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Research article

Multidimensional Associations Between Health-Related Quality of Life and Digital Inclusion, Socioeconomic, and Agricultural Characteristics Among Rural Farmers

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Abstract: Health-related quality of life (HRQoL) among rural farmers reflects a complex interplay of demographic, socioeconomic, agricultural, household, and digital characteristics. However, their multivariate relationships with multidimensional HRQoL remain insufficiently understood. This cross-sectional study examined these relationships among 311 farmers in Nakhon Si Thammarat Province, Thailand, using canonical correlation analysis (CCA). HRQoL was assessed using a researcher-developed 60-item questionnaire covering six domains: physical health, mental well-being, social relationships, environmental quality, work participation, and economic welfare. The questionnaire was reviewed by three experts for content validity (IOC = 0.80–1.00) and pilot-tested among 30 farmers. Internal consistency was acceptable (Cronbach's α = 0.89; domain-level α = 0.78–0.86). CCA yielded six canonical functions, of which only the first was statistically significant (Wilks' λ = 0.396, Rc = 0.583, Rc^2 = 0.340, $p < 0.001$), indicating a moderate multivariate association between the predictor and HRQoL variable sets. The largest positive structure coefficients among predictors were observed for digital training score (rs = 0.716), internet accessibility (rs = 0.579), farm size (rs = 0.571), and family relationship (rs = 0.535), while age showed a negative coefficient. (rs = −0.309). Among HRQoL domains, mental well-being (rs = 0.847), work participation (rs = 0.829), physical health (rs = 0.802), and economic welfare (rs = 0.774) showed the largest coefficients. The predictor canonical variate accounted for 21.3% of the variance in HRQoL, whereas the HRQoL canonical variate accounted for 2.9% of the predictor variance. These findings indicate a meaningful multivariate association rather than causal effects and should be interpreted within the study context.

Keywords: Agricultural characteristics; health-related quality of life; digital inclusion; rural farmers; canonical correlation analysis

1. Introduction

Improving health-related quality of life (HRQoL) has become a major public health priority because it reflects individuals' overall well-being beyond the absence of disease, encompassing physical, psychological, social, and functional health [1, 2]. As populations continue to age and the burden of chronic diseases and health inequalities increases, HRQoL has been widely adopted as a comprehensive outcome for evaluating population health and the effectiveness of public health interventions [3, 4]. Unlike traditional clinical indicators, HRQoL captures individuals' perceptions of their ability to perform daily activities, maintain

social relationships, participate in work, and achieve overall well-being, making it an important indicator for monitoring health at both individual and community levels [5].

Farmers represent one of the occupational groups vulnerable to poor HRQoL because they are routinely exposed to multiple health, environmental, and socioeconomic challenges [6]. Physically demanding work, occupational injuries, pesticide exposure, climate variability, unstable agricultural income, and limited access to healthcare and social services may be associated with both physical and mental health [7–9]. These challenges may also affect work participation, economic security, and social well-being, thereby relating to multiple dimensions of HRQoL [10]. Consequently, improving the health and well-being of farming populations has become an important objective of both public health and rural development policies [11]. Digital inclusion has recently emerged as an important social determinant of health, particularly in rural communities [12]. Beyond access to the internet or digital devices, digital inclusion encompasses the ability to effectively use digital technologies to obtain health information, agricultural knowledge, financial services, government support, and social resources [13]. Previous studies have reported that greater digital inclusion is associated with improved health literacy, healthcare accessibility, economic opportunities, and quality of life (QoL) [14–16]. However, digital inclusion does not operate in isolation and may interact with demographic, socioeconomic, agricultural, and household characteristics in relation to overall health and well-being [12].

From a conceptual perspective, the present study considers HRQoL as a multidimensional outcome that may be associated with multiple layers of individual and contextual characteristics. Demographic characteristics such as age and sex may reflect differences in health status and access to resources; socioeconomic characteristics such as education and household income may relate to material resources and opportunities; agricultural characteristics such as farm size and farming experience reflect occupational and livelihood conditions; household characteristics may reflect social and living environments; and digital inclusion characteristics may relate to access to information, services, and opportunities. These domains are therefore considered as interrelated contextual characteristics that may jointly correspond to different dimensions of HRQoL rather than as isolated determinants. Although numerous studies have investigated factors associated with HRQoL among farmers, most have examined individual factors using conventional regression-based or other statistical approaches that evaluate one outcome at a time [6, 17, 18]. Such approaches provide valuable evidence regarding specific associations but may provide limited insight into how a set of demographic, socioeconomic, agricultural, household, and digital characteristics is jointly related to several interrelated HRQoL domains. Because HRQoL is inherently multidimensional, examining multiple predictor characteristics and multiple HRQoL domains simultaneously may provide a more comprehensive understanding than evaluating each factor separately [19].

Canonical correlation analysis (CCA) provides a suitable multivariate framework for the research question because it examines the relationship between two sets of variables simultaneously. In the present study, one set comprises demographic, socioeconomic, agricultural, household, and digital inclusion characteristics, whereas the second set comprises six HRQoL domains. CCA identifies linear combinations of variables from each set that maximize their association, thereby allowing the overall relationship between the two variable sets to be examined rather than requiring a single HRQoL domain to be specified as the outcome. This differs from conventional multivariable regression, which generally models a specified outcome variable, and from multivariate multiple regression, which focuses on predicting a specified set of dependent variables from predictors. Structural equation modeling (SEM) is more appropriate when the research objective involves testing a predefined network of relationships among observed and/or latent variables. Because the present study primarily sought to characterize multivariate associations between two variable sets rather than test a predefined causal or latent-variable model, CCA was selected as the principal analytical approach [20, 21].

Previous research has provided evidence that demographic, socioeconomic, agricultural, household, and digital characteristics are individually associated with health and quality-of-life outcomes among rural and farming populations [6, 14–18]. However, these approaches generally do not reveal how multiple characteristics are simultaneously organized in relation to multiple dimensions of HRQoL. CCA can provide additional insight by identifying a multivariate pattern linking a combination of predictor characteristics with a combination of HRQoL domains. This approach is particularly relevant when the outcome is multidimensional and the domains are

expected to be interrelated. Nevertheless, CCA has been less frequently applied to examine such multidimensional relationships among rural farming populations than conventional regression-based approaches [22]. This methodological and empirical gap is particularly relevant in Na San Subdistrict, Phra Phrom District, Nakhon Si Thammarat Province, Thailand, where rubber and oil palm cultivation are predominant livelihoods, and farmers continue to face challenges related to occupational health, economic uncertainty, and unequal access to digital resources [23]. The present study therefore contributes by applying a multivariate variable-set approach to examine the simultaneous associations between diverse demographic, socioeconomic, agricultural, household, and digital inclusion characteristics and multiple dimensions of HRQoL among rural farmers. The novelty of the present study lies in examining these multidimensional associations simultaneously using CCA within the specific context of rural farming communities in southern Thailand.

The six HRQoL domains examined in this study, namely physical health, mental well-being, social relationships, environmental quality, work participation, and economic welfare, were selected based on the HRQoL conceptual framework and relevant literature, with consideration of the multidimensional characteristics of QoL in rural farming contexts. Together, these domains represent health, psychological, social, environmental, occupational, and economic aspects of farmers' everyday lives and living conditions. The six-domain structure was therefore used to capture HRQoL beyond physical health alone and to reflect dimensions that are relevant to the rural agricultural context. Therefore, this study aimed to examine the multidimensional associations between HRQoL and digital inclusion, socioeconomic, household, and agricultural characteristics among rural farmers in Na San Subdistrict, Phra Phrom District, Nakhon Si Thammarat Province, Thailand, using CCA. By simultaneously evaluating relationships between multiple predictor characteristics and multiple HRQoL domains, this study seeks to provide a more comprehensive understanding of the multivariate patterns underlying HRQoL in rural farming communities and to provide context-specific evidence that may inform public health, digital inclusion, and rural development strategies.

2. Materials and Methods

2.1 Study Design and Participants

This community-based cross-sectional study was conducted among farmers residing in Na San Subdistrict, Phra Phrom District, Nakhon Si Thammarat Province, Thailand. According to the official records of the Na San Subdistrict Municipality, the study population consisted of 1,395 farming households distributed across seven villages [24]. The required sample size was estimated using Yamane's formula with a 95% confidence level and a 5% margin of error, resulting in a minimum sample of 311 participants. The sample size was determined based on the target population using Yamane's formula; no formal a priori power analysis specific to canonical correlation analysis was performed. Participants were selected using a simple random sampling technique based on the municipal household registration database. Eligible participants were farmers aged 18 years or older, had engaged in farming for at least one year, were able to communicate in Thai, and voluntarily agreed to participate in the study. Individuals who did not meet the eligibility criteria or declined to provide informed consent were excluded. A total of 311 eligible farmers participated in the study, and no eligible participants declined participation.

2.2 Study Instrument

Data were collected using a structured questionnaire developed by the researchers based on a review of relevant literature and the conceptual framework of the World Health Organization Quality of Life (WHOQOL). The questionnaire consisted of five sections: (1) demographic characteristics, (2) agricultural characteristics, (3) household characteristics, (4) digital characteristics, and (5) HRQoL. The demographic section included sex, age, marital status, educational attainment, and monthly household income. Agricultural characteristics comprised type of farming, farm size (rai), and farming experience (years). Household characteristics included living arrangement, household size (number of household members), and family relationship. Family relationship was assessed using a five-category ordinal scale ranging from very poor to very good, with higher categories indicating stronger family relationships.

Digital characteristics were assessed using three variables. Participation in digital training was measured using an ordinal score ranging from 0 to 4, where 0 indicated no participation in digital training and higher

scores represented greater participation in digital training activities. Internet accessibility was assessed using four ordered categories ranging from poor to very good, with higher categories indicating better internet access. Smartphone/tablet ownership was recorded as a dichotomous variable (yes/no). To reflect the occupational and socioeconomic context of rural farming communities, the HRQoL component included six domains: physical health, mental well-being, social relationships, environmental quality, work participation, and economic welfare. The first four domains were informed by the WHOQOL conceptual framework, while work participation and economic welfare were additionally incorporated to reflect the specific context of rural farmers. The final researcher-developed questionnaire consisted of 60 newly developed items, with 10 items for each domain. The items were newly developed based on the conceptual framework, relevant literature, and the contextual characteristics of rural farming communities and were not directly adapted from the WHOQOL-BREF. All items were rated on a five-point Likert scale ranging from 1 (lowest) to 5 (highest). Domain scores were calculated by averaging the responses to the 10 items within each domain, resulting in mean scores ranging from 1 to 5, with higher scores indicating better perceived HRQoL. The questionnaire was reviewed by three experts to establish content validity using the Item-Objective Congruence (IOC) method, with IOC values ranging from 0.80 to 1.00. A pilot study involving 30 farmers from a neighboring community was conducted before the main survey. The questionnaire demonstrated good internal consistency, with an overall Cronbach's alpha coefficient of 0.89, while Cronbach's alpha coefficients for the six HRQoL domains ranged from 0.78 to 0.86, indicating acceptable internal consistency.

2.3 Data Collection

Data were collected between February and March 2026 through face-to-face interviews conducted by the principal investigator. Before each interview, participants received a detailed explanation of the study objectives and procedures, and written informed consent was obtained. Each interview required approximately 25–30 minutes to complete. Completed questionnaires were reviewed immediately after each interview to ensure completeness and consistency before data entry. Questionnaires were checked for missing responses during data collection, and no missing observations were identified in the final dataset. Therefore, no imputation or complete-case exclusion was required. To protect participant confidentiality, all questionnaires were anonymized using unique identification codes and stored securely throughout the research process.

2.4 Statistical Analysis

All statistical analyses were performed using R version 4.5.3 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were computed using the stats package. Continuous variables were summarized using means and standard deviations (SD), whereas categorical and ordinal variables were presented as frequencies and percentages. CCA was performed using the CCA package to examine the multivariate associations between the predictor variable set and the HRQoL variable set [20], while the statistical significance of the canonical functions was assessed using the CCP package. The predictor variable set initially comprised demographic, socioeconomic, agricultural, household, and digital characteristics. For CCA, continuous variables included age, farm size, farming experience, and household members. Digital training participation was represented by an ordinal score ranging from 0 to 4, with higher scores indicating greater participation in digital training activities. Family relationship and internet accessibility were treated as ordinal variables and coded according to their ordered response categories. Nominal categorical variables were incorporated into the CCA using $k - 1$ dummy coding to avoid imposing an artificial numerical ordering on unordered categories. Sex was represented by one indicator variable, with male as the reference category. Marital status was represented by two indicator variables, with single as the reference category. Educational attainment was represented by five indicator variables, with no formal education as the reference category. Monthly household income was represented by three indicator variables, with income below 3,000 THB as the reference category. Type of farming was represented by four indicator variables, with rice cultivation as the reference category. Living arrangement was represented by four indicator variables, with living alone as the reference category. Smartphone/tablet ownership was represented by one indicator variable, with no ownership as the reference category. After dummy coding, the predictor variable set comprised 27 variables. The criterion

variable set consisted of six HRQoL domains: physical health, mental well-being, social relationships, environmental quality, work participation, and economic welfare.

Prior to CCA, continuous variables were standardized using z-score transformation. The dummy-coded categorical variables and ordinal variables were retained on their respective measurement scales because they represented indicator or ordered-score variables rather than continuous measurements. Pairwise correlations among predictor variables were examined before CCA to identify potential associations among predictors and to assess the possibility of multicollinearity. Multicollinearity was further evaluated using variance inflation factors (VIFs). Inter-domain Pearson correlations among the six HRQoL domains were also examined to assess the degree of association and potential redundancy among the outcome variables before conducting CCA. The assumptions relevant to CCA were evaluated before model estimation. Linearity was assessed using scatterplots and examination of the relationships among variables. Multivariate normality was assessed using Mardia's test [25]. Multicollinearity was evaluated using VIFs. The statistical significance of the canonical functions was assessed using Wilks' lambda with Rao's approximate F-test [25]. Canonical correlation coefficients were used to quantify the strength of the multivariate associations between the two variable sets. Only statistically significant canonical functions ($p < 0.05$) were retained for substantive interpretation.

For the statistically significant canonical function, standardized canonical coefficients, structure coefficients (canonical loadings), and cross-loadings were examined. Structure coefficients were emphasized in interpretation because they represent the correlations between each original variable and its corresponding canonical variate and provide a more direct indication of each variable's contribution to the canonical variate. Variables with absolute structure coefficient values ($|rs|$) of 0.30 or greater were considered to have meaningful contributions to the canonical variates, consistent with commonly accepted guidelines for interpreting canonical loadings [34]. Redundancy indices were also calculated to quantify the proportion of variance in one variable set that could be accounted for by the canonical variate derived from the other variable set. These indices were used alongside the squared canonical correlation to provide a more conservative assessment of the practical explanatory contribution of the canonical relationship.

A two-sided p-value of < 0.05 was considered statistically significant.

2.5 Ethical Considerations

The study protocol was approved by the Human Research Ethics Committee of Nakhon Si Thammarat Rajabhat University (Approval No. 011/2569). Participation was entirely voluntary, and written informed consent was obtained from all participants before enrollment. All personal identifiers were removed prior to analysis to ensure participant confidentiality. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

3. Results and Discussion

3.1 Participant Characteristics

A total of 311 farmers participated in the study. The mean age of the participants was 52.51 years. (SD = 11.32), with nearly half (49.52%) aged 40–59 years. Females accounted for 55.63% of the sample, and most participants were married (70.10%). Regarding educational attainment, primary school was the most common level of education (43.73%), followed by lower secondary school (19.94%). Regarding socioeconomic characteristics, the largest proportion of participants (42.44%) reported a monthly household income of 5,001–10,000 THB. In terms of agricultural characteristics, more than half of the participants (55.95%) were engaged in rubber or oil palm cultivation. The mean farm size was 8.81 rai (SD = 5.62), and the mean farming experience was 21.82 years (SD = 10.51). Most participants lived with their spouse (37.94%) or children (29.58%), with a mean household size of 4.22 persons (SD = 1.40). Family relationships were generally positive, with 79.10% reporting good or very good relationships. Regarding digital characteristics, the mean participation in digital training score was 2.41 (SD = 0.93). Overall, 64.31% of participants reported good or very good internet accessibility, and 92.28% owned a smartphone or tablet. Detailed participant characteristics are presented in Table 1.

Table 1. Characteristics of the Study Participants (n = 311)

Characteristic	n	%
Demographic characteristics		
Sex		
Male	138	44.37
Female	173	55.63
Age group (years)		
< 40	72	23.15
40–59	154	49.52
≥ 60	85	27.33
Age (years)) Mean ± SD = 52.51 ± 11.32(		
Marital status		
Single	48	15.43
Married	218	70.10
Widowed/Divorced/Separated	45	14.47
Education		
No formal education	12	3.86
Primary school	136	43.73
Lower secondary school	62	19.94
Upper secondary school	48	15.43
Vocational certificate/Diploma	28	9.00
Bachelor's degree or higher	25	8.04
Socioeconomic characteristics		
Monthly household income (THB)		
< 3,000	38	12.22
3,001–5,000	76	24.44
5,001–10,000	132	42.44
> 10,000	65	20.90
Agricultural characteristics		
Type of farming		
Rice cultivation	22	7.07
Vegetable cultivation	48	15.43
Fruit cultivation	41	13.18
Livestock farming	26	8.36
Rubber or oil palm plantation	174	55.95
Farm size (rai) Mean ± SD = 8.81 ± 5.62		
Farming experience (years) Mean ± SD = 21.82 ± 10.51		
Household characteristics		
Living arrangement		
Living alone	21	6.75
Living with spouse	118	37.94
Living with children	92	29.58
Extended family	65	20.90
Other	15	4.82

Table 1. Characteristics of the Study Participants (n = 311) (Continued)

Characteristic	n	%
Family relationship		
Very good	134	43.09
Good	112	36.01
Fair	41	13.18
Poor	18	5.79
Very poor	6	1.93
Household members (persons) Mean ± SD = 4.22 ± 1.40		
Digital characteristics		
Participation in digital training score Mean ± SD = 2.41 ± 0.93		
Internet accessibility		
Very good	96	30.87
Good	104	33.44
Moderate	71	22.83
Poor	40	12.86
Smartphone/tablet ownership		
Yes	287	92.28
No	24	7.72

3.2 Canonical Correlation Analysis

Canonical correlation analysis (CCA) was conducted to examine the multivariate association between the 27-variable predictor set and the six-domain HRQoL variable set. Six canonical functions were obtained. The first canonical function was statistically significant and showed a moderate canonical correlation between the predictor and HRQoL canonical variates ($Rc = 0.583$, $Rc^2 = 0.340$, $p < 0.001$). In contrast, canonical functions 2–6 were not statistically significant ($p > 0.05$) and were therefore not interpreted substantively. The significance tests for all six canonical functions are presented in Table 2.

Table 2. Significance Tests for the Canonical Functions

Function	Canonical Correlation	Squared Canonical Correlation (Rc^2)	Wilks' λ	Approx. F	df1	df2	*p-value*
1	**0.583**	**0.340**	**0.396**	**1.73**1	**162**	**1,641.64**	**<0.001**
2	0.409	0.167	0.600	1.162	130	1,384.55	0.112
3	0.345	0.119	0.721	0.965	100	1,120.52	0.578
4	0.298	0.089	0.818	0.821	72	849.59	0.854
5	0.251	0.063	0.898	0.690	46	572.00	0.941
6	0.205	0.042	0.958	0.576	22	288.00	0.938

The first canonical function indicated a statistically significant multivariate association between the combined predictor variables and the combined HRQoL domains. The squared canonical correlation indicated that the first pair of canonical variates shared 34.0% of their variance. However, the redundancy analysis provided a more conservative assessment of the variance accounted for across the original variables. The predictor canonical variate accounted for approximately 21.3% of the variance in the HRQoL variable set, whereas the HRQoL canonical variate accounted for approximately 2.9% of the variance in the predictor variable set. Thus, although the canonical association was statistically significant and moderate in magnitude, the redundancy analysis indicated that the predictor canonical variate accounted for 21.3% of the variance in the HRQoL variable set, leaving a substantial proportion of variance unexplained by the predictor set. The six HRQoL domains showed moderate positive inter-domain correlations, ranging from $r = 0.529$ to 0.631. The strongest correlation was observed between mental well-being and economic welfare ($r = 0.631$), followed by physical health

and work participation (r = 0.609). Overall, the moderate correlations indicated that the six HRQoL domains were related but not highly redundant. The complete inter-domain correlation matrix is presented in Table 3.

Table 3. Inter-domain Correlations among the Six HRQoL Domains (n = 311)

HRQoL domain	Physical health	Mental well-being	Social relationships	Environmental quality	Work participation	Economic welfare
Physical health	1.000					
Mental well-being	0.547	1.000				
Social relationships	0.543	0.529	1.000			
Environmental quality	0.537	0.552	0.559	1.000		
Work participation	0.609	0.555	0.538	0.551	1.000	
Economic welfare	0.589	0.631	0.585	0.587	0.594	1.000

Note: *Values are Pearson correlation coefficients* (r). *All correlations were positive and statistically significant,* $p < 0.001$.

3.3 Interpretation of the First Canonical Function

The first canonical function was interpreted primarily using the structure coefficients, which represent the correlations between the observed variables and their respective canonical variates. Structure coefficients were emphasized over standardized canonical coefficients because they provide a more direct indication of how strongly each observed variable is associated with its corresponding canonical variate, particularly when predictors are correlated and suppression effects may occur. Among the 27 predictor variables, digital training score ($rs = 0.716$) showed the largest positive structure coefficient, followed by internet accessibility ($rs = 0.579$), farm size ($rs = 0.571$), and family relationship ($rs = 0.535$). Other variables meeting the predefined criterion of $|rs| \geq 0.30$ included bachelor's degree or higher education ($rs = 0.423$), monthly household income above 10,000 THB ($rs = 0.400$), and household members ($rs = 0.302$). Age showed a meaningful negative structure coefficient ($rs = -0.309$), whereas farming experience showed a weaker negative association ($rs = -0.240$) and did not meet the predefined threshold. The remaining predictor variables had relatively small structure coefficients. These included sex, marital status, lower education categories, lower income categories, farming type, living arrangement, and smartphone/tablet ownership. Because nominal categorical variables were represented using $k - 1$ dummy variables, these coefficients represent associations of individual categories relative to their specified reference categories and should not be interpreted as ordered effects across categories.

On the HRQoL side, all six domains showed strong positive structure coefficients. Mental well-being ($rs = 0.847$) had the largest loading, followed by work participation ($rs = 0.829$), physical health ($rs = 0.802$), economic welfare ($rs = 0.774$), environmental quality ($rs = 0.745$), and social relationships ($rs = 0.744$). Thus, the first HRQoL canonical variate represented a broad multidimensional pattern encompassing psychological, occupational, physical, economic, environmental, and social dimensions of HRQoL. Taken together, the structure coefficients indicate that the first canonical function was characterized by a combination of digital, agricultural, socioeconomic, household, and demographic characteristics on the predictor side and a broad set of HRQoL dimensions on the criterion side. Digital training score and internet accessibility showed the strongest positive associations among the predictor variables, but these coefficients indicate their association with the canonical variate rather than independent effects or causal determinants of HRQoL. Age was negatively associated with the first predictor canonical variate, whereas farming experience showed a weaker negative association that did not meet the predefined interpretation threshold. These findings should be interpreted as components of the overall multivariate pattern rather than as independent effects, particularly because age and farming experience are conceptually related. Detailed standardized canonical coefficients, structure coefficients, cross-loadings, and redundancy indices for the first canonical function are presented in Table 4.

Table 4. Standardized Canonical Coefficients, Structure Coefficients, Cross-loadings, and Redundancy Indices for the First Canonical Function (n = 311)

A. Predictor Variable Set

Predictor Variable	Standardized Coefficient	Structure Coefficient (rs)	Cross-loading
Age	−0.519	−0.309	−0.180
Farm size	0.114	0.571	0.333
Farming experience	0.218	−0.240	−0.140
Household members	0.057	0.302	0.176
Digital training score	0.333	0.716	0.418
Family relationship	0.245	0.535	0.312
Internet accessibility	0.093	0.579	0.338
Sex: Female	−0.098	−0.093	−0.054
Marital status: Married	0.226	−0.040	−0.023
Marital status: Widowed/Divorced/Separated	0.231	0.111	0.065
Education: Primary school	0.182	−0.129	−0.075
Education: Lower secondary school	0.129	−0.048	−0.028
Education: Upper secondary school	0.219	0.299	0.175
Education: Vocational certificate/Diploma	0.197	0.270	0.158
Education: Bachelor's degree or higher	0.357	0.423	0.247
Income: 3,001–5,000 THB	0.201	0.080	0.047
Income: 5,001–10,000 THB	0.121	0.184	0.108
Income: >10,000 THB	0.183	0.400	0.233
Farming type: Vegetable cultivation	−0.047	−0.005	−0.003
Farming type: Fruit cultivation	−0.001	0.065	0.038
Farming type: Livestock farming	−0.011	0.013	0.008
Farming type: Rubber/oil palm plantation	−0.054	0.023	0.013
Living arrangement: Living with spouse	−0.152	0.040	0.023
Living arrangement: Living with children	−0.153	−0.082	−0.048
Living arrangement: Extended family	0.005	−0.032	−0.019
Living arrangement: Other	−0.137	−0.075	−0.044
Smartphone/tablet ownership: Yes	−0.035	0.171	0.100

Note: *Reference categories were Male for sex, Single for marital status, No formal education for educational attainment, <3,000 THB for monthly household income, Rice cultivation for farming type, Living alone for living arrangement, and No for smartphone/tablet ownership. Nominal categorical variables were dummy-coded using* $k - 1$ *indicator variables.*

B. HRQoL Variable Set

HRQoL Domain	Standardized Coefficient	Structure Coefficient (rs)	Cross-loading
Physical health	0.232	0.802	0.468
Mental well-being	0.358	0.847	0.494
Social relationships	0.158	0.744	0.434
Environmental quality	0.135	0.745	0.435
Work participation	0.289	0.829	0.484
Economic welfare	0.068	0.774	0.452

C. Redundancy Analysis

Statistic	Predictor Set	HRQoL Set
Average variance extracted	0.086	0.626

Redundancy index	0.029	0.213

Figure 1 illustrates the relationship between the first predictor canonical variate and the first HRQoL canonical variate. The distribution of canonical scores demonstrates a moderate positive association between the two canonical variates, consistent with the canonical correlation coefficient (Rc = 0.583). Participants with higher scores on the first predictor canonical variate generally tended to have higher scores on the first HRQoL canonical variate. This pattern is consistent with the moderate positive canonical correlation observed for the first canonical function.

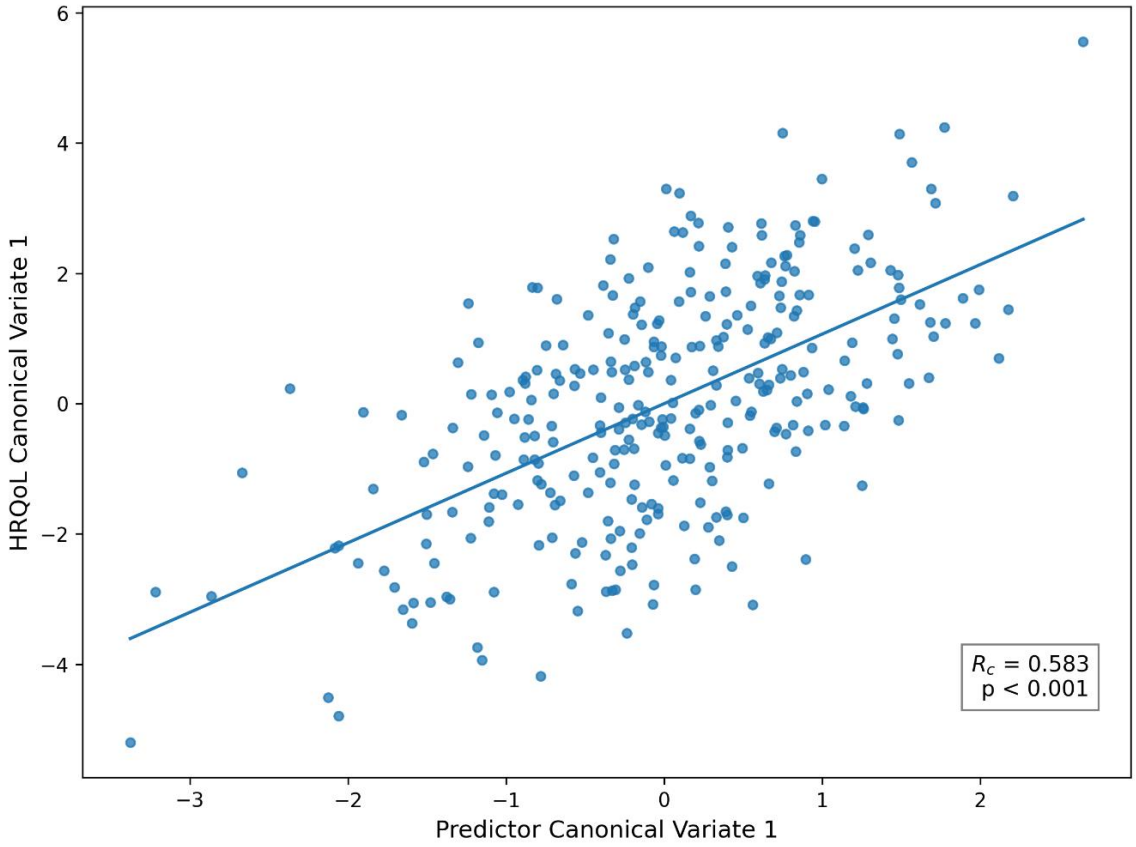


Figure 1. Canonical Score Plot for the First Canonical Function.
Canonical score plot showing the relationship between the first predictor canonical variate and the first HRQoL canonical variate (Rc = 0.583). Each point represents one participant; the fitted line indicates the moderate positive association between the two canonical variates.

Figure 2 presents the structure coefficients of the predictor variables and HRQoL domains for the first canonical function. The plot illustrates the relative strength and direction of the associations between individual variables and their respective canonical variates. Larger absolute structure coefficients indicate stronger associations with the corresponding canonical variates. Among the predictor variables, digital training score (rs = 0.72), internet accessibility (rs = 0.58), farm size (rs = 0.57), and family relationship (rs = 0.54) showed the largest positive structure coefficients. Among the HRQoL domains, mental well-being (rs = 0.85), work participation (rs = 0.83), physical health (rs = 0.80), and economic welfare (rs = 0.77) exhibited the largest structure coefficients with the first HRQoL canonical variate.

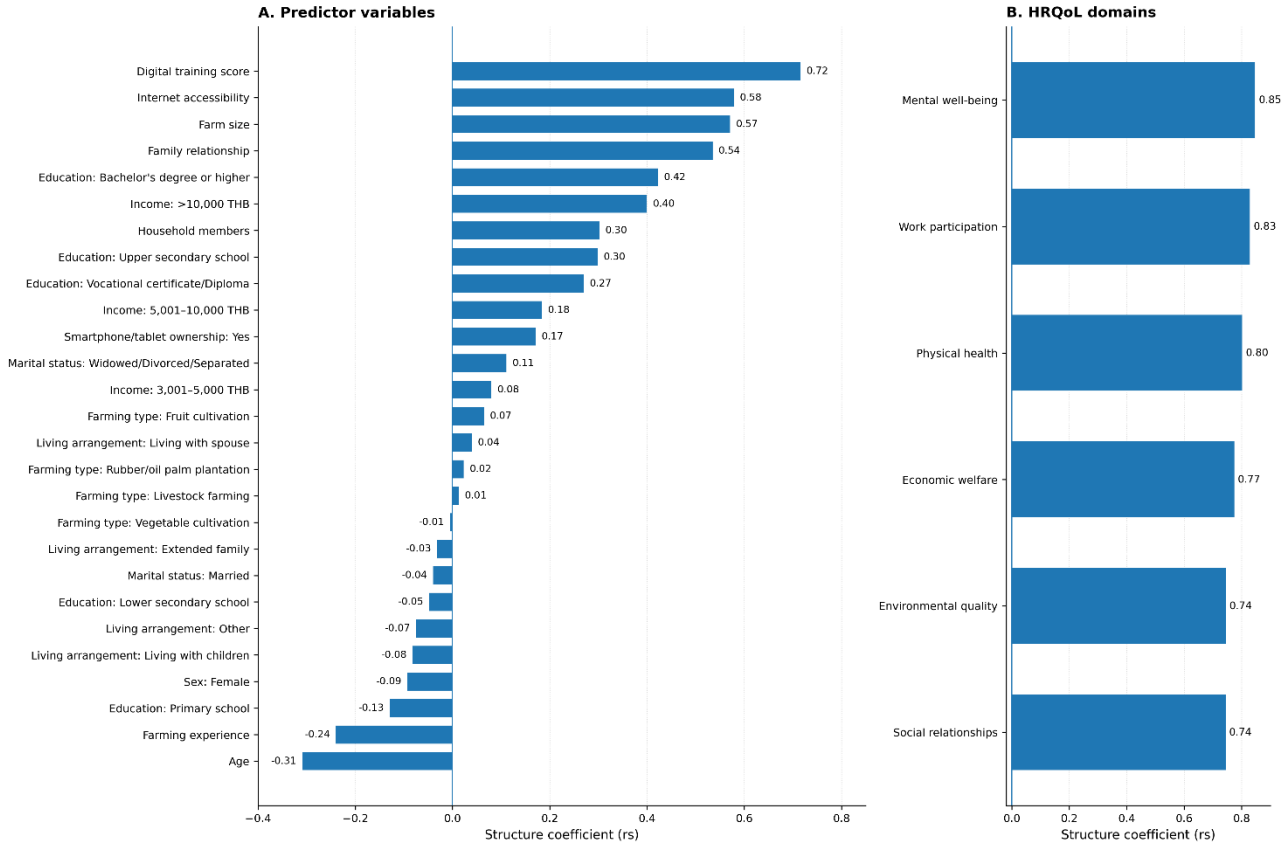


Figure 2. Structure Coefficients for the First Canonical Function.
Structure coefficient plot showing the structure coefficients (rs) of the predictor variables and HRQoL domains for the first statistically significant canonical function. Larger absolute values indicate stronger associations with the respective canonical variates. Only the first canonical function was statistically significant and interpreted.

Figure 3 presents the average variance extracted and redundancy indices for the first canonical function. The predictor variable set had an average variance extracted of 0.086 and a redundancy index of 0.029, whereas the HRQoL variable set had an average variance extracted of 0.626 and a redundancy index of 0.213. The redundancy index indicates that the predictor canonical variate accounted for approximately 21.3% of the variance in the HRQoL variable set, whereas the HRQoL canonical variate accounted for approximately 2.9% of the variance in the predictor variable set. These findings provide a more conservative assessment of the explanatory contribution of the canonical relationship than the squared canonical correlation alone.

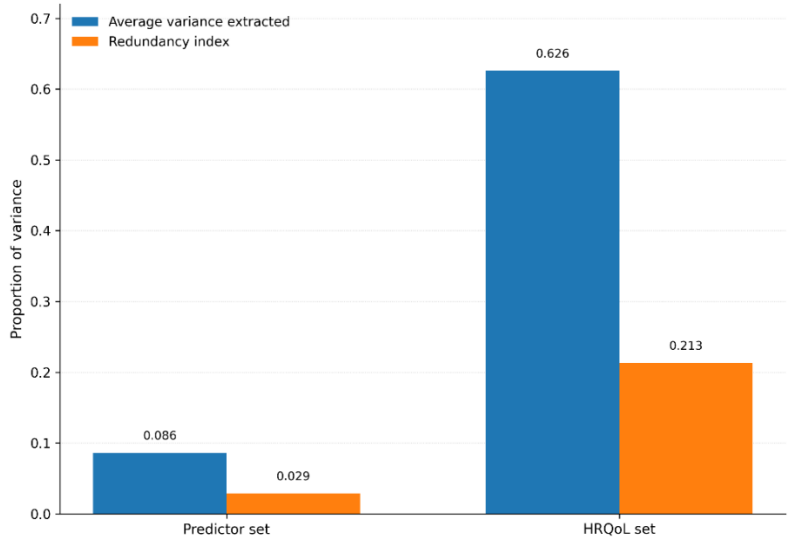


Figure 3. Variance Extraction and Redundancy Indices for the First Canonical Function.
Average variance extracted and redundancy indices for the predictor and HRQoL variable sets. The redundancy index represents the proportion of variance in one variable set accounted for by the canonical variate derived from the opposite variable set.

3.4 Discussion

3.4.1 Overview of the Main Findings

This study employed CCA to examine the multivariate associations between demographic, socioeconomic, agricultural, household, and digital characteristics and multiple domains of HRQoL among rural farmers. Unlike analytical approaches that examine individual predictors and outcomes separately, CCA enabled the simultaneous examination of two sets of variables and provided a multidimensional view of their associations with HRQoL [26]. The analysis identified one statistically significant canonical function, with a moderate canonical correlation (Rc = 0.583, Rc^2 = 0.340), indicating a significant multivariate association between the combined predictor variables and the multidimensional HRQoL variable set. Among the predictor variables, digital training score, internet accessibility, farm size, and family relationship showed the largest positive structure coefficients, while age and farming experience showed negative associations with the predictor canonical variate. Within the HRQoL variable set, all six domains showed strong positive structure coefficients, with mental well-being, work participation, physical health, economic welfare, environmental quality, and social relationships contributing to the first HRQoL canonical variate. However, the redundancy analysis indicated that the predictor canonical variate accounted for approximately 21.3% of the variance in the HRQoL variable set. Therefore, these findings should be interpreted as evidence of a multidimensional association rather than evidence that any individual factor is a causal determinant or dominant predictor of HRQoL. The inter-domain correlation analysis showed moderate positive correlations among the six HRQoL domains, ranging from r = 0.529 to 0.631. This pattern indicates that the domains were related to one another but were not highly correlated, suggesting that they captured related yet distinguishable aspects of HRQoL within the present dataset. These findings are consistent with a multidimensional interpretation of HRQoL while avoiding the assumption that the six domains represent completely independent constructs.

3.4.2 Digital Inclusion and Multidimensional HRQoL

One notable finding of this study was that digital training score (rs = 0.716) and internet accessibility (rs = 0.579) had relatively large structure coefficients on the first predictor canonical variate. These coefficients indicate that digital inclusion variables were strongly associated with the multivariate pattern represented by the first canonical function. This finding is consistent with previous studies reporting associations between digital inclusion and access to agricultural information, healthcare services, public resources, and social participation in rural communities [12, 27]. Similar studies have reported that farmers with better internet access may have greater opportunities to obtain agricultural information, market information, and digital services [28].

Importantly, the present findings do not establish that digital inclusion causes better HRQoL or that digital inclusion is the strongest determinant of HRQoL. Rather, the relatively large structure coefficients suggest that digital training and internet accessibility were strongly associated with the first predictor canonical variate within the multivariate pattern identified by CCA. Smartphone/tablet ownership showed a smaller structure coefficient (rs = 0.171), suggesting that device ownership alone was less strongly associated with this canonical pattern than digital training and internet accessibility. These findings suggest that future rural development initiatives may consider both access to digital connectivity and opportunities to develop digital skills. However, because the study was cross-sectional and the redundancy index indicated that approximately 21.3% of the variance in the HRQoL variable set was accounted for by the predictor canonical variate, such implications should be interpreted as areas for consideration rather than evidence of causal effects.

3.4.3 Socioeconomic and Household Factors

Beyond digital characteristics, farm size (rs = 0.571), family relationship (rs = 0.535), educational attainment at the bachelor's degree or higher level (rs = 0.423), and monthly household income above 10,000 THB (rs = 0.400) also showed relatively large positive structure coefficients on the first canonical variate. This pattern indicates that agricultural, socioeconomic, and household characteristics were associated with the same multivariate pattern of predictors that was related to the HRQoL canonical variate. Previous studies have similarly reported associations between income, education, family support, and QoL among rural populations and agricultural workers [29, 30]. Larger farm size may provide greater productive capacity or economic flexibility, while higher household income may provide greater opportunities to access healthcare, nutritious food, education, and agricultural resources. Supportive family relationships may provide emotional and practical resources during economic and agricultural challenges [31]. Educational attainment may also be associated with the ability to obtain and apply information related to health, agriculture, and digital technologies [32]. However, the CCA results should not be interpreted as demonstrating independent or causal effects of farm size, income, family relationship, or education on HRQoL. In addition, because categorical predictors were dummy-coded, the structure coefficients for education and income represent associations for specific categories relative to their reference categories rather than a continuous gradient across categories. These variables formed part of a broader multivariate association that also included digital, demographic, agricultural, and household characteristics. The findings therefore provide evidence of interconnected relationships rather than evidence that any single socioeconomic, agricultural, or household characteristic independently determines HRQoL.

3.4.4 Age and Farming Experience

Age and farming experience showed negative structure coefficients on the first canonical variate. Age had a structure coefficient of rs = −0.309, whereas farming experience had a smaller negative coefficient of rs = −0.240. These findings indicate that older age and longer farming experience were associated with lower scores on the predictor canonical variate within the multivariate pattern identified by CCA. Previous studies have reported associations between increasing age, physical functioning, work capacity, and QoL among older adults and agricultural workers [2, 9, 11]. These associations should not be interpreted as evidence that aging or longer farming experience directly reduces HRQoL. Age and farming experience are conceptually related, and their structure coefficients may partly reflect shared variation between these variables. Therefore, their individual canonical loadings should be interpreted as components of the broader multivariate association rather than as independent effects. The negative association with farming experience should also be interpreted within the broader socioeconomic and technological context of contemporary agriculture. Although farming experience may provide valuable practical knowledge, experienced farmers may also face challenges associated with climate variability, fluctuating commodity prices, increasing production costs, and technological change [9, 11]. Previous studies have reported that older farmers may be less likely to adopt digital technologies and participate in digital learning opportunities, which may affect their access to agricultural information and public services [13, 16, 29]. These findings suggest that lifelong learning, age-friendly digital technologies, and targeted agricultural extension services may be relevant areas for supporting rural farmers [13, 30, 33]. However, these implications should be interpreted cautiously because the present study identifies multivariate associations rather than causal effects.

3.4.5 Practical Implications

The practical implications of the findings should be considered in light of the moderate canonical association and the 21.3% redundancy index for the HRQoL variable set**.** The results support an integrated perspective in which digital, agricultural, socioeconomic, household, and demographic characteristics are considered together rather than treating any single factor as a dominant determinant of HRQoL.

3.4.5.1 Practical Implications for Public Health

The significant canonical function indicates that multiple demographic, socioeconomic, agricultural, household, and digital characteristics were jointly associated with multiple dimensions of HRQoL. Because all six HRQoL domains showed strong positive structure coefficients, public health planning in rural farming communities may benefit from considering physical, psychological, occupational, social, environmental, and economic aspects together. For example, community health activities could incorporate access to reliable health information and basic digital skills alongside existing health promotion services. These implications should be interpreted as areas for consideration rather than evidence that such interventions would directly improve HRQoL.

3.4.5.2 Practical Implications for Digital and Agricultural Development

Digital training score (**rs = 0.716**) and internet accessibility (**rs = 0.579**) showed the largest positive structure coefficients among the predictor variables. These findings suggest that digital capability and access were important components of the multivariate pattern identified by CCA. Agricultural extension programs could therefore incorporate practical digital training that enables farmers to access agricultural information, market information, and relevant public services. Improving reliable internet access could complement such training. These recommendations are supported by the observed associations but should not be interpreted as evidence that digital inclusion independently or causally improves HRQoL.

3.4.5.3 Practical Implications for Social and Rural Development

The structure coefficients for farm size (rs = 0.571), family relationship (rs = 0.535), educational attainment at the bachelor's degree or higher level (rs = 0.423), and monthly household income above 10,000 THB (rs = 0.400) indicate that agricultural, socioeconomic, and household characteristics were also associated with the multivariate pattern identified by CCA. These findings suggest that social and rural development strategies should consider the socioeconomic and social conditions in which farmers live and work, rather than addressing health, agricultural development, and digital inclusion as separate issues. Livelihood development initiatives may support farmers' access to agricultural knowledge, productive resources, income-generating opportunities, and relevant public services. At the community level, activities that strengthen family and social support networks may also be relevant, particularly because family relationships showed a relatively large positive structure coefficient. Educational and lifelong learning opportunities could also be incorporated into rural development programs to help farmers respond to changes in agricultural practices, markets, and digital technologies. In particular, agricultural extension programs could integrate livelihood-related knowledge with practical digital skills and information on relevant public services. Such community-based approaches may help connect farmers with economic, social, agricultural, and informational resources while complementing existing local development activities. However, these implications should be considered context-specific because the study was conducted in a single rural subdistrict, and the identified associations do not establish that these interventions would directly improve HRQoL. Further studies involving farming communities with different agricultural systems, socioeconomic conditions, and levels of digital infrastructure are needed to determine whether these patterns are applicable more broadly.

3.4.6 Strengths of the Study

This study has several strengths. First, the application of CCA enabled the simultaneous evaluation of multiple predictor variables and HRQoL domains, providing a multivariate perspective on the relationships between farmers' characteristics and multidimensional HRQoL. Second, the study adopted a multidimensional assessment of HRQoL encompassing physical health, mental well-being, social relationships, environmental quality, work participation, and economic welfare, thereby capturing a broad range of health and well-being

dimensions relevant to rural farming communities. Third, the integration of demographic, socioeconomic, agricultural, household, and digital characteristics within a single analytical framework allowed the study to identify patterns of association across multiple domains rather than focusing on a single predictor or outcome. Finally, the use of standardized canonical coefficients, structure coefficients, cross-loadings, and redundancy indices provided complementary information for interpreting the significant canonical function and assessing its practical explanatory contribution. Together, these features provide a comprehensive view of the multidimensional associations between farmers' characteristics and HRQoL.

3.4.7 Limitations

Several limitations should be acknowledged when interpreting these findings. First, the cross-sectional design precludes causal inference between the predictor variables and HRQoL. Second, the study was conducted in a single rural subdistrict in southern Thailand, which may limit the generalizability of the findings to farming populations in other regions with different agricultural, socioeconomic, and digital contexts. Third, although the researcher-developed HRQoL questionnaire demonstrated satisfactory content validity and internal consistency, factorial validity was not evaluated using exploratory or confirmatory factor analysis in the present study. Further studies should examine the construct validity and other psychometric properties of the instrument across diverse farming populations.

4. Conclusions

This study examined the multidimensional associations between HRQoL and demographic, socioeconomic, agricultural, household, and digital characteristics among rural farmers using CCA. The analysis identified one statistically significant canonical function with a moderate canonical correlation ($R_c = 0.583$, $R_c^2 = 0.340$). The predictor canonical variate accounted for approximately 21.3% of the variance in the HRQoL variable set, indicating that the identified multivariate pattern represented a meaningful but limited proportion of the variation in multidimensional HRQoL. Among the predictor variables, digital training score, internet accessibility, farm size, and family relationship showed the largest positive structure coefficients, while age showed a negative structure coefficient. These findings indicate that digital, agricultural, socioeconomic, household, and demographic characteristics were jointly associated with the multidimensional HRQoL pattern. In particular, digital training score and internet accessibility showed relatively strong associations with the first predictor canonical variate; however, these associations should not be interpreted as evidence that digital inclusion is a dominant determinant or causal driver of HRQoL. The findings have practical implications for integrated rural development. Agricultural extension programs could incorporate practical digital literacy training to help farmers access agricultural information, market information, and relevant public services, while improvements in reliable internet access could complement such training. Community-based initiatives could also consider family and social support alongside agricultural and livelihood development. These implications should be regarded as context-specific areas for consideration rather than evidence that particular interventions will directly improve HRQoL. Because the study was conducted in a single rural subdistrict in southern Thailand, the findings may not fully represent farming populations in other regions with different agricultural systems, socioeconomic conditions, and levels of digital infrastructure. Future studies should use longitudinal and multicenter designs to examine temporal and potentially causal relationships and should further evaluate the psychometric properties and factorial validity of the researcher-developed HRQoL instrument across diverse farming populations.

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