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Age-stratified characteristics of serum allergen-specific IgE profiles among 73,739 allergic patients in North China: A large-sample cross-sectional study

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Abstract

Background

Allergic diseases have become a global health challenge, with allergen profiles exhibiting marked regional and ethnic variations. North China is a densely populated region with distinct climatic features, yet large-sample, fine-grained epidemiological studies covering the full age spectrum are still lacking. This study aimed to systematically characterize the serum specific IgE (sIgE) profiles of patients in North China, with a focus on age-stratified distribution patterns and co-sensitization features.

Methods

A cross-sectional study design was used to retrospectively analyze the clinical data of 73,739 patients who underwent serum allergen testing at the Air Force Medical Center between July 2019 and September 2025. Total IgE and sIgE levels were measured, and stratified analyses were conducted by age groups: infants/toddlers (1–2 years), children (3–12 years), adolescents (13–17 years), adults (18–60 years), and older adults (> 60 years). Statistical analyses included the chi-square test, Spearman's correlation analysis, and association rule mining.

Results

The overall sensitization rate was 45.7%. The most prevalent allergens were egg (16.12%), mugwort mix (13.90%), and house dust mites (13.04%). The allergen spectrum demonstrated a distinct age-related evolution: food allergens predominated in early childhood (egg 43.97%, milk 40.92%), whereas the dominance of inhalant allergens increased with age, with cat epithelium (31.01%) and mugwort mix (27.38%) becoming the major triggers in adolescence. Total IgE levels were positively correlated with the number of sensitizations ($\rho = 0.401$, $P < 0.001$). Co-sensitization analysis revealed the strongest association between tree mix and mugwort mix ($r = 0.50$).

Conclusion

This study is the first to delineate fine-scale, age-specific allergen profiles in North China using a large dataset, identifying the evolutionary pathway from food sensitization to inhalant sensitization and specific co-sensitization patterns. These findings provide a critical epidemiological basis for precision diagnosis and age-specific prevention strategies in this region.

1. Background

According to the World Health Organization (WHO), allergic diseases have now become the fourth leading chronic disease worldwide, and it is estimated that by 2050, 50% of the global population will be

affected by allergies. Allergic diseases have therefore emerged as a major public health concern that affects individuals at every stage of life(1).

Since its discovery in 1967, immunoglobulin E (IgE) has been recognized as the central mechanism of type I hypersensitivity. Although its concentration in the body is low, IgE can trigger potent inflammatory immune responses in various tissues and organs(2). Consequently, serum specific IgE (sIgE) testing, valued for its objectivity and precision, has become an essential tool for clinical diagnosis and etiological screening(3, 4).

A substantial body of research demonstrates that the allergen spectrum is not static; rather, it is shaped by a complex interplay of factors including genetic background, geographical environment(5), climatic conditions(6), lifestyle, age(7), and sex(8). Among these, age is a key factor driving the dynamic evolution of allergen sensitization. As age advances, both clinical manifestations and the types of sensitizing allergens change. In general, allergic symptoms during infancy and early childhood are comparatively milder, yet the overall mortality rate is higher; conversely, adults tend to experience more severe symptoms but have a lower overall mortality rate(7).

North China is a densely populated and economically developed region, most of which is characterized by a temperate monsoon climate with four distinct seasons. Although some previous studies have investigated allergens in this region, the majority were limited by small sample sizes or focused exclusively on specific populations, such as children. There remains a conspicuous lack of large-scale, systematic studies spanning the full age spectrum from infancy to old age and involving tens of thousands of samples. As a result, clinicians lack a clear understanding of the overall landscape of the allergen spectrum and its age-specific patterns in this population, which hinders the development of precision prevention and control strategies for allergic diseases.

Therefore, the present study aims to conduct a large-scale cross-sectional investigation using serum allergen testing data accumulated over nearly five years from over 70,000 patients at a single center in North China. We sought to characterize the allergen profile of the study population, examine its variation with age and sex, explore the relationship between total IgE and sIgE, and delineate co-sensitization patterns, so as to provide evidence to support clinical practice and epidemiological research in this region.

2. Methods

2.1 Study design and population

This was a retrospective cross-sectional study. This study was approved by the Ethics Committee of the Air Force Medical Center of PLA (approval number: 2025-86-PJ01). The requirement for informed consent was waived due to the retrospective nature of the study. All patients who underwent serum allergen testing at the Allergy Department of the Air Force Medical Center between July 4, 2019 and September 15, 2025 were consecutively enrolled. The exclusion criteria were: (1) for patients with

multiple tests, only the first test record was retained; (2) records with missing key information (age or sex). A total of 73,739 patients were ultimately included.

2.2 Testing methods and data collection

Serum testing: Venous blood samples were collected from all patients using inert separation gel and clot activator tubes. After centrifugation, the supernatant serum was harvested for analysis.

Instruments and reagents: Testing was performed using the URANUS AE 95 automated enzyme immunoassay analyzer (Jiangsu HOB Biotech Co., Ltd.) together with the matching total IgE and specific IgE (sIgE) test kits.

Test parameters: Total IgE and sIgE were measured. The sIgE panel included inhalant allergens — house dust mites, cat epithelium, dog epithelium, cockroach, mold mix (Penicillium notatum, Alternaria alternata, Aspergillus fumigatus, Rhizopus nigricans), tree mix (common birch, plane tree, willow, cottonwood, cypress, pine), and mugwort mix (mugwort, ragweed, hop) — as well as food allergens — milk, crab, shrimp, egg, and wheat flour.

Positivity criteria: According to the kit instructions and expert consensus, the reference range for total IgE was 0–60 kUA/L for individuals > 6 years of age and 0–30 kUA/L for children 0–6 years of age. sIgE positivity was defined as a concentration ≥ 0.35 kUA/L.

Data extraction: Data on age, sex, total IgE concentration, and individual sIgE concentrations were exported from the hospital laboratory information system. For total IgE values exceeding the upper detection limit (> 2,000 kUA/L), the lower limit value of 2,000 kUA/L was used in statistical analyses.

2.3 Statistical analysis

Data were analyzed using Excel 2021 and R software (version 4.2.3). Normally distributed continuous data are presented as mean ± standard deviation, and non-normally distributed data as median (interquartile range, IQR). Categorical data are expressed as counts (percentages). Between-group comparisons were performed using the chi-square test. Non-normally distributed continuous variables between two groups were compared using the Mann-Whitney U test. The relationship between total IgE level and the number of sensitizing allergens was assessed using Spearman's rank correlation. Association rule mining was conducted using the "arules" package in R, with a minimum support of 0.01 and a minimum confidence of 0.50. Network visualization of strong association rules was generated using the "igraph" package. A two-sided $P < 0.05$ was considered statistically significant.

3. Results

A total of 73,739 patients were included in this study; their detailed characteristics are presented in Table 1. Males slightly outnumbered females (53.36% vs. 46.64%). Patient age followed a skewed distribution, with a median of 27 years (IQR: 10–40), indicating that the study population consisted predominantly of children and adults. Among the age groups, the adult group (18–60 years) accounted

for the largest proportion (58.95%), followed by the children group (24.11%) and the older adult group (7.74%). Total IgE levels also exhibited a skewed distribution, with a median of 102.47 kU/L (IQR: 31.24–334.11).

Table 1
Characteristics of the study population

Characteristic	Total (N = 73,739)	Male (N = 39,346,53.36%)	Female (N = 34,393,46.64%)
Age (years)			
Median (IQR)	27 (10–40)	25 (10–37)	28 (10–42)
Age group, n (%)			
Infants and toddlers (1–2 years)	3,759 (5.10%)	2,028 (2.75%)	1,731 (2.35%)
Children (3–12 years)	17,775 (24.11%)	9,693 (13.15%)	8,082 (10.96%)
Adolescents (13–17 years)	3,031 (4.11%)	1,547 (2.10%)	1,484 (2.01%)
Adults (18–60 years)	43,466 (58.95%)	22,871 (31.02%)	20,595 (27.93%)
Older adults (> 60 years)	5,708 (7.74%)	3,207 (4.35%)	2,501 (3.39%)
Total IgE (kU/L) Median (IQR)	102.47 (31.24–334.11)	126.69 (39.21–391.97)	80.95 (24.50–268.51)

Overall allergen profile

Among the 73,739 patients enrolled, 33,705 tested positive for sIgE, yielding an overall sensitization rate of 45.7%. The top 12 allergens ranked by positivity rate are shown in Table 2. Food allergens and inhalant allergens together constituted the major sensitizing allergens. Egg (16.12%) ranked first and was the most prevalent allergen. Among inhalant allergens, mugwort mix (13.90%) and house dust mites (13.04%) showed the highest positivity rates and were identified as important outdoor and indoor allergens, respectively. Other major inhalant allergens included cat epithelium (10.69%), tree mix (10.37%), and mold mix (9.01%), whereas cockroach, a common indoor allergen, had a positivity rate of only 1.48%. Among food allergens, in addition to egg, milk (10.12%) was another common sensitizing food, while wheat flour (5.81%), crab (3.44%), and shrimp (1.56%) exhibited relatively low sensitization rates.

Table 2
Top 12 allergens by sIgE positivity rate

Rank	Allergen	Category	No. of positive cases	Positivity rate (%)
1	Egg	Food	11,888	16.12
2	Mugwort mix	Inhalant	10,247	13.90
3	House dust mites	Inhalant	9,614	13.04
4	Cat epithelium	Inhalant	7,882	10.69
5	Tree mix	Inhalant	7,649	10.37
6	Milk	Food	7,466	10.12
7	Mold mix	Inhalant	6,646	9.01
8	Wheat flour	Food	4,281	5.81
9	Dog epithelium	Inhalant	4,019	5.45
10	Crab	Food	2,537	3.44
11	Shrimp	Food	1,148	1.56
12	Cockroach	Inhalant	1,092	1.48

Age-stratified allergen profile characteristics

The allergen profiles differed significantly across age groups (Table 3, χ^2 test, all $P < 0.001$). In infants/toddlers (1–2 years), the allergen profile was distinctly dominated by food allergens, with egg (43.97%) and milk (40.92%) being the absolutely predominant allergens, their positivity rates far exceeding those of other allergens. Wheat flour (15.30%) also accounted for a relatively high proportion. In children (3–12 years), the sensitization pattern shifted into a mixed sensitization stage. Although egg (41.64%) remained highly prevalent, the sensitization rates of multiple inhalant allergens increased markedly, such as mold mix (25.83%), mugwort mix (23.96%), and tree mix (17.35%). Notably, the positivity rate for milk (24.80%) remained high. In adolescents (13–17 years), the allergen profile underwent a fundamental transition to inhalant allergen predominance. Cat epithelium (31.01%), mugwort mix (27.38%), house dust mites (22.07%), tree mix (20.13%), and mold mix (20.22%) became the leading allergens, all with positivity rates exceeding 20%. In contrast, the positivity rates of food allergens dropped substantially. The overall sensitization levels in adults (18–60 years) and older adults (> 60 years) were markedly lower. In adults, house dust mites (14.11%), mugwort mix (11.08%), and cat epithelium (8.49%) were the main allergens. In the older adult group, the positivity rates of all allergens further declined to generally below 6%, with house dust mites (5.89%) and mugwort mix (3.92%) remaining the relatively more common sensitizers.

Table 3
Age-stratified sIgE positivity rates of 12 allergens (%)

Allergen	Infants/toddlers (1–2 y)	Children (3–12 y)	Adolescents (13–17 y)	Adults (18–60 y)	Older adults (> 60 y)
House dust mites	3.17	13.25	22.07	14.11	5.89
Cat epithelium	3.30	16.89	31.01	8.49	2.19
Dog epithelium	2.74	8.45	14.71	4.31	1.66
Milk	40.92	24.80	10.62	2.57	1.38
Crab	4.66	3.56	4.35	3.39	2.21
Shrimp	2.87	1.75	1.48	1.41	1.28
Egg	43.97	41.64	13.76	5.22	2.58
Wheat flour	15.30	15.12	3.33	1.82	2.19
Cockroach	0.32	0.60	1.19	1.96	1.51
Mold mix	6.76	25.83	20.22	2.45	2.12
Tree mix	2.18	17.35	20.13	8.59	2.44
Mugwort mix	3.09	23.96	27.38	11.08	3.92

Relationship between total IgE and specific sensitization

The median total IgE level in sIgE-positive patients (203.27 kU/L) was significantly higher than that in sIgE-negative patients (55.82 kU/L) (Mann-Whitney U test, $P < 0.001$). Moreover, total IgE levels increased significantly with the number of sensitizing allergens (Fig. 1). Spearman's correlation analysis confirmed a significant positive correlation between total IgE level and the number of sensitizing allergens ($\rho = 0.401$, $P < 0.001$).

Based on the correlation analysis, this study revealed notable co-sensitization patterns among allergic patients in North China (Fig. 2). Among all allergen pairs, tree mix and mugwort mix showed the strongest positive correlation ($r = 0.50$), highlighting a high degree of cross-sensitization between seasonal pollen allergens. Concurrently, cat epithelium and dog epithelium also exhibited a strong correlation ($r = 0.47$), confirming the cross-reactivity characteristic of pet allergens. Regarding food allergens, the correlation between crab and shrimp reached 0.48, reflecting the high consistency of crustacean shellfish allergy; the correlations between milk and egg ($r = 0.37$) and between egg and wheat flour ($r = 0.35$) revealed the co-sensitization features of common food allergens. The study further found

moderate correlations between cat epithelium and multiple outdoor allergens, including those with mugwort mix (r = 0.25), tree mix (r = 0.22), and mold mix (r = 0.21), suggesting a potential link between pet sensitization and outdoor allergen sensitization. Of note, house dust mites, a dominant allergen in this region, exhibited relatively weak correlations with other allergens, indicating that its sensitization pathway may be relatively independent. These findings provide an important basis for precision clinical diagnosis and personalized prevention and treatment.

4. Discussion

This large-sample cross-sectional study of over 73,000 patients in North China systematically characterized the sensitization profiles of patients with allergic diseases and their dynamic patterns of change. The findings not only provide important evidence for understanding the epidemiological characteristics of allergic diseases in northern China, but also carry profound implications for clinical practice and public health policy making.

The overall sensitization rate in this study was 45.7%, a figure of considerable epidemiological significance. Compared with the 70%–80% sensitization rates reported in southern China(9), the relatively lower sensitization burden in North China may reflect regional differences in climate, environment, and lifestyle. The dry climate with low rainfall in North China likely limits the proliferation of indoor allergens such as house dust mites and molds, while the comprehensive air pollution control measures implemented in recent years may have further reduced the burden of respiratory allergen exposure. Nevertheless, with accelerating urbanization, the burden of allergic diseases may be on the rise, underscoring the need for the establishment of a long-term surveillance system.

The age-related evolution of the allergen spectrum is one of the most valuable findings of this study. The observed "allergy march" pattern not only corroborates classical international theories(10, 11), but also reveals distinct characteristics specific to northern China. The exceptionally high sensitization rate to milk in infants/toddlers (40.92%) is a phenomenon that merits in-depth discussion. From an immunological perspective, this may be associated with an imbalance in immune tolerance resulting from the substantial intake of milk proteins in the context of an immature intestinal barrier function(12). Concurrently, the relatively early and frequent introduction of milk-based foods, as is customary in the complementary feeding practices of North China, may further aggravate this phenomenon. This finding holds important reference value for the revision of infant and young child feeding guidelines.

At the immunological level, the age-related transition observed in this study reflects the finely tuned regulation of immune system development. The predominance of food allergy during early childhood is intimately linked to the immaturity of gut-associated lymphoid tissue (GALT), whereas the shift toward inhalant sensitization with increasing age mirrors the complex balance between functional maturation of the mucosal immune system and environmental adaptation(13). Moreover, total IgE level was significantly positively correlated with the number of sensitizations (ρ = 0.401), suggesting that patients with higher IgE levels are more susceptible to polysensitization. This may be associated with the role of

Th2 cytokines in driving B cells to produce large amounts of IgE(14), as well as the influence of epigenetic regulation on the development of atopic constitution(15).

The analysis of co-sensitization patterns provides a theoretical foundation for precision medicine. The strong correlation between tree mix and mugwort mix not only reflects their taxonomic affinity, but also suggests that these pollen allergens may share important allergenic protein components, such as pan-allergens like profilin and polcalcin(16). This finding has direct guiding significance for optimizing allergen-specific immunotherapy (AIT) strategies. In contrast, the relatively independent sensitization pattern of house dust mites may imply that they act through immune recognition pathways distinct from those of pollen allergens, for example, through the activation of protease-activated receptors (PARs) or disruption of the epithelial barrier function(17).

The high sensitization rate to cat epithelium observed in this study mirrors the new norm of close human–pet contact in modern society, a trend that poses new challenges for allergy prevention strategies. It is noteworthy that early exposure to pet allergens exerts a "dual effect" on the development of allergic diseases—it may promote tolerance on the one hand, yet may also increase the risk of sensitization on the other(18). This complexity necessitates that prevention strategies take into account the interaction between individual genetic background and environmental factors.

The limitations of this study should be acknowledged. First, the single-center design and the selection of a hospital-based population may limit the generalizability of the results. Second, the lack of clinical symptom data prevents us from distinguishing between sensitization status and clinical manifestation. Additionally, the absence of environmental exposure data limits our ability to explore gene–environment interactions in depth.

5. Conclusions

In conclusion, this study is the first to use a large dataset to systematically delineate the age-specific evolutionary pattern of the allergen spectrum in North China, with an overall sensitization rate of 45.7%. The findings demonstrate that food allergy predominates in infancy and early childhood, and that this gradually shifts to a pattern dominated by inhalant sensitization with increasing age. Furthermore, the study confirms the positive correlation between total IgE levels and sensitization load, and identifies specific co-sensitization features. These findings provide key data support for age-directed early allergen screening, precision diagnosis, and individualized preventive interventions in North China.

Abbreviations

AIT
allergen-specific immunotherapy
GALT
gut-associated lymphoid tissue
IgE

immunoglobulin E
IL
interleukin
IQR
interquartile range
PARs
protease-activated receptors
sIgE
specific immunoglobulin E
WHO
World Health Organization

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Air Force Medical Center of PLA (approval number: 2025-86-PJ01). The requirement for informed consent to participate was waived due to the retrospective nature of the study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analyzed during this present study are available from the corresponding author on reasonable request.

Competing interests

All authors report no conflicts of interest.

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Authors' contributions

CS: Conceptualization, Data curation, Formal analysis, Writing – original draft. FJ: Investigation, Data curation. HZ: Investigation. XX: Investigation. SC: Investigation. YZ: Conceptualization, Supervision, Writing – review & editing, Project administration. JN: Conceptualization, Supervision, Writing – review & editing, Project administration. All authors read and approved the final manuscript.

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Figures

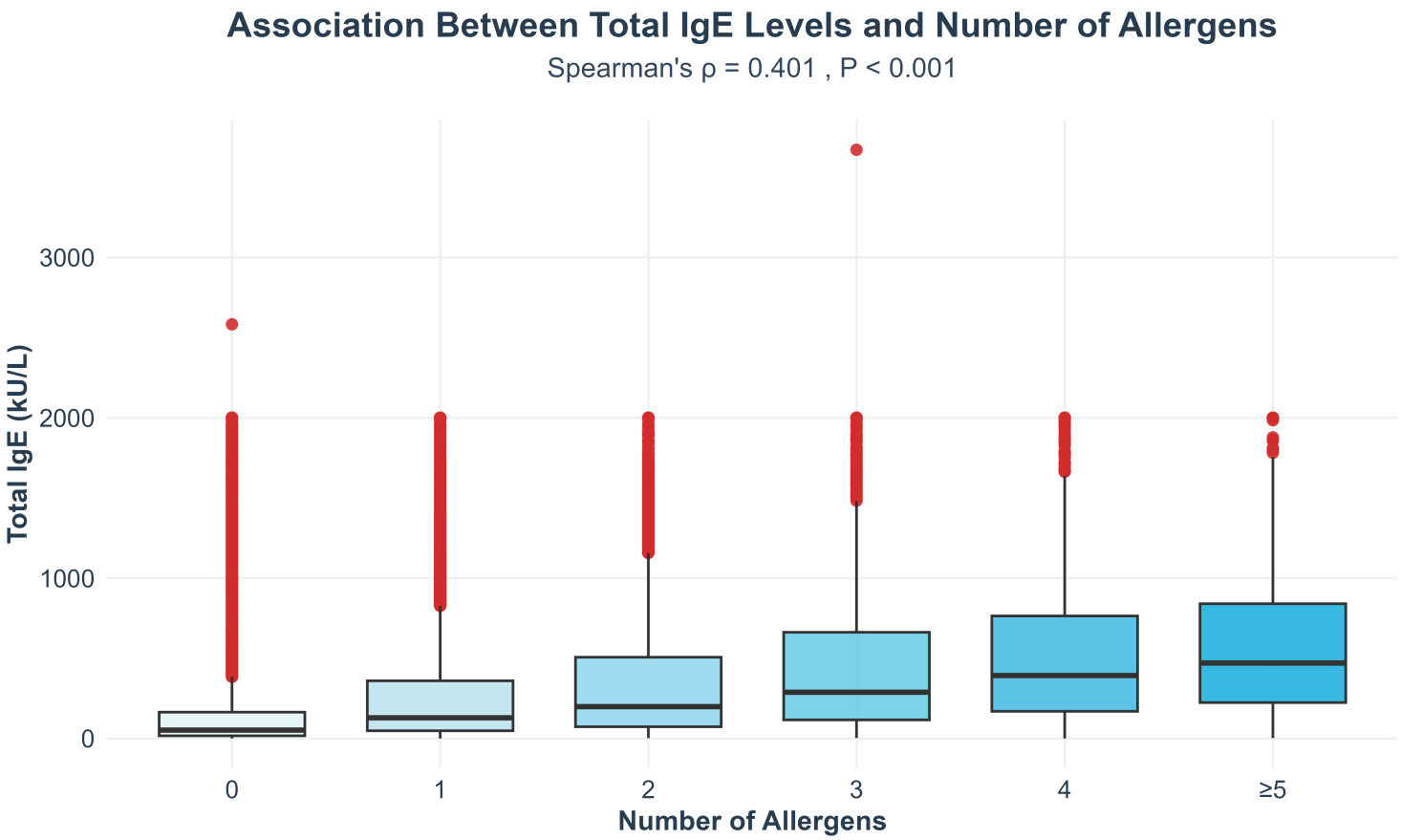


Figure 1

Relationship between total IgE levels and the number of sensitizing allergens.

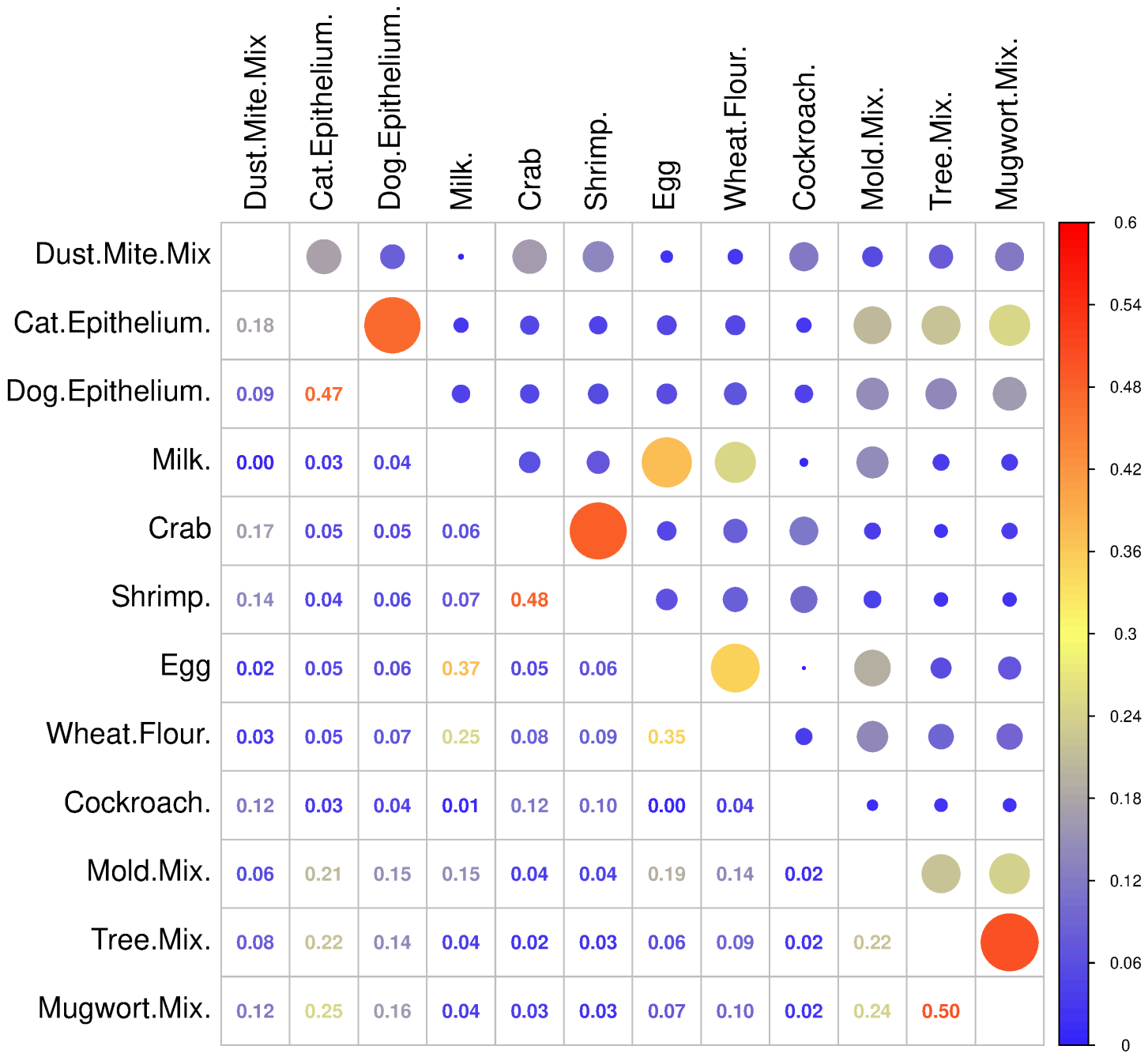


Figure 2

Analysis of co-sensitization patterns among allergic patients.