Tls
Tl
Hat(p)
Hat
UL_Radial
Tle
Tcs
Tli
Hcs
W_Radial
Has(p)
Hcs(p)
Hae
Hct(p)
Dimension 1; Eigenvalue: .03583 (62.28% of Inertia)
Dimension 2; Eigenvalue: .02170 (37.72% of Inertia)
Chi²=63.796 df=46 p=0.04228
Hcs
Hae(p)
Hct
Hci(p)
Hae
Hat
Hce
W_Ulnar
Tci
UL_Radial
Has
Hai(p)
Hce(p)
Hci
Hct(p)
Tce
Tl
Tcs
Tc
Tli
Tls
Hat(p)
Tle
Hai
Hcs(p)
W_Radial
Has(p)
Dimension 1; Eigenvalue: .03552 (60.91% of Inertia)
Dimension 2; Eigenvalue: .02279 (39.09% of Inertia)
Chi²=71.150 df=42 p=0.00332
W_Radial
Tci
Hai
Hct
Tl
Hat
Hae
Tcs
Tce
Hci(p)
Hci
Tle
Hcs
Hce
UL_Radial
Tli
Hat(p)
W_Ulnar
Tc
Has
Hce(p)
Hcs(p)
Hai(p)
Has(p)
-0.4
-0.2
0.0
0.2
0.4
0.6

Figure7



	Hat	Hat(p)	Tl	Tc	Tcs	Tci	Tce	Tls	Tle	Tli	Hci	Hct	Hcs	Has	Hce	Hcs(p)	Hce(p)	Hci(p)	Hai(p)	Hae(p)	Has(p)	Hai	Hae	Hct(p)
▨ China	14.93	13.72	11.08	6.26	5.86	5.38	4.98	4.82	4.82	3.77	3.53	3.37	2.97	2.57	2.49	2.17	1.85	1.36	1.04	0.88	0.88	0.64	0.40	0.24
▨ Colombia	24.12	13.91	15.62	0.94	6.87	3.09	4.64	1.46	1.89	2.66	3.43	3.18	1.72	3.43	4.72	1.20	1.29	0.94	1.72	1.80	0.26	0.34	0.60	0.17
▨ Nigeria	14.61	11.36	14.88	2.90	4.75	4.23	5.37	4.58	4.67	3.43	2.46	6.25	2.29	3.79	3.52	1.23	0.79	1.06	1.85	3.61	0.53	0.79	0.70	0.35
▨ Romania	27.57	11.31	16.57	0.80	4.70	2.23	4.30	1.91	2.23	1.83	2.07	3.59	1.83	5.18	5.34	0.24	0.56	0.40	0.08	0.00	0.16	2.71	4.38	0.00

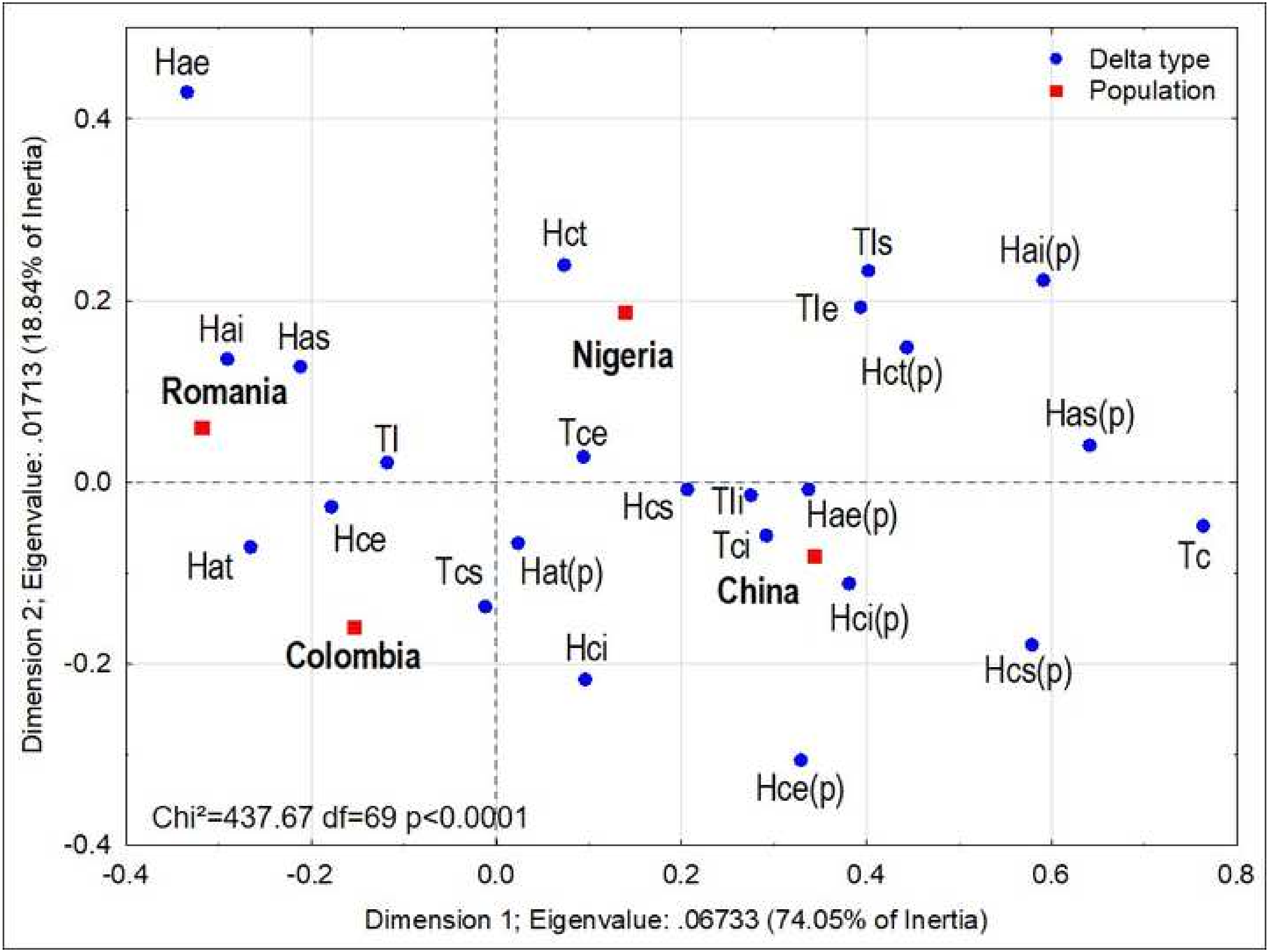
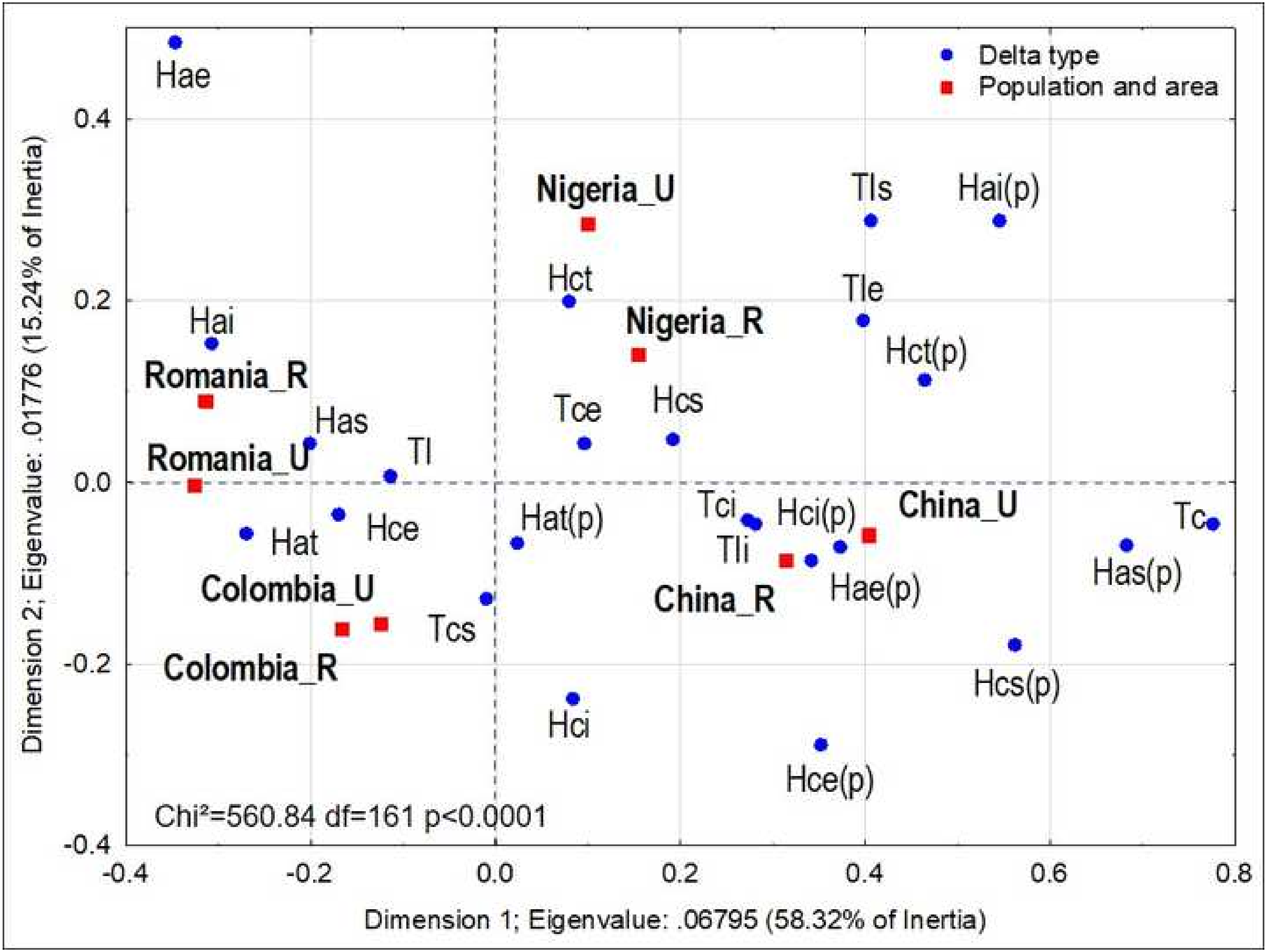
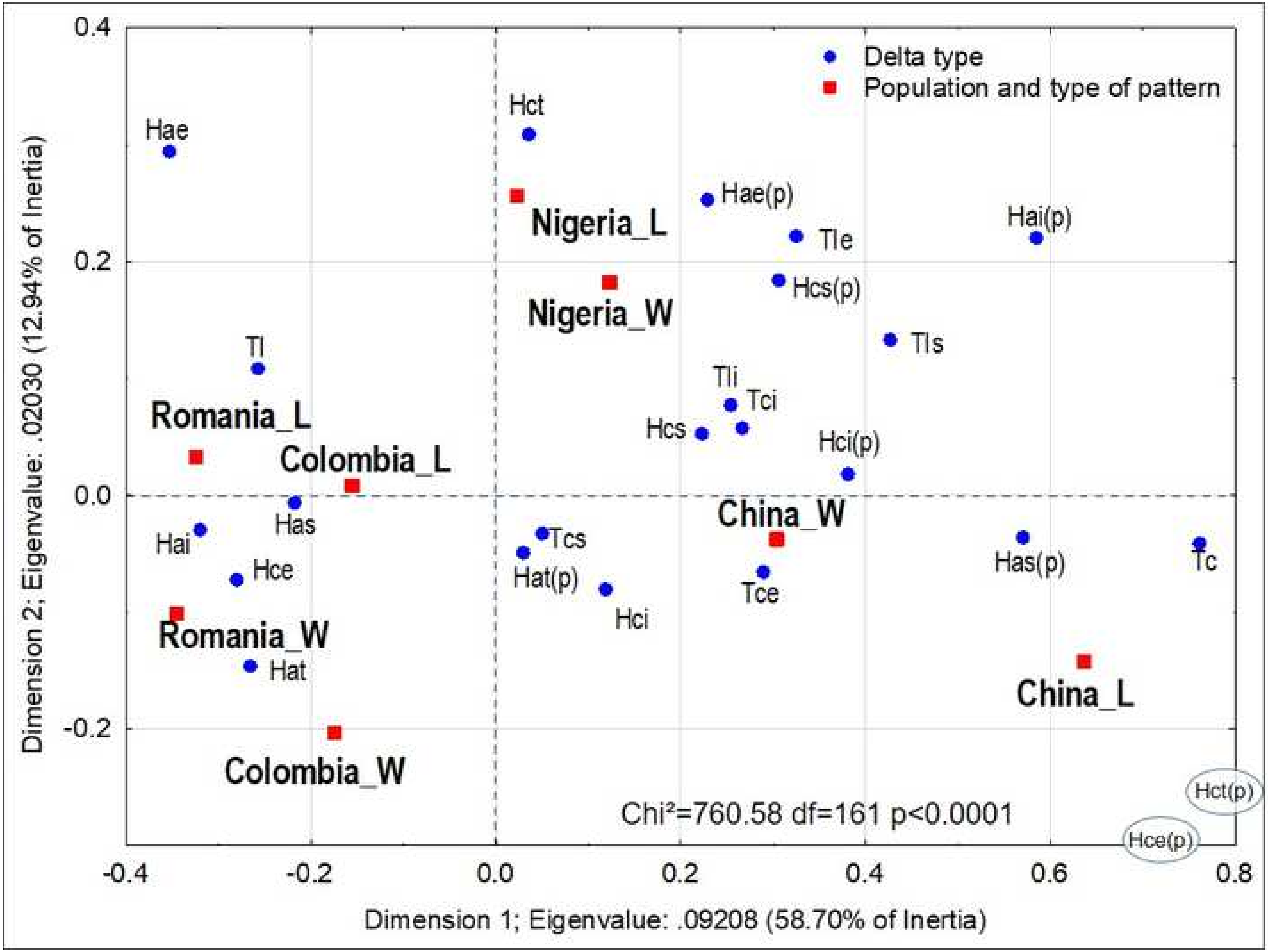

Hae
Hct
Tls
Hai(p)
Delta type
Population
0.4
0.2
Tle
Hai
Has
Nigeria
Hct(p)
Romania
Has(p)
Tl
Tce
0.0
Hcs
Tli
Hae(p)
Hce
Hat
Tci
Tc
Tcs
Hat(p)
China
Hci(p)
Colombia
Hci
Hcs(p)
-0.2
Hce(p)
Chi²=437.67 df=69 p<0.0001
-0.4
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
Dimension 1; Eigenvalue: .06733 (74.05% of Inertia)
Dimension 2; Eigenvalue: .01713 (18.84% of Inertia)

Figure9


● Delta type
■ Population and area
Hae
Hai
Romania_R
Has
Romania_U
Tl
Hat
Hce
Colombia_U
Colombia_R
Tcs
Nigeria_U
Hct
Nigeria_R
Tce
Hcs
Hat(p)
Hci
Tls
Hai(p)
Tle
Hct(p)
Tci
Hci(p)
China_U
Tli
China_R
Hae(p)
Hce(p)
Tc
Has(p)
Hcs(p)
Chi²=560.84 df=161 p<0.0001
Dimension 1; Eigenvalue: .06795 (58.32% of Inertia)
Dimension 2; Eigenvalue: .01776 (15.24% of Inertia)
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
0.4
0.2
0.0
-0.2
-0.4



0.4
0.2
0.0
-0.2
-0.4
0.6
0.8
Dimension 2; Eigenvalue: .02030 (12.94% of Inertia)
Dimension 1; Eigenvalue: .09208 (58.70% of Inertia)
● Delta type
■ Population and type of pattern
Hae
Hct
Nigeria_L
Hae(p)
Tle
Hai(p)
Nigeria_W
Hcs(p)
Tls
Tl
Tli
Tci
Romania_L
Hcs
Hci(p)
Colombia_L
China_W
Has
Hai
Tcs
Has(p)
Tc
Hce
Hat(p)
Tce
Hci
Romania_W
Hat
China_L
Colombia_W
Hct(p)
Hce(p)
Chi²=760.58 df=161 p<0.0001

	CHINA				COLOMBIA				NIGERIA				ROMANIA			
	A	UL	RL	W	A	UL	RL	W	A	UL	RL	W	A	UL	RL	W
F1	0	36	1	63	4	45	0	51	14	44	2	40	1	47	0	52
F2	5	29	11	55	15	36	22	27	11	42	11	36	9	30	19	42
F3	0	66	2	32	8	73	1	18	10	62	2	26	4	74	1	21
F4	0	29	0	71	2	46	4	48	4	49	0	47	2	46	0	52
F5	1	62	0	37	1	82	0	17	3	82	0	15	0	80	1	20
F6	3	40	0	57	4	53	1	42	16	46	3	35	3	59	0	38
F7	5	30	11	54	15	39	14	32	10	47	10	33	7	34	21	38
F8	1	52	2	45	10	70	3	17	10	66	0	24	4	67	0	28
F9	1	32	0	67	5	54	1	40	2	59	1	38	1	50	1	49
F10	0	69	0	31	1	86	1	12	3	86	0	11	0	87	1	12