Development and Optimization of Ready-to-Cook Indian Summer and Winter Vegetable Soup Mix Formulations

Thesis submitted in partial fulfillment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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December 2024

Dedicated

to

my dear sister

Hemanthika

School of Agro and Rural Technology
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Certificate

It is certified that the addressed research work and reported findings in this Ph.D. thesis entitled **"Development and Optimization of Ready-to-Cook Indian Summer and Winter Vegetable Soup Mix Formulations"** and submitted by **Mrs. Akasapu Kumudhini** for the award of the degree of Doctor of Philosophy has been carried out under my supervision in the School of Agro and Rural Technology, Indian Institute of Technology Guwahati. To the best of my knowledge, this work is not submitted elsewhere for the award of any other degree or diploma.

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Disclaimer

The experimental, modelling, formulation and characterization related methodology and data presented in this Ph.D. thesis was carried out by me and is reported after due verification. To the best of my knowledge, the work and findings summarized in this Ph.D. thesis is not submitted elsewhere for the award of any other degree or diploma.

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The combined influence of the dynamic alterations in the lifestyle of the working population, ever increasing urbanization, altered consumer demographics such as busy lifestyle prompts upon a growing demand for convenient foods and ready to cook healthy food products such as soups. Such an emphasis necessitates upon the need for the development of more readily acceptable soup products. For such products, consumer requirements in terms of both sensory and nutritional acceptability shall be met. Further, commercial soup mix RTC products need research emphasis to bypass the utilization of more common and scarcely available vegetables such as leeks, carrots and peas and balanced emphasis on nutrition and taste. Also, available soup mixes can be evaluated to be dominant in thickening agents and vegetable portion does not constitute 5 to 10 percent of the entire dry soup mix. For such primary reason, commercial soup products can be inferred to inadequately supplement the nutritional needs of the consumer.

Considering these aspects and aiming towards the development of nutritionally rich and sensory analysis based acceptable soup mix formulations, the Ph.D. thesis emphasizes upon the utilization of abundant and nutritious Indian summer and winter vegetables along with indigenously produced cereal and legume based thickening agents and their compositional optimization in terms of the sensory and nutritional characteristics of the dried vegetable soup formulations. The thesis further targeted the development of the novel score deviation sensory evaluation technique for effective identification of best summer and winter vegetable combinations for the soup mix formulations. This was followed through the trial and error and statistical optimization of vegetable and thickening agent mix compositions and for the considered responses such as sensory and nutritional characteristics. Addressed characterization include proximate characteristics, nutritional characteristics such as antioxidant, total phenolic, vitamin C, minerals, in-vitro bio accessibility of nutrients, sensory, rheological and storage characteristics of developed soup formulations.

Accordingly, the Ph.D. thesis, on a hierarchical basis, targeted the fulfilment of the objectives namely (a) Optimal processing of summer (Tricosanthes diocia (pointed gourd), Luffa acutangular (ridge gourd), Tricosanthes cucumerina (snake gourd), Momordica dioica (spine gourd), Luffa ageyptiaca (sponge gourd) and Vigna unguiculata (yardlong bean)) and winter vegetables (Benincasa hispida (ash gourd), Phaseolus vulgaris (beans), Momordica charantia (bitter gourd), Lagenaria siceraria (bottle gourd), Cucurbita moschata (pumpkin) and Sechium edule (squash)) and through the blanching followed by tray drying operation at optimal drying time and for maximum nutrient retention, (b) Identification of best summer and winter vegetable mix combinations for soup mix formulations and through the comparative assessment of 9-point hedonic scale and score deviation sensory evaluation techniques (c) Trial-and-error experimental methodology-based optimization of soup mix formulations (vegetable mix (25-50 wt%), corn flour (20-30 wt%) and spice mix (30-50 wt%)) through the comparative assessment of 9-point hedonic scale, score deviation and fuzzy logic sensory evaluation techniques and subsequent nutritional characterization, (d) Application of response surface methodology based mixture model design towards the optimization of only dried vegetable mix constitution with respect to overall acceptability (OA) (9-point hedonic scale), overall score and deviation index (OSDI) (score deviation method) and antioxidant activity (AA) and with subsequent evaluation of nutritional characteristics and invitro bio accessibility (e) To evaluate the effect of chick pea, rice and Bengal gram flours as alternative thickening agents to corn flour and optimization of only thickening agent composition in terms of the sensory, nutritional, rheological and storage characteristics of soup formulations. The most important and subjective findings for each mentioned objective are as follows.

The first objective targeted the investigation of sensitivity of moisture content and nutritional characteristics of the sliced mentioned vegetables that were subjected to hot water blanching (95 ^{o}C for 4 min) and tray drying (60 ^{o}C temperature and 2 m/s air velocity with an intermittent air flow mode). The findings affirmed that the tray dried powders of summer vegetables namely pointed gourd, spine gourd, yardlong bean and winter vegetables namely ash gourd, bitter gourd, bottle gourd possessed highest combinations of antioxidant activity (AA), total phenolic content (TPC) and vitamin C content. Further, for all vegetables, drying alone affirmed better retention of mentioned nutrients in comparison to blanching followed by drying treatment. However, a retention greater than 50% of the nutrients in comparison to the fresh vegetable samples was affirmed for most vegetable cases.

The findings of second objective affirmed soup mix formulation being constituted with 25% vegetable mix (40% spine gourd, 40% sponge gourd, 20% yardlong bean), 25% corn flour, 50% spice mix and 1:16 reconstitution ratio as best summer vegetable-based soup mix (SF20) among twenty summer vegetable soup formulations. For the case, an overall acceptability (OA) of 7.70, overall score (OS) of 74.56 and deviation index (DI) of 19.28 was achieved. Similarly,

soup mix formulation constituted with 25% vegetable mix (40% ash gourd, 40% bottle gourd, 20% squash), 25% corn flour, 50% spice mix and 1:18 reconstitution ratio was achieved as the best winter vegetable-based soup mix (WF8). For the case, an OA of 7.48, OS of 74.56 and DI of 19.28. Further, the SDI method provided useful inferences upon the weightage contributed by each sensory parameter to the overall score of a formulation and uniformity within the sensory parameters through the DI value.

The findings of third objective affirmed optimality of the SE formulation (50% vegetable mix (40% spine gourd, 40% sponge gourd, 20% yardlong bean), 20% corn flour, 30% spice mix and 1:16 reconstitution ratio) and with 8.00 OA, 81.26 OS and 21.96 DI as the best summer vegetable formulation and WE2 formulation (50% vegetable mix (40% ash gourd, 40% bottle gourd, 20% squash), 25% corn flour, 30% spice mix and 1:22 reconstitution ratio) with 8.1 OA, 81.35 OS and 17.79 DI as the best winter vegetable formulation. Further, the findings of SDI method conveyed that the taste index (TI) exhibited maximum contribution to the OS of the best summer (48.80) and winter (46.67) vegetable-based soup formulations. As per fuzzy logic-based similarity index values, taste was assessed as extremely important sensory parameter for the SE formulation and aftertaste as highly important parameter for the WE2 formulation.

The relevant findings of the fourth objective based on analysis of variance (ANOVA) and numerical optimization affirmed 13.4 wt% spine gourd, 23.2 wt% sponge gourd and 13.4 wt% yardlong bean as optimum dried summer vegetable composition (MS). For the case, optimum values of AA (0.548%), OA (7.63) and OSDI (77.42) with a desirability of 0.816 was achieved. Similarly, dried winter vegetable composition (MW) being constituted with 10% ash gourd, 29.7% bottle gourd and 10.3% squash was assessed as the best case. For the case, optimum values of AA (0.815%), OA (8.10) and OSDI (82.67) with a desirability of 0.789 was achieved. Further, the findings affirmed a better prediction in terms of R^2 values for the OSDI response. This was not the case for the OA response. Further, MMD optimization of vegetable mix composition affirmed enhanced sensory characteristics through significantly lower DI values being obtained for MS (7.30) and WS samples (9.50).

The final objective targeted replacement of 20 wt% corn flour content in the MS and MW formulations and with varied proportions of chick pea, rice and Bengal gram flour. The experimental tail and error methodology was duly followed for their optimality of the thickening agents only constitution. Among the thirty-two evaluated formulations, the best

formulations being constituted with alternate thickening agents were TS14 formulation being constituted with 20 wt% thickening agent mix (17 wt% chick pea, 66 wt% rice and 17 wt% Bengal gram flour), TS13 being constituted with 20 wt% thickening agent mix (66 wt% chick pea, 17 wt% rice and 17 wt% Bengal gram flour) and TW8 formulation being constituted with 20 wt% thickening agent mix (75 wt% chick pea and 25 wt% rice flour). The obtained sensory scores were assessed to be marginally lower in comparison to the MS and MW samples but in acceptable range (OA: 7.38 to 7.63, OS: 74.00 to 75.56, DI: 6.84 to 12.95). Further, the findings affirmed up to 5 times higher bio-accessible AA of the mentioned optimal samples in comparison to the MS and MW samples being constituted with corn flour. The TS14, TS13 and TW8 samples were also assessed with higher protein content in comparison to the MS and MW samples. All best identified formulations demonstrated pseudoplastic shear thinning behaviour with flow behaviour index (n) lower than 1. Finally, the half-time for antioxidant activity degradation was evaluated as 57, 76, 64, 55 and 68 days for MS, TS14, TS13, MW and TW8 samples respectively.

In summary, the Ph.D. thesis presented a generic and hierarchical experimental methodology for the successful achievement of the soup mix formulations with higher vegetable mix proportion (50 wt%) in the entire soup mix and with 20 wt% legume and cereal based thickening agent proportion. The best formulations ascertained higher in-vitro bio-accessible antioxidant activity and protein content in the soup product. Further, the Ph.D. thesis demonstrated the efficacy of the novel score deviation technique as an effective sensory evaluation tool. Thereby, the significant inferences being obtained in the Ph.D. thesis in terms of the sensory evaluation and optimization techniques are anticipated to further customize and conveniently address the most stringent subjective challenges in dried vegetable soup mix formulations and for optimality of both sensory and nutritional characteristics.

Novelty Statement

The subjective novelties of the Ph.D. thesis work are listed as follows:

1. For the first time, sensorially acceptable and nutritionally rich ready to cook soup mix formulations being constituted with abundant Indian vegetable (spine gourd, sponge gourd, yardlong bean as dried summer vegetables and ash gourd, bottle gourd, squash as dried winter vegetables) along with cereal and legume based thickening agents have been developed. Further, the thesis witnessed the successful achievement of the soup mix formulations with higher vegetable mix proportion (50 wt%) in the entire soup mix and with 20 wt% thickening agent proportion. These ascertained higher in-vitro bio-accessible antioxidant activity and protein content in the soup product.
2. For the first time, the novel score deviation (SDI) sensory evaluation technique was designed and developed. The SDI method provided useful inferences on the weightage of sensory parameters on the overall score (OS) and as well ascertained uniformity among sensory parameters through the deviation index (DI) values. Thereby, the findings affirmed upon the selection of best formulations with higher confidence level.
3. For the first time, comparative assessment of the novel SDI method, 9-point hedonic scale method and fuzzy logic analysis was addressed. Thereby, useful inferences with respect to the efficacy of each sensory evaluation technique were achieved.
4. For the first time, mixture model based statistical optimization of soup mix composition with respect to both sensory i.e., overall acceptability (obtained with 9-point hedonic scale method) and OSDI (obtained with the novel SDI method) and nutritional parameters (antioxidant activity) was assessed. This approach is very important and highly subjective.

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Nomenclature

Abbreviations

AA	Antioxidant activity
AG	Ash gourd
AI	Aroma Index
ANOVA	Analysis of variance
B	Blanched
BD	Blanched and dried
BS	Beans
BIG	Bitter gourd
BOG	Bottle gourd
D	Dried
DI	Deviation Index
DCPIP	2,6-dichlorophenol indophenol sodium salt
DPPH	2,2-diphenyl-1-picrylhydrazyl
DM	Dry mass
EI	Extremely important
Ex	Excellent
FTIR	Fourier transform infrared radiation
F	Fair
FCR	Folin Ciocalteu reagent
G	Good
HI	Highly important
I	Important
LDPE	Low-density polyethylene
M	Medium
MC	Moisture content
MMD	Mixture Model Design
NS	Not satisfactory

NI	Not at all important
OA	Overall acceptability
OS	Overall score
OSDI	Objective function of overall score and deviation index
P	Pumpkin
PI	Physical Index
PG	Pointed gourd
RH	Relative humidity
RG	Ridge gourd
RSM	Response surface methodology
S	Squash
SG	Snake gourd
SPIG	Spine gourd
SPOG	Sponge gourd
SI	Somewhat important
SP	Soluble protein
SDI	Score deviation
TI	Taste Index
TPC	Total polyphenolic content
VITC	Vitamin C
YB	Yardlong bean

Nomenclature

SF1 – SF20	Mixed vegetable soup formulations with varied combinations of summer vegetables to identify best summer vegetable combination
WF1 – WF20	Mixed vegetable soup formulations with varied combinations of winter vegetables to identify best winter vegetable combination
SA - SE	Summer vegetable soup formulations for trial-and-error methodology-based optimization of vegetable mix, corn flour and spice mix composition

WA – WE WE1 - 2	Winter vegetable soup formulations for trial-and-error methodology-based optimization of vegetable mix, corn flour and spice mix composition
MS1 – MS16	Formulations for mixture model-based optimization of summer vegetable composition
MW1 – MW16	Formulations for mixture model-based optimization of winter vegetable composition
MS	Mixture model predicted optimal summer vegetable soup mix formulation
MW	Mixture model predicted optimal winter vegetable soup mix formulation
TS1 – TS16	Summer vegetable formulations for thickening agent mix composition optimization
TW1 – TW16	Winter vegetable formulations for thickening agent mix composition optimization

Notations

a_w	Water activity
M_s	Weight of fresh sample, g
M_d	Weight of oven dried sample, g
M_t	Weight of tray dried sample, g
M_l	Weight loss after ignition in muffle furnace, g
W_e	Weight of extract, g
W_{ash}	Weight of ash, g
A_c	Absorbance of control
A_s	Absorbance of sample
A_{std}	Absorbance of standard
C_1, C_2	Volume of ascorbic acid and sample extract, mL
N_i	Specific nutrient content
n_i	Specific nutrient content corresponding to a vegetable
W_1, W_2, W_3	Proportions of each vegetable
$a1, a2, a3$	Absolute scores of TI, AI, PI

$b1, b2, b3$	Comparative scores of TI, AI, PI
Si, Mi, Ai	Absolute score for each sub parameter of TI
APi, Ci, Ui	Absolute score for each sub parameter of PI
Ts, *Ps*	Sum of absolute scores of sub parameters of TI and PI respectively
Sm, Mm, Am	Scores out of 100 for sub parameters of TI
APm, Cm, Um	Scores out of 100 for sub parameters of PI
Xm	Mean out of 100
$S_i S_\gamma$	Triplets for sensory scores obtained for sensory attributes
SQ_γ	Triplets obtained for overall sensory attributes
B_y	Overall membership function
S_v	Similarity index value
τ	Shear stress, Pa
K	Flow consistency index, $Pa.s^n$
n	Flow behaviour index
γ	Shear rate, s^{-1}
W_s	Dry solids weight (kg)
X_c	Critical moisture content (db)
X_i	Initial moisture content (db)
θ	Storage time (days)
K	Permeability of packaging material (kg water/ m^2/ day/ Pa)
k	First order rate constant (day^{-1})
A	Antioxidant activity at storage day (θ)
A_o	Antioxidant activity at storage day zero
$t_{1/2}$	Half-life time

Chapter 1:

Introduction and Literature Review

Introduction and Literature Review

Overview of the Chapter

Section 1.1 of this chapter details upon the necessity for the preservation and processing of the horticultural produces, techniques adopted for preservation of horticultural produces and the growing demand for custom designed foods such as vegetable soup mix developed from the horticultural produces. The section also discusses upon the methodology often adopted for the optimal vegetable soup mix with improved sensory as well as nutritional characteristics. Section 1.2 summarizes the available prior art for the selection of the ingredients, sensitive influence of drying time and temperature on the nutritional characteristics of the selected ingredients. Accordingly, the section details upon the available state of the art methodology being followed for the standardization and optimization of the ingredient's composition in vegetable soup mix formulations and the sensitive influence of thickening agents on the sensory, nutritional and rheological characteristics of vegetable soup mix formulations. It further details upon the available prior art on various methods being applied for the sensory evaluation of vegetable soups. Section 1.3 of the thesis summarizes the available lacunae and elucidates upon the possible scope for further research in the contextual relevance of sensory properties-based optimization of alternate vegetable soup mix formulations. Thereafter, section 1.4 of the thesis summarizes the thesis objectives based on the elucidated research gaps. Finally, section 1.5 presents a brief account of the organization of the Ph.D. thesis.

1.1Background and Orientation

1.1.1 Overview of Ready to Cook (RTC) Vegetable Soup Mix Products

The ready to cook (RTC) and ready to eat (RTE) food product market in India is growing rapidly and is expected to reach INR 248 billion during 2024 to 2031 (Opportunity Analysis and Industry Forecast, 2022-2031). Stringent alterations in the life style of people, ever increasing urbanization, altered consumer demographics such as busy lifestyle are the major factors that drive the persistent growth of the RTC food sector. Accordingly, various types of RTC and RTE food products such as RTE snacks, RTC soups, rice mixes and breakfast cereals have been targeted and realized. Among these RTC foods, there has been increasing demand for the RTC dried soup mix products. This is due to the growing consumer awareness towards nutritional requirements, emphasis upon well-balanced diet and increasing preference for the plant-based diets. According to the GlobalData analysis, the Indian soup market is expected to grow from INR 7230 million in 2019 to INR 9023 million in 2024 and with a compound annual growth rate of 4.5% (GlobalData, 2021). Hectic lifestyles, demand for tasty, light and healthy foods are the key reasons that drive the growth of dried soup product market. A dried vegetable soup mix product constitutes dried vegetables, thickening agents and spices as its primary ingredients. An insight into the market available commercial soup mix products conveys that several primary limitations exist such as vegetables utility based on a Western landscape and vegetable proportion accounting to less than 10% in the entire soup mix. Thereby, the soups are mostly dominant with thickening agents such as corn flour. Henceforth, commercial soup products are often not sought to meet the adequate nutritional needs of the consumer. In order to overcome these issues, research emphasizing upon the creation of healthy and nutritional soup products is the need of the hour. In this regard, with India being a vast resource of abundantly produced vegetables such as gourds and beans, the soup formulations research needs thrust and emphasis on such vegetables. Thereby, novel formulations can be custom designed with a better combination of nutritional properties. Such an approach will also assist to reduce the wastage of these vegetables and as well fosters a sustainable rural economy. Also, the adaptation of a matured methodology which enables the development of a soup mix with maximum proportion of vegetables and alternative protein rich thickening agents facilitates the realization of a soup mix product with adequate and proportionate supply of nutrients. Thus, the current PhD thesis emphasizes on a structured methodology that involves the preliminary screening of vegetables that are abundantly produced in India based on their nutritional and sensory properties followed by the identification of best combination of vegetables, thickening agents and spices for optimal soup mix through various sensory evaluation techniques and nutritional characterization methods. Figure 1.1 depicts the flow chart for soup mix development.

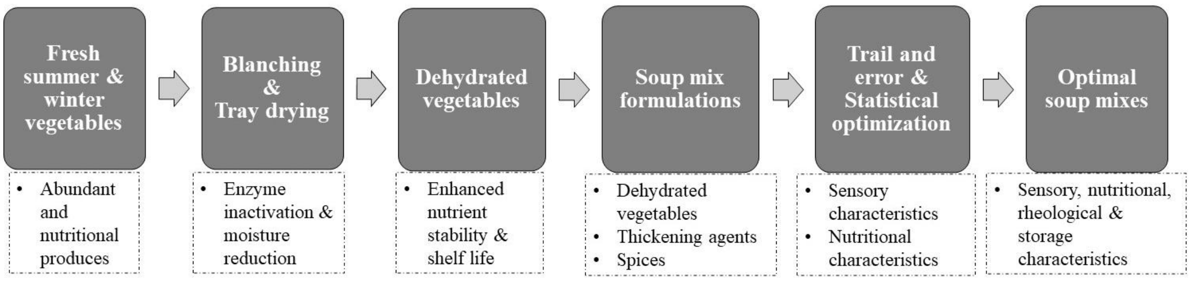


Figure 1.1: Flow chart for soup mix development.

1.1.2 Constitution of a Standard Vegetable Soup Formulation

Typically, a vegetable soup mix formulation consists of a sizable proportion of dehydrated vegetables, thickening agents and spices. However, many existing soup mix products constitute vegetables such as carrots, tomatoes, leeks, potatoes and peas (Abdel-Haleem & Omran, 2014; Abeysinghe & Illeperuma, 2006; Ranaweera KKDS, 2014). In this regard, it is a known fact that vegetables such as leeks are not commonly available in India and are more specific to the western landscape. Also, few vegetables such as potatoes and peas are well known for their rich carbohydrate content and their incompatibility for people with health disorders such as diabetes. Thus, considering these aspects, it is important to explore wider varieties of vegetables by considering factors such as production rate, abundancy, wastage, nutritional characteristics and palatability of the vegetables in the soup mix formulation research. Also, in most soups, corn flour thickening agent is constituted as a major ingredient. Thus, it is important to explore alternate thickening agents. Such ingredients can replace corn flour for two reasons. Firstly, nutritional characteristics can be improved or retained. Secondly, abundant rural horticultural produces of India can be better utilized. Accordingly, soup mix formulation with good combinations of wholesome Indian rural produce-based nutrients and taste can be achieved.

1.1.3 Significance of Abundant Horticultural Produces in Vegetable Soup Mix Products

Among various horticultural produces such as vegetables, fruits, plantation and aromatic plants, vegetables dominated the global horticultural sector with an abundant produce of 1159 MT in 2014. With China being in the first place, India is the 2nd largest producer of vegetables and contributes 14% of the total world vegetable produce (Indian horticulture database 2013-14, National Horticulture Board, Ministry of Agriculture, Government of India). Among numerous varieties of vegetables being cultivated in India, vegetables with promising features such as nutritional constituents and rich soluble and insoluble fibre content refer to cucurbits and legume family vegetables. Amongst various cucurbits and legume vegetables, the Ph.D. thesis emphasizes upon the relevance of few summer vegetables namely Tricosanthes diocia (pointed gourd), Luffa acutangular (ridge gourd), Tricosanthes cucumerina (snake gourd), Momordica dioica (spine gourd), Luffa ageyptiaca (sponge gourd), Vigna unguiculata (yardlong bean) and winter vegetables namely Benincasa hispida (ash gourd), Phaseolus vulgaris (beans), Momordica charantia (bitter gourd), Lagenaria siceraria (bottle gourd), Cucurbita moschata (pumpkin), Sechium edule (squash) for their effective utilization in soup mix formulations and thereby address the mentioned issues for the existing soup products. Figure J1 and J2 in Appendix J of the Ph.D. thesis respectively depict photographic images of the mentioned summer and winter vegetables. These vegetables have been analysed to possess many essential nutritional components such as proteins, carbohydrates, fibres, vitamins and minerals (JR, 2013). They also possess phytochemicals and polyphenols which exhibit antioxidant and anti-inflammatory properties and are also known for their health benefitting properties such as protection against viral and bacterial infections, arthritis, diabetes, gastric ulcers, heart diseases and hypertension (Devaki et al., 2015). Despite such remarkable nutritional properties, these vegetables are extremely perishable due to their high moisture content (80-90%). To overcome this issue, appropriate processing, preservation, and storage techniques at an affordable processing cost shall be considered to achieve processed vegetables with appropriately higher combinations of shelf life and nutritional parameters at an affordable processing cost and with simpler processing schemes. Such appropriately processed vegetables have a great potential towards the development of ready to cook food products especially vegetable soup mixes with longer shelf life. Thereby, the incorporation of appropriately dried vegetables in optimal proportions in the prepared soup mix formulations would only provide desired sensory and nutritional characteristics. The prepared mix vegetable soup formulations should be easily digestible and shall ascertain proportionate nutrient supply after human consumption. Therefore, the developed soup formulations were targeted to meet the nutritional requirements of a wider group of consumers. Since the soup preparation is easy, their best organoleptic features further render them to be relevant for wider consumption. Also, they are expected to facilitate ease of consumption and good digestibility in the human digestive system. Thus, it is anticipated that the optimally prepared soups could be readily accepted by children, professionals, housewives and even elderly people. Further, since the utilized vegetables and the legume-based thickening agents are well known for their lower glycaemic index, the optimally prepared soups could be beneficial for consumers with diabetics and similar ailments. Such a strategy not only assists to overcome the problem of food wastage but also foster balance in the demand and supply chain of the Indian horticultural produces in the along with meeting nutritional requirement of consumers.

1.1.4 Preservation Based on Vegetable Processing Technologies

Among alternate methods of horticultural produce preservation, drying can be regarded as one of the most inexpensive and affordable technology. Variant competent drying technologies for such applications refers to technologies and techniques such as sun drying, oven drying, tray drying, fluidized bed drying, vacuum drying, freeze drying etc. Among these, despite being one among the oldest drying techniques, sun drying has few disadvantages in terms of longer drying time (almost more than 24h), lower product quality, irrelevance for winter and moderate climate dominant regions of India and especially North-east India, and instability of nutrients in the dried products. Further, major shortcomings of the oven drying process is that it does not provide adequate air flow, a feature facilitated by the tray drying scheme. Henceforth, oven drying is not promising in terms of taste and nutrient retention (El Safy, 2014). Thus, the accomplishment of drying in a shorter period along with the maintenance of the shelf life and quality of the dried product is a challenge in the oven drying systems. Fluidized bed dryers are known for their faster drying rates but have a limitation of scalability. Also, vacuum and freeze-drying techniques are quite expensive and are not suggested for the production of dried vegetables in a larger scale and at affordable prices (Drouzas et al., 1999; Nindo & Tang, 2007). Comparatively, tray dryers have the advantage of faster drying rate with good nutrient stability along with scalability. Considering the pros and cons, among all these dryers, tray dryer has the edge due to being inexpensive and relevant technology for the retention of nutrients in the dried vegetables. In the tray drying process, temperature, time and velocity are few important parameters that sensitively influence the tray dried product characteristics. Since alternate vegetables have altered optimal combinations of time and temperature for maximum nutrition retention, it is important to consider these features in the preparation of optimal vegetable soup mix formulations.

1.1.5 Thickening Agents for Soup Mix Products

Corn flour, corn starch, potato starch and edible gums are few commonly used thickening agents for the thickening of soups. However, the inclusion of whole cereals, legumes and other vegetables with desired thickening and sensory properties to the vegetable soup mix assists to ensure a better nutrition and improved taste features of the vegetable soup mix. Also, due to the fact that most vegetables contain moderate amounts of protein, the inclusion of protein rich sources such as legume flours as thickening agents will aid to the development of a soup product with proportionate nutrients. Another important role of the various thickening agents is their contribution towards the rheological properties of the reconstituted soups. The rheological properties play a vital role on the sensory quality of liquid foods, especially foods such as soups in terms of their flow behavior and viscosity. Flow properties are used for categorizing foods as either Newtonian fluids or non-Newtonian fluids (shear thinning or pseudo-plastic, shear thickening or dilatant, rheopectic and thixotropic) (Ibanoglu & Ibanoglu, 1999). Based on the viscosity-shear rate relation, most soups constituted with cereal and pulses based thickening agents have been categorized as shear thinning or pseudo-plastic fluids (Noordraven et al., 2021; Fasogban & Taiwo, 2019).

1.1.6 Vegetable Soup Mix Product Development Methodologies

The methodologies adopted for standardization and optimization of the formulation play a vital role to ascertain upon a readily acceptable soup product. Soup formulations can be targeted by mixing all the available ingredients based on the literature formulations and proceeding towards sensory and nutritional optimization. In this regard, existing prior art on soup formulation research delineates either upon nutritional characterization (Rekha et al., 2010) , or sensory evaluation-based optimization (Ranaweera KKDS, 2014), or nutritional along with sensory evaluation (Abdel-Haleem & Omran, 2014), or sensory evaluation followed by nutritional characterization and vice versa (Abeysinghe & Illeperuma, 2006; Alozie & Ene-Obong, 2018; Alvarez et al., 2015; Verma, 2017). However, such a trial and error-based approach may not be effective to proceed in a systematic evolution of sensory parameters. Also, such dominant approaches may not always lead to the identification of best formulations due to the consideration of sensory and nutritional characteristics on a non-equal priority. Therefore, the adaptation of a level-by-level hierarchy which involves initial screening of vegetables with respect to their nutritional and sensory properties followed by optimization of vegetable mix and optimality of thickening agents and spice combinations can ensure upon an improvised approach for the formulation of tasty and nutrient rich soup mix formulations. Further, considering the significant relation of the viscosity and flow behavior properties of a soup product with its organoleptic properties, investigations targeting the rheological properties of soups constituted with various thickening agents can provide useful inferences on the thickening agents' role on the viscosity and sensory characteristics of the soup. Such a categorization is well known for its utility in the structural and sensory assessment of liquid foods such as soups.

Sensory analysis which involves the assessment of the various sensory properties of food such as taste, aroma, mouth feel, after taste etc., and consumer likeliness of the developed product plays an important role to achieve a final product with better acceptability among wider consumer subjects. For many years, various sensory evaluation techniques such as discriminative or difference tests, descriptive tests (quantitative descriptive analysis, flavour and texture profile method, free choice profiling etc.,) and affective tests (hedonic scale testing) have been employed for the sensory evaluation of various food products (Vivek et al., 2020). Among such various existing sensory evaluation techniques, 9-point hedonic scale method is the most commonly used technique for the evaluation of the consumer liking of a food product and its acceptability (Xia et al., 2021). For the past few decades, this scale has been used by many researchers for the sensory evaluation of soup products (Bukya et al., 2018; Mondal et al., 2020a; Ranaweera KKDS, 2014; Sonkar et al., 2015). Nevertheless, despite being one of the most frequently employed methods for sensory evaluation, the scale system has certain limitations. A crucial limitation of the method is in terms of the greater role of individual bias in determining the overall acceptability score. Such a bias has been attributed to the hypothesis that the parameter deemed most essential in assessing upon the aggregate acceptability score may vary with respect to the subject. Consequently, there could be a bias in the aggregate acceptability score. Subsequently, these limitations of the 9-point hedonic scale may not always permit the selection of the optimal formulation based on the overall acceptability score. In addition, there could be lesser confidence in the decision-making process for the identification of optimal formulation selection decision. These limitations of the well-known 9-point hedonic scale technique necessitate upon the need for the development of precise decision-making techniques for the determination of optimal products. Therefore, it is necessary to target and develop newer sensory evaluation techniques for the sensory evaluation of food products.

1.2 Prior Art

Targeting a hierarchical experimental methodology for the development and optimization of nutritionally and sensorially acceptable soup formulations, the prior art has been classified into following sections:

a) Selection of vegetables for the development of soup mix formulations.

b) Evaluation of the sensitive influence of blanching and tray drying on the nutritional characteristics of the selected vegetables.

c) Standardization and optimization of soup mix formulations.

d) Development and identification of rigorous and optimal sensory evaluation technique for the identification of optimal vegetable soup mix formulations.

e) Effect of alternate thickening agents on the sensory, nutritional, bio-accessibility of nutrients and rheological characteristics of soup mix formulations.

1.2.1 Selection of Vegetables for Soup Mix Formulation Research in Indian Context

More than forty varieties of vegetables belonging to diverse groups, namely, cucurbitaceous, solanaceous, leguminous, cruciferous, root crops and leafy vegetables are grown in tropical, sub-tropical and temperate regions of India (Samantaray et al., 2009). Among these, potato, tomato, cauliflower, cabbage, eggplant, beans and gourds are few widely cultivated vegetables. However, since these vegetables are perishable in nature, they are processed into convenient and RTE foods such as sauces, vegetable soup mix, purees etc. for the enhancement in the nutrient stability and shelf-life parameters. Further, these perishable vegetables are mostly seasonal. Thus, it is necessary to consider few vital factors during the selection of the vegetables for the development of processed foods. These factors refer to the production rate, seasonality, abundancy, wastage, palatability and nutritional characteristics. Most investigated vegetable soup products in the literature and those available commercially constitute vegetables such as carrots, peas, leeks and tomato (Abeysinghe & Illeperuma, 2006; Anita S et al., 2016; Ranaweera KKDS, 2014; Thara, 2018). Thus, there is a need to explore wider varieties of vegetables by considering the above-mentioned factors. Table 1.1 and Table 1.2 respectively outline various deployed ingredients in literature summarized soup formulations and commercially available soup formulations.

Among various varieties of vegetables, few important vegetables of cucurbit genus, namely, squash, pumpkin, gourds, melon, cucumber and few bean varieties are grown in many parts of the world and have major utility as food and industrial crops. In a study conducted by Hashash et al., 2017, the nutritional potential, mineral composition, and antioxidant activity of squash were targeted. The authors reported that the vegetable exhibited a DPPH free radical scavenging activity of 643.09 μg/ ml. The findings revealed that the nutritional composition of squash vegetables was 3.17% crude fiber, 4.45% protein and potassium content of 189.3mg/100g. The total phenols and total flavonoids of the vegetable were 49.80±0.4 mg GA eq./g extract and 27.30±1.22 mg RE eq./g extract respectively. Accordingly, the study revealed that the vegetable has a rich source of crude fiber and β-carotene. Squash is a source of carbohydrates, soluble fiber, pro-vitamin A and protein (Brown & Myers, 2002). It is also known for its medicinal properties such as anti-diabetic, antifungal, antibacterial and anti-inflammatory properties (Caili et al., 2006).

JR, 2013 conducted a study on the antioxidant and nutritional analysis of pointed gourd and spine gourd vegetables. The results obtained from the study reported 218.93mg/100g of iron, 1.11g/100g of protein and 9.33mg/100g of vitamin C content in pointed gourd vegetable. Similarly, 177.3mg/100g of iron, 0.97g/100g of protein and 16.67mg/100g of vitamin content were obtained for the spine gourd vegetable. Spine gourd and pointed gourd have been characterized with diuretic, laxative, antivenomous, antihypertensive, anti-inflammatory, anti-asthmatic and antidiabetic characteristics (Bawara et al., 2010).

Common beans belong to the genus *Phaseolus* and are one of the most widely cultivated legumes in the world (FAO, 2003). They are a valuable source of calories and proteins along with essential micronutrients namely iron, calcium, B-complex vitamins and fiber. Yardlong bean is another leguminous vegetable grown widely in Asia. In the study conducted by Ano &

Ubochi, 2008, the nutrient content of the yardlong bean were determined. These were 23.52-26.27% digestible protein and 102.69-120.02 mg/kg iron. Therefore, the above cited relevant literature depicts the nutritional potential of few selected gourd and bean vegetables and the need to explore their application towards utilization in dried vegetable mix soup systems. Table 1.3 summarizes the nutritional composition of vegetables investigated till date in the above-mentioned relevant prior art.

1.2.2 Effect of Blanching and Drying Temperature and Time on the Nutritional Characteristics of Selected Vegetables

Till date, various reported studies convey a significant influence of the prior and post processing treatments and especially blanching and drying techniques on the quality of dried food products. Such assessments have been in terms of both physical and nutritional properties (L. A. Adepoju et al., 2021; Attkan et al., 2017; Bhattacharjee et al., 2016; Jadhav et al., 2010; Kiharason et al., 2017; Limpaiboon et al., 2011; Mashitoa et al., 2021; Mondal et al., 2019; Singh & Sagar, 2013; Siriwattananon & Maneerate, 2016; Wen et al., 2010). Among these, the most relevant prior art have been briefly discussed as follows.

Mondal et al., 2019 conducted a study to determine the effect of various drying methods namely intermittent air flow assisted tray drying and oven drying on the nutritional characteristics of ash gourd. In this study, the tray dryer and oven systems were operated at 60 °C for 10h. Further, in the tray dryer case, a constant air velocity of 4.5 m/s was maintained along with an intermittent flow condition of 20 sec. From the reported results, it can be inferred that the retention of nutrients was better for the case of tray dried ash gourd vegetable. Accordingly, the best results refer to a moisture content of 7.3%, protein content of 7.05%, fiber content of 12.04%, vitamin C content of 304.37mg/100g and an antioxidant activity of 21.36% in the tray dried ash gourd sample.

Table 1.1: A summary of deployed vegetables, thickening agents and spices utilized in literature reported soup mix formulations.

S.No	Reference	Vegetables	Thickening agents	Spice mix
1	Thara, 2018 (Little millet-based vegetable soup mix)	• Peas • Carrot	• Little Millet • Corn Flour	• Pepper Powder • Salt
2	Anita S et al., 2016 (Millet based dehydrated vegetable soup)	• Carrot • Peas • Potato	• Millets (Foxtail, Pearl, Finger Millet, Sorghum) • Maize • Oats	• Black Pepper Powder • Onion Flakes • Garlic Fakes • Coriander Powder • Cumin Powder • Black Salt
3	Senanayake et al., 2014 (Vegetable soup mix with modified sweet potato starch)	• Carrots • Leeks • Tomato	• Sweet Potato Starch • Dehydrated Dhal	• Salt • White Pepper • Garlic • Cinnamon • Curry Leaves
4	Abeysinghe & Illeperuma, 2006	• Tomato Powder • Carrots • Leeks • Cabbage	• Lentil Powder • Potato Flour • Corn Flour • Whey Powder	• Salt • Celery • Sugar • Vegetable Fat • Onion Pepper • Garlic

Table 1.2: A summary of vegetables, thickening agents and spices used in commercially available soup mix formulations.

S.No	Brand Name	Reference	Soup	Vegetable formulation	Thickening agents	Spice mix	Price
1	Knorr	www.knorr.in	Mixed Vegetable Soup	• Carrot Flakes (4%) • Peas (4%) • Leeks (0.4%) • Onion Powder (2%)	• Potato Starch • Xanthan Gum • Milk Solids	• Salt, Sugar • Dried Glucose Syrup • Edible Vegetable Fat • Hydrolyzed Vegetable Protein • Spices, Mustard • Celery	Rs.10/- per 12g
2	Knorr	www.knorr.in	Sweet Corn Vegetable Soup	• Carrot Flakes (6%) • Corn (7%) • Cabbage Flakes (2%) • Leeks (0.7%)	• Refined Wheat Flour • Maize Starch	• Salt • Edible Vegetable Fat • Hydrolyzed Vegetable Protein • Spices • Celery (0.2%)	Rs.55/- per 44g
3	Batchelors	www.amazon.in	Golden Vegetable Soup	• Dehydrated vegetables (8%) (Carrots, Leeks, Peas, Swede, Onion)	• Maize Starch	• Vegetable Oil • Salt, Sugar • Yeast Extract, MSG • Celery, Turmeric •	Rs.350/- per 82g
4	Knorr	www.knorr.in	Hot N Sour Veg Soup	• Carrot Flakes (3%) • Leeks (0.4%) • Onion Bits (2%) • Garlic Bits (2%) • Onion Powder	• Potato Starch • Xanthan Gum	• Sugar • Salt • Hydrolyzed Vegetable Protein • Spices • Mustard	Rs.10/-11g

Table 1.3: Nutritional characteristics of vegetables studied in the mentioned prior art.

S.No	Reference	Selected vegetables	Nutritional components	Functionality
1	Hashash et al., 2017	• Squash	• 643.09 µg/ ml DPPH free radical scavenging activity	• Antioxidant rich • Therapeutic properties
2	JR, 2013	• Pointed gourd (Trichosanthes dioica) • Spine gourd (Momardica dioica)	• Iron (218.93mg/100g), protein (1.11g/100g), vitamin C (9.33mg/100g) • Iron (177.3mg/100g), Protein (0.97g/100g), Vitamin C (16.67mg/100g)	• Laxative, anti-hypertension, anti-diabetic properties • Protein rich vegetables
3	Ano & Ubochi, 2008	• Yardlong bean	• Digestible Protein 23.52-26.27% • Iron 102.69-120.02mg/kg iron	• Rich fiber source

Attkan et al., 2017 targeted the optimization of hot air-drying process parameters for the drying of onion slices. The authors followed response surface methodology-based optimization for the optimization of hot air-drying temperature (50, 60 and 70°C), slice thickness (3, 5 and 7 mm), and pretreatment (0.1, 0.3 and 0.5% $K_2S_2O_5$) with respect to drying time, color change, pyruvate content, rehydration ratio of the dried onion slices. The findings depicted 60°C temperature, 3 mm slice thickness and 0.5% $K_2S_2O_5$ as the optimum combination of drying parameters. For this optimal process condition, the maximum retention of colour, flavor, taste and maximum overall acceptability (7.6) have been assessed.

In a study conducted by Siriwattananon & Maneerate, 2016, the authors focused on the determination of effect of different drying techniques (sun, hot air oven and freeze drying) on the dietary fiber content of yardlong bean and pumpkin. The obtained results have affirmed a higher constitution of dietary fiber content i.e., 28% and 10.5% in dried yardlong bean and dried pumpkin respectively. Also, the dietary fiber content has been significantly higher in the dried samples in comparison to the fresh samples.

Singh & Sagar, 2013 studied the effect of various drying techniques (solar, low temperature and cabinet drying) on the nutritional characteristics of bitter gourd rings. From their reported findings, cabinet drying (58-60°C) can be inferred to ascertain highest retention of nutrients namely ascorbic acid (57.34mg/100g), total chlorophyll (11.78mg/100g), total carotenoids (2.11mg/100g) and β-carotene (0.86mg/100g). However, the drying resulted in a loss of nutrients in comparison to the fresh samples. However, the loss was found to be lowest for cabinet dried samples in conjunction to the samples obtained through solar and low temperature drying processes. Also, cabinet drying depicted a higher drying rate and hence a drying time of 8h was enough to achieve the dried product.

Bhattacharjee et al., 2016, studied the effect of steam blanching and hot water blanching on the rehydration ratio of bitter gourd slices. The conducted study involved blanching of bitter gourd slices for 1 min, 2 min and 3 min in either steam or hot water. This was followed by cabinet drying at 65 ^oC, 60 ^oC and 55 ^oC. Accordingly, highest rehydration ratio was achieved for samples blanched in hot water for 2 min followed by cabinet drying at 60 ^oC.

In another study conducted by Jadhav et al., 2010, the authors targeted the central composite design-based optimization of hot water blanching parameters of bitter gourd slices prior to their drying with the solar cabinet drying system. In the conducted investigations, the blanching time and potassium bisulfite concentration were varied between 1-5 min and 0.2-0.5% respectively. Eventually, blanching for 4.24 min at a concentration of 0.49% potassium bisulfite resulted in the maximum retention of chlorophyll (20 mg/100g). A summary of the best findings in the discussed prior-art have been presented in Table 1.4.

1.2.3 Standardization and Optimization of Soup Mix Formulations

In this section, a brief overview of various techniques being followed for the standardization of formulation and approaches being adopted for the optimization of vegetable soup mixes have been delineated. The adaptation of a hierarchical approach which involves stage by stage optimization of the ingredients with equal prioritization of both nutritional and sensory characteristics has an important role in converging upon the desirable constitution of the soup. Thereby, the prior art in this theme have been discussed in terms of two hierarchical perspectives namely the standardization approach being adapted for the formulation of soup mix with various ingredients followed by the adopted methodology for the optimization of soup formulation. The standardization procedure enables the affirmation of the proportion of each ingredient. This can be achieved through few preliminary trials that involve the specification of the quantities of various spices, corn flour and each dehydrated vegetable.

Table 1.4: Effect of blanching, drying temperature and drying time on the nutritional characteristics of the vegetables.

S.No	Reference	Selected vegetables	Drying technique	Nutritional components	Key findings
1	Mondal et al., 2019	• Ash gourd	• Oven drying and intermittent air flow assisted tray drying • Drying temperature:60^{0}C • Drying time: 10h • Air velocity in tray dryer: 4.5m/s	• Oven dried: 8.54% moisture, 5.8% protein, 12.8% fiber, 280mg/100g vitamin C,18% antioxidant activity • Tray dried: 7.3% moisture, 7.05% protein, 12.04% fiber, 304.37mg/100g vitamin C 21.36% antioxidant activity	• Highest antioxidant activity**:** tray dried (60^{0}C for 10h) vegetables
2	Attkan et al., 2017	• Onion slices	• Response surface methodology-based optimization of hot air-drying process parameters • Blanching followed by tray drying	• Pyruvate content: 12.93 µmol/g • Rehydration ratio: 4.98 • Drying time: 671.6 min • Overall acceptability: 7.6	• Optimum combination: 60°C temperature, 3 mm slice thickness and 0.5% $K_2S_2O_5$
3	Siriwattananon & Maneerate, 2016	• Yardlong bean (Vigna unguiculata subsp. Sesquipedalis) • Pumpkin (Curcubita pepo)	• Sun drying until constant moisture • Hot air oven drying at 70^{0}C until constant moisture • Freeze drying (-45^{0}C for 24h)	• Fresh Yardlong bean: 88.74% moisture, 2% dietary fiber and 0.6% protein • Oven dried yardlong bean: 5.58% moisture, 28% dietary fiber and 5% protein • Fresh Pumpkin: 84.57% moisture, 3.50% dietary fiber and 0.37% protein • Oven dried pumpkin: 6.72% moisture, 10% dietary fiber and 3.8% protein	• Oven drying time: 24h • Highest fiber content found in oven dried samples
4	Singh & Sagar, 2013	• Bitter gourd rings	• Solar dryer (40-50ºC) • Cabinet drying (58-60ºC, 1.2-1.8 m/s) • Low temperature drying (40ºC)	• Ascorbic acid: 57.34mg/100g • Total Carotenoids: 2.11mg/100g • β-carotene: 0.86mg/100g • Total chlorophyll: 11.78mg/100g	Lower drying time (8h) and better nutrient retention in cabinet drying

Further, the optimization of the formulation involves hierarchical alteration of the proportions of various ingredients either through trial-and-error based or statistical design-based approaches to affirm upon an optimal composition of the ingredients for optimum set of soup characteristics. In the past few years, various studies have been conducted by researchers in the theme of soup mix formulation standardization and optimization (Abeysinghe & Illeperuma, 2006; Anita S et al., 2016; Chavan et al., 2015; Dhiman et al., 2017; Ismail et al., 2022; Jabeen et al., 2021; Manhivi et al., 2020; Ranaweera KKDS, 2014; Sonkar et al., 2015; Sugumar & Guha, 2020; Thara, 2018). Accordingly, a brief account of the most relevant prior art has been delineated as follows.

Thara, 2018 targeted a millet-based vegetable soup mix formulation. For this, the authors adopted a trial-and-error methodology for the optimization of the ingredient's constitution. The authors studied four formulations with varied proportions of corn flour/rice and little millet and for fixed amounts of vegetable mix and spice mix. The weight ratios of corn flour/rice to little millet were varied as 100:0, 40:60, 30:70 and 20:80. After appropriate characterization of sensory and nutritional characteristics, of alternate formulations, the formulation constituted with 80 wt% little millet has been reported as the best with an overall acceptability value of 8.95.

Dhiman et al., 2017 targeted the development of a dehydrated pumpkin soup. The investigations involved an initial optimization phase of the soup formulation that considered only vegetables in the formulation. Following this, the formulation with highest overall acceptability was selected for the incorporation of three different starch sources (rice, corn and potato on an individual basis) in three alternate formulations (quantity of 10g). Accordingly, four soup formulations with varied proportions of spice mix and for a fixed quantity of vegetables were subjected to sensory evaluation. Thereby, the formulation with 20g pumpkin flour, 5g moong dhal powder, 6g vegetable mix, 15g tomato powder and 11.4g spice mix has been reported as the best with an overall acceptability of 7.89. Finally, the best vegetable mix formulation with 10g corn starch has been reported to exhibit highest overall acceptability (7.94), protein content (12.70%) and β-carotene (7%) contents.

The research investigation of Sonkar et al., 2015 targeted trial and error based compositional optimality of soup formulation. The authors targeted okra, barley and black rice in their formulation. Accordingly, the authors developed three alternate formulations through a variation in the proportional weight ratios of barley, okra and black rice as 40:10:50, 35:15:50 and 30:20:50. Finally, the formulation with 35:15:50 weight ratio and 40:10:50 weight ratio constitution of barley, okra and black rice have been reported as the best in terms of overall acceptability (8.93) and nutritional content respectively.

In a study conducted by Chavan et al., 2015, an optimal tomato soup pre-mix was targeted with the response surface methodology based central composite rotatable design. In the study, the constitution of four independent variables namely tomato powder (30-34g), whey powder(38-42g), sugar (9-11g) and salt (10-12g) were subjected to optimization with respect to response variables namely appearance, odour, texture, taste, flavour and after flavour. For optimal values of the responses namely appearance (6.68), odour (5.57), texture (8.14), taste (6.51), flavour (6.66) and after flavour (6.10), the optimal formulation referred to 34g of tomato powder, 42g of whey powder, 11.13g of sugar, 9.87g, of salt, 2g of yeast extract, 1g of citric acid, 2g of cream powder and 2g of skim milk powder.

Manhivi et al., 2020 targeted the optimization of soup formulation constituted with a mixture of leafy vegetable cocktail, pumpkin flour, sweet potato flour, potato starch and spice mix through the response surface methodology based I-optimal cubic mixture design. Leafy vegetable cocktail (5-15g) and pumpkin flour (15-25g) were optimized with respect to total phenolic content and colour (L^*, a^* and b^*) properties. Finally, the authors reported 9g leafy vegetable cocktail and 21g pumpkin flour as the optimal formulation based on the optimal values of the responses.

Sugumar & Guha, 2020, targeted the development of an optimal soup formulation through the incorporation of *S.nigrum* leaves and with D-optimal mixture model design. Accordingly, the independent variables namely leaf powder content, starch and spice mix were varied as 1-5%, 25-35% and 60-70% respectively. In the conducted study, viscosity and overall acceptability were considered as the response variables for the soup formulation optimization study. Finally, 3.964% leaf content, 30.036% starch content and 66% spice mix content have been assessed as the optimal combination for the optimum responses of viscosity (1900 cp) and overall acceptability (5.98). The optimum soup mix formulation was further characterized for phenols (31.50 mg GAE/ g), crude protein (32%) and antioxidant activity (75%).

A summary of the best data in the mentioned prior art for various standardization and optimization methodologies has been presented in Table 1.5.

1.2.4 Role of Various Sensory Evaluation Techniques in Soup Mix Formulation Optimization

Owing to the importance of sensory analysis in determining the acceptability of a food product, significant research has been addressed till date on the sensory analysis of various food products. Among them, very few studies deployed descriptive tests for the sensory analysis of food products such as soups (Huang et al., 2022) and ham (Henrique et al., 2015). Most such studies implemented hedonic scale based sensory analysis of soups (Abdallah & Chove, 2021; O. T. Adepoju & Daboh, 2020; Alozie & Ene- Obong, 2018; Anita S et al., 2016; Bukya et al., 2018; Islam et al., 2023a; Lafarga et al., 2019; Mondal et al., 2020b; Nandhini et al., 2020;

Table 1.5: Literature data summary of ingredients proportion in the research theme of vegetable soup mix formulation standardization and optimization.

S.No	Reference	Materials	Research Methodology	Response variable	Key findings
1	Sugumar & Guha, 2020 Solanum nigrum leaves soup	• Solanum nigrum leaves • Starch • Spice mix	• D-optimal mixture model-based optimization • Leaf powder (1-5%), starch (25-35%) and spice mix (60-70%)	• Viscosity • Overall acceptability	• Optimal formulation: 3.964% leaf powder, 30.036% starch and 66% spice mix • 75% antioxidant activity, 32% crude protein, 31.50 mg GAE/g phenol content
2	Thara, 2018 (Little millet-based vegetable soup mix)	• Little millet • Corn flour • Beans, peas and spices	• Trial and error-based formulation optimization • All ingredients added together with corn flour and little millet varied as 100:0, 40:60, 30:70 and 20:80 ratios	• Nutritional composition • Overall acceptability	• Best formulation: 20% corn flour, 80% little millet flour, 4% vegetable mix, 2% corn, 3.5% spice mix • Overall acceptability: 8.95 • 7.6% protein and 6.8% fiber
3	Dhiman et al., 2017 (Pumpkin soup)	• Pumpkin • Rice starch • Corn starch • Potato starch	• Sensory based only vegetable composition optimization with trial-and-error method • Optimal vegetable formulation added with 10g of each starch in three different variants	• First optimization: overall acceptability • Effect of thickening agent: nutritional (β-carotene, protein and fibre) and sensory analysis	• Best only vegetable mix formulation: 20g pumpkin powder, 5g moong dhal powder, 16g tomato powder and 18g spice mix • Corn starch-based soup: Higher β- carotene (7.01mg/100g), protein (12.65%) and overall acceptability (7.94) • Rice starch-based soup: high fiber (2.09%)

Ranaweera KKDS, 2014; Sonkar et al., 2015; Sugumar & Guha, 2022; Thara, 2018; Upadhyay et al., 2017; Verma, 2017) and other food products (Abdeldaiem et al., 2023; Pauline et al., 2017a). Amongst these, a detailed discussion of the most relevant prior art has been presented as follows.

In a study conducted by Abdel-Haleem & Omran, 2014, the authors targeted the organoleptic evaluation of dried vegetable soup product supplemented with legumes. In their studies, the authors followed a 10-point hedonic scale methodology for the sensory evaluation of alternate soup samples. Thereafter, each 10g soup mix sample was reconstituted with 65 mL water and various sensory attributes of soup such as taste, flavor, colour, thickness, appearance, dissolution rate and overall acceptability were evaluated by 10 panel members. For each attribute, a score out of 10 was assigned by the subjects and the overall acceptability score was determined as a mean of the scores of all attributes. Finally, the vegetable mix incorporated with 35% lentils has been identified as the most acceptable with an overall acceptability score of 45.85. Incidentally, the scores obtained for all other parameters altered in the range of 9.05 - 9.45. Pauline et al., 2017, targeted 9-point hedonic scale based sensory analysis of maize-banana alcoholic beverage. The samples were evaluated by a 12-member panel. In the scale system, 9 corresponded to excellent and 1 corresponded to poor rating. All samples were evaluated for the sensory parameters namely colour, taste, odour and aroma. Accordingly, colour has been reported as the attribute with highest scores and taste as the attribute with lowest scores. Finally, formulation which obtained highest scores for aroma and colour with a significant difference from the scores of other two formulations has been reported as the best.

Alozie & Ene- Obong, 2018 targeted the sensory evaluation of wild spinach and water leaf soup with the 9-point hedonic scale method. In this method, 9 corresponded to like extremely, 5 corresponded to neither like nor dislike and 1 corresponded to dislike extremely. A 20-

member panel evaluated the sensory attributes of the samples. These were namely colour, taste, mouth feel, flavour, aroma, consistency and overall acceptability. The sample reported as the best achieved a score of 8 for colour, 8.05 for taste, 7.50 for mouth feel, 7.62 for flavour, 7.62 for aroma, 7.93 for consistency and 8.25 for overall acceptability.

In a study conducted by Lafarga et al., 2019, the authors targeted the organoleptic evaluation of micro algae incorporated broccoli soup and through a 9-point hedonic scale-based technique. A 30-member panel evaluated various sensory parameters namely appearance, flavour texture and overall acceptability. The scale ascertained a maximum score of 9. Further, acceptability index of each sample was determined based on their respective overall acceptability scores. Finally, the formulation with 0.5% micro algae content has been reported to be the best with the highest acceptability index of 82.2. For the case, the scores of individual parameters were obtained as 7.8 for appearance, 7.3 for flavour, 8.1 for texture and 7.4 for overall acceptability.

Mondal et al., 2020b targeted 9-point hedonic scale based sensory analysis of soup mix formulation being prepared with the leafy vegetables. Four alternate formulations (each 20g) with varied ratios of vegetable mix and corn flour were reconstituted with 400 mL of water. Thereby, the samples were evaluated by a sensory panel consisting of 10 members. Finally, the sample with 40% vegetables and 60% corn flour which obtained an overall acceptability of 8.4 out of 9 has been reported as the best. Taste, texture, flavour, consistency, mouthfeel, appearance and after feel parameters of the best formulation have been reported with respective scores of 8.2, 8, 8.2, 8.5, 8.1, 7.8 and 7.9.

In their investigations, Islam et al., 2023b targeted 9-point hedonic scale sensory analysis of soups incorporated with the jack fruit pectin. A 20-member panel evaluated various sensory parameters of the soups such as appearance, colour, smell, taste, sharpness, thickness and overall acceptability. Finally, the best sample was reported with an overall acceptability of 8.5.

Further, in their findings, the authors qualitatively reported that the colour as an important parameter influenced the overall acceptability of the sample.

In a recent study, Sugumar & Guha, 2022 targeted the sensory evaluation of a functional soup formulation incorporated with *solanum nigrum* leaves. Their investigations involved a comparative assessment of the fuzzy logic analysis and 9-point hedonic scale method for the identification of optimal soup formulations. Accordingly, 11 formulations prepared with varied percentage proportions of powdered leaf, starch and spice mix were prepared as per the combinations generated through the D-optimal mixture model design. The formulations, after reconstitution with water in the ratio of 1:20, were evaluated by a panel of 25 members. Both 9-point hedonic scale technique and fuzzy logic analysis have been used for the assessment of various sensory parameters namely colour, flavour, texture, taste and overall acceptability. The temperatures during reconstitution and sample serving have been reported as 95^{o}C and 45^{o}C respectively. For the case of hedonic scale testing, the panel members evaluated the samples through an assigning of the scores ranging from 1 to 9 in the hedonic scale system. For the case of fuzzy logic analysis, the samples and sensory attributes were assessed in terms of various linguistic categories that varied as excellent to satisfactory, and extremely important to not at all important respectively. Finally, based on the hedonic scores, the sample with 3% powdered leaf, 35% starch and 62% spice mix has been reported as the best with highest overall acceptability score of 6.4. For the case of fuzzy logic analysis, with highest similarity index value being reported for the linguistic category of satisfactory, the sample constituted with 4% powdered leaf, 28% starch and 68% spice mix has been reported as the most acceptable. Further, based on the Pearson correlation of hedonic based sensory data and similarity index values obtained through fuzzy logic analysis, both flavour and taste have been identified as the sensory attributes to sensitively influence the overall acceptability of the formulations in both cases. Table 1.6 summarizes the best findings reported in this field of study.

1.2.5 Effect of Alternate Thickening Agents on Sensory, Nutritional and Rheological Characteristics of Soup Mix Formulation

In the past few years, research has been conducted to evaluate the effectiveness of various thickening agents on the sensory, nutritional, and rheological properties of alternate vegetable soup mix formulations. The most relevant available prior art have been discussed as follows in this section.

Abdel-Haleem & Omran, 2014, targeted the development of legume supplemented dried vegetable soup. In their studies, the authors evaluated the effect of three alternate legumes namely green pea, chickpea and lentil on the physical, chemical, rheological and sensory properties of the soup mix. Four alternate formulations, F1 (39.5% potato, 35.5% barley, 19% vegetable and 6% spices by weight), F2 (35% lentil, 22% potato, 18% barley, 19% vegetable and 6% spices by weight), F3 (35% green pea, 22% potato, 18% barley, 19% vegetable and 6% spices by weight) and F4 (35% chickpea, 22% potato, 18% barley, 19% vegetable and 6% Spices by weight) were evaluated by the authors. Firstly, their findings depicted highest protein content (15.59%), protein digestibility (72.67%) and Fe bioavailability (28.12%) for the case of vegetable soup supplemented with the lentils and highest Zn bioavailability (45.45%) for the case of vegetable soup mix supplemented with the chickpea. Secondly, among the potato-based soup mix and legume-based soup mixes, legume incorporated soup mixes have been reported to exhibit lower viscosity. Thirdly, among the three soup mixes supplemented with alternate legumes, lentil-based soup mix has been reported to ascertain highest overall acceptability of 45.85 on a scale of 50. Fourthly, lowest water activity (0.38), and moisture content (8.51%) have been reported for the legume-based vegetable soup. Also, highest rehydration ratio was reported for the lentil-based vegetable soup followed by green pea-based

Table 1.6: Literature data summary of the sensory evaluation of soups and other products.

S.No	Reference	Product	Sensory evaluation technique	Sensory parameters	Key findings
1	Sugumar & Guha, 2022	• Solanum nigrum leaves soup mix	• 9-point hedonic scale • Fuzzy logic analysis • 25 panel members • Dry mix: water is 1:20	• Colour, flavour, texture, taste and overall acceptability	• 9-point hedonic scale: 3% leaf powder, 35% starch and 62% spice mix with overall acceptability of 6.4 • Fuzzy logic analysis: 4% leaf powder, 28% starch and 68% spice mix was most acceptable. • Flavour and taste exhibited maximum influence on overall acceptability
2	Mondal et al., 2020b	• Leafy vegetable soup	• 9-point hedonic scale • 10 panel members • Dry mix to water is 1:20	• Taste, texture, flavour, consistency, mouthfeel, appearance, after feel and overall acceptability	• Best formulation: 40% vegetables and 60% corn flour with 8.2 for taste, 8 for texture, 8.2 for flavour, 8.5 for consistency, 8.1 for mouthfeel, 7.8 for appearance, 7.9 for after feel and 8.4 for overall acceptability
3	Alozie & Ene-Obong, 2018	• Wild spinach and water leaf soup	• 9-point hedonic scale • 20 panel members	• Colour, taste, mouthfeel, flavour, aroma, consistency and overall acceptability	• Overall acceptability: 8.25 • Other sensory parameter scores: 7.50 to 8.05
4	Pauline et al., 2017	• Maize-banana alcoholic beverage	• 9-point hedonic scale • 12 panel members	• Colour, taste, odour and aroma	• Best formulation: Highest scores for aroma (6.9) and colour (7.8)

vegetable soup. Chickpea based vegetable soup and potato-based vegetable soup exhibited almost similar and lowers values of rehydrated ratio.

In another study conducted by Sonkar et al., 2015, the effect of variant ratios of black rice, okra and barley (50:10:40, 50:15:35, 50:20:30) on the nutritional and sensory properties of the soup mix have been targeted. The findings reported that the soup formulations with 10% okra and 40% barley possessed highest protein (9.04%) and iron (2.45%) content. The findings depicted that the protein content enhanced with an increase in the concentration of barley powder. However, in terms of overall acceptability, the sample with 15% okra and 35% barley has been reported to exhibit highest overall acceptability of 8.93 followed by the sample with 10% okra and 40% barley.

In their investigations, Dhiman et al., 2017 targeted the formulation of pumpkin based soup mix with the incorporation of three alternate thickening agents namely rice starch, corn starch and potato starch. The authors targeted the effect of these thickening agents on nutritional and sensory characteristics of the optimal pumpkin-based soup formulation. The results depicted a higher combination of β- carotene (7.01mg/100g), fibre (1.24%) and protein (12.65%) content in the corn starch based pumpkin soup mix. Lowest moisture content (4.48%), water activity (0.339), total sugar (37.48%) and reducing sugar (10.26%) has been reported for the rice based pumpkin soup mix. Further, highest overall acceptability was reported for the corn based pumpkin soup (7.94) followed by rice (7.62) and potato based (7.60) pumpkin soup mix formulations.

Thara, 2018 studied the effect of variant proportions of corn flour and little millet on the nutritional and sensory aspects of the soup formulations. The authors prepared and evaluated four alternate soup formulations with variant proportions of little millet and corn flour (0:100, 60:40, 70:30 and 80:20 by weight %). The reconstituted (40g soup mix in 300 mL water) soup samples were evaluated for various nutritional properties and sensory acceptability. The findings reported highest carbohydrate content for the soup mix with only corn flour (78.2%) followed by the soup mix with 40% corn flour and 60% little millet. The highest total fibre content (6.8%) and protein content (7.6) has been reported for the soup mix with 80% little millet. Further, the soup mix with 80% little millet has been reported to have the highest overall acceptability of 8.95 followed by soup mix with 60% little millet (8.80).

In a study conducted by Yadav et al., 2022, the authors developed a rice flour and moringa oleifera leaf powder based instant soup mix. The mix has been constituted with 45.95% rice flour, 7.38% moringa leaf powder, 23.23% vegetables and 23.45% spice mix. For the formulation, the authors reported an antioxidant capacity of 60.54 mg/g, 52.31 mg/100g total phenols and 7.73 mg/g chlorophyll. The reconstituted soup system (12g soup mix in 88 mL water) has been reported to ascertain upon an overall acceptability score of 8.29.

The best findings in the prior art in this field of study have been summarized in Table 1.7.

1.3 Lacunae and Possible Scope for Further Research

1.3.1 Need for Dominant Nutritionally Rich Mixed Vegetable Soup Formulations

Till date, even though research has been well addressed on the formulation of vegetable soup mixes, significant lacunae exist in the selection of vegetables for the formulation of vegetable soup mixes. Based on the composition of the commercially available soup mix formulations, it can be observed that most soup mixes have been constituted with vegetables such as tomato, carrots, leeks, cabbage and mushrooms and with corn starch and potato starch as the commonly incorporated thickening agents. Similarly, for the case of literature summarized soup formulations, most research used similar vegetables that have been utilized in the commercially available soup mix formulations.

Table 1.7: A summary of literature data of thickening agents influence on the sensory, nutritional and rheological properties of various soup formulations.

S.No	Reference	Materials	Research Methodology	Response variable	Key findings
1	Dhiman et al., 2017 (Pumpkin soup)	• Pumpkin • Rice starch • Corn starch • Potato starch	• Vegetable mix optimization with trial-and-error method • Optimal vegetable mix added with 10g of each starch in three variants	• First optimization: Overall acceptability • Effect of thickening agent: nutritional (β-carotene, protein and fibre) and sensory analysis	• Best only vegetable mix formulation: 20g pumpkin powder, 5g moong dhal powder, 16g tomato powder and 18g spice mix • Corn starch-based ISM: Higher β- carotene (7.01mg/100g), protein (12.65%) and overall acceptability (7.94) • Rice starch-based ISM: high fiber (2.09%)
2	Sonkar et al., 2015 (Black rice and okra soup)	• Black rice • Okra powder • Barley •	• Sensory based trial and error optimization • Ingredient composition varied as ratios of 50:10:40, 50:15:35, 50:20:30	• Overall acceptability and Protein	• Best formulation with highest overall acceptability (8.08): 50g black rice, 15g okra powder, 35g barley • Best formulation with highest protein content (9.04%): 50g black rice, 10g okra powder, 40g barley
3	Abdel-Haleem & Omran, 2014	• Dehydrated vegetables • Potato • Barley • Lentil • Green Pea Chick Pea	• Trial and error method optimization • Ingredients added together	• Nutritional and sensory analysis • Rheological characteristics	• Best formulation: 35g lentil, 22g potato, 18g barley, 20g dehydrated vegetables and 2g spice mix • Overall acceptability: 45.85 • Protein content (15.59%), in vitro protein digestibility (72.67%), in vitro iron availability (28.12%) Non-Newtonian pseudoplastic behaviour

Very few studies (Dhiman et al., 2017; Farzana et al., 2017) devoted to the utilization of vegetables such as pumpkin and moringa leaf. However, their constitution has been lower in the formulations that are dominant with other ingredients such as thickening agents and spices. Also, researchers often targeted the utilization of only a single vegetable but not a mix of vegetables. Thus, the commercially available soup formulations and literature summarized soup formulations convey a limitation in terms of the utilization of common vegetables that are more pertinent to the landscape of western countries and also being dominant in other ingredients but not the vegetables. In most cases, these other ingredients constituted sugars and flavoring agents which are well known to be abundant with carbohydrates. Thus, such formulations have a limitation in terms of not being suitable for the consumption by people of all age groups and especially by the patients with diabetic disorders. Also, in many cases, the supply of only a single nutrient has been observed. This is due to the utilization of a limited proportions of the vegetables in the soup mix system.

However, in few studies, (Abeysinghe & Illeperuma, 2006; Anita S et al., 2016; Ranaweera KKDS, 2014) the researchers targeted the development of soup formulations with a mix of vegetables. However, in these cases, the total composition of vegetables has been lower in comparison to the overall composition. This resulted in the development of soup formulations that are not dominant in vegetables. Since the available literature and commercial formulations have utilized typical produces of Western landscape which are not abundantly produced in India, the formulations also have a limitation in terms of the utilization of expensive and non-abundant produce. Henceforth, there is a great necessity to address the use of various abundantly produced vegetables such as gourds and beans which have been identified to possess potential nutritional properties for the formulation of soup mixes with adequate and proportionate nutrient supply to address the needs of the consumers. Also, in contrast to the utilized thickening agents which have been reported till date in the commercially available and literature summarized soup formulations, protein rich and indigenously available ingredients can be explored for their utilization as potential thickening agents. Such constituents can be utilized individually or as a mixture. Accordingly, the Ph.D. thesis aims to address these aspects for the realization of a wholesome nutrient rich vegetable soup mix with good and promising characteristics.

1.3.2 Need for Processing Research in The Field of Blanching Pre-treatment and Drying

The available prior art depicts several studies that have been conducted to determine the effect of tray drying parameters on the nutritional characteristics of vegetables. Nevertheless, such research mostly focused upon the drying of few vegetables only and a wider range of the vegetables have not been studied. However, due to variant constitution of water content and other constituents, each vegetable has its own optimal combination of drying time and temperature to retain nutrition and yet achieve good shelf-life parameters of the dried product. Addressing these issues for cucurbits, beans and few other vegetables, the available prior art provided only few insights with respect to the role of blanching, drying (Mondal et al., 2019; Singh & Sagar, 2013) and their combination (Bhattacharjee et al., 2016; Jadhav et al., 2010). Such studies devoted to their optimal process parametric choice for the production of nutritionally rich optimally dried vegetables. Despite gaining few useful insights from the available prior art, a significant sparsity in terms of holistic characterization of vegetables has been observed as the influence of processing or treatment on very few nutritional characteristics has been studied. For example, for bitter gourd ring samples, Singh & Sagar, 2013 inferred that among solar, cabinet and low temperature drying methods, the cabinet drying operated at 58-60^{o}C provided highest nutritional retention in terms of ascorbic acid (57.34 mg/100g), total carotenoids (2.11 mg/100g) and β-carotene (0.86 mg/100g). For the yardlong bean and pumpkin vegetables, Siriwattananon & Maneerate, 2016 carried out investigations using sun, oven and freeze drying processes for the evaluation of their dietary fiber content. Among all processes, the oven drying process affirmed highest dietary fiber content of 28 and 10.5% for the bean and pumpkin samples respectively. Similarly, in the investigations carried out by Mondal et al., 2019 using tray drying and oven drying for ash gourd, the tray drying process affirmed highest retention of nutrients at a temperature of 60^{o}C and drying time of 10h. However, in all these investigations, the blanching pre-process investigation and its critical influence on the dried vegetable nutritional parameters and characterization of other nutritional parameters have not been considered by the authors. Such approaches may not help in the appropriate selection of combinations of vegetables based on their processing and nutritional parameters in due course of the development of nutritionally rich soup mixes. This is due to a scarcity in the comprehensive methodology and associated studies. Thus, there is great necessity to further research on such aspects for the assessment of the sensitive effect of blanching pretreatment on the drying time, moisture and nutritional properties of the selected vegetables. Apart from this, since blanching also influences the sensory properties of most vegetables (due to inactivation of peroxidase enzyme and prevention of off flavors and undesirable colour due to oxidation), it is important to study the sensitive influence of blanching pretreatment prior to the drying scheme.

In few other studies, the authors (Bhattacharjee et al., 2016; Jadhav et al., 2010) targeted both blanching pretreatment and drying of bitter gourds. In the investigations carried out by Bhattacharjee et al., 2016, blanching in hot water for 2 min followed by cabinet drying at 60^{o}C affirmed highest rehydration ratio. However, the authors determined the effect of blanching and drying on the rehydration characteristics only and their influence on the nutritional properties of the bitter gourd slices was not studied. Since blanching and drying are well known to significantly affect the nutritional composition of the vegetables, there is a great scope and necessity to further research on the combined effect of blanching and drying on various nutritional properties of the vegetables. Since nutritional composition of a product is one of the vital aspects in the acceptability assessment of the product, it is important to determine appropriate combination of blanching and drying process and their effect on the retention of nutrients in the vegetables. In another study conducted by Jadhav et al., 2010, blanching for 4.24 min in hot water with 0.49% potassium bisulfite followed by solar cabinet drying ascertained upon the maximum retention of chlorophyll. However, the authors only targeted the assessment of the effect of blanching and drying on the chlorophyll content of bitter gourd slices. Thus, other nutrients were not studied by the authors. Nevertheless, markers such as antioxidant activity and vitamin C content are well known to be significantly influenced by the blanching and drying treatments. Hence, there is a necessity to carry out further research in this perspective and thereby determine the effect of blanching and drying temperature on the antioxidant activity and other nutritional characteristics. Also, since the authors targeted solar cabinet drying technique in their studies, further research can be conducted for the tray drying system along with the blanching pretreatment as tray drying on its own has been effective to ascertain better nutrient retention in studies reported by few researchers.

1.3.3 Systematic Ingredient Composition Optimization for Vegetable Soup Mix Formulations

Till date, relevant research has been conducted by various research groups on the standardization and optimization of ingredient composition for vegetable soup mix formulation. However, there is a significant lacuna towards the systematic optimization of ingredient compositions. For example, in the research conducted by Thara, 2018, the author only optimized the corn flour to little millet ratio and opted for a fixed choice of the vegetable and spice composition. In the conducted study, the optimal proportion of little millet was ascertained based on the highest amount of proximate nutrients and overall acceptability. However, the authors did not target a stage-by-stage optimization which involved optimization of both the vegetable mix composition and the thickening agent composition. Similarly, in a study conducted by Sonkar et al., 2015, the authors targeted an okra, black rice and barley-based soup, In the conducted study, the ingredients were altered for variant proportions and with a trial-and-error methodology. Thus, in the above cited literature, it can be observed that only trial and error approach was followed. Thereby, all the ingredients were mixed and optimized together rather than adopting the stage-by-stage mature optimization methodology.

However, in a study conducted by Dhiman et al., 2017, despite addressing trial-and-error methodology, the authors also addressed a mature optimization methodology. Accordingly, the vegetable composition was optimized with respect to the sensory parameters and then with the optimization of thickening agents. Despite adopting a stage-by-stage methodology, the optimization technique used in this study was only based on a trial-and-error approach. Thus, a mature methodology is profoundly missing to provide conceptual insights that enable useful knowledge data base for the fitness of compositional parameters, nutritional characteristics and sensory parameters. In this regard, only few studies targeted the development and optimization of soup formulations using various statistical optimization techniques. For example, Chavan et al., 2015 targeted the optimization of tomato soup mix using rotatable central composite design of the response surface methodology. However, the authors targeted the optimization of tomato, whey powder, sugar and salt constitution for the best achievement of sensory parameters such as appearance, odour, texture, taste, flavour and after flavour. Thus, it can be observed that the optimization was carried out by only considering the sensory properties but not the nutritional aspects. The possibility to achieve a soup mix formulation with both nutritional and sensory acceptability necessitates upon the adaptation of optimization methodologies that target both nutritional and sensory properties. Also, since central composite design facilitates efficient optimization of process parameters, there is a great scope for such methodology to facilitate insights into the efficacy of statistical optimization models such as mixture model design. Such a model design is well known for its flexibility to optimize a certain composition of a mixture or an entire mixture. In this respect, in the recent years, few authors (Manhivi et al., 2020; Sugumar & Guha, 2022) targeted the optimization of soup mix formulations with the mixture model design methodology. Among these, while Manhivi et al., 2020 targeted the optimization of leafy vegetable cocktail and pumpkin flour, the optimization was carried out by considering only total phenolic content and colour properties as the response variables. In other words, no sensory parameters were considered for the optimization. On the other hand, in the study conducted by Sugumar & Guha, 2022, the authors optimized the leaf powder, starch and spice mix contents with the D-optimal mixture model design methodology and considered viscosity and overall acceptability were considered as the responses. Nevertheless, the authors targeted only the sensory properties for the optimization and also the proportion of leaf powder was varied in the lower proportion range (less than 5 wt% of the entire mix). Thus, the available prior art depicts those various studies either targeted only a trial-and-error approach or only either sensory or nutritional properties for the optimization. Also, despite considering both the nutritional and sensory properties, few studies targeted soup mixes with lower proportion of vegetables. Accordingly, the Ph.D. thesis aims to address these issues and target the optimization and development of soup mix formulations with equal emphasis upon both sensory and nutritional characteristics. To do so, a matured methodology with stage-by-stage optimization of ingredients composition will be followed.

1.3.4 Sensory Evaluation of Vegetable Soup Mix Formulations

The available prior art affirms that several studies have been conducted by various researchers on the sensory analysis of soups and other food products. However, 9-point hedonic scale sensory evaluation has been the most commonly deployed sensory evaluation technique. However, very few studies followed other techniques such as fuzzy logic analysis. Despite being one of the most frequently deployed sensory evaluation technique, the 9-point hedonic scale method has its own limitations. For example, Abdel-Haleem & Omran, 2014 in their studies targeted sensory evaluation of vegetable soup supplemented with legumes and with the 10-point hedonic scale method. Their findings affirmed upon the identification of the best formulation based on the highest overall acceptability score only. Apart from overall acceptability score, even though other sensory parameters obtained individual scores out of 10, the findings affirmed only upon the preference or acceptability of samples but not the weightage or influence of individual sensory parameters on the overall acceptability score. Similar has been the study conducted by Pauline et al., 2017b. Here, the authors evaluated banana and maize based alcoholic beverage with the 9-point hedonic scale method. In their studies, the authors identified colour to be the highest scored sensory attribute and taste to be the least scored sensory attribute. This was based on the scores assigned by the subjects. Despite assuring the identification of the order of sensory attributes based on the obtained scores, the authors did not infer upon the relative importance of each attribute. Also, overall acceptability was not considered as a sensory attribute in the conducted study by the authors. Similar has been the case for the investigations conducted by Alozie & Ene- Obong, 2018a. In their studies, the authors considered overall acceptability as one of the sensory parameters. In the article, the scores of sensory attributes ranged between 7.51 and 8.12, but the score corresponding to overall acceptability was achieved as 8.25. Yet, the authors failed to infer upon the importance or weightage of individual sensory parameters on the overall acceptability score. Similarly, Mondal et al., 2020c targeted 9-point hedonic scale based sensory evaluation of leafy vegetable soups. Despite assuring the identification of formulation based on mathematical significance, the authors did not deduce upon the weightage of individual attribute through the 9-point hedonic scale method. In another study conducted by Islam et al., 2023, the authors qualitatively inferred that the appearance/colour had an important role on the acceptability of jack fruit-based soup product. However, quantitative identification of attributes weightage or most influential attribute was not considered by the authors. Overcoming few of these limitations, Sugumar & Guha, 2022, in their investigations carried out a comparative assessment of fuzzy logic analysis and 9-point hedonic scale method for the determination of the optimal soup formulations. Their findings affirmed that the fuzzy logic analysis exhibited better features with respect to the 9-point hedonic scale method in terms of the determination of the level of sensory attribute importance. Even though the authors determined the order of preference or importance of each sensory attribute, they failed to deduce upon the quantitative weightage of individual sensory parameters through the fuzzy logic analysis. Thus, the above cited literature depicts few limitations of the 9-point hedonic scale method such as the strong role of individual bias on the overall acceptability score of a product, and also inability to determine the individual sensory parameter weightage through both 9-point hedonic scale method and fuzzy logic analysis. Therefore, there is a great necessity to explore upon the development of precise novel sensory evaluation techniques for the identification of optimal or best formulations with higher confidence and better understanding of the role of individual sensory parameters on the overall acceptance of a product. Accordingly, the Ph.D. thesis targets to develop a novel sensory evaluation technique that overcomes the mentioned existing limitations.

1.3.5 Role of Individual and Combination of Thickening Agents on the Sensory, Nutritional, Bio-accessibility and Rheological Properties of Soup Mix Formulations

The available prior art affirms that several studies have been conducted by various researchers for the determination of the role of few vegetable, legume and cereal based thickening agents on various properties of soup mix formulations. Yet, significant lacuna exists in terms of the methodology adapted for the incorporation of thickening agents, their influence on the bio accessibility of nutrients, and rheological and shelf-life properties of soup formulations. The investigations reported by Abdel-Haleem & Omran, 2014, targeted four different predefined formulations with potato; lentil and potato; green pea and potato; chick pea and potato respectively along with other ingredients such as barley and spices. Even though the authors reported the effect of individual thickening agents on the bioavailability of minerals, water activity, moisture content and sensory acceptability of the formulations, the effect of a combination of thickening agents at variant proportions has not been targeted on the mentioned responses. Also, further studies shall be targeted for other nutritional parameters such as antioxidant activity, total phenolic content and their bio accessibility. Similarly, in the studies conducted by Dhiman et al., 2017, the authors investigated the individual effect of three alternate thickening agents on the nutritional and sensory characteristics of pumpkin soups. Thus, there is a significant scope to explore the combinatorial effect of the thickening agents and especially as a combination of two or three ingredients at varied proportions in the mixture of thickening agents. Such alterations could depict a significant influence on the nutritional and sensory properties of the soup mix. Thus, even though investigations addressed nutritional and sensory properties of soup mixes with various thickening agents, further research can be conducted to determine their effect on the rheological properties as the viscosity of soups may get affected due to the constitution of alternate thickening agents and their mixed proportions. Also, further studies can be conducted on the utilization of protein rich thickening agents such as legume flours as a substitute to the thickening agents studied in their investigations. Further, in another study conducted by Sonkar et al., 2015, even though the authors investigated the effect of various proportions of black rice, okra and barley on the protein and iron contents and overall acceptability of the soups, viscosity analyses were not considered. Also, all ingredients were added at once and no mature optimization technique has been followed for the optimization of ingredient composition. Thereby, the determination of the effect of thickening agents on the sensory characteristics of vegetable soup mix could not be addressed effectively. Similarly, in the studies conducted by Thara, 2018, no studies were conducted to determine the effect of thickening agents on the rheological properties of the soups and bio accessibility of nutrients. Also, Yadav et al., 2022 did not study the bio-accessibility of nutrients in the developed soup formulation. Therefore, considering the existing lacunae, the Ph.D. thesis aims to utilize indigenously produced protein rich thickening agents and their compositional optimization in terms of the sensory and nutritional characteristics of the vegetable soup formulations.

1.3.6 Scope and Limit of Study

In summary, the scope of the targeted investigations can be briefly stated as follows. The optimal dried vegetable soup mix formulations being constituted with abundant Indian vegetable produces and cereal and legume based thickening agents have been targeted for successful accomplishment in the Ph.D. thesis. This was aimed through stage-by-stage formulational optimization studies that targeted the design of novel score deviation sensory evaluation technique and with the trial-and-error based and statistical based optimization techniques. The novel score deviation method is expected to provide important inferences on the weightage and uniformity among sensory parameters. This enhanced the associated confidence level and rigorous identification of the best formulations. Further, the developed vegetable soup formulations being incorporated with legume and cereal based thickenings could provide proportionate nutrient supply along with acceptable sensory characteristics to the consumers.

Significant limitations of the targeted investigations could involve inability to reduce processing time and compositional optimization using methods that are not statistical in nature (such as the mixture model design or MMD). However, these could be addressed after achieving mentioned confidence levels. Also, ensemble representation of antioxidants, polyphenols were considered and a further functional constituents' analysis has not been addressed in this work. This can be as well addressed in future investigations.

1.4 Objectives of the Ph.D. Thesis

Based on the identified lacunae, the objectives of the Ph.D. thesis have been outlined as follows:

a) To investigate the influence of blanching and drying parameters on the moisture content, nutritional characteristics and yield of selected abundantly produced summer and winter vegetables. These are Tricosanthes diocia (pointed gourd), Luffa acutangular (ridge gourd), Tricosanthes cucumerina (snake gourd), Momordica dioica (spine gourd), Luffa ageyptiaca (sponge gourd) and Vigna unguiculata (yardlong bean) (summer) and Benincasa hispida (ash gourd), Phaseolus vulgaris (beans), Momordica charantia (bitter gourd), Lagenaria siceraria (bottle gourd), Cucurbita moschata (pumpkin) and Sechium edule (squash) (winter).

b) To identify the best summer and winter vegetable mix combinations for soup mix formulation through the comparative assessment of 9-point hedonic scale and score deviation sensory evaluation techniques.

c) To optimize vegetable mix, corn flour, and spice mix proportional ratio through the comparative assessment of 9-point hedonic scale, score deviation and fuzzy logic sensory analysis techniques followed by nutritional characterization.

d) To statistically optimize vegetable mix constitution with respect to antioxidant activity and sensory scores using RSM based mixture model methodology and subsequent evaluation of nutritional characteristics and invitro bio accessibility.

e) To investigate the sensitive influence of chick pea flour, rice flour and sattu flour as alternate options for thickening agents and optimization of their composition with respect to sensory nutritional, rheological, storage characteristics of soup formulations.

1.5 Organization of the Thesis

The Ph.D. thesis has been organized into nine chapters. A brief account of the following chapters has been presented in the following paragraphs.

Chapter 2 provides a brief account of the materials and methods that have been adopted to carry out the Ph.D. thesis work. It details upon the (a) raw materials and chemicals used in the thesis work, (b) procedures adapted for the blanching and tray drying of selected vegetables, (c) analytical techniques followed for the determination of various moisture and nutritional characteristics of the fresh and processed vegetables, (d) Trial and error based soup formulation methodologies and statistical based soup formulations optimization using RSM based mixture model design (e) 9-point hedonic scale, score deviation and fuzzy logic analysis sensory evaluation techniques and their comparative assessment for the identification of optimal soup formulations and sensory evaluation procedure and (f) procedures adopted for the determination of bio accessibility of nutrients and rheological properties of soup mix formulations and (g) methodologies addressed for storage characteristics and conceptual cost analysis

Chapter 3 addresses the influence of blanching and tray drying on the moisture and nutritional characteristics of mentioned summer and winter vegetables. It also details upon the identification of optimal drying time for blanched and unblanched summer and winter vegetables followed by nutritional characterization of optimally dried and optimally blanched and dried summer and winter vegetables.

Chapter 4 targets the identification of best summer vegetable mix combination and best winter vegetable mix combination for vegetable soup mix formulations. This is targeted through a trial-and-error methodology-based optimization of the sensory properties of various summer and winter vegetable soup formulations. The chapter also details upon a novel score deviation sensory evaluation technique being developed and implemented for the first time and its efficacy towards the identification of optimal vegetable soup mix formulations.

Chapter 5 targets further optimization of vegetable mix, corn flour and spice mix proportional ratios of mentioned summer and winter vegetable soup formulations that have been identified as the best in the previous chapter. Thereby, a soup mix formulation with better combination of nutritional and sensory properties has been targeted in this chapter. Accordingly, the chapter summarizes the trial-and-error methodology being adopted to optimize the soup mix formulations. It also discusses the role of 9-point hedonic scale, score deviation and fuzzy logic sensory evaluation techniques for the identification of optimal soup formulations.

Chapter 6 elucidates upon the statistical optimization of the vegetable mix composition of the soup mix formulations being identified in the previous chapter. This chapter details upon the role of RSM based mixture model design and its ability to optimize a mixture composition in terms of antioxidant activity and sensory scores obtained through 9-point hedonic scale method and score deviation method. This chapter also reports the optimization of composition of three vegetables in a vegetable mixture of soup formulation for fixed constitution of spice mix and corn flour for the maximization of antioxidant activity and sensory scores of the formulations.

Chapter 7 targets the substitution of corn flour with chick pea flour, sattu flour and rice flour. Thereby, their role as thickening agents has been assessed upon the sensory, nutritional and rheological properties of soup formulations. This chapter also elucidates upon the trial-and-error methodology-based optimization of thickening agent composition. Individual, two agents, and three individual agent's combinations have been addressed to achieve maximum responses of nutritional parameters and sensory characteristics and appropriate rheological characteristics. For comparative purpose, optimal corn flour thickening agent-based formulation was also considered additionally for rheological analysis.

Chapter 8 summarizes the storage stability and conceptual cost analysis of the developed summer and winter vegetable-based soup mix formulations.

Chapter 9 summarizes notable conclusions of the Ph.D. thesis work and present a brief overview of the future research perspectives.

Chapter 2:

Materials and Methods

Materials and Methods

Overview of the Chapter

In this chapter, experimental and analytical procedures that were followed, soup formulations and optimization methodologies and various sensory evaluation and characterization techniques being adopted for the fulfillment of Ph.D. thesis objectives have been elucidated. Section 2.1 summarizes raw materials and utilized chemicals and procedures adopted for the sample preparation. Section 2.2 details upon the procedures adopted for the blanching and drying of the samples. The section also addresses methodologies associated to the identification of optimal drying time for blanched and unblanched samples and for the targeted reduced moisture content and enhanced nutritional characteristics of the dried samples. Section 2.3 details upon the methodologies adopted for the identification of best summer and best winter vegetable combinations for alternate soup mix formulations. The section further elaborates upon the procedures being followed for the sensory evaluation with either 9-point hedonic scale and score deviation method. Section 2.4 details upon the methodologies associated to trial and error-based standardization and optimization of summer and winter vegetables soup formulations. The section also elaborates upon the procedures being followed for fuzzy logic based sensory analysis and in-vitro bio-accessibility of nutrients. Section 2.5 elaborates upon the statistical optimization of summer and winter vegetables-based soup mix formulations and with mixture model design. Finally, section 2.6 details upon the procedures that were followed for the formulation and identification of best soup mixes with alternate thickening agents, rheological characterization and storage study of the soup mix formulations.

2.1 Materials

2.1.1 Raw Materials and Ingredients

The fresh summer and winter vegetables being investigated in this thesis were procured from the vegetable store in the market complex of Indian Institute of Technology Guwahati. The summer vegetables which are abundantly available during the months of March to September refer to *Trichosanthes dioica* (Pointed gourd), *Luffa acutangular* (Ridge gourd), *Trichosanthes cucumerina* (Snake gourd), *Momordica dioica* (Spine gourd), *Luffa aegyptiaca* (Sponge gourd) and *Vigna unguiculata* (Yardlong bean). The winter vegetables which are abundantly available during the months of September to March refer to *Benincasa hispida* (Ash gourd), *Phaseolus vulgaris* (Beans), *Momordica charantia* (Bitter gourd), *Lagenaria siceraria* (Bottle gourd), *Cucurbita moschata* (Pumpkin) and *Sechium edule* (Squash). In the conducted study, the vegetables were always procured from the same vendor to ensure upon the reproducibility of the data and authenticate upon the same origin of the horticultural produces in terms of the cultivated region and utilized species. The procured vegetables were also screened on the basis of their uniformity in terms of shape, appearance and color. Further authentication of the fresh vegetables was ensured through the regular and periodic analysis of their moisture content and mentioned nutritional characteristics.

Further, other ingredients that have been utilized in the vegetable soup mix formulation research are salt (Brand: Tata), ginger powder (Brand: Everest), black pepper powder (Brand: Everest), garlic powder (Brand: Only), onion powder (Brand: Only), coriander powder (Brand: Everest), tomato powder Brand: Nature vibe), milk powder (Brand: Everyday), corn flour (Brand: Weikfield), channa flour (Brand: Organic pulses), rice flour (Brand: Manna) and sattu flour (Brand: Anoop). All these ingredients were procured from the grocery store of Indian Institute of Technology Guwahati.

2.1.2 Chemicals

Absolute methanol, oxalic acid dehydrate, petroleum ether, sodium hydroxide pellets and sulfuric acid (98%) were purchased from Merck India. 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) extra pure, 2, 6-dichlorophenol indophenol sodium salt (DCPIP), Bovine Serum Albumin, Folin Ciocalteu Reagent and anthrone reagent were procured from SRL Pvt. Ltd., India. Bradford's reagent, sulfuric acid (98%), nitric acid, potassium chloride, sodium chloride, sodium bicarbonate, calcium chloride, hydrochloric acid, perchloric acid (60%), bile salts and bromocresol green were purchased from Merck India. Methyl red was procured from Rankem, India. Copper sulphate, sodium sulphate, sodium hydroxide pellets and Pepsin were procured from Himedia, India. Pancreatin was purchased from Sigma Aldrich, USA.

2.1.3 Preparation of Samples

Firstly, fresh vegetables were subjected to washing under running tap water condition for the removal of dirt and dust particles that may adhere to their surface. Further, adherent excess moisture to the vegetable's surface was removed with a clean cloth. Prior to slicing, all vegetables were peeled. Also, pumpkin and squash were deseeded after the removal of peel. The pumpkin and squash were cut into rectangular slices of 1 mm thickness. All other gourd vegetables were cut into circular slices of 2 mm thickness. Yardlong bean was cut into pieces of 5 mm length.

2.2 Determination of Optimal Tray Drying Time for Blanched and Unblanched Summer and Winter Vegetables

2.2.1 Blanching Treatment

The blanching of the vegetable samples was carried out in hot water. For this purpose, 100g of peeled and sliced vegetable was contacted with 100 mL hot water at 95^{o}C and for 4 min duration. After blanching, the vegetables were immediately cooled by placing them in ice water for 1 min. The blanching time and temperature were specified as per the literature reported best conditions (Bhattacharjee et al., 2016; Chhe et al., 2018).

2.2.2. Tray Drying of Vegetables

Based on the available prior art (Mondal et al., 2019; Singh & Sagar, 2013), tray drying has been chosen as an effective drying technique for better retention of nutrients along with appropriate affirming of the desired quality of the dried vegetables. A laboratory scale tray dryer (Make: ICT; Model: QT) was used for the drying of vegetables (schematic presented as Figure J3 in Appendix J). An intermittent airflow drying approach was followed to achieve effective drying and nutrient retention. The tray dryer system was maintained at an intermittent air velocity of 2 m/s (Limpaiboon et al., 2011 and Taşeri et al., 2018) and with 20 s run/off mode set process condition that ascertained periodic air flow and stagnation. The cut fresh vegetables (pumpkin and squash were cut into rectangular slices of 1 mm thickness, other gourd vegetables were cut into circular slices of 2 mm thickness and yardlong bean was cut into pieces of 5 mm length) with and without blanching pre-treatment were arranged in single layers and were placed on the dryer trays (18” x 18”x 2” tray dimensions). The vegetables were dried at a temperature of 60 ^{o}C. Corresponding drying time was varied as 6 – 12 h. This was based on few preliminary trials that affirmed insignificant moisture removal from samples for drying times lower than 6 h. The drying parameters namely drying time and drying temperature were set as per the best findings reported in the relevant literature (Kumari & Sharma, 2018; Malik & Kajla, 2020 and Mondal et al., 2019). Thereby, the optimal drying temperature was set as 60 ^{o}C for all vegetables. The optimal drying time for each vegetable was affirmed in terms of storage stability based optimal moisture content and corresponding antioxidant activity.

2.2.3 Drying Time Optimization

For the evaluation of optimal drying time of each vegetable, moisture content and antioxidant activity of the unblanched and dried (D) and blanched and dried (BD) vegetable samples were considered as the critical responses. Moisture content lower than 8% was targeted for the dried vegetables to ascertain upon the prevention of the spoilage of soup mix formulation by the microorganisms (Rokhsana et al., 2007). Further, it shall be noted that the antioxidant activity, an important parameter to consider during the formulation of a food product, is heat sensitive. Since blanching and drying operations involve heat treatment of the vegetable samples, the antioxidant activity was considered as a critical response variable for the assessment of optimal drying time. Thus, the retention of maximum antioxidant activity has been targeted for the affirming of the optimal drying time. Further, since drying was carried out at 60 ^{o}C, with prolonged time, the moisture content reduced to a value lower than 8 percent and no significant changes were observed in the color of the dried vegetable samples. All the dried vegetables retained color closer to that of fresh vegetables.

2.2.4 Proximate and Nutritional Characterization

Fresh, blanched (B), unblanched and dried (D) and blanched and dried (BD) vegetables were evaluated for various proximate and nutritional characteristics. These include moisture content, yield, crude fibre, antioxidant activity, vitamin C content, total phenolic content and soluble protein content. The following sub-sections present the methodologies adopted for the evaluation of various proximate and nutritional characteristics.

2.2.4.1 Moisture Content (MC)

The MC is the amount of water that exists in the sample and is related to the wet mass basis. The fresh and tray dried vegetable moisture content was determined with the prior art mentioned method (AOAC, 2010). Accordingly, a glass petri dish loaded with the vegetable sample was weighed and was placed in an oven for 14 h at 105 ^{o}C. Subsequently, the cooled sample in a desiccator was again weighed. The moisture content was determined with the following expression:

$$MC(\%) = \frac{M_s - M_d}{M_s} \times 100 \tag{2.1}$$

where M_s and M_d are the weights of the initial sample and the oven dried sample, respectively.

2.2.4.2 Yield

The yield refers to the dry matter being obtained after drying operation and is related to the dry matter content. The yield of the dried samples was determined by following the method mentioned in the relevant literature (Mondal et al., 2019). Accordingly, weight measurements were carried out for samples prior to and after drying. Using these values, the yield was determined with the following expression:

$$Yield(\%) = \frac{M_t}{M_s} \times 100 \tag{2.2}$$

where M_t and M_s are the weights of tray dried and fresh sample, respectively.

2.2.4.3 Crude Fibre

The fresh and tray dried vegetable's crude fibre content was obtained with a method reported in a relevant prior art method (Sadasivam & Manickam, 1992). To do so, firstly, continuous stirring of 1g of the sample with 100 mL of 1.25% H_2SO_4 and for 30 min on a magnetic hot plate was carried out. Further, the sample was filtered with a muslin cloth and the acid was removed by washing the residue with the boiling water. The obtained residue was subjected to the same treatment with 1.25% NaOH. This was followed by filtration and washing with the boiling water. Subsequently, the obtained residue was washed sequentially washed with 1.25% H_2SO_4 containing boiling water, 50 mL distilled water and 25 mL alcohol. Finally, the residue was kept in an oven for 2 h at 130°C. The cooled sample was weighed and placed in a muffle furnace for ignition at 600°C and 30 min. Thereafter, the final sample weight was noted. Using measured sample weights, the crude fibre content was estimated with the following expression:

$$Crude\ fibre(\%) = \frac{M_l}{M_s} \times 100 \tag{2.3}$$

where M_l and M_s correspond to the weight loss during ignition in muffle furnace and weight of the fresh sample, respectively.

2.2.4.4 Antioxidant Activity

The Antioxidant activity (AA) of the samples was determined by following the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay procedure being reported in a relevant prior art (Mondal et al., 2019). To do so, firstly, 0.1 g of dried sample was extracted with absolute methanol (20 mL) for 30 min in a sonicator (model: Elmasonic S 30H, make: Elma). However, for the fresh vegetable sample, 1 g of the sample was considered. Thereafter, 1 mL of the solution obtained after filtration with Whatman no.1 filter paper was mixed with 3 mL of 0.002% methanolic DPPH solution. Also, a control sample was prepared as a mixture of 1mL absolute methanol and 3 mL methanolic DPPH solution. After thorough mixing with a vortex mixer, the samples were incubated for 30 min in a dark chamber. Finally, the absorbance was measured at 517 nm for the control and desired samples and with a UV spectrophotometer (Make: SHIMADZU; Model: UV-2600). Using these measured values, the antioxidant activity was determined with the following expression:

$$Antioxidant\ activity(\%) = \frac{A_c - A_s}{A_c} \times 100 \tag{2.4}$$

where A_c and A_s are the absorbance of the control and sample respectively.

2.2.4.5 Vitamin C Content

The Vitamin C content of the fresh and treated samples was determined by following the 2, 6-dichlorophenol indophenol (DCPIP) dye titration method (Sadasivam & Manickam, 1992). Accordingly, 20 mL of 4% oxalic acid was used to extract 0.1 g of dried sample or 1 g of fresh sample. After filtration, the titration was conducted for a mixture of 5 mL filtrate and 10 mL of 4 % oxalic acid. The titration was carried out with the DCPIP dye solution (a mixture of 42 mg, 52 mg and 200 mL of sodium bicarbonate, dye powder and distilled water respectively). A blank titration run was also carried out with the 100 ppm standard ascorbic acid solution. The titration was affirmed through the visualization of pale pink colour in the solution that existed for a few seconds (end point). Using the measured titration volumes and sample weight, the Vitamin C content of the sample was determined as:

$$Vitamin\ C\left(\frac{mg}{100g}\right) = \frac{0.5 \times C_2 \times 20 \times 100}{C_1 \times 5 \times M_s} \tag{2.5}$$

where C_1 and C_2 correspond to mL of ascorbic acid and sample extract consumed and M_s is the weight of the sample taken.

2.2.4.6 Total Phenolic Content

The total phenolic content of the samples was determined with the Folin Ciocalteu reagent (FCR) that was reported in a relevant literature (Wani & Uppaluri, 2022). Accordingly, 0.1 g of dried sample was extracted with distilled water (20 mL) for 30 min in a sonicator (model: Elmasonic S 30H, make: Elma). Also, for the case of the fresh vegetable sample, 1 g of the sample was considered. Thereafter, 1 mL of the solution obtained after filtration with Whatman no.1 filter paper was mixed with 1 mL of Folin Ciocalteu reagent (1 mL FCR in 10 mL distilled water). After vortex mixing of the sample, 10 mL of 7% sodium carbonate was added. The mixture was again vortexed after adding 4 mL of distilled water. After thoroughly mixing with a vortex, the sample was incubated for 90 min in a dark chamber. Finally, the absorbance at 750 nm was measured for the sample and with a UV spectrophotometer (Make: SHIMADZU; Model: UV-2600). Finally, the amount of total phenolic content has been represented in terms of gallic acid equivalent (mg GAE/g of sample). To do so, the total phenolic content of sample was determined with the calibration curve that was prepared with the gallic acid standard samples of variant known concentrations.

2.2.4.7 Soluble Protein

The soluble protein content of the samples was determined by following the Bradford method (Bradford, 1976). Accordingly, 0.1 g of dried sample was first extracted with 20 mL distilled water. However, for the case of fresh sample, 1g fresh sample was taken and similar procedure was followed for the extraction. Thereafter, 1 mL filtrate was added with 2 mL Bradford's reagent and the mixture was vortexed thoroughly. Finally, the absorbance at 595 nm was measured for the sample and with a UV spectrophotometer (Make: SHIMADZU; Model: UV-2600). The soluble protein content (g/100g) was assessed through the calibration curve being prepared with the BSA (Bovine serum albumin) standard solutions.

2.3 Overall Methodology for the Identification of Optimal Soup Mix Formulations

In general, mixed vegetable soup formulation constitution refers to the affirmation of the appropriate proportions of vegetables, thickening agents and spices. To do so, about 10 to 20 ingredients shall be specified and optimized. Sensory analysis-based optimization has been the standard protocol for soup mix formulations optimization. Usually, after sensory optimization, other characterizations such as proximate, nutritional, rheological and storage analysis are considered. The Ph.D. thesis follows similar research methodology i.e., sensory optimization followed by all other characterizations.

To affirm upon the detailed analysis of alternate soup formulations, a standard pallatte of all ingredients shall be established as the starting point. This is often termed as the standardization of the soup formulation. Subsequently, either a trial-and-error based approach or a statistical design-based approach can be followed to hierarchically alter the type of vegetables, vegetable proportion, types of thickening agents, thickening agents' proportion, types of spices and spices composition. Considering the exhaustive nature of such research, the Ph.D. thesis aimed to only target vegetables and thickening agents' constitutional optimization. This is due to the fact that the adopted spices have not been regional. However, this has not been the case for the targeted vegetables and thickening agents.

The following hierarchy or phases had been followed to represent the overall soup formulation research methodology:

a) ***Identification of best summer and winter vegetables combinations for soup mix formulations***

   In this phase, for the identification of best summer and winter vegetable combinations for soup mix formulations, firstly, the ingredients composition for a 10g dry soup mix formulation was standardized based on few initial trials. Appendix A summarizes a detailed account of the methodology and findings associated to the standardization phase.

Thereafter, twenty summer and twenty winter vegetable-based soup mix formulations were prepared with a fixed choice of the thickening agent and spice compositions and for altered proportions of dried vegetables in the soup formulation. The fixed constitution of spices and thickening agents was based on the findings of the standardization phase. In the Ph.D. thesis, the dried vegetables mix was based on the altered combination (and constitution) of any three vegetables. Subsequently, sensory evaluation based preliminary screening has been carried out to identify five best formulations. The screened formulations were evaluated for nutritional characteristics to identify the soup mix formulations with best summer and best winter vegetable combinations.

b) Optimization of trial-and-error methodology-based soup mix formulations

In this section, the screened soup formulations with best summer and winter vegetables combinations were further subjected to sensory analysis-based trial-and-error based optimization of vegetable mix, thickening agent and spice mix compositions. For this purpose, five alternate summer vegetable soup formulations and seven alternate winter vegetable soup formulations with varied proportions of vegetable mix (25-50 wt%), thickening agent (20-30 wt%) and spice mix (30-50 wt%) have been evaluated. The alternate soup mix formulations were developed through proportionate variation of ingredients with respect to the soup constitution of the best identified combinations of the summer and winter vegetables. The soup mix formulations were identified in this phase with the sensory analysis data obtained with the sensory evaluation techniques namely, the novel score deviation (SDI) method, 9-point hedonic scale method and fuzzy logic analysis. Thereafter, nutritional properties were determined for the best cases.

c) ***Mixture model methodology-based optimization of vegetable mix composition***

In this section, the statistical optimization of best identified summer and winter vegetable-based soup mix formulations from the previous section was carried out. To do so, the thickening agent and spice mix composition of the best identified soup formulations were kept fixed (20 and 30 wt% respectively) and only the vegetable mix composition (50 wt%) of the soup mix formulation was optimized. The proportion of each of the three vegetables in the vegetable mix (50 wt%) was varied in the range of 5-30 wt% as per the software generated experimental run data. Finally, alternate soup formulations prepared with varied proportion of vegetables in the vegetable mix and fixed proportions of thickening agent and spice mix were optimized with respect to the sensory scores (obtained with the novel SDI method and 9-point hedonic scale method) and antioxidant activity using Mixture model design. The optimal summer and winter vegetable-based soup formulations were assessed for various nutritional characteristics and their in-vitro bio-accessibility.

d) ***Effect of alternate thickening agents on nutritional, rheological and storage characteristics of soup formulations***

In this section, the corn flour content in the optimal summer and winter vegetables-based soup mix formulations have been replaced with alternate thickening agents namely channa flour, rice flour and sattu flour. Thereby, alternate summer and winter vegetable soup mixes have been formulated with respect to the ingredients composition of optimal formulations being identified in the previous section. To do so, the vegetable mix and spice mix composition were considered as a fixed choice (50 and 30 wt% respectively) and the thickening agents' proportion (incorporated individually or as a combination of either any two or three thickening agents) was varied in the range of 0-100 wt% within the thickening agent mix composition (20 wt%) of a soup formulation.

Subsequently, soup mix formulations with best thickening agent mix constitution have been identified based on the sensory analysis and nutritional characteristics.

A graphical representation of the overall methodology for the identification of optimal soup mix formulations has been presented in Figure 2.1.

2.4 Identification of Best Summer and Winter Vegetables Combinations for Soup Mix Formulations

In the following sub-section, the methodologies being followed for the standardization of ingredient composition, identification of best summer and winter vegetable combinations for soup mix formulations and sensory evaluation of soup samples have been delineated.

2.4.1 Standardization of Ingredients Proportion

The standardization procedure facilitated the affirmation of the proportion of each ingredient. This was based on few preliminary trials that involved specification of the quantity of each dried vegetable, corn flour and various spices. Appendix A summarizes a detailed account of the methodology and findings associated to the standardization phase. Thereafter, for each soup formulation, sensory evaluation was carried out in terms of taste, aroma and consistency properties. Thereby, the standardized constitution of vegetable, corn flour and spices were identified as per the best sensory attributes of the formulations. Table 2.1 presents the standardized ingredients proportion that was achieved through the mentioned preliminary experimental trials. In this regard, it shall be noted that both summer and winter vegetables were considered with random proportions of their mixtures in the conducted trials. In the following phase, while items 2-10 in Table 2.1 have been chosen as fixed choice, the item 1 in the table would be subjected to sensory optimization studies. This was based on the choice of three types of vegetables.

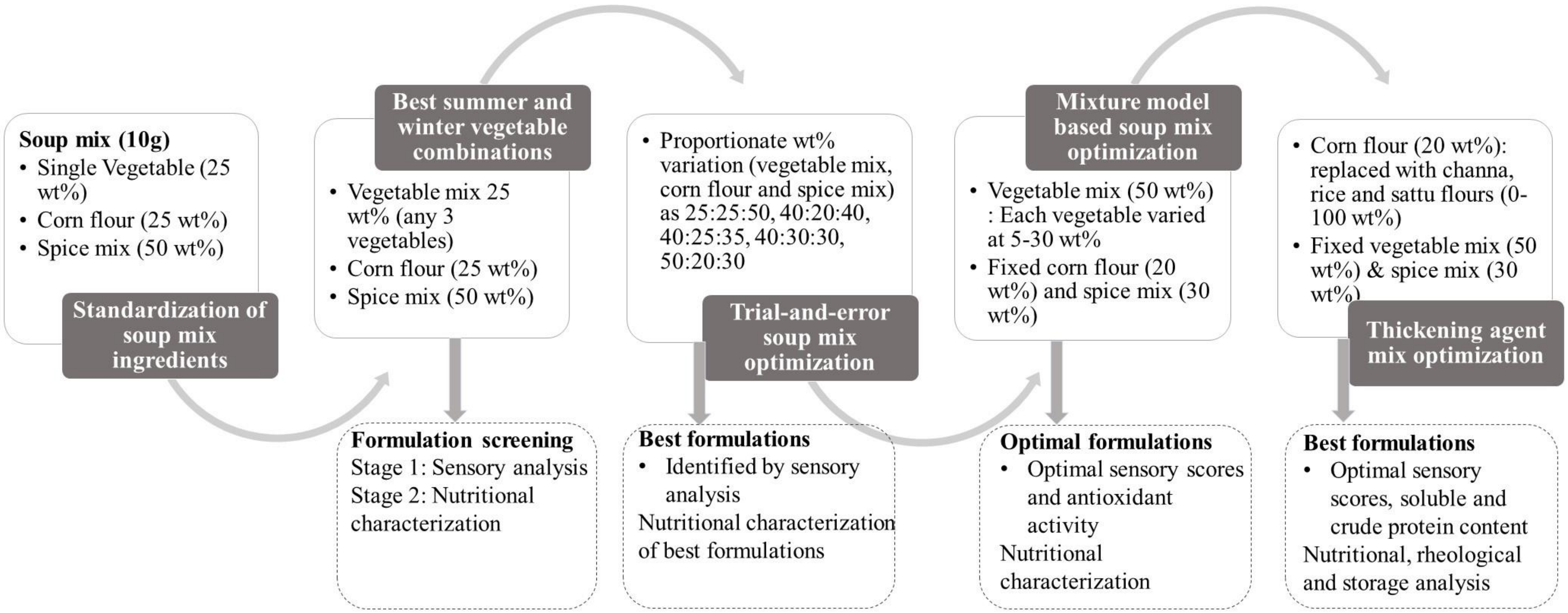


Figure 2.1: Overall Ph.D. thesis methodology for the identification of optimal soup mix formulations.

2.4.2 Identification of Best Summer Vegetable and Winter Vegetable Combinations

For the identification of best dried summer and best winter vegetable combinations, various soup formulations were prepared. For this purpose, using six summer vegetables, 20 possible combinations in groups of three and without repetitions were generated with the COMBIN function in Microsoft Excel (Table 2.2). Similarly, 20 possible combinations for dried winter vegetables were generated with the mentioned function in Microsoft Excel (Table 2.3). Based on the generated combinations, various soup mixes, each soup mix (10g formulation) with a combination of three dried vegetables (40:40:20 ratio of 25%), corn flour (25%) and spice mix (50%) were formulated. The proportion of each vegetable as per the aforementioned ratio was selected based on sensory data obtained through preliminary sensory evaluation of single vegetable based alternate soup mixes. The single vegetable formulation consisted one vegetable (25 wt%), corn flour (25 wt%) and spice mix (50 wt%) and as per the proportions mentioned in Table 2.1. In the preliminary vegetable combinatorial studies, conceptualization of either low or high constitution of any vegetable in the vegetable mix prompts upon the set ratio of 40:40:20. Accordingly, the value of 40 in the ratio refers to higher proportion and the value of 20 in the ratio refers to the lower proportion of the respective vegetable in the vegetable mix being prepared with any three mentioned vegetables.

Table 2.1: Ingredients proportion in the best soup mix formulation obtained in the preliminary standardization phase.

S.No.	Ingredients	Amount (g)
1	Vegetable	2.5
2	Corn flour	2.5
3	Onion powder	0.5
4	Garlic powder	0.5
5	Ginger powder	0.5
6	Tomato powder	0.5
7	Coriander powder	0.25
8	Black pepper	0.25
9	Milk powder	1.25
10	Salt	1.25

Table 2.2: A summary of twenty alternate summer vegetable combinations for the standardization-based vegetable soup mix formulations.

Summer Formulation	40 percent	40 percent	20 percent
SF1	Pointed gourd	Snake gourd	Ridge gourd
SF2	Spine gourd	Ridge gourd	Pointed gourd
SF3	Pointed gourd	Sponge gourd	Ridge gourd
SF4	Pointed gourd	Yardlong bean	Ridge gourd
SF5	Snake gourd	Spine gourd	Pointed gourd
SF6	Pointed gourd	Sponge gourd	Snake gourd
SF7	Pointed gourd	Snake gourd	Yardlong bean
SF8	Spine gourd	Sponge gourd	Pointed gourd
SF9	Pointed gourd	Spine gourd	Yardlong bean
SF10	Pointed gourd	Sponge gourd	Yardlong bean
SF11	Snake gourd	Spine gourd	Ridge gourd
SF12	Sponge gourd	Ridge gourd	Snake gourd
SF13	Ridge gourd	Snake gourd	Yardlong bean
SF14	Spine gourd	Sponge gourd	Ridge gourd
SF15	Spine gourd	Ridge gourd	Yardlong bean
SF16	Ridge gourd	Sponge gourd	Yardlong bean
SF17	Spine gourd	Sponge gourd	Snake gourd
SF18	Spine gourd	Snake gourd	Yardlong bean
SF19	Snake gourd	Sponge gourd	Yardlong bean
SF20	Spine gourd	Sponge gourd	Yardlong bean

Table 2.3: A summary of twenty alternate winter vegetable combinations for the standardization-based vegetable soup mix formulations.

Winter Formulation	40 percent	40 percent	20 percent
WF1	Ash gourd	Bitter gourd	Beans
WF2	Ash gourd	Bottle gourd	Beans
WF3	Ash gourd	Pumpkin	Beans
WF4	Ash gourd	Squash	Beans
WF5	Ash gourd	Bottle gourd	Bitter gourd
WF6	Ash gourd	Pumpkin	Bitter gourd
WF7	Ash gourd	Squash	Bitter gourd
WF8	Ash gourd	Pumpkin	Bottle gourd
WF9	Ash gourd	Bottle gourd	Squash
WF10	Ash gourd	Pumpkin	Squash
WF11	Bitter gourd	Bottle gourd	Beans
WF12	Bitter gourd	Pumpkin	Beans
WF13	Bitter gourd	Squash	Beans
WF14	Bitter gourd	Beans	Pumpkin
WF15	Bottle gourd	Squash	Beans
WF16	Pumpkin	Squash	Beans
WF17	Bottle gourd	Pumpkin	Bitter gourd
WF18	Bottle gourd	Bitter gourd	Squash
WF19	Pumpkin	Bitter gourd	Squash
WF20	Bottle gourd	Pumpkin	Squash

Accordingly, inferences were arrived at in terms of the sensory characteristics of a vegetable being incorporated either with a lower or a higher proportion. Further, along with the sensory attributes of each vegetable, the nutritional composition (antioxidant activity, total phenolic content, vitamin C, soluble protein and crude fibre) was also considered to assess upon the proportion of each dried vegetable. Thus, the sensory and nutritional characteristics of each vegetable assisted in the decision making for the proportion of each vegetable in alternate dried vegetables mix-based soup formulation.

For the identification of best summer and best winter vegetable combinations, sensory evaluation of the twenty summer vegetable soups and twenty winter vegetable soups with alternate combinations of vegetables as summarized in the previous section has been carried out. For this purpose, 10g soup mix (25% vegetable mix, 25% corn flour and 50% spice mix) with ingredients composition as summarized in Table 2.1 were prepared with each mentioned combination of vegetables. The sensory evaluation was conducted with two alternate techniques namely 9-point hedonic scale method and score deviation (SDI) method. Further, overall acceptability scores obtained through 9-point hedonic scale method, and overall score and deviation index values obtained through the SDI method have been considered as responses for the screening of sensory evaluation based alternate formulations. Thereby, the obtained sensory evaluation data through either method was considered as the primary criteria to screen best five formulations among either twenty summer and twenty winter formulations. For this purpose, firstly all the formulations were assigned ranks based on scores obtained through both sensory evaluation techniques. For the 9-point hedonic scale method, formulations were ranked from 1 to 20. This was based on their overall acceptability score. For the SDI method, formulations were ranked by considering the highest score and lowest deviation index as the criterion. Also, a commercial soup product (Knorr mixed vegetable soup) has been considered as a control case during the sensory evaluation and the scores obtained for all formulations were compared with those of the commercial soup mix product. Based on the scores and the ranks, five alternate formulations from summer and winter vegetable-based mixes were selected. The nutritional composition of the five screened formulations screened as per sensory scores was further estimated through mixing rule-based assessment and with the experimentally determined nutritional value of each vegetable. Based on the estimated overall nutritional composition of each formulation, summer and winter vegetable formulations with best sensory rankings and highest nutritional composition were identified as the best formulations.

The mixing rule based nutritional composition of these best formulations was further confirmed through experimental analysis of important nutritional characteristics (antioxidant activity, vitamin C content, total phenolic content and soluble protein content). The mixing rule based nutritional composition of the vegetable soup mix was determined with the following expression:

$$N_i = (W_1 \times n_i) + (W_2 \times n_i) + (W_3 \times n_i) \tag{2.6}$$

where N_i represents the specific nutrient content (either antioxidant activity, vitamin C content, total phenolic content or soluble protein content) of a soup mix formulation, n_i represents the specific nutrient content corresponding to a vegetable and W_1, W_2, W_3 represent the weights (0.4, 0.4 and 0.2) of vegetable 1, vegetable 2 and vegetable 3 respectively. The proportion of each vegetable as per the aforementioned ratio was selected based on sensory data obtained through preliminary sensory evaluation of single vegetable based alternate soup mixes that were prepared as per the proportions mentioned in Table 2.1. Along with the sensory attributes of each vegetable, the nutritional composition was also considered to assess upon the proportion of each dried vegetable.

2.4.3 Sensory Evaluation of Mixed Vegetable Soup Formulations

The adopted methodologies for the preparation of soup samples, selection of sensory evaluation panel and detailed procedures of the sensory evaluation techniques have been presented in the following subsections.

2.4.3.1 Reconstitution of Soups

Prior to the sensory evaluation, the summer vegetable based and winter vegetable based dry soup mix formulations were reconstituted with water. For the case of summer vegetables-based soup formulations, 10g of each dry soup mix (vegetable mix, corn flour and spice mix) was reconstituted with 160 mL boiling water (1:16 ratio). The mixture was subsequently boiled for 5 min and under continuous stirring condition. For the case of winter vegetables-based soup formulations, 10g of each dry soup mix (vegetable mix, corn flour and spice mix) was reconstituted with 180 mL boiling water (1:18 ratio) and was subsequently boiled for 5 min and under continuous stirring condition. The mentioned reconstitution ratios were determined based on few preliminary experiments and literature reported values (Manhivi et al., 2020; Mondal et al., 2020b; Nandhini et al., 2020; Ranaweera KKDS, 2014).

2.4.3.2 Selection of Sensory Analysis Panel

The subjects for sensory evaluation were selected by considering three factors namely the interest of the subject in sensory analysis and with at least average frequency of tested soup product consumption, the ability of the subject to perceive and sensitively respond and identify the alteration in sensory characteristics and health of participants. A group of 25 members volunteered to participate in the sensory evaluation of the freshly prepared soup samples. Prior to the sensory evaluation procedure, the ingredients used in the soup formulation were explained to the subjects and participants who were allergic to any of the mentioned ingredients were omitted. Thereafter, participants were screened based on their ability to perceive alternate primary tastes such as salt, sweet, bitter and sour at their minimum concentrations and as per the method suggested by Lyon et al.,1992. Finally, based on their ability to perceive these tastes, 15 participants were selected for the study. Further, the panelists were trained in the sensory analysis procedures. The training was in terms of corresponding assigning of the scores in the sensory score card. Even subjects with expertise in sensory characteristics evaluation methods were familiarized with each sensory attribute (Bratcher, 2013). Targeting the omission of any ambiguity in the sensory evaluation process and score assignment, the selected 15 panelists were maintained without any substitution in all sessions of the sensory analysis. Also, a written consent that confirmed their non-allergic reactions to any of the used ingredients was obtained along with the subject’s willingness to participate in the conducted sensory study. The sensory study also received formal approval (Ref. No. IHEC/RVSU/17/2023) from the Institute Human Ethics Committee of IIT Guwahati. The obtained approval was for the conduct of the sensory evaluation with the human subjects. Also, it was ensured that the panelists abstained from eating and drinking for a full hour prior to the sensory assessment time slot. Since the consumption of other products consumption affects sensory features, sensitive alteration in the sensory ratings was henceforth prevented. Additionally, drinking water was provided to the subjects for the timely and intermittent rinsing of their mouths.

2.4.3.3 9-point Hedonic Scale Technique

In the 9-point hedonic scale technique, the panelists evaluated the reconstituted soup samples with the hedonic scale. The scale ranged from 1 to 9 score and was assigned as per the preference of the tested samples (Mondal et al., 2020). In the hedonic scale-based score system, 1 corresponds to dislike extremely, 2 corresponds to dislike very much, 3 corresponds to dislike moderately, 4 corresponds to dislike slightly, 5 corresponds to neither like nor dislike, 6 corresponds to like slightly, 7 corresponds to like moderately, 8 corresponds to like very much and 9 corresponds to like extremely. Sensory attributes such as taste, mouthfeel, aftertaste, aroma, appearance, consistency, uniformity and overall acceptability were considered for the sensory analysis. From the literature, taste, mouthfeel, aroma, appearance, texture and overall acceptability were identified to be the most frequently deployed attributes for the soup sensory analysis (Abdallah & Chove, 2021; Adepoju & Daboh, 2020; Alozie & Ene- Obong, 2018a; Islam et al., 2023; Lafarga et al., 2019; Mondal et al., 2020b; Sugumar & Guha, 2022; Upadhyay et al., 2017) . Also, few literature studies considered texture to represent various aspects such as consistency, particle size etc. However, in order to reduce the complexity that may occur to the panelists in understanding a single attribute which is a generalized representation of two or more aspects, the present study considered only consistency, uniformity and aftertaste parameters as the alternatives to represent the texture parameter.

2.4.3.4 Score Deviation (SDI) Method

To the best of the knowledge of the author, the SDI method has not been used till date and has been implemented for the first time in this study for vegetable soup formulation assessment. The scoring scale used in the followed SDI method is a numerical scale. In this method, the sensory parameters were classified into main parameters (Taste Index (TI), Aroma Index (AI) and Physical Index (PI)) and sub-parameters (Satisfaction; Mouthfeel; Aftertaste under TI and Appearance; Uniformity; Consistency under PI). In this method, based on the consensus, the attributes were categorized into main and sub-parameters. Soup formulations for sensory evaluation were prepared as per the method elucidated in section 2.3.4.1. In the SDI method, based on their liking, the subjects assessed each formulation by giving an absolute score out of 100 for each main and sub sensory parameter. Also, comparative scores out of total 100 for each main parameter were sought. The overall scores were evaluated by considering both comparative and absolute scores being obtained for the main parameters (Equation 2.7). Further, absolute scores obtained for the sub-parameters were used to determine the score deviation index. For this purpose, equations 2.8, 2.9, 2.10, 2.11, 2.12, 2.13, 2.14, 2.15 and 2.16 were utilized. The primary intention for the assessment of deviation index was to assess upon the extent of deviation of the sub-parameter score from the mean value. A 10% bias was set for the deviation index for appropriate comparison within the formulations whose scores and deviation index are closer to one another. Finally, the formulations were ranked by considering both overall score and deviation index values for all formulations. Appendix B delineates upon the SDI method and as well provides a sample calculation for a soup-mix case.

The following expression was used to determine overall score (OS):

$$OS = \left(\frac{a1}{100}\right) b1 + \left(\frac{a2}{100}\right) b2 + \left(\frac{a3}{100}\right) b3 \tag{2.7}$$

where, a1, a2 and a3 refer to the absolute scores of Taste Index (TI), Aroma Index (AI) and Physical Index (PI) respectively and b1, b2 and b3 refer to the comparative scores of TI, AI and PI respectively.

Also, the deviation index (DI) was determined with the expression:

$$DI = \frac{[(|Sm - Xm|) + (|Mm - Xm|) + (|Am - Xm|) + (|APm - Xm|) + (|Cm - Xm|) + (|Um - Xm|)]}{Xm} \times 100 \tag{2.8}$$

where, Xm is the mean out of 100 for each assessed sub-parameter.

The following expressions were used to determine the score out of 100 for each sub-parameter of TI namely satisfaction (*Sm*), mouthfeel (*Mm*) and aftertaste (*Am*) and overall parameter Ts.

$$Sm = \frac{Si \times 100}{Ts} \tag{2.9}$$

$$Mm = \frac{Mi \times 100}{Ts} \tag{2.10}$$

$$Am = \frac{Ai \times 100}{Ts} \tag{2.11}$$

$$Ts = Si + Mi + Ai \tag{2.12}$$

where, *Si*, *Mi* and *Ai* correspond to the absolute scores of each sub parameter of TI namely satisfaction, mouthfeel and aftertaste respectively.

The following expressions were used to determine the score out of 100 (*APm*, *Cm* and *Um*) for each sub-parameter of PI namely appearance (*APm)*, consistency (*Cm)* and uniformity (*Um)* and overall parameter Ps:

$$APm = \frac{APi \times 100}{Ps} \tag{2.13}$$

$$Cm = \frac{Ci \times 100}{Ps} \tag{2.14}$$

$$Um = \frac{Ui \times 100}{Us} \tag{2.15}$$

$$Ps = APi + Ci + Ui \tag{2.16}$$

where, *APi*, *Ci* and *Ui* correspond to the absolute scores of each sub parameter of PI namely appearance, consistency and uniformity respectively.

2.4.4 Nutritional Characteristics Assessment

Nutritional characteristics namely antioxidant activity, Vitamin C content, total phenolic content and soluble protein were experimentally evaluated for the soup formulations. To do so, the procedures summarized in the respective sections namely 2.2.4.4, 2.2.4.5, 2.2.4.6 and 2.2.4.7 of the Ph.D. thesis were duly followed.

2.4.5 Summary

Following the methodologies adopted in this section, the summer and winter vegetables-based soup mix formulations with best combination of summer and best combination of winter vegetables, respectively were identified based on the sensory optimization. Thereafter, best formulations were assessed for moisture and nutritional characteristics. These soup mix formulations were thereafter subjected to further optimization of vegetable mix, corn flour and spice mix composition. These have been elucidated in the following sub-section.

2.5 Optimization of Trial-And-Error Methodology-Based Soup Mix Formulations

2.5.1 Formulation of Summer and Winter Vegetable-Based Soup Formulations with Varied Proportions of Vegetable Mix, Corn Flour and Spice Mix

The vegetable mix, corn flour and spice mix proportions of the soup formulation with summer vegetable combination being identified as the best was further optimized to achieve a soup mix formulation with improved nutritional and organoleptic properties. Accordingly, five alternate soup mix formulations were prepared. In these formulations, vegetable mix: corn flour: spice mix weight % ratios were chosen as 25:25:50 (SA), 40:20:40 (SB), 40:25:35 (SC), 40:30:30 (SD) and 50:20:30 (SE). For example, the ‘50 wt%’ specification refers to 50% of dried vegetable mix content in the entire soup mix (for example 5g dried vegetable mix content in 10g soup mix formulation). The 50 wt% vegetable mix constitutes three dried vegetables and at their mentioned wt% proportion. These weight ratios of the ingredients were set based on a trial-and-error methodology. Based on the standardized ingredient composition being achieved as per the methodology summarized in section 2.3.1 of the Ph.D. thesis, the ingredients composition was varied in formulations SB, SC, SD and SE and on a proportionate basis with respect to the composition of formulation SA. For example, in the SA formulation, ash gourd, bottle gourd, squash, corn flour, onion powder, garlic powder, ginger powder, coriander powder, black pepper, salt, milk powder and tomato powder were set as 01%, 10%, 5%, 25%, 5%, 5%, 5%, 25%, 25%, 12.5%, 12.5% and 25% respectively. These were respectively and proportionately altered as 16%, 16%, 8%, 20%, 4%, 4%, 4%, 2%, 2%, 10%, 10% and 4% in the SB formulation.

The ingredients composition in the samples SA to SE have been summarized in Table 2.4. Similar procedure was followed for the further optimization of winter vegetable soup mix with best combination of winter vegetables. Accordingly, five winter vegetables-based formulations with variant proportions of vegetable mix, corn flour and spice mix as 25:25:50 (WA), 40:20:40 (WB), 40:25:35 (WC), 40:30:30 (WD) and 50:20:30 (WE) were prepared (Table 2.5). Based on the composition of ingredients in formulation WA being identified as the best winter vegetable combination-based formulation, the ingredients of formulations WB, WC and WD were proportionately varied. However, for the case of sample WE, proportional variation of the spice mix did not result in an acceptable soup formulation in terms of taste and aroma. Therefore, the spice mix composition of sample WE has been further standardized through trial based approach. However, the proportion of each vegetable in the vegetable mix and corn flour were varied proportionately with respect to sample WA.

2.5.2 Identification of Optimal Proportion of Vegetable mix, Corn flour and Spice mix

The optimal proportion of vegetable mix, corn flour and spice mix for summer and winter vegetable-based soup formulations were identified through sensory evaluation and with three alternate sensory evaluation techniques namely 9-point hedonic scale method, SDI method and fuzzy logic analysis. In the Ph.D. thesis, to overcome the limitation of the 9-point hedonic scale technique, the novel SDI method has been developed and implemented.

Further, to also identify the efficacy of SDI method with a secondary sensory evaluation technique such as fuzzy logic, in the third objective of the Ph.D. thesis, the fuzzy logic approach has been as well considered along with the 9-point hedonic scale and SDI techniques for the sensory evaluation of the alternate soup formulations. Accordingly, the summer vegetable formulations (SA, SB, SC, SD and SE) and winter vegetable formulations (WA, WB, WC, WD, WE, WE1 and WE2) were evaluated through the mentioned three alternate sensory evaluation techniques. Based on the overall acceptability scores obtained through 9-point hedonic scale method, overall score and deviation index values obtained through SDI method

Table 2.4: A summary of alternate summer vegetable soup formulations being targeted with the proportional alteration of vegetables, corn flour and spice mix.

Ingredients/ Sample	Overall %	SA	Overall %	SB	Overall %	SC	Overall %	SD	Overall %	SE
Spong gourd (g)	25%	1	40%	1.6	40%	1.6	40%	1.6	50%	2
Bottle gourd (g)		1		1.6		1.6		1.6		2
Squash (g)		0.5		0.8		0.8		0.8		1
Corn flour (g)	25%	2.5	20%	2	25%	2.5	30%	3	20%	2
Onion powder (g)		0.5		0.4		0.35		0.3		0.35
Garlic powder (g)	50%	0.5	40%	0.4	35%	0.35	30%	0.3	30%	0.35
Ginger powder (g)		0.5		0.4		0.35		0.3		0.15
Coriander powder (g)		0.25		0.2		0.175		0.15		0.15
Black pepper (g)		0.25		0.2		0.175		0.15		0.15
Salt (g)		1.25		1		0.875		0.75		0.8
Milk powder (g)		1.25		1		0.875		0.75		0.75
Tomato powder (g)		0.5		0.4		0.35		0.3		0.3

and similarity index values obtained through fuzzy logic analysis, the preference order of summer vegetable-based soup samples and winter vegetable-based soup samples was determined for the case of each sensory evaluation technique. Finally, the best summer and winter vegetable-based soup formulations with optimal proportion of vegetable mix, corn flour and spice mix were identified based on the obtained sensory data. The best ranked summer vegetable soup mix and the best winter vegetable soup mix formulation were further characterized for proximate (moisture content, water activity, crude protein content, carbohydrate content, fat content and ash), nutritional characteristics (antioxidant activity, vitamin C content, total phenolic content, soluble protein), mineral content (Fe, Zn and Mn) and bio-accessibility of antioxidants, total phenolic content and

Table 2.5: A summary of alternate winter vegetable soup formulations being targeted with the proportional alteration of vegetables, corn flour and spice mix.

Ingredient/ Sample	Overall %	WA	Overall %	WB	Overall %	WC	Overall %	WD	Overall %	WE
Ash gourd (g)	25%	1	40%	1.6	40%	1.6	40%	1.6	50%	2
Bottle gourd (g)		1		1.6		1.6		1.6		2
Squash (g)		0.5		0.8		0.8		0.8		1
Corn flour (g)	25%	2.5	20%	2	25%	2.5	30%	3	20%	2
Onion powder (g)	50%	0.5	40%	0.4	35%	0.35	30%	0.3	30%	0.15
Garlic powder (g)		0.5		0.4		0.35		0.3		0.15
Ginger powder (g)		0.5		0.4		0.35		0.3		0.05
Coriander powder (g)		0.25		0.2		0.175		0.15		0.05
Black pepper (g)		0.25		0.2		0.175		0.15		0.15
Salt (g)		1.25		1		0.875		0.75		1.75
Milk powder (g)		1.25		1		0.875		0.75		0.5
Tomato powder (g)		0.5		0.4		0.35		0.3		0.2

soluble protein. All nutritional characteristics being assessed for the soup mix formulations have been represented on a dry mass basis.

2.5.3 Sensory Evaluation of Alternate Soup Formulations with 9-point Hedonic Scale, SDI and Fuzzy Logic Analysis Techniques

For the sensory analysis of soups with the 9-point hedonic scale method and SDI method, procedures similar to those summarized in sections 2.4.3.3 and 2.4.3.4 respectively of the Ph.D. thesis were followed. The reconstitution of summer and winter vegetable-based soup mix formulations prior to sensory analysis was carried out as per the procedure summarized in section 2.4.3.1 of the Ph.D. thesis. However, marginal modifications in the reconstitution ratio of winter vegetable-based soup formulations were carried out as summarized in the following sub-section. The reconstitution ratio of summer vegetable-based formulations was fixed as 1:16, as further enhancement in the reconstitution ratio resulted in soup formulations with very thin consistency. Further, the detailed account of the sensory evaluation procedure being followed for the fuzzy logic analysis has been presented in the section 2.5.3.2 of the thesis.

2.5.3.1 Reconstitution of Winter Vegetable-Based Soup Mix Formulations

Prior to the sensory evaluation, five dry soup mix formulations (WA, WB, WC, WD and WE) were reconstituted with water and in the weight ratio of 1:18. Thus, 10g soup mix was added with 180 mL water and was boiled for 5 min (as per procedure summarized in section 2.4.3.2). However, due to very high consistency texture exhibited by the WE formulation with 50% vegetables, the dry soup mix WE alone was also reconstituted with the elevated ratios of 1:20 (WE1) and 1:22 (WE2). However, as this was not the case for WA, WB, WC and WD samples, the reconstitution ratio was fixed as 1:18. Further, an increment of the dry mix to water ratio beyond 1:22 for the WE sample resulted in the soups with higher flowability and very thin consistency. Also, the reduction of reconstitution ratio below 1:18 resulted in very thick consistency of the prepared soups. This is due to the starchy nature of the vegetables utilized in the formulation. Thus, the reconstitution ratios for formulation WE were set as 1: 18, 1:20 and 1:22 and for formulations WA, WB, EC and WD, the reconstitution ratio of 1:18 was set. Also, for the WA, WB, WC and WD formulations, an enhancement of reconstitution ratio resulted in very thin soup appearance. This is attributed to the lower vegetable proportion in comparison to that of WE sample.

2.5.3.2 Fuzzy Logic Analysis Methodology

In the fuzzy logic sensory analysis approach, the soup samples assessment was conducted as per the procedure delineated by Vivek et al., 2020. Accordingly, sensory analysis was carried out by the subjects and through the assignment of responses in linguistic terms. These terms are Excellent, Good, Medium, Fair and Not satisfactory. The linguistic responses were evaluated as triangular membership functions. Accordingly, (100 25 0), (75 25 25), (50 25 25), (25, 25, 25) and (0 0 25) have been used as the triplet values to represent the linguistic terms namely Excellent (Ex), Good (G), Medium (M), Fair (F) and Not Satisfactory (NS) respectively. Also, Extremely Important (EI), Highly Important (HI), Important (I), Somewhat Important (SI) and Not at all Important (NI) respectively were considered for the sensory attributes and were used to represent the corresponding membership functions of the sensory scale. A standard 6-point fuzzy scale consisting of values F1 to F6 were defined. In these, a set of maximum 10 numbers were assigned between two consecutive points from 0 to 100. The F1 represents (1, 0.5, 0, 0, 0, 0, 0, 0, 0, 0) NS/NI case, the F2 represents (0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0) F/SI case, the F3 represents (0, 0, 0.5, 1, 1, 0.5, 0, 0, 0, 0) satisfactory/necessary case, the F4 represents (0, 0, 0, 0, 0.5, 1, 1, 0.5, 0, 0) G/I case, the F5 represents (0, 0, 0, 0, 0, 0, 0.5, 1, 1, 0.5) very good (VG)/HI case and the F6 represents (0, 0, 0, 0, 0, 0, 0, 0, 0.5, 1) Ex/EI case. The membership function of each sensory scale follows a triangular distribution with a maximum membership value of 1. Further, for the ranking of samples and sensory attributes, firstly, based on the linguistic data obtained through the sensory analysis, overall sensory scores of soup samples and sensory attributes were obtained in the form of triplets (determined with Equations 2.17 and 2.18). This was followed by the determination of triplets for relative weightage of quality attributes (determined with Equations 2.19 and 2.20) and overall sensory score of samples (determined with Equations 2.21 and 2.22). Secondly, using the standard fuzzy scale, overall membership functions were estimated (using equations 2.23, 2.24 and 2.25). Thirdly, the similarity values were estimated (using Equation 2.26). Finally, the soup samples were assigned ranks based on the linguistic category with highest similarity index values. All calculations were performed with the Microsoft Excel. Relevant expressions can be summarized as follows:

$$S_i S_\gamma = \frac{n1(0\ 0\ 25) + n2(25\ 25\ 25) + n3(50\ 25\ 25) + n4(75\ 25\ 25) + n5(100\ 25\ 0)}{n1 + n2 + n3 + n4 + n5} \tag{2.17}$$

$$SQ_\gamma = \frac{n1(0\ 0\ 25) + n2(25\ 25\ 25) + n3(50\ 25\ 25) + n4(75\ 25\ 25) + n5(100\ 25\ 0)}{n1 + n2 + n3 + n4 + n5} \tag{2.18}$$

where, $S_i S_\gamma$ represents the triplets for the sensory scores obtained for different sensory attributes of samples; SQ_γ represents the triplets obtained for the overall sensory attributes; *n1*, *n2*, *n3*, *n4* and *n5* represent the number of subjects providing response to corresponding linguistic category namely NS/NI, F/SI, M/I, G/HI and Ex/EI*;* γ represents the quality attribute and *i* represents the sample name. Other relevant expressions are:

$$Q_{sum} = \sum SQ_{\gamma 1} \tag{2.19}$$

$$Q_{\gamma_{rel}} = \left(\frac{Q_{\gamma 1}}{Q_{sum}}\ \frac{Q_{\gamma 2}}{Q_{sum}}\ \frac{Q_{\gamma 3}}{Q_{sum}} \right) \tag{2.20}$$

where, Q_{sum} represents the sum of first term of triplets of each sensory attribute; $Q_{\gamma_{rel}}$ represents the relative weightage of sensory attribute in the form of triplets; $Q_{\gamma 1}, Q_{\gamma 2}\ and\ Q_{\gamma 3}$

represent the first term in triplets of the corresponding quality attribute.

$$SO_i = \sum (S_i\, S_\gamma * Q_{\gamma_{rel}}) \tag{2.21}$$

where, SO_i represents overall sensory score of a sample; $S_i S_\gamma$ represents triplets (a b c) corresponding to sensory scores of samples; $Q_{\gamma_{rel}}$ represents triplets (p q r) corresponding to relative weightage of quality attributes. The multiplication of triplets was performed as per the expression:

$$(a\ b\ c) * (p\ q\ r) = (a * p \quad a * q + p * b \quad a * r + p * c) \tag{2.22}$$

For the calculation of overall membership function of sensory scores on a standard fuzzy scale, let ($a\ b\ c$) be the triplets for overall sensory scores of samples and the membership function of each sample overall sensory score is determined by a set of 10 numbers. These numbers are the maximum values of the overall membership function (B_y) from 0 to 100 in the mentioned range of y between (a-b) and (a+c) and at 10 intervals (0<y<10, 10<y<20, 20<y<30, 30<y<40, 40<y<50, 50<y<60, 60<y<70, 70<y<80, 80<y<90, 90<y<100). Thus, relevant expressions are:

$$B_y = \frac{y - (a - b)}{b} \text{ for } (\mathrm{a} - \mathrm{b}) < \mathrm{y} < \mathrm{a} \tag{2.23}$$

$$B_y = \frac{(a + c) - y}{c} \text{ for } \mathrm{a} < \mathrm{y} < (\mathrm{a} + \mathrm{c}) \tag{2.20}$$

$$B_y = 0 \text{ for } \mathrm{y} < (\mathrm{a} - \mathrm{b}) \text{or } \mathrm{y} > (\mathrm{a} + \mathrm{c}) \tag{2.21}$$

$$S_v(F_\sigma, B_y) = \frac{F_\sigma * B_y^T}{Max(F_\sigma * F_\sigma^T \ and\ B_y * B_y^T)} \tag{2.22}$$

where, S_v represents similarity index value; F_σ refers to either of F1, F2, F3, F4, F5 and F6; $F_\sigma^T \ and\ B_y^T$ represent the transpose of $F_\sigma \ and\ B_y$ respectively.

2.5.4 Proximate Analysis

The moisture content of the best summer and winter vegetable-based soup mix formulations

was determined as per the procedure summarized in section 2.2.4.1 of the Ph.D. thesis. Further, water activity (a_w), crude protein, carbohydrate, fat and ash contents were determined as per the procedures summarized in the following respective sub sections.

2.5.4.1 Water Activity

The water activity of the dry soup mix samples was determined with the portable water activity meter (Make: BIOBASE and Model: WA-60A).

2.5.4.2 Crude Protein Content

The crude protein content of the dry soup mix samples was determined by following the literature reported procedure and with marginal alterations (Beljkaš et al., 2010). To do so, firstly, 1g of dry sample was taken in a digestion tube and was added with 2.3g catalyst mixture (Sodium sulphate and Copper sulphate in the ratio of 10:1) and 10 mL concentrated sulphuric acid. The entire mixture was digested at 350 ^oC and for 3h. Thereby, the solution colour remained as a clear bluish green colour. Subsequently, the digested sample was added with 80 mL of distilled water and 40 mL of 40% sodium hydroxide. Further, the mixture was distilled with 20% of 4% boric acid solution containing 2 to 3 drops of indicator solution (methyl red and bromocresol green). Finally, the distillate was titrated against 0.1N hydrochloric acid and the end point referred to the appearance of a pale pink colour. Similar procedure was followed for the blank sample. Further, the crude protein content was obtained with the following expression:

$$Nitrogen\ (\%) = \frac{14.01 \times 0.1 \times Titration\ value \times 100}{Sample\ weight(g) \times 1000} \quad (2.27)$$

where, 0.1 is the Normality (N) of the acid; $Titration\ value$ is evaluated as the difference between Titration value of sample and Titration value of blank; and crude protein (%) is computed as the product of *Nitrogen (%)* and a factor (6.25).

2.5.4.3 Carbohydrate Content

The carbohydrate content of the dry soup mix samples was determined with the Clegg anthrone method (Mondal et al., 2019). To do so, firstly, 1g sample was mixed with 10 mL distilled water and 13 mL of 62% perchloric acid. Thereafter, the mixture was stirred continuously for 20 min. Further, the mixture volume was made up to 250 mL with the distilled water. Subsequently, the mixture was filtered and 10 mL from the filtrate was transferred to another flask and was diluted with 90 mL of distilled water. Subsequently, 1 mL of the diluted solution was added with 5 mL of anthrone reagent. This was followed by the boiling in a hot water bath for 12 min. Also, the blank sample was prepared with 5 mL anthrone reagent and 1 mL distilled water Finally, the absorbance of the evaluated sample and the blank sample was measured at 630 nm. The carbohydrate content was thereafter determined with the following expression:

$$Carbohydrate(\%) = \frac{A_s}{A_{std}} \times 25 \tag{2.28}$$

where, A_{std} and A_s are the absorbance of the standard and sample respectively.

2.5.4.4 Fat Content

The fat content of the dry soup mix samples was estimated with the AOAC, 2010 method (Horwitz, 2010). To do so, firstly, 5g of dry sample was extracted with 150 mL of petroleum ether in a Soxhlet apparatus for 6h. Subsequently, after the separation of petroleum ether, the sample was placed aside for the removal of any remaining petroleum ether through the evaporation at room temperature.

Finally, the fat content was evaluated with the following expression:

$$Fat\ (g) = \frac{W_e}{W_s} \times 100 \tag{2.29}$$

where, W_e and W_s correspond to the weight of extract and weight of initial sample respectively.

2.5.4.5 Ash Content

The AOAC 2010 method was followed to determine the ash content of dry soup mix samples (Horwitz, 2010). To do so, firstly, 5 g of dry sample was weighed in a crucible. Thereafter, the sample in the crucible was incinerated at 600 ^{o}C for 6h in a muffle furnace (Make: REICO, Model: Assembled). Finally, the ash content was obtained with the following equation:

$$Ash(\%) = \frac{W_{ash}}{W_s} \times 100 \tag{2.30}$$

where, W_{ash} and W_s correspond to weight of ash and initial weight of sample respectively.

2.5.5 Nutritional Analysis

The nutritional characteristics namely antioxidant activity, vitamin C content, total phenolic content and soluble protein content of best summer and winter vegetable-based soups were respectively evaluated as per the procedures summarized in 2.2.4.4, 2.2.4.5, 2.2.4.6 and 2.2.4.7 sections of the Ph.D. thesis.

2.5.6 Mineral Content

The soup mix samples were analysed for the minerals namely Fe, Zn and Mn. For the determination of the contents of these minerals, the samples were digested by following the procedure reported in a relevant prior art (Arasaretnam et al., 2018) and with minor modifications. Firstly, soup mix weighing about 5g was taken in a crucible and was subjected to a temperature of 600°C for 6h in a muffle furnace. The obtained ash was subjected to digestion through the addition of 2.5 mL of 1N nitric acid. Following the digestion, the content was filtered and the filtrate volume was enhanced to 50 mL with the distilled water. Finally, Atomic Absorption Spectrophotometer (Varian Spectra AA 220 FS, Netherlands) was used to measure the contents of Fe, Zn and Mn. The measurements were at wavelengths of 248, 213, and 279 nm respectively.

2.5.7 Nutrient Bio-accessibility

Dry and liquid soup samples were subjected to in-vitro digestion studies. Thereby, the bio-accessible content in terms of antioxidant activity, total phenolics, soluble protein, Fe, Zn and Mn were assessed. The in-vitro digestion involved the subjecting of samples to the simulated gastric and intestinal phases. These were followed as per the procedure reported in a relevant prior art (Wahengbam et al., 2019). To do so, firstly, 5g of dry or 5 mL of liquid soup samples were subjected to digestion. Thereby, 30 mL solution comprising of 140mM NaCl and 5mM KCL were added to the measured samples. This was followed with the addition of 0.5 mL pepsin solution. Further, the pH of the samples was adjusted to 2.0 and the samples were incubated in a shaking water bath (100 rpm) for 2h at 37 °C. Subsequently, pancreatin-bile solution (2.5 mL) was added to the incubated samples. This was followed with the addition of 40 µL of 0.3M $CaCl_2$. The pH of samples was adjusted to 7.0. Following this, the sample was incubated in a shaking water bath (100 rpm) at 37°C for 2h. The digested samples were subjected to centrifugation for 40 min at 4600 rpm. Finally, the bio-accessible amount of antioxidant activity, total phenolics, soluble protein, Fe, Zn and Mn in the digested samples were measured as per the respective procedures delineated in sections 2.2.4.4, 2.2.4.6, 2.2.4.7 and 2.5.6 of the Ph.D. thesis.

2.5.8 Summary

To summarize, in this section, trial-and-error methodology and sensory optimization based best soup mix formulations with optimal proportions of vegetable mix, corn flour and spice mix were identified by following the relevant methodology. The best soup formulations were characterized for various proximate and nutritional characteristics and in-vitro bio-accessibility of nutrients. In the following section, statistical optimization of only vegetable mix composition is addressed. Thereby, the corn flour and spice mix constituents were chosen at fixed choice.

2.6 Mixture Model Methodology-Based Optimization of Vegetable Mix Composition

The summer and winter vegetable-based soup mix formulations being identified as the best from the first adopted trial-and-error methodology (section 2.5.2 of the Ph.D. thesis) were further considered for a statistical based optimization of only vegetable mix constitution. A detailed procedure of the adopted methodology is presented in the following sub-sections.

2.6.1 Experimental Design for Vegetable Mix Constitution in the Summer and Winter Vegetable-Based Soup Formulations

The vegetable mix composition of the best summer and winter vegetable-based soup mix formulations were further optimized with the D-optimal mixture model design (MMD). This was achieved through the Design Expert 7.00 software. The mixture model design approach of the response surface methodology facilitates the optimization of a certain composition (up to 100%) of an entire mixture. Also, flexible constraints can be facilitated in the software environment. The soup mix consisted of three major constituents namely vegetable mix (constituted with three vegetables), corn flour and spice mix. The MMD has an advantage to optimize an entire mixture within a total weight proportion of the constituents (up to 100%).

Further, within this total of 100%, MMD also enables optimization of specific variables set to particular range of the concentration. Invariably, the concentration of other parameters shall be kept fixed. Thus, in this work, the constitution of the three alternate vegetables in the vegetable mix (50%) were considered as three variables (constraints) for optimization. Thereby, corn flour (25%) and spice mix (25%) were fixed choice. For the case of summer vegetables-based formulations, the lower and upper limits of three dried vegetables content were varied as 10% to 30% for spine gourd, 10% to 30% for sponge gourd and 5% to 20% for yardlong bean. Similarly, for the case of winter vegetables-based formulations, the lower and upper limits of three dried vegetables content were varied as 10% to 30% for ash gourd, 10% to 30% for bottle gourd and 5% to 20% for squash. These ranges were as per few trials. Accordingly, the total vegetable mixture composition must be equal to 50 wt% of the dried total weight of the soup formulation mix for the case of both summer and winter vegetables-based formulations. Accordingly, the vegetable mix composition was optimized in terms of the responses namely overall acceptability (OA), overall score (OS) and deviation index (DI) and antioxidant activity. In total, 16 runs with 6 model points, 5 lack of fit points and 5 replicate points were generated by the software. The soup samples were prepared as per the proportions affirmed by the software were evaluated for antioxidant activity (AA), overall acceptability (OA), OS and DI. For the case of OS and ID obtained with the SDI method, both OS and ID were considered as a single objective function (OSDI) and as OS-(0.4×DI). Thus, vegetable mix composition was optimized in terms of response variables namely AA, OA and OSDI.

2.6.2 Analysis of the Responses

The three responses namely antioxidant activity, overall acceptability and OSDI (Objective function of OS and DI) for each experimental run were determined as per the respective procedures detailed in sections 2.2.4.2, 2.3.4.3 and 2.3.4.4 of the Ph.D. thesis.

2.6.3 Model Fitness and ANOVA Studies

The statistical analysis of the responses was carried out through the model fitness approach and with the regression and Analysis of Variance (ANOVA) methods. These statistical analyses were carried out to determine the effect of the three independent variables on the responses. The best fit model for the case of each response was determined with the following criteria: high F-value and a low p-value (< 0.05); insignificant lack of fit value ($p>0.05$); and acceptable higher value of adjusted R^2 and predicted R^2 values. Further, the responses can be expressed as a function of input or independent variables and with the following expression:

$$Y = f(X_1, X_2, X_3, \ldots \ldots \ldots . X_n) \tag{2.31}$$

2.6.4 Optimization and Validation

The three responses were optimized through the numerical optimization routine of the Design expert software. The numerical optimization targeted the maximization of all three responses (antioxidant activity, OA and OSDI) and with the independent variables being set to alter in a specified range. Accordingly, the criteria for optimization were defined as per the range for each independent variable and with Maximize option for each response. Subsequently, the optimum compositions of vegetable mix (independent variables) were obtained for both summer and winter vegetable-based soup formulations. Further, for the validation of the model, experiments were conducted at the optimal conditions. Thereby, the experimental findings were validated.

2.6.5 Proximate and Nutritional Characterization of Optimal Soup Formulations

2.6.5.1 Moisture and Proximate Composition

The moisture content, water activity, crude protein content, carbohydrate content, fat and ash content of optimal soup formulations were evaluated as per the respective procedures summarized in sections 2.2.4.1, 2.5.4.1, 2.5.4.2, 2.5.4.3, 2.5.4.4 and 2.5.4.5 of the Ph.D. respectively.

2.6.5.2 Nutritional Characterization and In-vitro Bio-accessibility

The antioxidant activity, vitamin C, total phenolic content and soluble protein content of the optimal soup mix formulations were evaluated as per the respective procedures detailed in sections 2.2.4.4, 2.2.4.5, 2.2.4.6 and 2.2.4.7 of the Ph.D. thesis. Further, Fe, Zn and Mn contents and in-vitro bio-accessibility of nutrients in the optimal soup formulations were evaluated as per the respective procedures summarized in sections 2.4.6 and 2.4.7 of the Ph.D. thesis.

2.6.6 Summary

In summary, optimal soup mix formulations with optimal vegetable mix constitution in terms of sensory scores and antioxidant activity were identified by following the relevant methodologies in this section. The optimal soup mix formulations were further characterized for various proximate and nutritional characteristics and in-vitro bio-accessibility. In the following section, the corn flour content in these optimal soup mix formulations is replaced with alternate thickening agents at various proportions. Thereby, the vegetable mix and spice mix compositions are specified at a fixed constitution.

2.7 Effect of Alternate Thickening Agents on the Nutritional, Rheological and Storage Characteristics of Soup Formulations

The soup mix formulations with optimal composition of summer vegetable mix and optimal composition of winter vegetable mix were further evaluated to determine the effect of alternate thickening agents on the soup mix properties. For this purpose, the corn flour content in the optimal soup formulations was replaced with alternate thickening agents namely channa flour, rice flour and sattu flour and at various proportions (0-100 wt%) of each thickening agent in the 20% total weight proportion of thickening agent mix in the entire soup mix. The procedures adopted for the formulation of soup mixes with alternate thickening agents and characterization of the formulated soup mixes have been detailed in the following sub sections.

2.7.1 Formulation of Soup Mixes with Alternate Thickening Agents

The proportion of ingredients in optimal summer and winter vegetable-based soup mix formulations identified through mixture model-based optimization constituted 50% vegetable mix, 20% corn flour and 30% spice mix in a 10g dry soup mix formulation. In this objective, the 20% corn flour was replaced with alternate thickening agents namely channa flour, rice flour and sattu flour being incorporated individually (100% of a single thickening agent) and also as a combination of two (any two thickening agents at varied proportions) and three thickening agents (three thickening agents at varied proportions). Accordingly, based on a trial-and-error methodology, sixteen alternate soup mixes have been formulated. The percentage of each thickening agent within the 20% thickening agent proportion in the entire soup mix (10g) with other ingredients namely vegetable mix (with optimum proportion of each vegetable and at 50% total weight proportion) and spice mix (spice mix ingredients composition as summarized in Tables 2.4 and 2.5 and at 30% total weight proportion is presented in Table 2.6. Accordingly, the formulations as per the compositions summarized in Table 2.6 were prepared for the case of both summer and winter vegetable-based soup mix formulations.

2.7.2. Identification of Soup Formulations with Optimal Thickening Agent mix Constitution

All sixteen summer and sixteen winter soup formulations with varied proportions of thickening agents were evaluated for the responses namely soluble protein content, crude protein content,

Table 2.6: Soup mix formulations being targeted with alternate proportions of thickening agents.

Summer formulation/ Winter formulation	Thickening agent (25%)			Vegetable mix (%)	Spice mix (%)
	Channa flour (%) in the thickening agent mix	Rice flour (%) in the thickening agent mix	Sattu flour (%) in the thickening agent mix		
ST1/WT1	100	0	0	50	30
ST2/WT2	0	100	0	50	30
ST3/WT3	0	0	100	50	30
ST4/WT4	50	50	0	50	30
ST5/WT5	50	0	50	50	30
ST6/WT6	0	50	50	50	30
ST7/WT7	25	75	0	50	30
ST8/WT8	75	25	0	50	30
ST9/WT9	25	0	75	50	30
ST10/WT10	75	0	25	50	30
ST11/WT11	0	25	75	50	30
ST12/WT12	0	75	25	50	30
ST13/WT13	66	17	17	50	30
ST14/WT14	17	66	17	50	30
ST15/WT15	17	17	66	50	30
ST16/WT16	33.5	33.5	33.5	50	30

carbohydrate content, overall acceptability, overall score and deviation index. The responses were also compared with the responses obtained for optimal summer and winter vegetable-based soup formulations being constituted with the corn flour thickening agent. Finally, summer and winter vegetable soup formulations with higher overall acceptability, higher overall score, lower deviation index and higher protein content were identified as soup formulations with optimal thickening agent mix (channa, rice and sattu flour). Thereby, thebest summer and winter vegetable-based soup mix formulations incorporated with corn flour as thickening agent (identified through mixture model optimization) and the best summer and winter vegetable-based soup mix formulations incorporated with channa, rice and sattu flours as thickening agents (identified through trial-and-error methodology) were evaluated for nutritional, rheological and storage characteristics. Rheological studies were also performed for optimal vegetable soup mix formulations incorporated with a single thickening agent. Thereby, the effect of a individual thickening agent on the rheological behaviour of the soup mix formulations was assessed.

2.7.3 Sensory analysis, Proximate and Nutritional Characterization of Optimal Soup Formulations

2.7.3.1 9-point Hedonic Scale and SDI based Sensory Analysis of Soup Formulations

For the determination of overall acceptability and overall score and deviation index values, the soup formulations were evaluated with the 9-point hedonic scale and SDI methods respectively. The reconstitution of summer and winter vegetable-based soups prior to sensory evaluation was carried out as per the respective procedures summarized in sections 2.4.3.1 and 2.5.3.1 of the Ph.D. thesis. Further, the respective procedures detailed in section 2.4.4.3 and 2.4.4.4 of the Ph.D. thesis were followed for the sensory evaluation of soup formulations with the 9-point hedonic scale method and SDI method.

2.7.3.2 Moisture and Proximate Composition

The moisture content, water activity, crude protein content, carbohydrate content, fat and ash content of optimal soup formulations were evaluated as per the respective procedures summarized in sections 2.2.4.1, 2.5.4.1, 2.5.4.2, 2.5.4.3, 2.5.4.4 and 2.5.4.5 of the Ph.D. thesis.

2.7.3.3 Nutritional Characterization and In-vitro Bio-accessibility

The antioxidant activity, Vitamin C, total phenolic content and soluble protein content of the optimal soup mix formulations were evaluated as per the respective procedures detailed in sections 2.2.4.4, 2.2.4.5, 2.2.4.6 and 2.2.4.7 of the Ph.D. thesis. Further in-vitro bio-accessibility of nutrients in the optimal soup formulations were evaluated as per the respective procedures summarized in section 2.5.7 of the Ph.D. thesis.

2.7.4 Rheological Characterization of Reconstituted Soup Formulations

The reconstituted soup samples prepared with best summer and winter vegetable based dry soup mix formulations incorporated with corn flour and similarly with a combination of alternate thickening agents were subjected to rheological characterization. The rheological study was carried out with the Physica MCR 301, Anton par Rheometer. A CP50 probe with cone and plate geometry was used for the study. The steady state flow behavior and the time dependent rheological characteristics of the soup samples were evaluated as per the procedures summarized in a relevant prior art (Mondal et al., 2020). For the steady state flow behavior, the soup samples were evaluated at various temperatures and for varied shear rates (0.1 – 100 s^{-1}). The shear rate versus shear stress data obtained through the steady state rheology study was investigated for the model fitness and with the following models:

$$Power\ law\ model: \tau = K(\gamma)^n \quad (2.32)$$

where, τ, K, n and γ represent shear stress (Pa), flow consistency index ($Pa.s^n$), flow behavior index and shear rate (s^{-1}), respectively.

2.7.5 Storage Stability Study

2.7.5.1 Accelerated Storage Stability Study

The accelerated storage study of the developed dry soup mix formulations was carried out in an environment maintained at 38±2 ^oC and 90% relative humidity (RH). The mentioned condition was maintained in a desiccator being hosted with a saturated salt solution of potassium nitrate. To do this, 5g of dry soup mix powder of the best identified samples (MMD based optimal soup formulations and soup formulations with best thickening agent mix composition) were packed in low density polyethylene (LDPE) zipper pouches (14 cm×10 cm) and were Six such pouches were prepared for each sample and for an interval of 7 days time period, one of the pouches was taken out from the controlled environment and the contents were evaluated for moisture content and water activity (Bala et al., 2023). The moisture content and water activity were also assessed for samples stored at ambient condition and for a period of 28 days. The moisture content and water activity were assessed by following the respective procedures summarized in sections 2.2.4.1 and 2.5.4.1 of the Ph.D. thesis.

2.7.5.2 Shelf-Life Prediction

The samples stored at 38±2 °C and 90% RH were evaluated for their moisture content and water activity (Jaya & das, 2005). Such evaluations were conducted until the samples reached a critical moisture content value of 12%. The critical moisture content (Xc) has been set based on the stability of the soup mix powder. As per the relevant prior art (Akharume et al., 2018), most vegetables are stable for a moisture content range of 12 to 15 percent. The prepared soup mix formulations were constituted with various ingredients. Henceforth, beyond a moisture content of 12% of the soup mix, lump formation was apparent. Considering this aspect, the Xc value was set as 12% (0.12 kg/ kg dry solid). Similarly, Jaya & Das, 2005, reported the critical moisture content of mango powder as 0.089kg water/ kg dry solid. This was on the basis of stickiness observed in the samples that possessed moisture content beyond the mentioned value. Subsequently, the shelf life was estimated with the following expression:

$$W_s \frac{X_c - X_i}{d\theta} = \mathrm{K}A(RHp - a_w p) \tag{2.33}$$

where, W_s denotes dry solids weight (kg), X_c refers to the critical moisture content (db), X_i refers to the initial moisture content, A denotes area of packaging material (m^2), p refers to saturation vapour pressure (Pa) of water at storage temperature and K refers to the permeability of packaging material (kg water/ m^2/ day/ Pa). In the above expression, K was determined with the following expression:

$$K = \frac{dw/d\theta_s}{Ap} \tag{2.34}$$

where, $dw/d\theta_s$ is the slope of the straight-line fit to the plot between storage time and weight gained by silica gel placed in the packaging material and stored at 38±2 °C.

2.7.5.3 Degradation Kinetics of Antioxidant Activity

The antioxidant activity of the samples being stored at accelerated storage condition (38±2 °C and 90% RH) and room temperature was measured at regular intervals of 7 days and for a total time period of 28 days (Bala et al., 2023). Further, the reduction of antioxidant activity of all the best samples during storage at accelerated condition and room temperature was validated with the first order degradation kinetics being expressed with the following equation:

$$\ln(A) = ln(A_o) - k\theta \tag{2.35}$$

where, θ is the storage time in days, k denotes the first order rate constant (day^{-1}), A and (A_o) represent the antioxidant activity at storage day (θ) and zero storage day respectively. Further, the time required for the antioxidant activity to reduce to 50% of the initial value was calculated as the half-life time period and with the following equation:

$$t_{1/2} = \ln(2)/k \tag{2.36}$$

Table 2.7: A summary of the targeted soup formulations in the Ph.D. thesis.

Chapter No.	Formulations	Objective
4	SF1 – SF20 WF1 – WF20	To identify best summer (any three) and winter (any three) vegetable combinations for soup mix formulations with the 9-point hedonic scale and SDI method sensory techniques.
5	SA – SE WA – WE2	Trial and error method assisted sensory based optimization of vegetable mix, corn flour and spice mix composition with the 9-point hedonic scale, SDI and fuzzy logic sensory methods.
6	MS1 - MS16 MW1 – MW16	Mixture model-based optimization of summer and winter vegetable soup mix formulations.
6	MS and MW	Mixture model predicted optimal summer and winter vegetable soup mix formulations.
7	ST1 – ST16 WT1 – WT16	Trial and error methodology based thickening agent mix composition optimization of summer and winter vegetable soup mix formulations.

2.7.6 Summary

In summary, trial-and-error approach based best soup mix formulations with optimal thickening agent constitution, vegetable mix and spice mix constitution were identified through the consideration of optimal sensory scores and nutritional characteristics (soluble protein and crude protein). Finally, the best summer and winter vegetables-based soup mix formulations with optimal vegetable mix constitution, spice mix and corn flour (identified through methodologies in the previous section); and optimal vegetable mix constitution, spice mix and optimal alternate thickening agent mix constitution were assessed for rheological and storage characteristics. The soup formulations that have been targeted in the following chapters to achieve the objectives of this Ph.D. thesis are presented in Table 2.7.

Chapter 3:

Moisture and Nutritional Characteristics of Optimally Tray Dried Summer and Winter Vegetables

Moisture and Nutritional Characteristics of Optimally Tray Dried Summer and Winter Vegetables

Overview of the Chapter

In this chapter, the results related to the identification of the optimal tray drying time for chosen summer and winter vegetables with respect to their moisture and nutritional characteristics have been summarized. In addition, the results associated with the holistic characterization of various nutritional characteristics of the optimally treated vegetables have been summarized. After a brief introduction in section 3.1, section 3.2 summarizes the findings associated with the nutritional composition of fresh vegetables. Section 3.3 of the chapter elucidates upon the influence of blanching and tray drying treatment on the moisture content and antioxidant activity of the fresh and treated vegetables. This is followed by the identification of optimal drying time. Sections 3.4, 3.5, 3.6, 3.7 and 3.8, respectively summarize upon the findings associated with the total phenolic content, vitamin C content, soluble protein content, crude fibre content and yield of the optimally treated vegetables. Section 3.9 details upon the nutritional potential of vegetables towards their utilization in vegetable soup mix formulations. Finally, section 3.10 presents an overall summary of the research findings in terms of the influence of processing treatments on the selected vegetables and their nutritional potential.

3.1 Introduction

In this chapter, a holistic characterization of twelve abundantly produced Indian vegetables such as gourds and beans to identify their potentiality towards the development of Ready to Cook (RTC) soup mixes was carried out. In this regard, six summer vegetable namely, *Tricosanthes diocia* (pointed gourd, PG), *Luffa acutangular* (ridge gourd, RG), *Tricosanthes cucumerina* (snake gourd, SG), *Momordica dioica* (spine gourd, SPIG), *Luffa ageyptiaca* (sponge gourd, SPOG) and *Vigna unguiculata* (yardlong bean, YB) and six winter vegetables namely, *Benincasa hispida* (ash gourd, AG), *Phaseolus vulgaris* (beans, BS), *Momordica charantia* (bitter gourd, BIG), *Lagenaria siceraria* (bottle gourd, BOG), *Cucurbita moschata* (pumpkin, P) and *Sechium edule* (squash, S) were chosen. The sensitivity of moisture content, yield and important nutritional characteristics such as antioxidant activity, total phenolic content, vitamin C, soluble protein and crude fibre in due course of heat treatments namely hot water blanching (95 ^{o}C for 4 min) and tray drying (60 ^{o}C temperature and 2 m/s air velocity with an intermittent air flow mode) was investigated. Initially, vegetables were dried for 12 h and moisture content (MC) and antioxidant activity (AA) were evaluated at 1 h intervals from 6th hour onwards to infer upon the optimal drying time. Further, other nutritional parameters (total phenolic content (TPC), vitamin C (VITC) content, soluble protein (SP) content, crude protein (CP) content) and yield were evaluated for all the vegetables treated at their corresponding optimal drying time.

3.2 Fresh Vegetable Parameters

Among winter vegetables, ash gourd possessed highest moisture content (94.74%) and pumpkin possessed lowest moisture content (91.20%). Among summer vegetables, snake gourd and yardlong bean possessed highest (95.12%) and lowest (86.28%) moisture content respectively.

Among winter vegetables, bottle gourd and pumpkin possessed highest (5.77%/mg) and lowest (0.07%/mg) antioxidant activity respectively. Among summer vegetables, highest and lowest antioxidant activity was observed for yardlong bean (3.39%/mg) and pointed gourd (0.15%/mg). Among winter vegetables, highest and lowest TPC was observed for bottle gourd (722.02 mg/g) and squash (163.90 mg/g). Among summer vegetables, yardlong bean (492.42 mg/g) and snake gourd (135.90 mg/g) possessed highest and lowest TPC respectively. Among winter vegetables, bitter gourd (674.60 mg/100g) and squash (78.43 mg/100g) possessed highest and lowest VITC content respectively. Among summer vegetables, spine gourd (572.52 mg/100g) and pointed gourd (68.84 mg/100g) possessed maximum and minimum VITC content correspondingly.

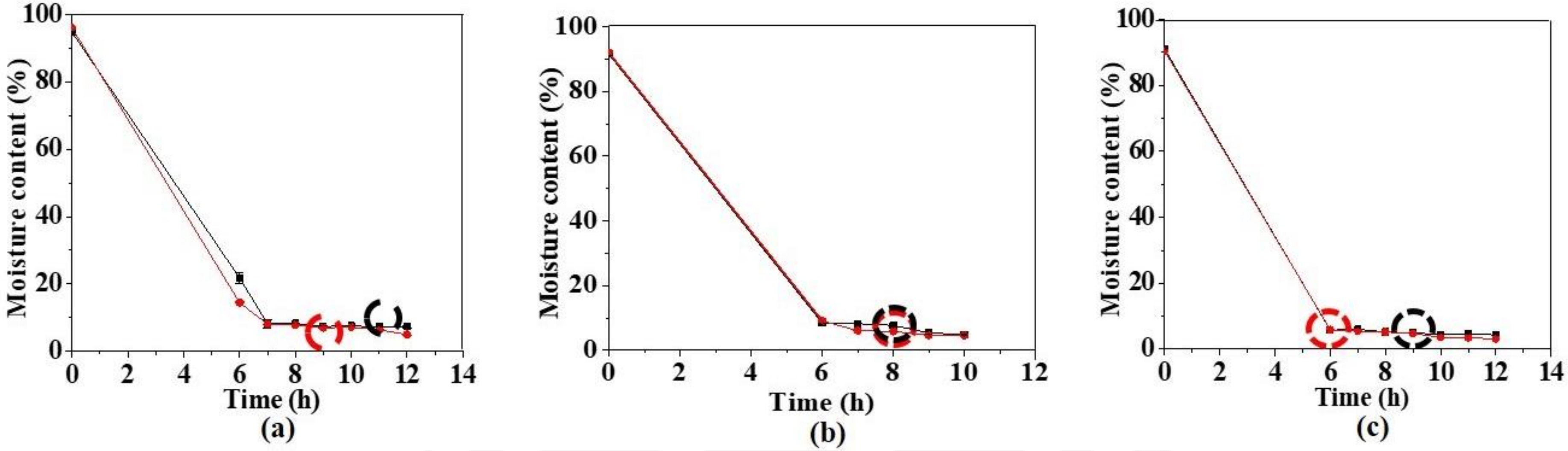
Among winter vegetables, ash gourd (97.77%) and pumpkin (89.18%) possessed highest and lowest crude fibre content respectively. Similarly, among summer vegetables, yardlong bean (97.02%) and ridge gourd (92.06%) possessed highest and lowest crude fibre content respectively. Among winter vegetables, beans (28.26 mg/g) and pumpkin (15.00 mg/g) possessed highest and lowest soluble protein content respectively. Similarly, among the summer vegetables, sponge gourd (25.85 mg/g) and spine gourd (11.93 mg/g) possessed highest and lowest soluble protein content respectively.

3.3 Influence of Blanching and Tray Drying on Moisture Content and Antioxidant Activity and Identification of Optimal Drying Time

3.3.1 Moisture Content and Drying Time

The optimal drying time with respect to the moisture content of dried and blanched dried winter and summer vegetables has been depicted in Figure 3.1 and Figure 3.2 respectively. Moisture content of blanched winter vegetables varied from 90.50 (BIG) – 96.05% (AG). Among the blanched summer vegetables, sponge gourd and pointed gourd affirmed highest (96.36%) and lowest (86.93%) moisture content respectively. These findings for blanched pumpkin and pointed gourd agree with those reported in the relevant prior art (Fadupin et al., 2014) and Kumari & Sharma, 2018).

Among the optimally dried winter vegetables, bitter gourd (9h) and Squash (9h) possessed lowest (4.97%) and highest (7.78%) moisture content. Among optimally blanched dried winter vegetables, pumpkin and ash gourd possessed the lowest (5.08%) and highest (7.00%) moisture content for a drying time of 8h and 9h respectively. The results obtained for dried ash gourd and blanched dried bottle gourd are in good agreement with the findings of Mondal et al. 2019 and Shinde et al. 2016. Among summer vegetables, lowest (4.34%) and highest (7.56%) moisture content was obtained for optimally dried pointed gourd (8h) and sponge gourd (12h). Among blanched and optimally dried summer vegetables, lowest (5.19%) and highest (6.09%) moisture content was obtained for pointed gourd (9h) and ridge gourd (10h). Among all optimally dried vegetables, the obtained results affirm a moisture content less than 8 percent (wet basis) and hence good shelf life characteristics based on the general rules of thumb (Rokhsana et al., 2007). Thus, the investigations inferred that, except for pointed gourd and yardlong bean, the moisture removal rate was faster for blanched vegetables. This is due to the faster transport of moisture from the inner sections to the outer surface due to the tissue softening achieved through the blanching process (Orikasa et al., 2018).


Moisture content (%)
Time (h)
(a)
Moisture content (%)
Time (h)
(b)
Moisture content (%)
Time (h)
(c)

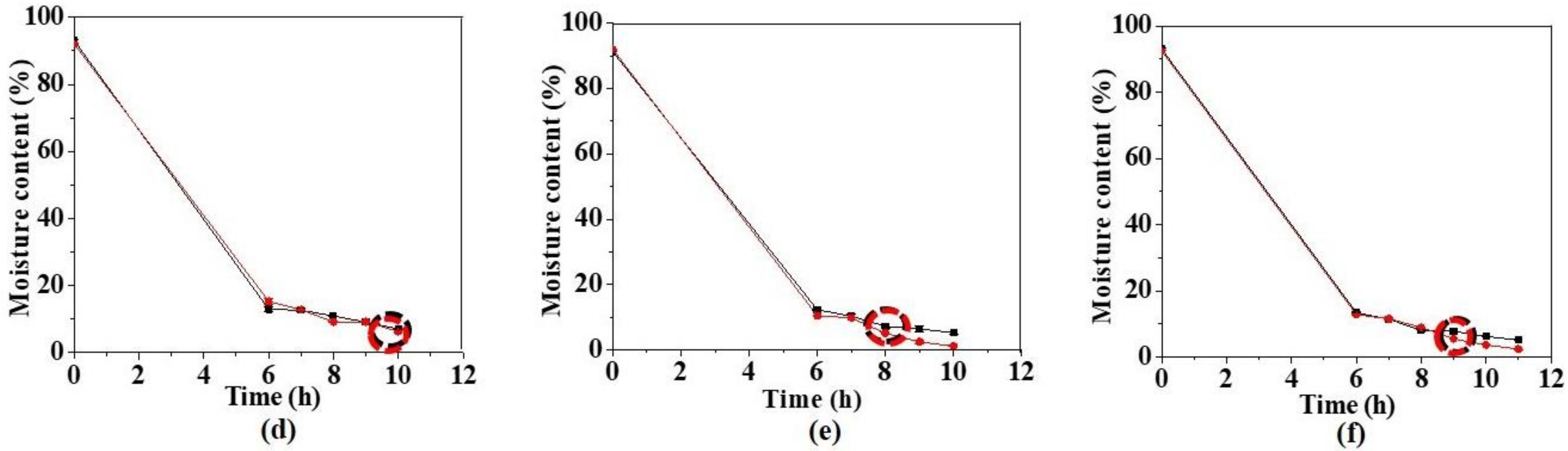
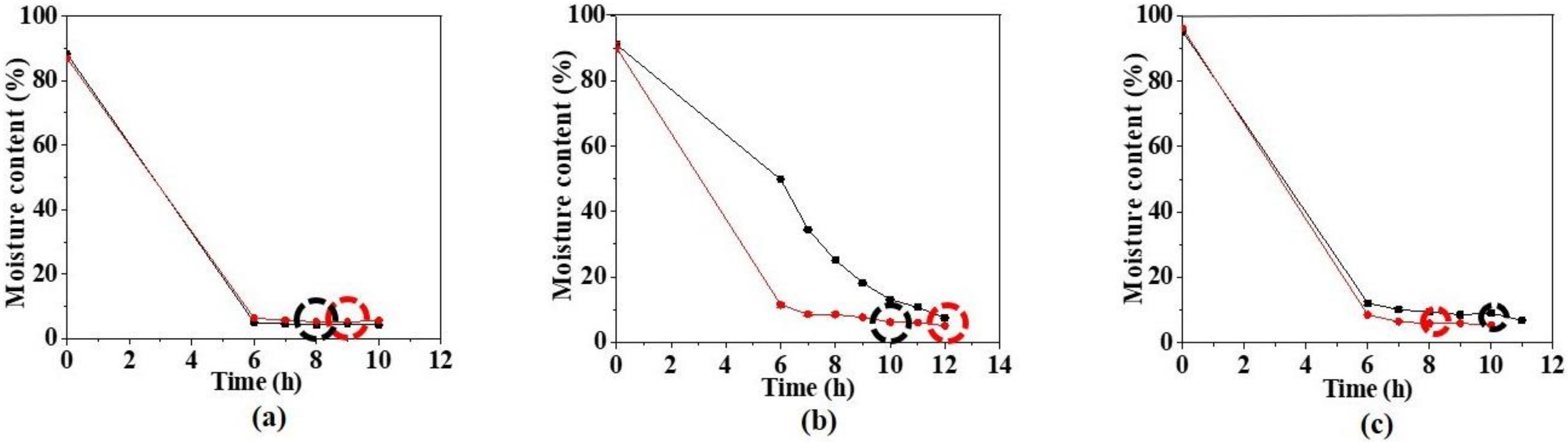


Figure 3.1. Optimal drying time of dried (■) and blanched dried (●) winter vegetables in terms of the moisture content of (a) ash gourd (b) beans (c) bitter gourd (d) bottle gourd (e) pumpkin and (f) squash vegetables.


Moisture content (%)
Time (h)
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Moisture content (%)
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Time (h)
(c)

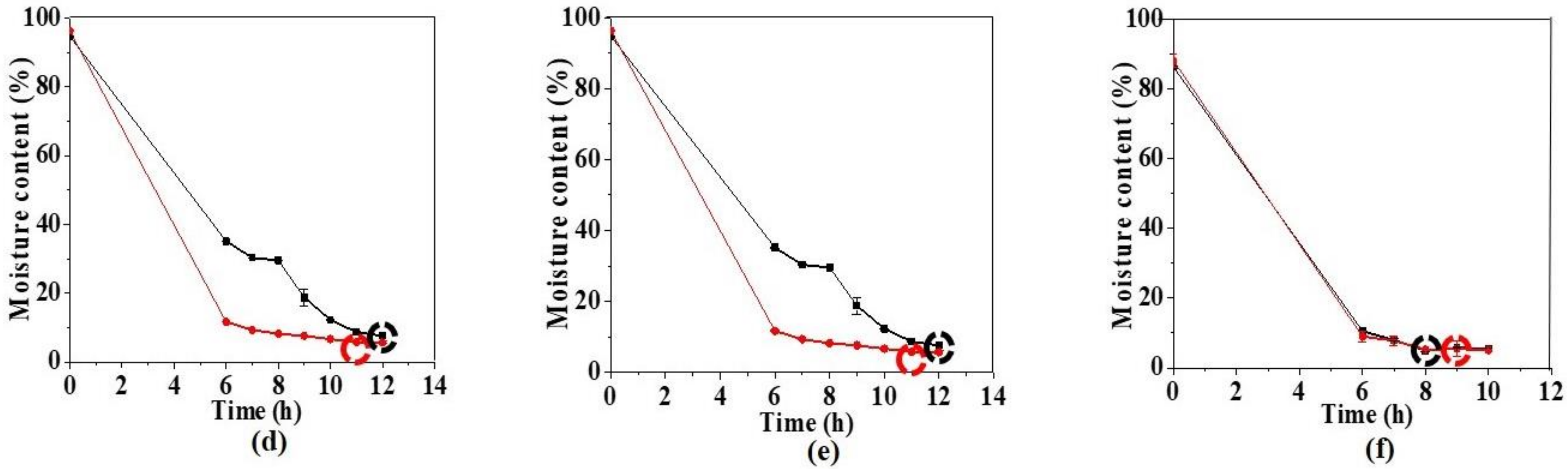


Figure 3.2. Optimal drying time of dried (■) and blanched dried (●) summer vegetables in terms of the moisture content of (a) pointed gourd (b) ridge gourd (c) snake gourd (d) spine gourd (e) sponge gourd and (f) yardlong bean vegetables.

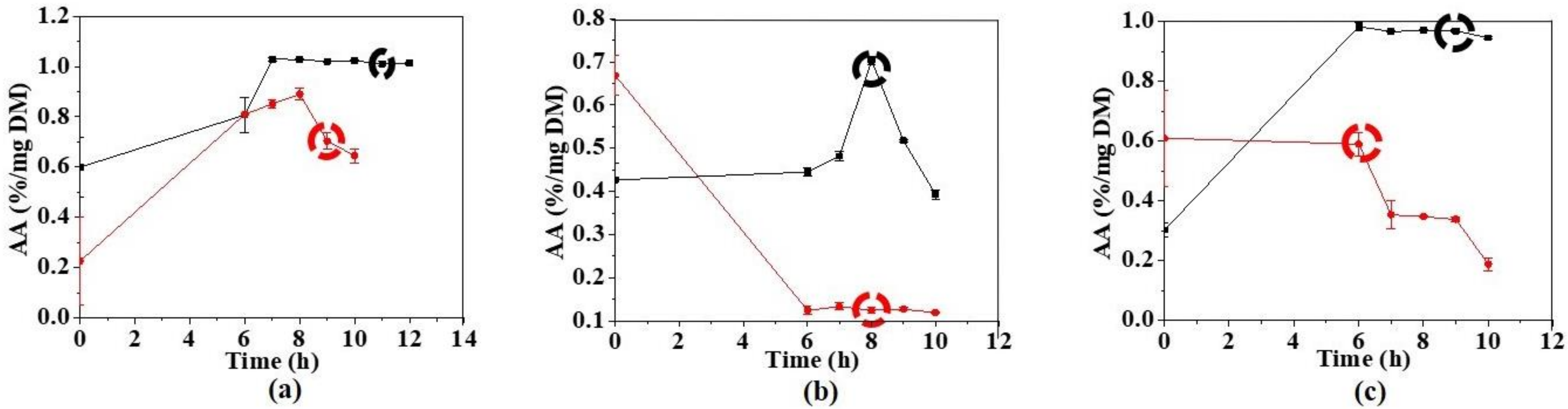
3.3.2 Antioxidant Activity and Drying Time

The optimal drying time with respect to the antioxidant activity of dried and blanched dried winter and summer vegetables have been presented in Figure 3.3 and Figure 3.4 respectively. Antioxidant activity of blanched winter and summer vegetables varied from 0.06 (P) – 3.79%/ mg (bottle gourd) and 0.08 (pointed gourd) – 4.13%/ mg (yardlong bean) respectively. The results obtained for fresh beans, bitter gourd and squash and blanched spine gourd are in agreement with the findings reported in the relevant prior art (Stangeland et al. 2009; Ng & Kuppusamy, 2019; Hashash et al. 2017; and Kumar et al. 2021). It has been perceived that blanching had a significant effect on the antioxidant activity of the fresh vegetables. However, the effect was positive for few vegetables and detrimental for few other vegetables. Among the chosen winter and summer vegetables, the antioxidant activity of ash gourd, bottle gourd, pumpkin, squash, pointed gourd, ridge gourd, spine gourd and sponge gourd reduced after blanching. Similar trend was reported in the prior art for green peas (Xu & Chang, 2008) and long bean (Wen et al., 2010). Such a reduction may be ascribed to the loss of water-soluble antioxidant compounds due to leaching. However, for the beans, bitter gourd, snake gourd and yardlong bean vegetables, the antioxidant activity increased after blanching. Similar trend was reported in the relevant prior art for green beans (Turkmen et al., 2005) and bitter gourd (Ng & Kuppusamy, 2019). For these enhancing trends, the possible reason can be correlated to the inactivation of peroxidase enzyme during blanching to thereby reduce the pro-oxidants content in the processed vegetable (Gazzani et al., 1998).

Among dried winter vegetables, pumpkin and bottle gourd possessed lowest (0.31%/ mg) and highest (1.02%/ mg) antioxidant activity respectively. Among dried summer vegetables, ridge gourd and spine gourd possessed lowest (0.62%/ mg) and highest (1.01%/ mg) antioxidant activity respectively.

The percent variation in antioxidant activity of dried and blanched dried vegetables with respect to the fresh vegetables has been illustrated in Figure 3.5. The figure depicts that drying alone fostered enhanced antioxidant activity for most vegetables but not bottle gourd and yardlong bean. Such positive influence of drying upon the antioxidant activity can be ascribed to the formation of new antioxidant compounds through the Maillard reaction along with the release of bounded antioxidants due to the disruption of cell wall (Mashitoa et al. 2021). On the contrary, a detrimental influence of drying on the antioxidant activity may be correlated to the heat sensitivity of most antioxidant constituents in the processed vegetable (Sarkar et al., 2021).

For the case involving blanching followed with drying, the positive influence of the processing scheme on the antioxidant activity was observed for only few vegetables (ash gourd, bitter gourd, pumpkin, pointed gourd, snake gourd and spine gourd). Similar trend was reported for Moringa leaves in the relevant prior art (Wickramasinghe et al., 2020). Such findings have been correlated to the inactivation of the polyphenol oxidase enzyme during blanching and release of bound antioxidant compounds due to cell wall disruption, and formation of new antioxidant compounds during drying. However, for all other vegetables, a negative influence was observed due to the combined processing scheme. Such detrimental influence has been reported for cabbage by Sarkar et al. 2021. The authors indicated the potential role of heat sensitivity of antioxidant compounds in due course of vegetable drying. Among all winter vegetables, the combined processing scheme indicated lowest (0.11%/mg) and highest (0.70%/mg) antioxidant activity for squash and ash gourd respectively. Among all summer vegetables, the corresponding lowest and highest values were obtained for snake gourd (0.16%/mg) and spine gourd (0.99%/mg) respectively. Further, for all vegetables, a combination of blanching and drying always indicated lower antioxidant activity than those achieved through the tray drying process alone. This has been attributed to the comparatively prolonged heat exposure of vegetables during the combined process scheme.


AA (%/mg DM)
Time (h)
(a)
AA (%/mg DM)
Time (h)
(b)
AA (%/mg DM)
Time (h)
(c)

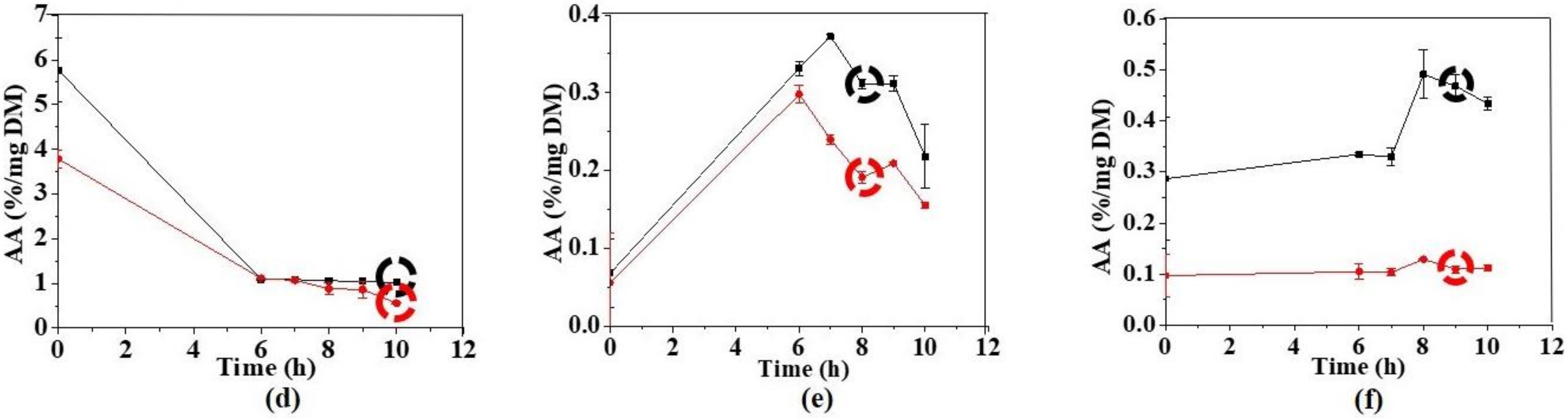
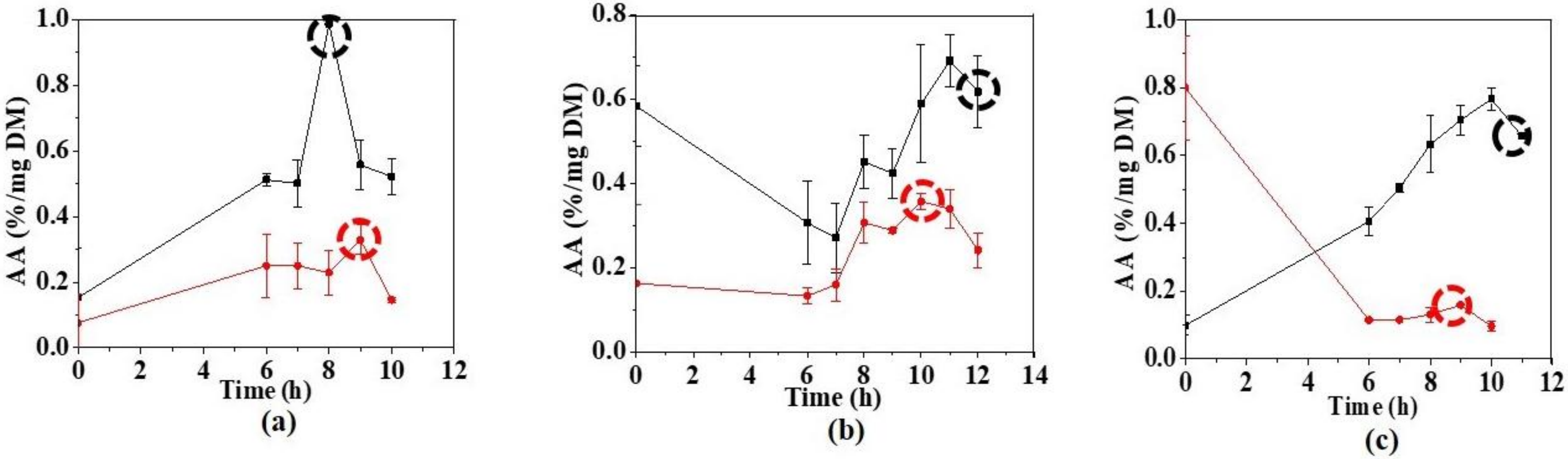


Figure 3.3. Optimal drying time of dried (■) and blanched dried (●) winter vegetables in terms of the antioxidant activity of (a) ash gourd (b) beans (c) bitter gourd (d) bottle gourd (e) pumpkin and (f) squash vegetables.


AA (%/mg DM)
Time (h)
(a)
AA (%/mg DM)
Time (h)
(b)
AA (%/mg DM)
Time (h)
(c)

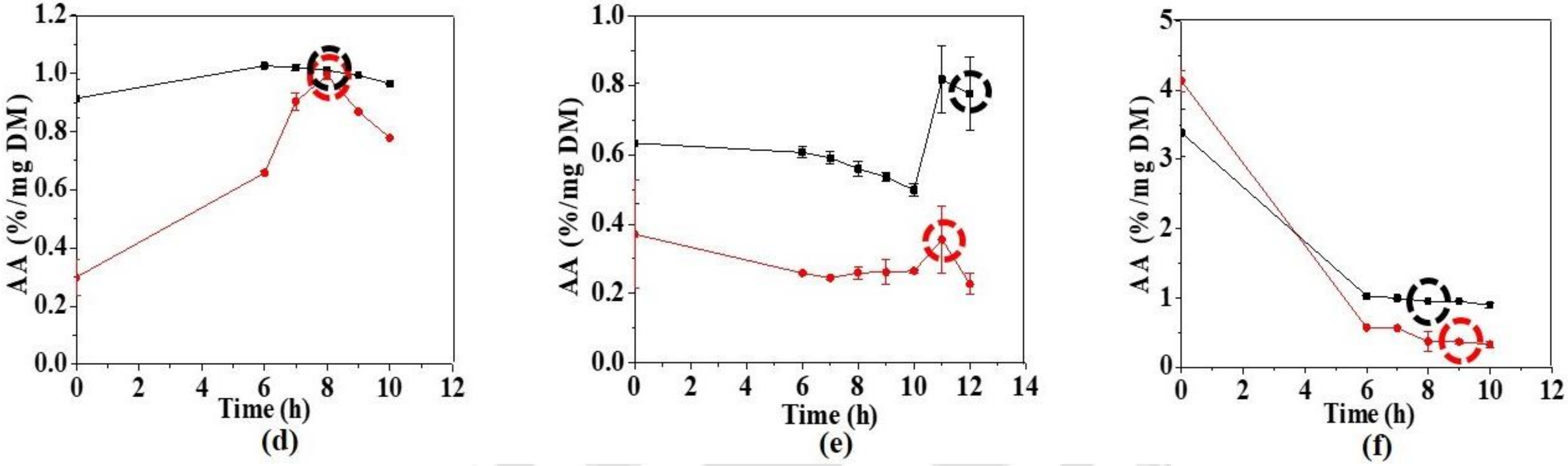


Figure 3.4. Optimal drying time of dried (■) and blanched dried (●) summer vegetables in terms of the antioxidant activity of (a) pointed gourd (b) ridge gourd (c) snake gourd (d) spine gourd (e) sponge gourd and (f) yardlong bean vegetables.

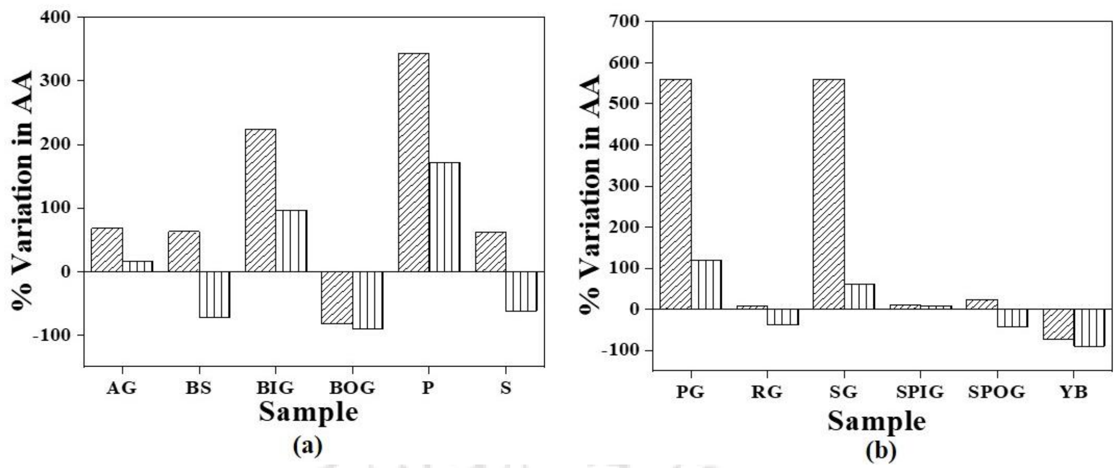


Figure 3.5. Percentage variation in AA of dried (//////) and blanched dried (||||||) samples in comparison to the fresh sample of (a) winter and (b) summer vegetables.

A comparative enhancement of the combined scheme towards percentage retention of antioxidant activity has been presented in Figure 3.6. Among winter vegetables, maximum (69.31%) and minimum (17.14%) retention were indicated for ash gourd and beans respectively. Further, among summer vegetables, spine gourd and pointed gourd indicated maximum (98.02%) and minimum (33.33%) retention respectively. Also, it is interesting to note that the antioxidant activity retention of all vegetables except beans and squash was close to or more than 50%. The findings thereby affirm that for vegetables such as bitter gourd and spine gourd blanching can be used as a preprocessing treatment for the development of dried vegetables with good sensory and nutritional aspects. The detrimental/enhancing trends of antioxidant activity for various considered treatments have been analyzed to be due to a combination of several chemical and surface phenomena. These include synergistic effects of antioxidants and polyphenolic compounds, influence of bioactive constituents in the raw material, heat sensitive behavior of antioxidant and polyphenolic constituents and cell wall structure of the vegetables. In this regard, it shall be noted that tougher cell walls may not get disrupted during the suggested process schemes. Henceforth, they do have a strong influence on the observed trends (Kaseke et al., 2020; Tan et al., 2021).

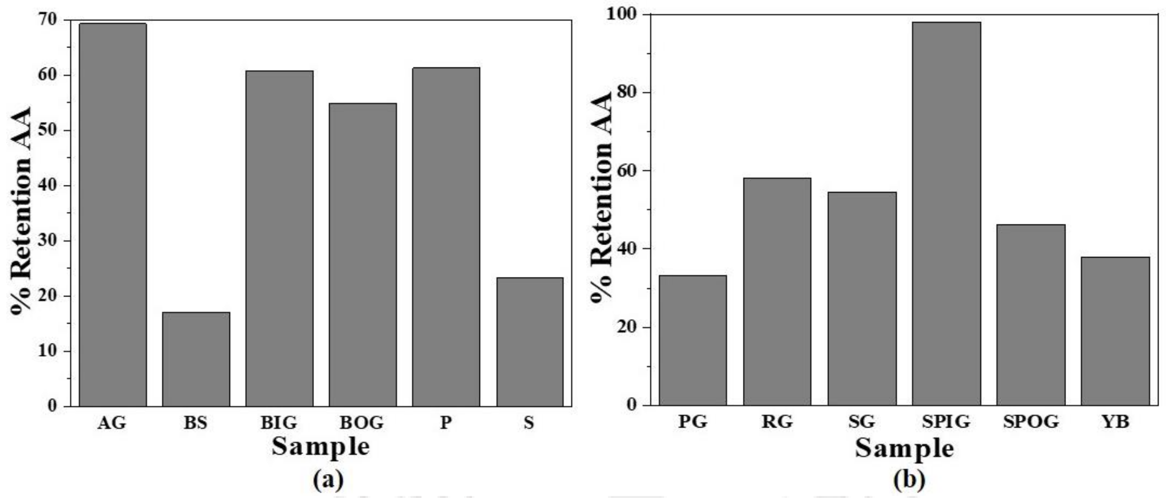


Figure 3.6. Percentage retention of AA in blanched dried samples in comparison to the dried samples of (a) winter and (b) summer vegetables.

3.3.3 Total Phenolic Content of Optimally Dried Vegetables

The TPC of blanched winter and summer vegetables varied from 102.87 (S) – 808.11 mg/ g (BOG) and 91.05 (RG) – 413.50 mg/ g (SPOG) respectively. The results depicted a significant effect of blanching on the TPC. Among the chosen winter and summer vegetables, blanching resulted in the TPC reduction of all vegetables but bottle gourd and sponge gourd.

Among dried winter vegetables, ash gourd (332.50 mg/g) and pumpkin (143.69 mg/g) possessed highest and lowest TPC respectively. Among dried summer vegetables, yardlong bean (273.90 mg/g) and sponge gourd (164.31 mg/g) possessed highest and lowest TPC respectively. Among all winter vegetables subjected to the combined processing scheme, bitter gourd (204.51 mg/g) and pumpkin (34.76 mg/g) indicated highest and lowest TPC respectively. Among all summer vegetables, the corresponding highest and lowest values were obtained for yardlong bean (289.70 mg/g) and snake gourd (100.83 mg/g) respectively. The percent variation in TPC of dried and blanched dried vegetables with respect to the fresh vegetables has been illustrated in Figure 3.7. The figure depicts that drying alone fostered enhanced TPC for ash gourd, beans, squash, pointed gourd, ridge gourd and spine gourd.

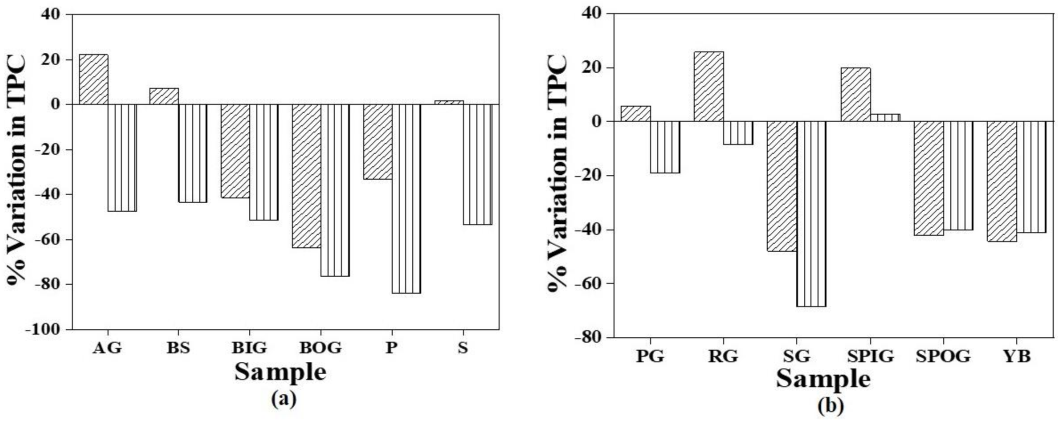


Figure 3.7. Percentage variation in TPC of dried (//////) and blanched dried (||||||) samples with respect to fresh sample of (a) winter and (b) summer vegetables.

For the case involving blanching followed with drying, the positive influence of the processing scheme on the TPC was observed for only spine gourd. For most vegetables subjected to various treatments, the similar trend observed for TPC and antioxidant activity can be correlated to the synergistic influence between both constituents (Zheng & Wang, 2001). However, the varied trends may be attributed to factors like sensitivity of few compounds to heat treatments and changes in the cell wall structures due to the alternate treatments.

A comparative enhancement of the combined scheme towards percentage retention of TPC has been presented in Figure 3.8. Among winter vegetables, maximum (82.68%) and minimum (24.19%) retention were indicated for bitter gourd and pumpkin respectively. Further, among summer vegetables, yardlong bean and snake gourd indicated maximum (105.77%) and minimum (60.36%) retention respectively.

3.3.4 Vitamin C Content of Optimally Dried Vegetables

Among all chosen vegetables, except snake gourd, blanching proved to be unfavorable for the retention of vitamin C content. The possible reason for such vitamin C enhancement in Snake gourd could be due to inactivation of ascorbic acid oxidase in due course of blanching

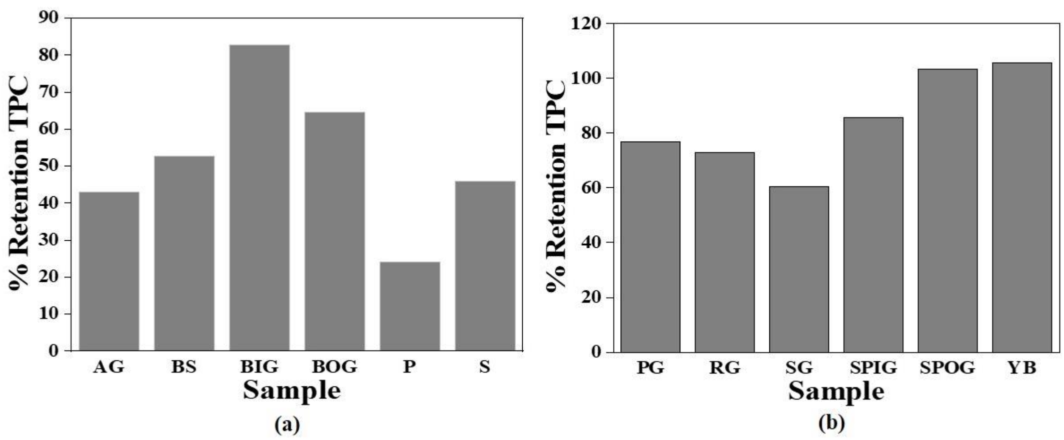


Figure 3.8. Percentage retention of TPC in blanched dried samples in comparison to dried samples of (a) winter and (b) summer vegetables.

(Munyaka et al., 2010). The contrary trend has been due to the leaching-based vitamin C loss driven with its water-soluble nature. Among blanched winter vegetables, bitter gourd (318.26 mg/100g) and squash (48.28 mg/100g) possessed highest and lowest vitamin C content. Similarly, among blanched summer vegetables, pointed gourd (41.67 mg/100g) and spine gourd (319.20 mg/100g) respectively possessed the lowest and highest vitamin C contents respectively.

Figure 3.9 depicts the percentage variation in the vitamin C content of dried and blanched dried vegetables with respect to the fresh vegetables. It has been observed that drying alone facilitated an enhancement in the vitamin C content of most vegetables but not bitter gourd, pumpkin, ridge gourd and yardlong bean. Such pertinent enhancement could be possibly due to the intact structure of the cell wall matrix that prevented the thermal or oxidative damage of the vitamin C constituents (Khraisheh et al., 2004). In few vegetables, the detrimental influence of drying on the Vitamin C content can be corroborated with its heat sensitivity characteristics and oxidation based loss (Managa et al., 2020; Mashitoa et al., 2021; Sarkar et al., 2021). Among the dried winter vegetables, lowest (89.60 mg/ 100g) and highest (559.25 mg/ 100g) content of vitamin C were observed for squash and bitter gourd samples respectively. Among dried summer vegetables, ridge gourd and spine gourd possessed lowest (99.41 mg/ 100g) and highest (733.68 mg/ 100g) vitamin C content respectively.

For the case of combined blanching and drying scheme, except pointed gourd, all other vegetables indicated reduction in the vitamin C content. Similar trend was reported in the relevant prior art (Ojwang et al., 2021; Sarkar et al., 2021). Leaching during blanching and thermal and oxidative degradation during drying have been accounted to be primarily responsible for such detrimental influence of the combined processing scheme. Among blanched dried winter vegetables, squash and bitter gourd possessed minimum (69.52 mg/100g) and maximum (522.87 mg/100g) vitamin C content respectively. Similarly, among blanched dried summer vegetables, ridge gourd and spine gourd possessed minimum (67.99 mg/100g) and maximum (103.82 mg/100g) vitamin C content respectively. The percent retention of vitamin C content of blanched dried vegetables with respect to dried vegetables has been depicted in Figure 3.10. The illustration infers that despite processing ensuring a reduction of vitamin C content, the retention was close to 50% for spine gourd and more than 50% for all other vegetables. Among winter vegetables, bitter gourd and bottle gourd refer to maximum (93.49%) and minimum (50.28%) retention. Corresponding maximum and minimum retention among summer vegetables refer to yardlong bean (74.12%) and spine gourd (41.64%) respectively. For all vegetables, Vitamin C content of dried vegetables was higher in comparison to the content that existed in the corresponding blanched dried vegetables. This is due to the leaching of vitamin C during blanching followed with heat sensitive constituent loss in due course of prolonged exposure to the hot air during drying (Sarkar et al., 2021).

3.3.5. Soluble Protein Content of Optimally Dried Vegetables

Among blanched winter vegetables, ash gourd (19.56 mg/g) and squash (7.83 mg/g) possessed highest and lowest soluble protein content. Among blanched summer vegetables, sponge gourd

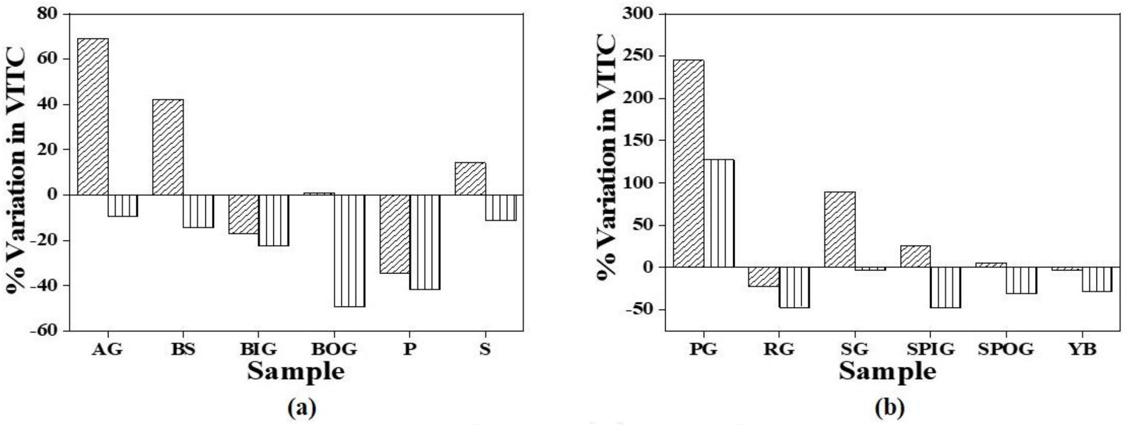


Figure 3.9. Percentage variation in VITC of dried (//////) and blanched dried (||||||) samples with respect to fresh sample of (a) winter and (b) summer vegetables.

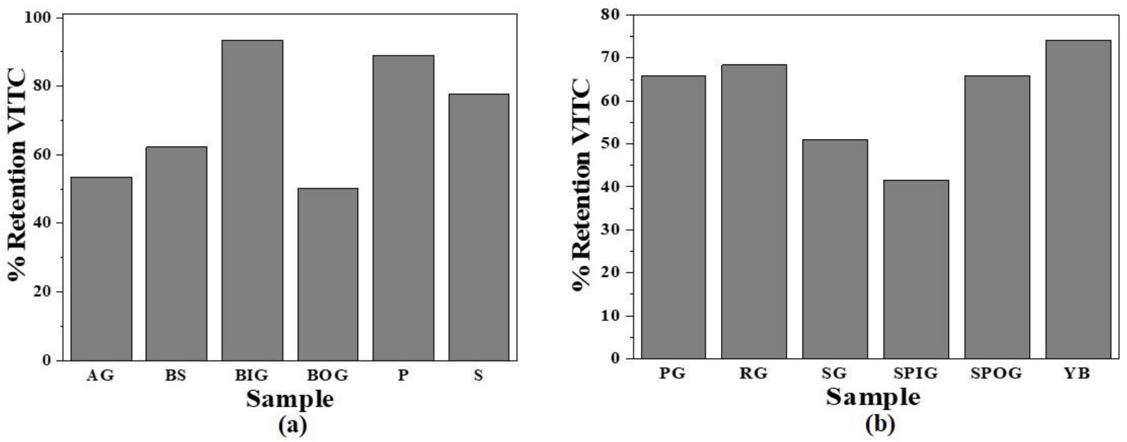


Figure 3.10. Percentage retention of VITC in blanched dried samples in comparison to dried samples of (a) winter and (b) summer vegetables.

(24.76 mg/g) and pointed gourd (5.65 mg/g) possessed highest and lowest soluble protein content respectively. Among dried winter vegetables, pumpkin (15.94 mg/g) and ash gourd (10.56 mg/g) possessed highest and lowest soluble protein content. Similarly, among dried summer vegetables, ridge gourd (18.43 mg/g) and pointed gourd (13.34 mg/g) possessed highest and lowest soluble protein content respectively. Among all winter vegetables subjected to the combined processing scheme, beans (9.15 mg/g) and pumpkin (7.16 mg/g) possessed highest and lowest soluble protein content. Similarly, among summer vegetables subjected to combined processing, ridge gourd (9.49 mg/g) and snake gourd (6.85 mg/g) possessed maximum and minimum soluble protein content. In most cases, a reduction in soluble protein content in due course of various treatments has been observed. However, for very few cases, a marginal increase has been noticed. However, the enhancement was observed to be very minimal. This reduction could be ascribed to the leaching of soluble compounds during blanching and removal along with moisture during drying (Mondal et al. 2019).

3.3.6. Crude Fibre Content of Optimally Dried Vegetables

Among all optimally treated winter vegetables, ash gourd (98.45%) and pumpkin (90.16%) possessed highest and lowest crude fibre content respectively. Similarly, among summer vegetables, crude fibre content of dried and blanched dried vegetables varied from 93.61 – 98.82% and 95.55 – 97.94% respectively. Among dried and blanched dried summer vegetables, yardlong bean and pointed gourd possessed highest and lowest amounts of crude fibre content respectively. In most winter and summer vegetables, it has been observed that blanching and drying resulted in marginal enhancement of the crude fibre content. This marginal enhancement may be attributed to the variation of the total solid content of the sample due to the losses of sugar, mineral and vitamin constituents (Wennberg et al., 2003). For both pointed gourd and spine gourd, drying fostered a marginal reduction in the crude fibre content. This is attributed to the heat based solubilization of fibre compounds such as cellulose, hemicellulose, and pectin (Chantaro et al., 2008).

3.3.7. Effect of Blanching and Drying on Yield

Among dried and blanched dried winter vegetables, the yield varied from 4.30 – 10.96% and 3.48 – 9.24% respectively. Among dried winter vegetables, bottle gourd (4.30%) and bitter gourd (10.96%) samples possessed lowest and highest yield respectively. Similarly, among blanched dried winter vegetables, bottle gourd (3.48%) and beans (9.24%) provided lowest and highest yield respectively. Among dried summer vegetables, ridge gourd (4.05%) and spine gourd (11.80%) affirmed lowest and highest yield. However, among blanched dried summer vegetables, the sponge gourd (1.72%) and pointed gourd (9.00%) possessed lowest and highest yield respectively. In summary, dried vegetables facilitated higher yield characteristics in comparison with the blanched dried vegetables. Such generalized inference is in agreement with those being inferred for the broccoli vegetable by Kaur et al. 2018. This comparatively greater yield is attributed to the specific losses in due course of the blanching process.

3.4 Literature Reported and Assessed Best Vegetables in Terms of Nutritional Composition

Among dried winter vegetables, the best vegetable correspond to the ash gourd due to appropriate processing time (11h), highest antioxidant activity (1.01%/ mg), TPC (332.50 mg/g)and vitamin C (362.19 mg/100g); bitter gourd due to appropriate processing time (9h), highest antioxidant activity (0.97%/ mg), TPC (247.34 mg/g) and vitamin C (559.26 mg/100g) and bottle gourd due to appropriate processing time (10h), highest antioxidant activity (1.02%/ mg), TPC (261.76 mg/g) and appropriate vitamin C (143.45 mg/100g) content. Similarly, blanched and dried bitter gourd is the best due to lowest processing time (6 h), high antioxidant activity (0.59%/ mg), TPC (204.51 mg/g) and highest vitamin C (522.87 mg/100g) content.

Among dried summer vegetables, the best vegetables correspond to pointed gourd due to appropriate processing time (8 h), highest antioxidant activity (0.99%/ mg) and vitamin C (237.54 mg/100g); spine gourd due to appropriate processing time (8 h), highest antioxidant activity (1.01%/ mg) and vitamin C (733.68 mg/100g) and yardlong bean due to appropriate processing time (8 h), highest antioxidant activity (0.95%/ mg) and appropriate vitamin C (150.08 mg/100g) content. Similarly, blanched and dried spine gourd is the best due to appropriate processing time (8 h), highest antioxidant activity (0.99%/ mg), TPC (206.83 mg/g) and vitamin C (305.53 mg/100g) content. Table 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, E1, E2, E3, E4, E5 and E6 summarize the moisture, yield and nutritional parameters of fresh and optimally treated ash gourd, bitter gourd, bottle gourd, pointed gourd, spine gourd, yardlong bean, beans, pumpkin, squash, ridge gourd, snake gourd and sponge gourd respectively. As wet basis is not a standard norm to compare and contrast vegetables with variant moisture content in due course of drying, all relevant nutritional parameters have been mentioned with respect to the dry basis. However, this was not the case in the available prior art and hence for literature comparison purposes, both wet basis and dry mass basis values have been provided. Further, the reported literature data has been presented as the mean value. Also, as applicable, reported standard deviation values have been mentioned in the literature data summary tables.

3.5 Summary

In this chapter, a systematic study for holistic characterization of nutrients of various summer and winter vegetables to identify their potential towards the development of ready to cook soup mixes has been addressed. In summary, ash gourd; bitter gourd; bottle gourd and pointed gourd; spine gourd; yardlong bean can be inferred to be the most relevant vegetables to represent maximum constitution in the winter and summer vegetable-based dry soup mix formulations respectively due to their proportionate and adequate nutritional composition. Another important inference being drawn from conducted investigation is that both blanching-drying and drying processes are competent to achieve the desired nutritional characteristics. However, among these, for all vegetables except bitter gourd and spine gourd, only drying is recommended for the considered responses due to the higher retention during drying. It is well known that vegetables such as bitter gourd and spine gourd have to be inevitably blanched to mitigate bitterness and enhance sensory characteristics of associated soup mix formulations. However, though a reduction has been observed in such cases, the nutritional content was still

Table 3.1: Moisture and nutritional characteristics data of fresh and optimally treated ash gourd.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	94.74 ± 0.12^{b}	NA	NA	97.67 ± 0.10^{d}	18.66 ± 1.71^{a}	0.60 ± 0.12^{b}	272.43 ± 5.19^{b}	214.21 ± 10.71^{b} (11.27 ± 0.56)
	D	7.19 ± 0.06^{c}	11	9.38	98.45 ± 0.05^{b}	10.56 ± 0.82^{b}	1.01 ± 0.01^{a}	332.50 ± 9.45^{a}	362.19 ± 9.27^{a} (336.15 ± 8.61)
	B	96.05 ± 0.02^{a}	NA	NA	98.15 ± 0.12^{c}	19.56 ± 1.26^{a}	0.23 ± 0.17^{c}	225.33 ± 29.68^{c}	190.17 ± 8.23^{c}
	BD	7.00 ± 0.11^{d}	09	5.60	98.76 ± 0.06^{a}	8.14 ± 0.20^{c}	0.70 ± 0.03^{b}	142.84 ± 5.52^{d}	193.85 ± 6.06^{c}
Gupta et al., 2021	F	96.05							(9.85)
Mondal et al., 2019	D	7.30	10	4.61	-	5.98	-	-	(304.37)
Shinde et al., 2016	BD	4.00	08	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; n = 3).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table 3.2: Moisture and nutritional characteristics data of fresh and optimally treated bitter gourd.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	91.12 ± 0.07^{a}	NA	NA	94.82 ± 0.08^{a}	16.47 ± 1.45^{a}	0.3 ± 0.02^{c} (0.04 ± 0.002)	421.81 ± 59.71^{a}	674.60 ± 3.66^{a}
	D	4.97 ± 0.06^{d}	09	10.96	94.61 ± 0.02^{b}	13.47 ± 0.03^{b}	0.97 ± 0.004^{a}	247.34 ± 11.84^{b}	559.25 ± 6.85^{b}
	B	90.50 ± 0.05^{b}	NA	NA	94.85 ± 0.15^{a}	8.21 ± 1.42^{c}	0.60 ± 0.16^{b} (0.06 ± 0.02)	177.25 ± 20.17^{c}	318.26 ± 3.42^{d}
	BD	5.90 ± 0.06^{c}	06	8.03	94.33 ± 0.09^{c}	7.96 ± 0.92^{c}	0.59 ± 0.04^{b}	$204.51 \pm 17.05^{b,c}$	522.87 ± 3.46^{c}
Ng & Kuppusamy, 2019	F	-	-	-	-	-	0.05	-	-
	B	-	-	-	-	-	0.07	-	-

Superscripted means in a column differ significantly ($p < 0.05$; n = 3).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table 3.3: Moisture and nutritional characteristics data of fresh and optimally treated bottle gourd.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	93.20 ± 0.12[a]	NA	NA	96.24 ± 0.11[c]	25.04 ± 0.22[a]	5.77 ± 0.72[a]	722.07 ± 8.45[b]	142.22 ± 27.78[a] (8.08 ± 0.86)
	D	7.05 ± 0.17[c]	10	4.30	97.56 ± 0.10[a]	10.66 ± 0.56[b]	1.02 ± 0.002[c]	261.76 ± 5.08[c]	143.45 ± 3.50[a]
	B	92.15 ± 0.10[b]	NA	NA	96.86 ± 0.08[b]	8.80 ± 0.09[c]	3.79 ± 0.2[b]	808.11 ± 2.73[a]	88.51 ± 10.96[b] (6.95 ± 0.86)
	BD	6.26 ± 0.43[d]	10	3.48	97.65 ± 0.30[a]	7.47 ± 0.27[d]	0.56 ± 0.02[c]	169.00 ± 1.68[d]	72.12 ± 6.01[b]
Shinde et al., 2016	F	-	-	-	-	-	-	-	(13)
	D	-	-	-	-	-	-	-	
Gajera et al., 2014	B	-	-	-	-	-	-	-	(6.99)
Shinde et al., 2016	BD	4.00	08	-	-	-	-	-	

Superscripted means in a column differ significantly ($p < 0.05$; n = 3).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table 3.4: Moisture and nutritional characteristics data of fresh and optimally treated pointed gourd.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	88.27 ± 0.10[a]	NA	NA	95.74 ± 0.66[a]	12.86 ± 0.28[a]	0.15 ± 0.15[c]	162.30 ± 1.83[b]	68.84 ± 2.77[c] (8.08 ± 0.33)
	D	4.34 ± 0.08[d]	08	6.55	93.61 ± 0.55[b]	13.34 ± 0.36[a]	0.99 ± 0.001[a]	171.35 ± 2.16[a]	237.54 ± 6.80[a]
	B	86.93 ± 0.32[b]	NA	NA	96.17 ± 1.43[a]	5.65 ± 0.25[c]	0.08 ± 0.09[c]	127.26 ± 1.64[d]	41.67 ± 6.58[d]
	BD	5.19 ± 0.07[c]	09	9.00	95.55 ± 0.74[a]	7.51 ± 0.37[b]	0.33 ± 0.04[b]	131.57 ± 2.17[c]	156.48 ± 9.08[b]
Kumari & Sharma, 2018	F	92.00	-	-	-	-	-	-	-
	B	91.50	-	-	-	-	-	-	-
	BD	7.50	11	-	-	-	-	-	-
JR, 2013	F	-	-	-	-	-	-	-	(9.33)

Superscripted means in a column differ significantly ($p < 0.05$; n = 3).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table 3.5: Moisture and nutritional characteristics data of fresh and optimally treated spine gourd.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	88.09 ± 0.12^{a}	NA	NA	96.52 ± 0.51^{a}	11.93 ± 0.33^{b}	0.91 ± 0.07^{b}	201.40 ± 1.32^{c}	575.52 ± 17.91^{b} (68.54 ± 2.13)
	D	6.83 ± 0.07^{c}	08	11.80	95.19 ± 0.15^{b}	14.20 ± 0.03^{a}	1.01 ± 0.003^{a} (0.94 ± 0.002)	241.22 ± 2.93^{a}	733.68 ± 9.24^{a}
	B	87.41 ± 0.12^{b}	NA	NA	96.31 ± 0.18^{a}	7.27 ± 0.33^{d}	0.30 ± 0.06^{c} (0.04 ± 0.01)	168.68 ± 2.95^{d}	319.20 ± 15.72^{c}
	BD	5.96 ± 0.05^{d}	08	8.70	95.80 ± 0.62^{a,b}	8.28 ± 0.03^{c}	0.99 ± 0.013^{a,b}	206.83 ± 2.28^{b}	305.53 ± 15.85^{c}
JR, 2013	F	84.23	-	-	-	-	-	-	(39.40)
Kumar et al., 2021	D	-	-	-	-	-	(0.83)	-	-
Ng & Kuppusamy, 2019	B	-	-	-	-	-	(0.07)	-	-

Superscripted means in a column differ significantly ($p < 0.05$; n = 3).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table 3.6: Moisture and nutritional characteristics data of fresh and optimally treated yardlong bean.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	86.28 ± 0.34^{a}	NA	NA	97.02 ± 1.09^{b}	17.73 ± 1.54^{a}	3.39 ± 0.03^{b}	492.42 ± 1.56^{a}	154.67 ± 2.37^{a}
	D	4.90 ± 0.33^{b}	08	11.00	98.82 ± 0.83^{a}	12.43 ± 0.45^{b}	0.95 ± 0.004^{c}	273.90 ± 7.69^{d}	150.08 ± 9.05^{a,b}
	B	88.07 ± 1.95^{a}	NA	NA	98.69 ± 0.04^{a}	7.02 ± 0.41^{c}	4.13 ± 0.15^{a}	400.10 ± 11.69^{b}	140.09 ± 2.73^{b}
	BD	5.46 ± 2.12^{b}	09	8.25	97.94 ± 0.49^{a,b}	6.93 ± 0.42^{c}	0.36 ± 0.03^{d}	289.70 ± 6.01^{c}	111.24 ± 6.88^{c}
Siriwattananon & Maneerate, 2016	F	88.74		-	-	-	-	-	-
	BD	13.96	-	-	-	-	-	-	-
Manzoor et al., 2019		-	05	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; n = 3).
Values in parentheses refer to nutritional composition with respect to wet weight.

comparable to that of only dried vegetables and a retention of more than 50% was observed in the nutritional parameters. From the perspective of processing time, among dried and blanched dried winter vegetables, lowest processing time was achieved for Pumpkin (8 h) and bitter gourd (6 h) respectively. Similarly, among dried and blanched dried vegetables, lowest processing time was achieved for pointed gourd (8 h) and spine gourd (8 h) respectively. The important inferences drawn from the present investigation have been utilized for the determination of these vegetables proportions towards the development of nutritionally rich optimal ready to cook vegetable soup mixes.

Thereby, in the following chapters, a stage-by-stage optimization of vegetables and other ingredient proportions with respect to the sensory and nutritional characteristics has been addressed to achieve optimal soup formulations.

Chapter 4:

Identification of Best Summer and Winter Vegetable Mix Combinations for Soup Mix Formulations

Identification of Best Summer and Winter Vegetable Mix Combinations for Soup Mix Formulations

Overview of the Chapter

This chapter presents the results associated to the identification of best summer and winter vegetable mix combinations (any three) for the soup mix formulation studies. This is addressed through the comparative assessment of 9-point hedonic scale and score-deviation sensory evaluation techniques. After a brief overview in section 4.1, section 4.2 details upon the findings associated with the sensory based ranking of single vegetable formulation. Section 4.3 summarizes the results associated with the optimality of soup mix formulations based on varied combinations of any three summer vegetables. Thereafter, in section 4.4, the findings associated with the optimality based on varied combinations of any three winter vegetables have been elucidated. Section 4.5 provides insights on the role of 9-point hedonic scale method and Score deviation method as techniques for sensory evaluation for the identification of soup mix formulations with the best combinations of summer and winter vegetables. Section 4.6 details upon the various nutritional characteristics of identified best soup mix formulations. Finally, section 4.7 presents an overall summary of the research findings in terms of the identification of best summer and winter vegetable mix combinations (any three vegetables) for the soup mix formulations through the comparative assessment of 9-point hedonic scale and score deviation sensory methods.

4.1 Introduction

This chapter ascertains upon the formulation, characterization and identification of optimal soup mixes through a structured methodology which involved sensory evaluation-based screening of few formulations followed by the nutritional characterization. To achieve this, a novel sensory evaluation technique named as score deviation (SDI) method was designed. This method was implemented in conjunction with the conventional 9-point hedonic scale method to achieve optimal soup formulations with increased confidence. A total of forty soups formulated with various combinations of any three of the summer and winter vegetable produces were evaluated for the sensory properties. This was achieved with a semi-trained panel of 15 subjects and with both the methods. All the developed formulations were compared with a commercial soup product which was taken as a control for the study. Finally, a few summer and winter vegetable formulations were screened based on the deviation index values obtained through score deviation method and sensory scores obtained through both the methods. Deviation index values which affirmed the extent of uniformity among the sensory parameters played a key role in better screening of the formulations. Subsequently, the screened summer and winter vegetable-based soup mix formulations were evaluated for moisture content, water activity and nutritional parameters namely antioxidant activity, total phenolic content, vitamin C content and soluble protein content.

4.2 Ranking and Priority Based on Single Vegetable Formulations

The sensory evaluation scores of summer and winter vegetable based single vegetable formulations obtained through 9-point hedonic scale evaluation method have been summarized in Figure 4.1. Further, the targeted mixed vegetable formulations have been summarized in Table 4.1. Further details of the followed procedures and methodology have been presented in section 2.4 of the Ph.D. thesis. The SDI sensory analysis-based ranking of mixed vegetable formulations has been depicted in Figure 4.2. Among the summer vegetable-based soups, formulations prepared with all the vegetables except yardlong bean possessed better overall acceptability with respect to the control formulation. Soup mixes formulated with both spine gourd and sponge gourd achieved highest overall acceptability (7.55) and higher scores in comparison to corresponding score of the control formulation (6.50). Further, soup mixes formulated with snake gourd, ridge gourd and pointed gourd possessed marginally lower or similar scores for consistency (6.45, 6.3 and 6.0 respectively) and appearance (6.85, 7.0 and 6.7 respectively) and higher scores for the remaining sensory parameters in comparison to the control formulation.

Table 4.1: SDI and 9-point hedonic based scores, DI and ranks of summer and winter vegetable formulations.

Summer Formu-lations	SDI method			9-point Hedonic method		Winter Formu-lations	SDI method			9-point Hedonic method	
	Score	DI	Rank	OA	Rank		Score	DI	Rank	OA	Rank
C	65.75	38.32	16	6.60	17	**C**	65.75	38.32	19	6.60	10
SF1	64.71	47.83	19	6.30	20	**WF1**	50.95	45.96	21	5.00	21
SF2	61.25	35.42	17	6.45	18	**WF2**	67.92	29.16	13	6.75	9
SF3	68.91	39.54	12	6.90	11	**WF3**	70.46	26.96	12	7.13	6
SF4	58.89	51.51	21	5.80	21	**WF4**	74.18	15.42	4	7.00	8
SF5	68.95	27.59	5	6.90	11	**WF5**	66.22	29.03	14	6.29	15
SF6	69.78	42.30	15	7.45	4	**WF6**	60.33	38.74	20	6.41	13
SF7	65.31	32.51	18	6.85	15	**WF7**	64.86	23.13	9	6.35	14
SF8	73.33	41.52	14	7.35	5	**WF8**	73.45	14.96	2	7.50	2
SF9	68.50	21.30	4	6.90	11	**WF9**	74.76	14.92	1	7.48	4
SF10	71.68	20.78	2	7.65	3	**WF10**	77.38	16.85	3	7.50	2
SF11	70.31	39.76	11	6.95	9	**WF11**	59.51	34.90	18	5.44	20
SF12	66.35	36.58	10	6.80	16	**WF12**	60.44	26.53	16	5.54	19
SF13	70.80	33.61	9	7.10	6	**WF13**	60.27	24.80	11	6.09	17
SF14	74.47	34.57	7	7.75	1	**WF14**	62.78	22.77	10	5.75	18
SF15	72.88	34.43	8	7.10	6	**WF15**	70.29	17.78	7	7.25	5
SF16	67.59	38.46	13	6.95	9	**WF16**	69.72	16.64	5	7.13	6
SF17	61.94	45.32	20	6.35	19	**WF17**	63.62	28.28	15	6.56	11
SF18	68.53	26.45	6	6.90	11	**WF18**	61.86	32.22	17	6.13	16
SF19	71.47	22.22	3	7.05	8	**WF19**	65.31	23.00	8	6.44	12
SF20	74.56	19.28	1	7.70	2	**WF20**	73.58	18.64	6	7.69	1

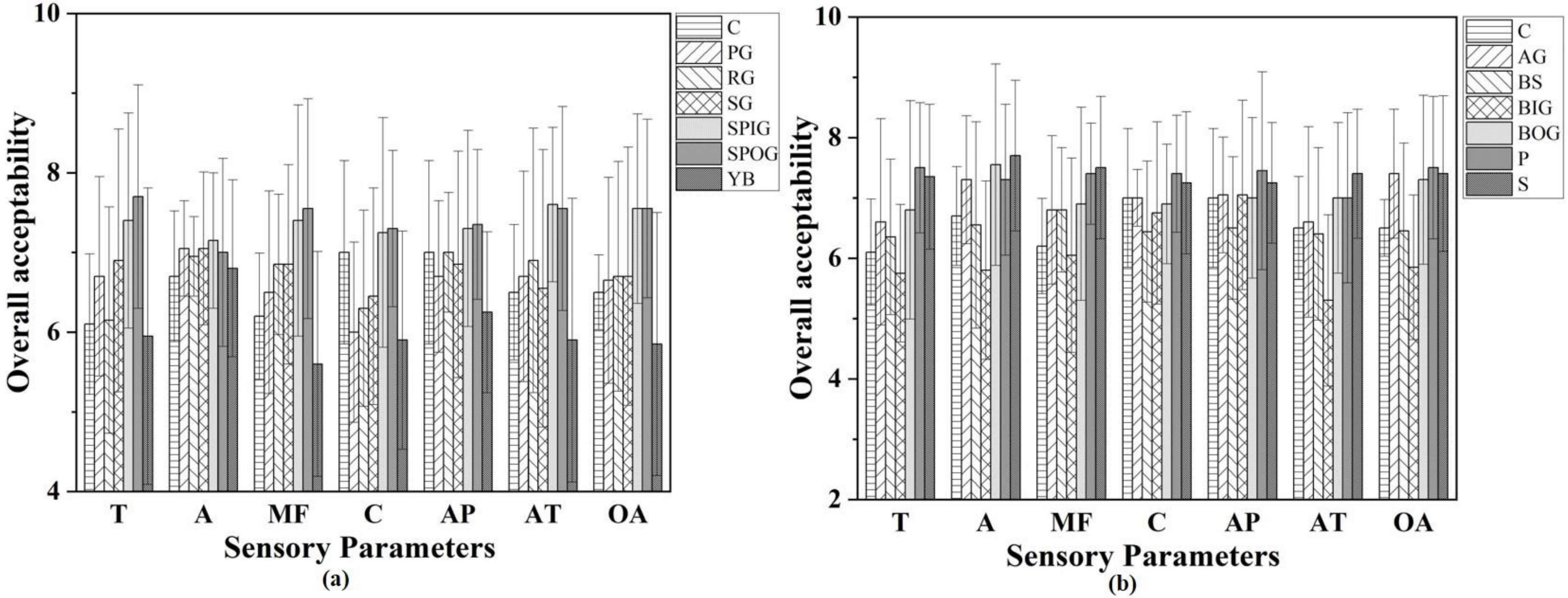


Figure 4.1. 9-point hedonic scale method based sensory scores of single vegetable formulations of (a) summer vegetables and (b) winter vegetables: T, Taste; A, Aroma; MF, Mouthfeel; C, Consistency; AP, Appearance; AT, Aftertaste; OA, Overall acceptability.

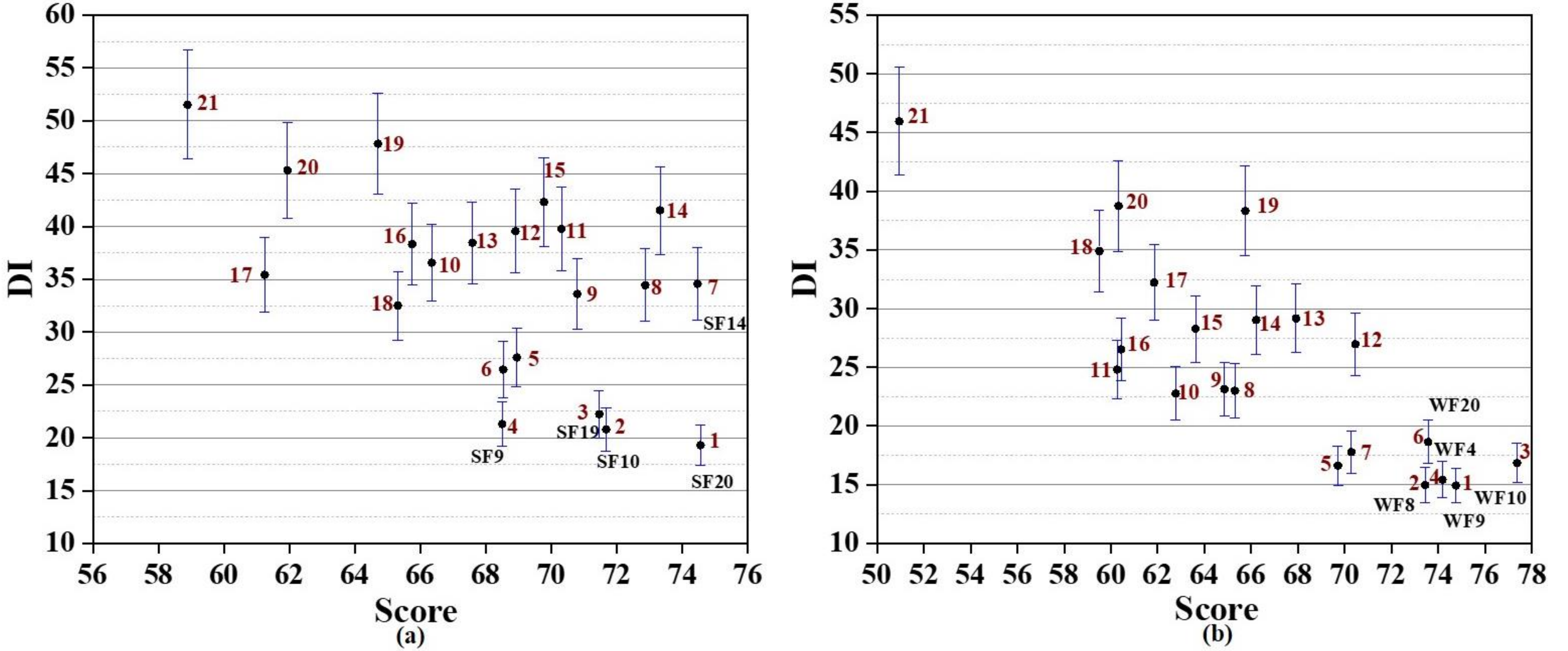


Figure 4.2. SDI sensory evaluation-based ranking of (a) summer vegetable formulations and (b) winter vegetable formulations.

Furthermore, lowest sensory scores were obtained for formulation with yardlong bean. Among winter vegetable-based soups, pumpkin and bitter gourd achieved highest (7.50) and lowest (5.85) overall acceptability scores respectively. Further, with respective scores of 7.50, 7.40, 7.40 and 7.30, soups constituted with pumpkin, ash gourd, squash and bottle gourd possessed better sensory scores over the control formulation (6.50).

The higher sensory scores obtained in most cases is possibly due to the positive interaction of the constituents with the taste buds which eventually favored in enhancing the sensory properties. Also, most gourd vegetables possessed good flavor characteristics that thereby enhanced the sensory properties. Such excellent sensory properties have been reported earlier for pumpkin soup (pumpkin powder at 29.67% in a 67.4g soup mix as per Dhiman et al., 2017). On the contrary, the lower sensory scores obtained for soup system with bitter gourd can be attributed to the persistent bitter taste that existed during and after the consumption of soup. This feature can also be correlated with the lower scores obtained for other sensory parameters such as taste, mouthfeel and aftertaste. For the yardlong bean soup case, the lower sensory scores obtained could be due to the unlikely dominance of vegetable taste and aroma. Altogether, the reported findings provided useful inferences with respect to the optimality of each summer and winter vegetable in terms of their sensory properties and thereby support mixed vegetable formulation research. Thus, among the summer vegetables, spine gourd and sponge gourd vegetables which exhibited higher sensory properties in comparison to pointed gourd, ridge gourd, snake gourd and yardlong bean can be incorporated in higher proportions in the scheduled mixed vegetable soup formulation research. Similarly, among the winter vegetables, due to their better sensory characteristics, ash gourd, bottle gourd, pumpkin and squash can be incorporated in a higher proportion in the scheduled mixed vegetable soup formulation in comparison to beans and bitter gourd vegetables.

4.3 Optimality Based on Varied Combinations of Summer Vegetables

The optimality study was carried out to identify the best vegetable mix constitution among the twenty combinations of summer vegetable formulations. To achieve the desired objective, firstly, twenty soup mixes that were formulated as per the twenty combinations generated using excel (as summarized in Table 2.2 of the Ph.D. thesis and one control formulation (commercial soup)) were evaluated by the subjects through both 9-point hedonic scale method and SDI method. During such investigations, three vegetables in a combination were taken in proportions of 1g: 1g: 0.5g in a vegetable mix of 2.5g (in the overall 10g soup mix i.e., 40%: 40%: 20% of 25% vegetable mix).

4.3.1 9-point Hedonic Scale Based Sensory Evaluation of Mixed Summer Vegetable Soup Formulations

Overall acceptability scores obtained for each formulation through 9-point hedonic scale method have been presented in Table 4.1. Thereby, the formulations have been ranked from 1 to 21 by considering their overall acceptability scores in descending order. Among all formulations, SF14 (spine gourd: sponge gourd: ridge gourd at 40%: 40%: 20%) can be analyzed to be the best with highest sensory scores for all parameters followed by SF20 (spine gourd: sponge gourd: yardlong bean at 40%: 40%: 20%) and SF10 (pointed gourd: sponge gourd: yardlong bean at 40%: 40%: 20%). The formulations SF14, SF20 and SF10 possessed an overall acceptability score of 7.75, 7.70, and 7.65 respectively.

4.3.2 SDI Method Based Sensory Evaluation of Mixed Summer Vegetable Soup Formulations

The overall score and deviation index for each formulation in terms of the sensory scores obtained with SDI method have been presented in Table 4.1. Thereby, the formulations have been ranked from 1 to 21 by considering the highest score and lowest deviation index as a criterion for ranking (Figure 4.2). Symbols representing the formulation codes have been included in the figure for only selected five summer formulations. According to the overall scores and deviation index obtained through the SDI method, SF20 (spine gourd: sponge gourd: yardlong bean at 40%: 40%: 20%) can be analyzed to be the best with highest overall score (74.56) and lowest deviation index (19.28) followed by SF10 (pointed gourd: sponge gourd: yardlong bean at 40%: 40%: 20%) with 71.68 overall score and 20.78 DI; SF19 (snake gourd: sponge gourd: yardlong bean at 40%: 40%: 20%) with 71.47 overall score and 22.22 DI and SF9 (pointed gourd: spine gourd: yardlong bean at 40%: 40%: 20%) with 68.50 score and 21.30 DI.

4.3.3. Identification of Best Summer Vegetable Mix Constitution through Comparative Analysis of 9-point Hedonic and SDI Scores

Considering the overall scores, deviation index and ranks assigned to all formulations, five formulations have been selected for further screening of best summer vegetable mix constitution. The selected five formulations refer to SF20 (spine gourd: sponge gourd: yardlong bean at 40%: 40%: 20%), SF10 (pointed gourd: sponge gourd: yardlong bean at 40%: 40%: 20%), SF19 (snake gourd: sponge gourd: yardlong bean at 40%: 40%: 20%), SF9 (pointed gourd: spine gourd: yardlong bean at 40%: 40%: 20%) and SF14 (spine gourd: sponge gourd: ridge gourd at 40%: 40%: 20%). Notable observations are as follows. Firstly, the high scores and corresponding hedonic rank (2) and SDI rank (1) for the formulation SF20 can be attributed to the exceptional sensory properties of each vegetable used in the combination. Despite exhibiting lower sensory properties, yardlong bean with a 20% constitution (0.5g in a vegetable mix of 2.5g) did contribute to good sensory scores in the SF20 formulation. Secondly, the sensory scores and corresponding hedonic rank (3) and SDI rank (2) for the formulation SF10 could be due to the better sensory properties of sponge gourd. Also, for the case, the lower hedonic scores obtained for aroma, consistency and uniformity could be possibly due to the poor aroma property of yardlong bean and lower consistency provided by pointed gourd and yardlong bean. However, the lower DI values obtained for SF20 (19.28) and SF10 (20.78) indicate better uniformity within the sensory parameters.

Thirdly, SF14 which obtained highest overall acceptability score with the hedonic scale method has been assigned the best rank of 1. Through the SDI methodology, the SF14 formulation obtained a score of 74.47. However, the formulation has been assigned a rank of 7 through SDI method due to its high DI value of 34.57. Such higher DI in comparison to the DI of SF20 and SF10 indicates greater non-uniformity among the sensory parameters of formulation SF14. To a large extent, non-uniformity was primarily obtained for taste, aftertaste and consistency attributes. The non-uniformity observed could be mainly due to the lower sensory properties of ridge gourd which eventually affected the sensory attributes of the formulation. Fourthly, the formulation SF19 has been assigned a rank of 8 through hedonic method and a rank of 3 through the SDI method. Marginally lower overall acceptability (7.05) for the case could be attributed to the lower to moderate taste, consistency and aftertaste properties of the snake gourd and yardlong bean. Finally, marginally lower scores in comparison to other four formulation and corresponding hedonic scale-based rank of 11 and SDI based rank of 4 for the SF9 formulation could be possibly due to the lower taste, consistency, mouthfeel and aftertaste exhibited by pointed gourd and yardlong bean.

Further, important nutritional characteristics namely antioxidant activity, total phenolic content, vitamin C content and soluble protein content have been estimated for the five formulations through the mixing rule and the formulation SF20 has been observed to possess highest nutritional composition followed by formulations SF9 and SF10 (Table F1). Finally, considering both the sensory aspects and the nutritional characteristics, SF20 (spine gourd: sponge gourd: yardlong bean at 40%: 40%: 20%) with an overall acceptability score of 7.70, highest SDI score of 74.76 and lowest DI value of 19.28 has been identified as the best summer vegetable formulation followed by SF10 with 7.65 overall acceptability score, 71.68 SDI overall score and 20.78 DI. Similar overall acceptability score was reported for non-leafy vegetables soup (kolphul: kaskal: komora: posola at 4.3%: 5%: 8.7%: 2% in a 20g soup mix as per Mondal et al., 2022).

4.4 Optimality Based on Varied Combinations of Winter Vegetables

To identify the best vegetable mix constitution among the twenty combinations of winter vegetable formulations, firstly, the twenty soup mixes that were formulated as per the twenty combinations generated using excel as depicted in Table 2.2 of the Ph.D. thesis and one control formulation (commercial soup) were evaluated by the subjects with both 9-point hedonic scale method and SDI method. For each case, three vegetables were taken in proportions of 1g: 1g: 0.5g in a vegetable mix of 2.5g (in the overall 10g soup mix i.e., 40%: 40%: 20% of 25% vegetable mix).

4.4.1 9-point Hedonic Scale Based Sensory Evaluation of Mixed Winter Vegetable Soup Formulations

Table 4.1 summarizes the overall acceptability scores obtained through 9-point hedonic scale evaluation method. Thereby, the formulations including control formulation were ranked from 1 to 21 by considering their overall acceptability scores in descending order. Among all formulations, the WF20 (bottle gourd: pumpkin: squash at 40%: 40%: 20%) formulation can be observed to be the best with highest overall acceptability score, followed by WF10 (ash gourd: pumpkin: squash at 40%: 40%: 20%), WF8 (ash gourd: pumpkin: bottle gourd at 40%: 40%: 20%) and WF9 (ash gourd: bottle gourd: squash at 40%: 40%: 20%). Also, lowest sensory scores were obtained for WF1 (ash gourd: bitter gourd: beans at 40%: 40%: 20%). The overall acceptability scores of WF20, WF10, WF8, WF9 and WF1 have been 7.69, 7.50, 7.50, 7.48 and 5.00 respectively.

4.4.2 SDI Method Based Sensory Evaluation of Mixed Winter Vegetable Soup Formulations

Table 4.1 summarizes the overall score and deviation index values obtained for various formulations with the SDI method. Thereby, formulations have been ranked from 1 to 21 by considering highest score and lowest deviation index as a criterion for ranking (Figure 4.2). Symbols representing the formulation codes have been included in the figure for only selected five winter formulations. According to this method, the formulation WF9 (ash gourd: bottle gourd: squash) can be observed to be the best with an overall score of 74.76 and lowest DI value of 14.92 followed by WF8 (ash gourd: pumpkin: bottle gourd at 40%: 40%: 20%) with 73.45 overall score and 14.96 DI; WF10 (ash gourd: pumpkin: squash at 40%: 40%: 20%) with 77.38 overall score and 16.85 DI; WF4 (ash gourd: squash: beans at 40%: 40%: 20%) with 73.58 overall score and 18.64 DI and WF20 (bottle gourd: pumpkin: squash at 40%: 40%: 20%) with 73.58 overall score and 18.64 DI. Despite achieving highest score for formulation WF10, formulations WF9 and WF8 have been considered to be better due to the lower DI and better uniformity among the sensory parameters.

4.4.3 Identification of Best Winter Vegetable Mix Constitution through Comparative Analysis of 9-Point Hedonic and SDI Scores

Among the 20 formulations, based on the obtained sensory scores, deviation index and ranks assigned, five formulations namely WF9 (ash gourd: bottle gourd: squash at 40%: 40%: 20%), WF8 (ash gourd: pumpkin: bottle gourd at 40%: 40%: 20%), WF10 (ash gourd: pumpkin: squash at 40%: 40%: 20%), WF20 (bottle gourd: pumpkin: squash at 40%: 40%: 20%) and

WF4 (ash gourd: squash: beans at 40%: 40%: 20%) were selected for further screening of best winter vegetable mix constitution. Thereby, notable observations are as follows. Firstly, WF20 (bottle gourd: pumpkin: squash at 40%: 40%: 20%) obtained highest overall acceptability and was henceforth assigned the rank 1 through hedonic method. and rank 6 based on SDI score and DI. On the other hand, despite highest overall acceptability score, a higher DI was also observed for WF20 in comparison to WF9, WF8, WF10 and WF4 which indicated a greater extent of non-uniformity among the sensory attributes of WF20. Henceforth, formulation WF20 has been assigned SDI rank of 6 due to its higher DI value in comparison to WF9, WF8, WF10 and WF4. The sensory data obtained for the WF20 primarily indicated non-uniformity in taste, appearance and uniformity parameters. These have been corroborated to the marginally moderate taste and consistency properties of the bottle gourd.

Secondly, WF10 (ash gourd: pumpkin: squash at 40%: 40%: 20%) which has been assigned a rank of 2 and 3 with hedonic and SDI respective approaches possessed highest SDI overall score (77.38) but lower overall acceptability score (7.50) and DI value (16.85) in comparison to the WF20. The marginally lower but acceptable hedonic scores obtained for mouthfeel in contrast with other sensory parameters for the case can be attributed to the moderately good mouthfeel scores exhibited by the ash gourd. Also, uniformity has been analyzed as the main parameter to influence the DI value. Thirdly, WF8 (ash gourd: pumpkin: bottle gourd at 40%: 40%: 20%) with similar overall acceptability score as that of WF10 has been assigned a rank of 2 based on hedonic scale approach. Also, based on the SDI score and DI, a rank of 2 has been assigned. For the case, marginally lower but acceptable hedonic scores for consistency could be due to the consistency scores exhibited by ash gourd. Fourthly, formulation WF9 (ash gourd: bottle gourd: squash at 40%: 40%: 20%) has been assigned a rank 4 based on hedonic score and a rank of 1 based on SDI score and DI. The lowest DI (14.92) for the WF9 affirmed better uniformity among sensory parameters in comparison with the WF8, WF10, WF20 and

WF4 formulations. Finally, WF4 (ash gourd: squash: beans at 40%: 40%: 20%) which obtained lowest overall acceptability among the five formulations has been assigned a rank of 8. Further, based on SDI score and DI, it has been assigned a rank of 4. The lower overall acceptability score for the case can be attributed to average sensory properties exhibited by the beans.

Thereafter, nutritional characteristics namely antioxidant activity, total phenolic content, vitamin C content and soluble protein content have been estimated for the five formulations through the mixing rule and the formulation WF9 has been analyzed to possess highest nutritional characteristics followed by WF8 (Table F1). Finally, considering both sensory aspects and nutritional characteristics, the formulation WF9 (ash gourd: bottle gourd: squash at 40%: 40%: 20%) with an overall acceptability score of 7.48, SDI overall score of 74.76 and lowest DI value of 14.92 has been identified as the best winter vegetable formulation followed by WF8 (ash gourd: pumpkin: bottle gourd at 40%: 40%: 20%) that possessed an overall acceptability score of 7.50, SDI score of 73.45 and DI value of 14.96. Similar overall acceptability scores have been reported for pumpkin soup (pumpkin powder at 29.67% in a 67.4g soup mix as per Dhiman et al., 2017), tomato mushroom soup (tomato powder at 24.7% in 47g soup mix as per Verma, 2017) and millet-based vegetable soup (vegetbale mixture at 4.5% in a 220g soup mix as per Anita S et al., 2016).

4.5 Comparative Assessment of 9-Point Hedonic Scale Method and SDI Method as Techniques for Sensory Evaluation and with Literature Data

The 9-point hedonic scale based sensory scores obtained for various parameters of alternate summer and winter vegetable based mixed formulations studied in this work have been presented in Tables F2 and Table F3 respectively. The 9-point hedonic scale-based methodology affirmed sensory scores for each sensory parameter of the tested formulation. Thereby, overall acceptability has been as well considered as an individual sensory parameter.

This parameter was evaluated and was assigned a score by each subject based on the perception of the subject towards all other sensory parameters of the tested formulation. This is applicable for all the summer and winter formulation studied in this work. However, a basic limitation of this methodology is that the parameter that exhibited maximum weightage on the overall acceptability score could not be assessed from the overall acceptability score itself. In other words, the sensitive inefficacies of the formulation could not be analysed from the ranking approach based on the overall acceptability score. For example, hedonic sensory scores for various sensory parameters of summer vegetable formulation SF20 (spine gourd, sponge gourd, yardlong bean) varied between 7.2 to 7.5. However, an overall acceptability pf 7.7 out of 9 was obtained for SF20. Thus, the score of 7.7 fails to capture the issue related to 7.2 lower score for parameter aroma. However, the formulation can be judged to be very good from the sensory analysis. Similar trend was observed in a study conducted by Alozie & Ene- Obong, 2018 (leafy vegetables at 41.2% in 1500g soup). In the article, the scores of sensory attributes ranged between 7.51 and 8.12, but the score corresponding to overall acceptability was observed as 8.25.

In few other studies conducted by Islam et al., 2023 and Abdeldaiem et al., 2023, the authors qualitatively inferred that the appearance/colour and texture had an important role on the acceptability of jack fruit-based soup product and ice cream supplemented with corn powder respectively. However, quantitative identification of attributes weightage or most influential attribute was not considered by the authors. Further, in studies conducted on various products such as water leaf and wild spinach soup (leafy vegetables at 41.2% in 1500g soup as per Alozie & Ene- Obong, 2018b), leafy vegetable soup (kolmou: jatilao: pui at 2%: 15%: 3% in a 20g soup mix as per Mondal et al., 2020), tomato-mushroom soup (tomato powder at 24.7% in 47g soup mix as per Verma, 2017) and gymnema and mixed vegetable soup (gymnema: broccoli: banana: pumpkin: moringa at 20%: 20%: 20%: 20%; 20% in 5g vegetable mix in overall 12g soup mix as per Nandhini et al., 2020), the authors adapted 9-point hedonic scale technique for the sensory evaluation of food samples. From their findings, it has been observed that, the authors have identified the best samples in terms of overall acceptability score. For the samples, a significant difference was achieved for the score in comparison to other formulations. However, despite the identification of formulation based on mathematical significance, the authors did not deduce upon the weightage of individual attribute through the 9-point hedonic scale method.

In contrast to 9-point hedonic scale method, categorization of sensory parameters into main and sub parameters in the SDI method provided better inferences upon the sensory attributes with maximum weightage on overall score of a formulation. This method has also aided in a better understanding of the extent of uniformity among the sensory parameters of a formulation through DI. For example, the comparative scores and absolute scores provided for each main parameter by the subjects indicated the weightage of each main parameter out of 100 and the score for each individual parameter out of 100 respectively. Further, the overall score for each formulation was determined by taking into consideration both comparative and absolute scores provided by the subjects for that formulation. So doing, the overall score obtained for a formulation involved the consideration of weightage of each main parameter. For example, for the SF20, an overall score of 74.56 involved both absolute and comparative scores of the formulation as well as weightage associated to each main parameter. Similar is the case for all other formulations. Hence, unlike the 9-point hedonic scale method, the weightage of sensory parameter in obtained overall score and also the extent of importance of each sensory parameter could be identified in the SDI method. Thereby, the SDI method eliminated the individual bias that exists in the 9-point hedonic scale method.

For example, in a study conducted by Lafarga et al., 2019, the authors determined the acceptability index of broccoli soup (47.8% boiled broccoli in 100g soup) by evaluating the scores obtained for individual parameters through 9-point hedonic scale method. However, the findings affirmed only the order of preference of the samples but not the weightage or uniformity of the attributes. Similar was the case for potato-barley-lentil based soups, where the overall acceptability was determined by calculating the mean of scores assigned to other sensory attributes using 9-point hedonic scale method (vegetable mix at 19% in a 100g soup mix as per Abdel-Haleem & Omran, 2014). In another study conducted by Pauline et al., 2017, sensory evaluation of banana and maize based traditional alcoholic beverage was conducted using 9-point hedonic scale method. In their study, the authors deployed a 9-point scale where 9 corresponded to excellent score and 1 corresponded to poor score. Four sensory attributes which did not include overall acceptability were used to determine the best formulation. Based on the scores obtained for all formulations, the authors identified colour as the highest scored attribute followed by odour, aroma and taste and accordingly identified the best formulation based on the scores obtained for the four attributes. Also, overall acceptability was not considered as a sensory attribute in the conducted study by the authors. Although the order of sensory attributes was identified based on the obtained scores, the authors did not infer upon the relative importance of each attribute. The findings of all these studies can be correlated to the individual bias observed in the 9-point hedonic scale methodology.

Further, in the SDI method, the extent of uniformity and non-uniformity within the sensory parameters and the most influential sensory parameters could be analysed and inferred through the DI values. This was not possible in the 9-point hedonic scale method. For example, the SF20 formulation with a lower DI of 19.28 indicated greater uniformity among the sensory parameters in comparison to SF14 formulation with a very high DI of 34.57 hence indicating greater non-uniformity among its sensory parameters irrespective of its high overall acceptability score of 7.75. Thereby, DI has played a vital role in providing inferences with respect to the uniformity among sensory parameters of each formulation. SDI method has also provided results with improved inferences regarding sensory characteristics in terms of parameter weightage and uniformity. Henceforth, considering the advantages pertinent in the SDI method, it can be adopted as an efficient alternate and a comparative sensory evaluation method to the commonly deployed 9-point hedonic scale method. Thereby, associated limitations can be mitigated for the 9-point hedonic scale method.

4.6 Literature Comparison for Nutrient Characteristics

Table 4.2 summarizes the antioxidant activity, vitamin C content, total phenolic content and soluble protein contents of the control commercial and literature formulation and the best summer and winter vegetable formulations that were identified through the conducted studies and with the detailed methodology in section 2.2.4 of the Ph.D. thesis. The antioxidant activity, total phenolic content, vitamin C and soluble protein content of the best formulations varied as 0.5- 0.83 % DM, 198.83- 294.21 mg/g DM, 1.03- 1.73 mg/g DM and 21.48- 23.46 mg/g DM respectively. Since sensory acceptability of a soup product plays a vital role along with its nutritional content, the thesis objectives were aimed to achieve an optimal vegetable soup mix formulation in terms of a higher sensory acceptability and nutritionally acceptable characteristics of the sensory analysis based best formulations. Among the summer vegetable formulations summarized in Table 4.2, the formulation being constituted with spine gourd, sponge gourd and yardlong bean exhibited higher scores for all parameters but antioxidant activity in comparison to the formulation being constituted with pointed gourd, sponge gourd and yardlong bean. However, only a very minimal difference (0.01%) was observed in the antioxidant activity. Accordingly, the formulation constituted with sponge gourd, spine gourd and yardlong bean has been identified as the best formulation. Similarly, among winter vegetable soups, formulation being constituted with ash gourd, bottle gourd and squash exhibited higher scores for all parameters but total phenolic content in comparison to that of the formulation constituted with ash gourd, pumpkin and bottle gourd. However, since the formulation with ash gourd, bottle gourd and squash affirmed higher scores for most parameters, it has been chosen as the best. Further, both formulations exhibited better scores in comparison to the commercial Knorr mixed vegetable soup. This conveys optimality and best combination of both sensory and nutritional characteristics. This is primarily due to the higher proportion of vegetables (25%) in the soup mix formulation. Also, all the formulations had a moisture content below the desired 8 percent value and had a water activity between 0.4 - 0.49. Similar water activity has been reported for legume-based vegetable soup mix (vegetable mix at 19% in a 100g soup mix as per Abdel-Haleem & Omran, 2014). These levels of moisture content and water activity affirm upon the safe storage condition of the dry soup mixes. This is due to the moisture content and water activity level being lower than that required for the prevention of microbial growth (10 percent moisture content and 0.6 a_w respectively).

4.7 Summary

Firstly, this chapter targeted the development of summer and winter vegetable-based soup mix formulations and identification of best summer and winter vegetable mix constitutions through a structured methodology that involved the equal consideration of both nutritional and sensory properties of the chosen vegetables. Secondly, the SDI method has been designed, implemented and verified for the first time as an alternative sensory evaluation technique and has been evaluated for its efficacy with respect to the most commonly used 9-point hedonic scale technique. Further, among the various formulations experimented with the summer vegetables, formulation SF20 (spine gourd, sponge gourd and yardlong bean at 40%: 40%: 20%) with 7.70 hedonic overall acceptability, highest overall score 74.56 and lowest DI 19.28, high antioxidant activity (0.5%), highest total phenolic content (247.82 mg/g dry mass (DM)) and highest

Table 4.2: A summary of best data obtained in this work and reported in the literature.

S.No	Vegetables in formulation	Overall accepta-bility	SDI Score	DI	MC (%)	Water activity (a_w)	AA (%/ DM)	TPC (mg/g DM)	VIT C (mg/g DM)	Soluble protein (g/g DM)	Reference
1	• Spine gourd • Sponge gourd • Yardlong bean	7.70	74.56	19.28	6.54 ± 0.06	0.40	0.5 ± 0.04 (46.35 ± 0.47)	247.82 ± 4.46 (231.62 ± 4.17)	1.73 ± 0.09 (1.62 ± 0.86)	0.22 ± 0.02 (0.21 ± 0.02)	This work
2	• Pointed gourd • Sponge gourd • Yardlong bean	7.65	71.68	20.78	7.19 ± 0.25	0.49	0.51 ± 0.04 (47.58 ± 3.62)	198.83 ± 4.46 (184.547 ± 20.12)	1.44 ± 0.13 (1.33 ± 0.12)	0.21 ± 0.01 (0.20 ± 0.09)	This work
3	• Ash gourd • Bottle gourd • Squash	7.48	74.76	14.92	6.81 ± 0.43	0.42	0.83 ± 0.02 (77.40 ± 1.95)	279.88 ± 12.32 (260.82 ± 11.48)	1.47 ± 0.07 (1.37 ± 0.65)	0.23 ± 0.03 (0.22 ± 0.03)	This work
4	• Ash gourd • Pumpkin • Bottle gourd	7.50	73.45	14.96	5.49 ± 1.24	0.47	0.72 ± 0.07 (68.30 ± 6.27)	294.21 ± 20.70 (278.35 ± 19.59)	1.03 ± 0.12 (0.98 ± 0.12)	0.23 ± 0.06 (0.22 ± 0.06)	This work
5	Commercial (Knorr)	6.60	65.75	38.32	3.11 ± 0.06	0.25	0.09 ± 0.02 (8.69 ± 1.67)	121.65 ± 1.23 (117.87 ± 1.19)	0.66 ± 0.09 (0.64 ± 0.86)	0.23 ± 0.09 (0.22 ± 0.09)	Commercial soup
6	• Pumpkin	7.94	-	-	4.91	0.34	-	-	-	0.13	Dhiman et al., 2017
7	• Carrot • Peas	8.1	-	-	3.70	-	38	47	-	1.00	Anita S et al., 2016

vitamin C content (1.73 mg/g DM) has been identified as the best through comparative assessment of sensory scores obtained through 9-point hedonic scale and SDI methods followed by nutritional characterization. Similarly, among the winter vegetable formulations, WF9 (ash gourd, bottle and squash at 40%: 40%: 20%) with 7.48 hedonic overall acceptability score, 74.76 overall score and lowest deviation index of 14.92, highest antioxidant activity (0.83%), high total phenolic content (279.88 mg/g DM) and highest vitamin C content (1.47 mg/g DM) has been identified as the best winter vegetable mix constitution. Finally, implementation of SDI method as an alternate sensory evaluation technique provided useful inferences upon important aspects such as weightage contributed by each sensory parameter to the overall score of a formulation and uniformity within the sensory parameters. Such inferences assisted in the effective identification of the best formulations with higher levels of confidence. Thus, SDI method can be utilized as an alternate sensory evaluation tool for the efficient evaluation of various soup and similar food products.

Thereby, in the following chapter, the formulations identified as best have been subjected to further optimization of the proportions of vegetable mix, corn flour and spice mix composition. These refer to the summer vegetable formulation, SF20 (spine gourd, sponge gourd and yardlong bean at 40%: 40%: 20%) and winter vegetable formulation, WF9 (ash gourd, bottle and squash at 40%: 40%: 20%). To achieve this, trial and error methodology-based optimization of vegetable mix (25 – 50 wt%), corn flour (20 – 30 wt%) and spice mix (30 – 50 wt%) proportions of the best identified formulations has been targeted. This has been addressed in the following chapter.

Chapter 5:

Optimization of Trial and Error Methodology Based Soup Mix Formulations

Optimization of Trial and Error Methodology Based Soup Mix Formulations

Overview of the Chapter

In this chapter, the results associated to the sensory optimality-based trial and error methodology assisted optimization of vegetable mix, thickening agent (corn flour) and spice mix compositions have been elucidated. To achieve this, alternate summer and winter vegetable-based soup formulations with varied proportions of vegetable mix, corn flour and spice mix were prepared and evaluated with the three sensory evaluation techniques namely, the the novel score deviation (SDI) method, 9-point hedonic scale method and fuzzy logic analysis. After a brief outline in section 5.1, section 5.2 elucidates upon the trial-and-error methodology-based optimization of summer vegetable soup mix formulations. Further, in section 5.3, the findings associated with the trial-and-error methodology-based optimization of winter vegetable soup mix formulations have been summarized. Sections 5.2 and 5.3 as well provides insights with respect to the efficacy of the novel score deviation (SDI) method, 9-point hedonic scale method and fuzzy logic analysis for the identification of soup formulation with optimal proportions of vegetable mix, corn flour and spice mix. Section 5.4 summarizes the nutritional composition and nutrient bio accessibility of the optimal summer and winter vegetable-based soup mix formulations. Finally, section 5.5 presents an overall summary of the research findings associated with the identification of soup mix formulations with optimal proportions of vegetable mix, corn flour and spice mix and with the comparative assessment methodology of score deviation, 9-point hedonic scale and fuzzy logic sensory methods.

5.1 Introduction

This chapter reports the findings associated to the optimality of soup mix formulation in terms of the proportions of vegetable mix, corn flour and spice mix through trial-and-error methodology assisted optimization. The major findings in the previous chapter ascertain upon the best combinations of three summer (spine gourd, sponge gourd and yardlong bean at 40%: 40%: 20%) and three winter vegetables (ash gourd, bottle and squash at 40%: 40%: 20%) in a vegetable mix of 2.5g in the overall 10g (25 wt% corn flour and 50 wt% spice mix) constitution of the summer and winter vegetables-based soup mix formulations respectively. In this chapter, the screened formulations with fixed proportions of vegetable mix, corn flour and spice mix were further optimized to affirm upon soup mix formulations with improved sensory and nutritional characteristics. To achieve this, five alternate summer vegetable soup formulations and seven alternate winter vegetable soup formulations were prepared though proportionate variation of the ingredients namely, vegetable mix (25-50 wt%), corn flour (20-30 wt%) and spice mix (30-50 wt%) with respect to the constitution of best identified soup formulations in the previous chapter. Thereby, the summer and winter vegetable soups with optimal proportions of vegetable mix, corn flour and spice mix among the developed alternate soup formulations were affirmed through the comparative assessment of the sensory analysis data obtained with the three sensory analysis methods namely the novel score deviation (SDI) method, 9-point hedonic scale method and fuzzy logic analysis methods. Subsequently, the optimal soup mix formulations were evaluated for nutritional composition and nutrient bio accessibility.

5.2 Trial and Error Methodology based Optimization of Summer Vegetable Soup Mix Formulations

After the identification of best vegetable mix combinations in the previous chapter, the chapter addresses the trial and error-based optimization-based findings for the identification of formulations with optimal proportions of vegetable mix, corn flour and spice mix. To achieve this, the vegetable mix, corn flour and spice mix proportions which were maintained at fixed proportions i.e., 25 wt%, 25 wt% and 50 wt% respectively in the overall 10g soup mix have been varied proportionately to thereby identify an optimal soup mix composition with improved sensory and nutritional characteristics. Accordingly, for the case of summer vegetable-based soup mix formulations, five alternate soup mix formulations with weight % ratios of vegetable mix: corn flour: spice mix varied as 25:25:50 (SA), 40:20:40 (SB), 40:25:35 (SC), 40:30:30 (SD) and 50:20:30 (SE) were prepared. Further, the developed soup formulations were evaluated for sensory parameters with the 9-point hedonic method, novel score deviation method and fuzzy logic sensory analysis techniques. Prior to the sensory analysis, each soup mix formulation (10g) was reconstituted with water in the ratio of 1:16 followed by boiling for 5 min with continuous stirring. The detailed procedures followed for the formulation and evaluation of soup mixes have been presented in section 2.5 of the Ph.D. thesis.

5.2.1 Optimal Summer Vegetable Formulation based on 9-Point Hedonic Scale Method

Table 5.1 summarizes the hedonic scale based sensory scores obtained for various sensory parameters of each sample. Firstly, among all soup formulations, sample SE (50% veg mix, 20% corn flour and 30% spice mix) affirmed highest overall acceptability (8.00) and was

Table 5.1: Sensory scores achieved with 9-point hedonic scale and SDI methods for samples SA-SE.

Sample	Taste	Mouth-feel	After-taste	Aroma	Appear-ance	Consis-tency	Uni-formity	Overall-acceptability	Score	DI	Average main parameter weightage out of 100 (S-DI)		
											Taste Index	Aroma	Physical Index
SA	7.4±1.1	7.5±1.08	7.5±1	7.2±1.06	7.4±1.2	7.4±1.07	7.45±0.9	7.7±0.98	74.56	19.28	36.67	36.67	26.67
SB	7.25±0.88	7.25±0.88	7.25±0.88	7.25±0.88	6.83±1.29	7.42±0.66	6.83±1.75	7.17±1.21	77.17	21.19	39.67	37.33	21.33
SC	7.17±0.52	6.92±0.66	6.83±0.98	7.33±1.33	6.75±1.41	6.92±1.02	6.5±1.64	7.25±0.88	75.08	27.36	43.33	34.17	22.5
SD	7.42±1.59	7.42±1.02	7.17±1.13	7.75±0.76	7.25±1.33	7.75±0.76	7±1.76	7.42±1.32	79.86	19.25	41.5	36.33	20.5
SE	7.83±0.75	7.92±1.02	7.83±0.75	8.00±0.55	7.42±1.36	7.58±0.8	7.17±1.83	8.00±0.71	81.26	21.96	48.8	28.8	22.4

inferred to be in the like very much category followed by samples SA (7.7), SD (7.42), SC (7.25) and SB (7.17). All these were inferred to be in the like moderately category. The sample SE also possessed highest sensory scores in terms of all sensory parameters but consistency. A marginally higher score in terms of consistency was obtained for sample SD (7.75) in comparison to the consistency score of sample SE (7.58). Secondly, for the samples SE, SD and SC, highest scores were obtained for aroma. The enhancement in the aroma of these soups could be attributed to the flavor constitution contributed by the increased content of vegetables. Also, spine gourd and sponge gourd were analyzed to exhibit better aroma property as per the findings reported for single vegetable formulations in section 4.2 of the Ph.D. thesis. Further, for the sample SB, highest scores were obtained for consistency. However, for sample SA, highest scores were obtained for mouthfeel and aftertaste. However, these scores were lower than the scores obtained for sample SE. In summary, sample SE with an overall acceptability of 8.00 was identified as the best through 9-point hedonic scale sensory analysis. A relatively higher overall acceptability (8.5) was reported for the soup formulated with 37.4% mixed vegetable (green peas at 65.79%, turnip at 13.16%, carrot at 10.53% and onion at 10.53%) and 12.5% pea pod powder (Hanan et al., 2020).

5.2.2 Optimal Summer Vegetable Formulation based on Score Deviation (SDI) Method

The overall score (OS), deviation index (DI) and weightage of sensory attributes obtained for the five soup formulations and the ranks assigned to the formulations have been presented in Table 5.1 and Figure 5.1 respectively. Firstly, among all the formulations, the sample SD achieved lowest DI of 19.25 for an OS of 79.86. This was followed by the sample E that obtained a DI of 19.28 for an OS of 74.56. However, despite sample E achieving a marginally higher DI of 21.96 in comparison to samples SD and SA, it has been assigned the rank 1. This is due to its higher OS and DI values that are within the 10% of the DI of SD and SA samples.

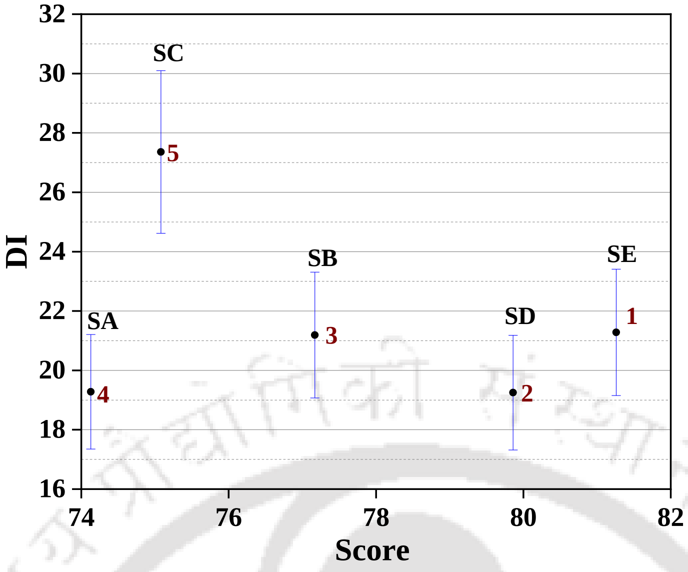


Figure 5.1. SDI based formulation ranking of alternate soup samples SA-SE.

Secondly, the sample SD has been assigned a rank of 2 followed by sample SB, which obtained higher OS (77.17) and marginally higher DI (21.19) in comparison to sample SA (being assigned a rank of 4). Thirdly, sample SC was assigned a rank of 5 due to its highest DI (27.36). This conveyed a greater non-uniformity among the sensory parameters. Also, the weightage of each main parameter namely taste index (TI), aroma (AI) and physical index (PI) on a sample's OS was determined through the SDI sensory scores. The scores obtained for sub parameters depicted attributes under PI to be exhibiting maximum contribution towards non-uniformity. Further, weightage of each main parameter on the OS was obtained based on the scores attained for the main sensory attributes. From the reported findings, it has been confirmed that, for all the formulations, the TI exhibited maximum weightage on the OS followed by AI and PI.

5.2.3 Optimal Summer Vegetable Formulation based on Fuzzy Logic Analysis

The linguistic sensory data obtained through fuzzy logic analysis was converted into numerical data and has been analyzed as similarity values for the ranking of the samples and associated sensory attributes. Similarity values obtained for the samples and the sensory attributes have been summarized in Tables 5.2 and 5.3 respectively. Firstly, for each case, the highest similarity value was obtained for the linguistic category as good. This conveyed that all the samples are acceptable and can be characterized in the category good. However, among all, highest similarity value of 0.735 was obtained for sample SE. Thereby, it affirmed sample SE to be the most preferred followed by samples SD (0.721), SC (0.707), SB (0.662) and SA (0.639). Secondly, among all sensory attributes, the taste achieved highest similarity value for the linguistic category extremely important. Further, mouthfeel, aftertaste, aroma and overall-acceptability were analyzed to be highly important attributes based on their similarity values. On the contrary, appearance, consistency and uniformity were observed to be important sensory attributes.

Table 5.2: Sample category similarity values of samples SA-SE in the fuzzy logic methodology-based case study.

Linguistic scale	SA	SB	SC	SD	SE
Not satisfactory	0.029	0.028	0.022	0	0
Fair	0.248	0.255	0.228	0.117	0.060
Satisfactory	0.582	0.604	0.578	0.441	0.298
Good	0.639	0.662	0.707	0.721	0.735
Very good	0.303	0.315	0.399	0.577	0.712
Excellent	0.032	0.034	0.073	0.158	0.234

Table 5.3: Sensory attributes similarity values in the fuzzy logic analysis-based case study.

Linguistic scale for sensory attributes	Taste	Mouth-feel	After-taste	Aroma	Appea-rance	Consis-tency	Uni-formity	Overall-acceptability
Not at all necessary	0	0	0	0	0	0	0	0
Somewhat necessary	0	0	0	0	0.042	0	0	0
Necessary	0	0	0	0	0.444	0.13	0.036	0
Important	0	0.035	0.223	0.227	0.469	0.507	0.459	0.468
Highly important	0.126	0.441	0.579	0.531	0.075	0.26	0.428	0.487
Extremely important	0.176	0.353	0.2	0.123	0	0	0.027	0.238

Finally, based on the linguistic categories and corresponding similarity values, sensory attributes hierarchy of importance was identified as taste (0.176 – Extremely important) > aftertaste (0.579 – Highly important) > aroma (0.531 – Highly important) > consistency (0.507 – Important) > appearance (0.469 – Important) > uniformity (0.459 – Important). In a study conducted by Sugumar & Guha, 2022, the fuzzy logic analysis of soup formulation incorporated with 3% solanum nigrum leaf powder, 35% starch and 62% spice mix affirmed that the taste was the most preferred sensory parameter followed by mouthfeel, flavor and colour. As the preference of parameters is mainly based on individual perception, the order of preference may vary with respect to the subjects personal interest for varied product palette. However, the results obtained through the fuzzy logic analysis provide inferences on the overall preference order of the sensory parameters and samples.

5.2.4 Optimal Summer Vegetable Formulation based on Assessed and Literature Data

Firstly, sample SE constituted with 50% vegetable mix was identified as the best through all the three sensory evaluation techniques. However, it has been observed that the samples preference order varied among the three techniques but for the best sample. Based on the 9-point hedonic scale technique, the sample preference sequence was identified as SE > SA > SD > SC > SB. For the case of SDI method and fuzzy logic analysis, sample preference sequence varied as SE > SD > SB > SA > SC and SE > SD > SC > SB > SA respectively. The variation in preference order observed in three evaluation techniques and especially for the samples with lower acceptability could be attributed to the varied perceptions of the panel members towards minute alterations in the sensory characteristics of the samples.

Secondly, in the 9-point hedonic scale based sensory evaluation, all sensory attributes including overall-acceptability have been assigned individual scores based on the 9-point scale and the sample preference and acceptability was identified. However, a limiting factor of this technique is that the sensory attribute with major influence or importance on the overall-acceptability of a sample could not be identified. For instance, the sensory scores of various attributes of sample SD varied between 7.00 to 7.75 where aroma and consistency achieved maximum scores while uniformity achieved the minimum score. Despite a wide range of scores of individual attributes, an overall-acceptability score of 7.42 was obtained for the sample. For the case, it could not be determined whether aroma and consistency with maximum scores or uniformity with minimum score or any among the other attributes that influenced the overall-acceptability of the sample. Thus, there exists an individual bias in 9-point hedonic scale technique, and this varies with respect to the preference of each individual. Similar limitation was observed for the case of other samples as well. Also, a similar issue was reported in a study conducted on the sensory acceptability of wild spinach and water leaf soup (leafy vegetables at 41.2% in 1500g aqueous soup). In this study, the attribute that exhibited maximum influence on the overall-acceptability of the product could not be determined (Alozie & Ene- Obong, 2018a).

In another study conducted for the jack fruit soup, qualitative inference of important attributes was reported by the authors but quantitative inference was not addressed (Islam et al., 2023a). In this regard, it can be interpreted that 9-point hedonic scale method aids in the identification of sample preference and acceptability. However, the method could not quantify upon the importance or weightage of individual sensory attribute. Thirdly, for the case of SDI method, the OS and DI values obtained through the classification of sensory attributes into main and sub parameters provided inferences on the acceptability of the samples and uniformity among the sensory parameters respectively. Additionally, SDI method also provided inferences upon the weightage of each main parameter. This could not be achieved through the 9-point hedonic scale method. Such an aspect aided in the identification of attributes that played major role on the acceptability of the samples. Thereby, it eliminated the individual bias that existed in the 9-point hedonic scale method. Similar aspects were apparent in the sensory evaluation studies conducted with both 9-point hedonic scale method and SDI method on mixed vegetable soup formulations. These findings have been delineated in sections 4.3.2, 4.3.3, 4.4.2 and 4.4.3 of the Ph.D. thesis. Fourthly, for the case of the fuzzy logic based sensory evaluation, inferences regarding the sample and sensory attribute preference were obtained along with corresponding linguistic categories of acceptance and importance respectively.

5.3 Trial and Error Methodology based Optimization of Winter Vegetable Soup Mix Formulations

To achieve the desired objective, five alternate soup mix formulations with weight % ratios of vegetable mix: corn flour: spice mix and being varied as 25:25:50 (WA), 40:20:40 (WB), 40:25:35 (WC), 40:30:30 (WD) and 50:20:30 (WE) were prepared with proportionate variation of ingredients. These were based on the best reported winter vegetables-based soup mix formulation in the previous chapter. However, for the case of sample WE, proportionate variation of the spice mix did not result in an acceptable soup formulation in terms of taste and aroma. Therefore, the spice mix composition of sample WE were further altered and standardized through trial experiments. Also, due to the very high consistency exhibited by formulation WE with 50% vegetables, dry soup mix WE was reconstituted with water in the ratios of 1:20 (WE1) and 1:22 (WE2) as well. However, for other samples, the reconstitution ratio was 1:18. Further details of the procedures followed for the formulation and evaluation of soup mixes have been presented in section 2.5 of the Ph.D. thesis.

5.3.1 Optimal Winter Vegetable Formulation based on 9-point Hedonic Scale Method

Sensory scores attained for the sensory attributes of each soup sample have been presented in Table 5.4. From the findings, it has been observed that sample WE2 with 50% vegetable mix (with reconstitution ratio of 1:22) achieved highest overall acceptability score of 8.10. Also, sample WE2 was identified to fall under like very much category with highest scores for all the sensory attributes in comparison to the sensory scores of other samples. Further, sample WE2 was followed by samples WA and WE1 which were observed to be in like moderately category with respective overall acceptability scores of 7.48 and 7.00. Based on the overall acceptability scores, the order of preference of samples was identified as WE2, WA, WE1, WC, WB, WE. Similarly, few studies which conducted 9-point hedonic scale based sensory analysis of soups and other products reported qualitative inferences on various sensory parameters but not quantitative inferences. For example, Islam et al., 2023, in their studies, reported that the appearance had a higher influence on the overall acceptability of the jack fruit based soup product.

In another study conducted by Abdeldaiem et al., 2023, the authors qualitatively inferred texture to have greater influence on overall acceptability of ice cream supplemented with corn flour. Further, in the present study, an increase in vegetable content resulted in increased score for the aroma property in the WE2, WE1, and WB samples. Similar findings were reported for the studies conducted with leafy vegetable soups (kolmou: jatilao: pui at 2%: 15%: 3% in a 20gsoup mix as per Mondal et al., 2020). In their study, the authors identified soup sample with leafy vegetable mix to corn flour in the mix of 40: 60 as the best. However, for a leafy vegetable mix to corn flour ratio of 50:50, the authors reported a decline in the overall acceptability scores. This is due to the pertinent herbal flavor contributed by the leafy vegetables. On the other hand, non-leafy vegetables used for the soup samples in the present study resulted in improved sensory properties for the case of their higher proportion. A higher proportion of vegetables in the soup formulation have contributed to the enhanced aroma of the soup.

Table 5.4: Sensory scores achieved with 9-point hedonic scale and SDI methods for samples WA-WE2.

Sample	Taste	Mouthfeel	Aftertaste	Aroma	Appear-ance	Consis-tency	Uniformity	Overall acceptability	Score	DI	Average main parameter weightage (SDI)		
											Taste Index	Aroma	Physical Index
WA	7.53±0.91	7.31±0.84	7.54±1.01	7.06±1.15	7.1±0.98	7±1.1	7.11±1.23	7.48±0.75	73.88	14.92	37.5	35	30.83
WB	6.71±1.07	6.43±1.48	6.79±1.15	7.29±1.41	7.29±1.11	7.29±1.11	6.64±1.55	6.79±1.29	71.54	34.52	44.17	24.17	31.67
WC	6.64±1.03	6.57±1.27	6.86±1.07	6.93±0.84	6.86±0.38	7.29±0.76	6.71±1.5	6.93±1.34	72.18	30.96	40	32.5	27.5
WD	5.5±1.55	6.07±1.24	6.07±1.1	6.93±1.02	6.86±0.9	6.93±0.93	6.43±1.4	6±1.29	69.35	24.21	36.67	41.67	23.33
WE	5.64±1.49	5.86±1.35	6.14±1.35	7±1.15	6.86±1.21	6.29±1.25	6.14±1.57	6.14±1.03	67.50	32.63	30.83	42.5	31.67
WE1	6.67±0.82	6.83±0.98	6.67±1.21	7.42±0.92	7.42±0.66	6.75±1.17	6.92±1.28	7±0.71	68.79	25.40	32.5	30.83	36.67
WE2	8.08±0.49	8.08±0.8	7.75±0.61	8±0.32	7.83±0.75	7.83±0.75	8.17±0.98	8.1±0.75	81.35	17.79	46.67	26.67	26.67

The vegetable used in these formulations namely ash gourd, bottle gourd and squash have also been identified to exhibit good taste and aroma properties as per the findings reported for single vegetable soup mix formulations in section 4.2 of the Ph.D. thesis. Thus, the better scores for taste and aroma at increased proportion of vegetables may be attributed to the excellent taste and aroma properties of each vegetable. However, at an increased proportion of vegetables i.e., the vegetable mix with 50% vegetable constitution, reconstitution ratio profoundly influenced the sensory properties of the soup samples. For example, for the case in which dry soup mix WE was reconstituted with water in the ratio of 1:18 and 1:20, lower scores were observed for taste and consistency parameters. This was primarily due to the very high viscosity caused due to the starchy nature of the vegetables incorporated in the soups. However, an enhancement of the reconstitution ratio to 1:22 resulted in the soup with improved sensory characteristics. However, for soup samples with 25 and 40% vegetables, a reduction in consistency was observed for the trials that involved enhanced reconstitution ratio of 1: 20 and 1:22. The soups were observed to have very high flowability and henceforth poor consistency. Finally, sample WE2 was identified to be the best with the 9-point hedonic scale based overall acceptability scores.

5.3.2 Optimal Winter Vegetable Formulation based on SDI Method

The OS and DI values obtained for the soup samples through SDI method have been summarized in Table 5.4. The samples were assigned ranks from 1 to 7. The ranking criterion considered highest score and lowest DI as a standard for the assignment of ranks (Figure 5.2). Firstly, among all the formulations, sample WA obtained lowest DI of 14.92 for an OS of 73.88. Secondly, sample WE2 which obtained a significantly higher OS (81.35) exhibited a marginally higher DI (17.79) in comparison to sample WA. Despite sample WA obtaining a marginally lower DI in comparison to the sample WE2, it can be observed that the OS of WA is significantly (10%) lower than that of sample WE. This conveys similar uniformity among the sensory parameters of sample WE2 and WA and better acceptability for the sample case WE2. Thus, sample WE2 has been assigned the rank 1 followed by rank 2 for the WA sample. Thirdly, WC, WB, WD and WE1 obtained OS and DI values of 72.18 and 30.96, 71.54 and 34.52, 69.35 and 24.21, and 68.79 and 24.50 respectively. Despite obtaining higher OS values for samples WC and WB in comparison to those obtained for WD and WE1, samples WC and WB were ranked after WD and WE1. This is due to their high DI values and henceforth affirmation of the greater degree of non-uniformity between the sensory attributes. Fourthly, sample WE, which obtained lowest OS (67.50) and high DI (32.63) has been assigned rank 7. Thereby, considering the OS and DI values, the sample preference order can be identified as WE2, WA, WD, WE1, WC, WB and WE. The lower DI values obtained for WA and WE2 indicated better uniformity among the sensory attributes in both samples. Also, from

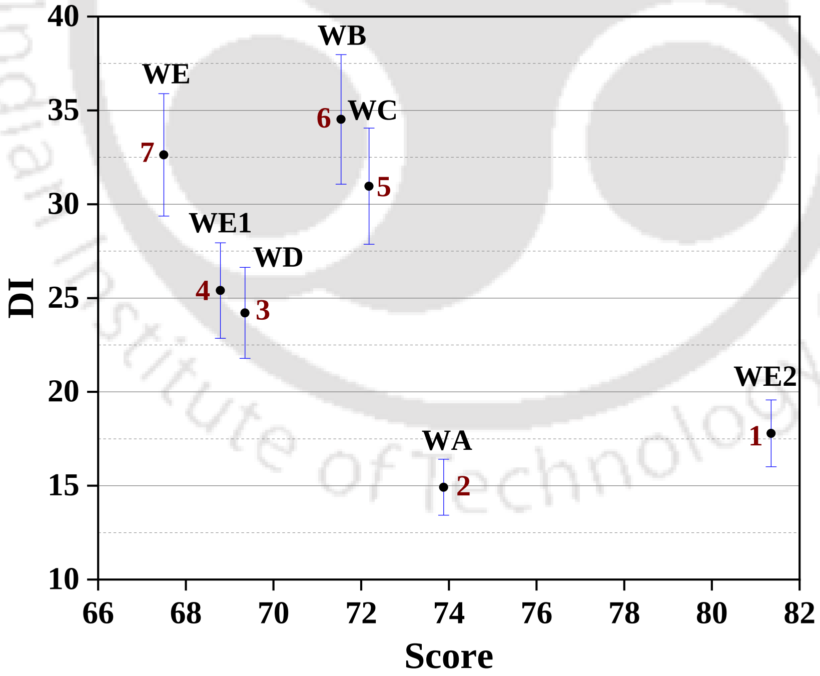


Figure. 5.2. SDI method-based sample ranking for WA-WE2 samples.

the OS and DI values of samples WE, WE1 and WE2, it can be inferred that the reconstitution ratio had a significant influence upon the sensory scores of the three samples. An increase in the reconstitution ratio from 1:18 to 1:22 for the samples WE to WE2 respectively enhanced OS and reduced DI. This confirmed better acceptability and better uniformity in the WE2 sample.

Further, the average main parameter weightage being obtained from the sensory data of each formulation has been presented in Table 2. In WA, WB, WC and WE2 samples, TI contributed maximum weightage in the OS of these samples. In samples WD and WE, AI exhibited maximum weightage on OS. However, in WE1 sample, PI exhibited maximum weightage on OS. From these findings, it can be quantitatively inferred that TI exhibited maximum weightage on the OS in most sample cases. This is followed by AI and PI. The findings also depict higher weightage of AI for formulations with higher proportion of vegetables i.e., 40% and 50%. However, it can be observed that the AI exhibited maximum weightage for the case of formulations with 40% vegetable, 30% spice mix and 50% vegetable, 30% spice mix. This affirmed 30% of spice mix constitution to be highly appropriate for best soup mix formulation. However, the variation in the reconstitution ratio for the WE1 and WE2 samples, affirmed varied weightage of main parameters. In this regard, it can be analyzed that even though AI exhibited maximum weightage in the WE sample (with a reconstitution ration of 1:18), the PI and TI exhibited maximum weightage in the WE1 and WE2 samples (with reconstitution ratio of 1:20 and 1:22). This confirmed upon the influence of reconstitution ratio on the aroma properties of the soups. Finally, since sample WE2 has been assigned rank 1, it can be inferred that TI exhibited a major role on the overall acceptance of the soups followed by equal contribution of AI and PI.

5.3.3 Optimal Winter Vegetable Formulation based on Fuzzy Logic Analysis

Fuzzy logic sensory data obtained from the subjects was interpreted and analyzed in terms of similarity values. Tables 5.5 and 5.6 summarize the similarity values obtained for the sensory attributes and the samples respectively.

Table 5.5: Sample category similarity values of samples WA-WE2 in the fuzzy logic methodology-based case study.

Linguistic scale	WA	WB	WC	WD	WE	WE1	WE2
Not satisfactory	0	0.018	0.024	0.032	0	0.02	0
Fair	0.082	0.205	0.239	0.294	0.113	0.204	0.061
Satisfactory	0.339	0.533	0.581	0.665	0.408	0.521	0.297
Good	0.62	0.718	0.718	0.732	0.715	0.686	0.59
Very good	0.649	0.486	0.447	0.310	0.596	0.417	0.707
Excellent	0.248	0.132	0.132	0.034	0.199	0.058	0.305

Table 5.6: Sensory attributes similarity values in the fuzzy logic methodology-based case study.

Linguistic scale for sensory attributes	Taste	Mouth-feel	After-taste	Aroma	Appea-rance	Consis-tency	Uni-formity	Overall-acceptability
Not at all necessary	0	0	0	0	0	0	0	0
Somewhat necessary	0	0	0	0	0	0	0	0
Necessary	0	0	0	0.019	0.115	0.037	0.218	0.019
Important	0.093	0.097	0.202	0.206	0.487	0.453	0.611	0.623
Highly important	0.451	0.467	0.596	0.455	0.293	0.517	0.271	0.560
Extremely important	0.239	0.247	0.219	0.054	0.013	0.097	0.011	0.160

Firstly, based on the similarity values obtained for the samples, the samples WE2 and WA can be in very good category with respective similarity values of 0.707 and 0.649. Among these two, WE2 (50% vegetable mix) with higher similarity value can be inferred to be more acceptable or preferred by the subjects followed by WA (25% vegetable mix). Secondly, samples WB, WC, WD, WE, WE2 obtained highest similarity values (0.718, 0.718, 0.732, 0.715 and 0.686 respectively) for the linguistic scale representing good and can be inferred to be in good category. Finally based on the similarity values and respective linguistic category, sample preference order was identified as WE2 > WA > WD > WB > WC > WE > WE1. Further, based on the similarity values obtained for overall sensory attributes, it has been observed that taste, mouthfeel, aftertaste, aroma and consistency obtained highest similarity values (0.451, 0.467, 0.596, 0.455 and 0.517 respectively) for the linguistic scale representing preference of the sensory attributes as "highly important" by the subjects. Among these samples, due to achieving higher similarity value, aftertaste was inferred as the highly important attribute followed by consistency. The remaining sensory attributes namely appearance, uniformity and overall acceptability obtained highest similarity values for linguistic scale representing "important" category. Finally, based on the magnitude of similarity values and the corresponding linguistic category, overall preference of the sensory attributes was identified as aftertaste > consistency > aroma > mouthfeel > taste > overall acceptability > uniformity > appearance.

Similar studies were conducted by Sugumar & Guha, 2022 to thereby infer upon the hedonic and fuzzy logic sensory analysis based findings of the soup mix. However, in their studies, the authors reported taste to be the most preferred attribute followed by mouthfeel, flavour and colour for the case of solanum nigrum leaves based soup formulation (3% leaf powder, 35% starch and 62% spice mix). In another study conducted by Kumar et al., 2021, taste was reported as an extremely important attribute followed by mouthfeel and aftertaste for the case of a soymilk beverage. Similarly, Jaya & Das, 2003, conducted fuzzy logic analysis of market available mango drinks and a formulated mango drink. Their findings reported taste to be the important attribute for the case of market available mango drinks. However, mouthfeel has been the important attribute for the formulated mango drink. From these findings, it can be inferred that the significance of a sensory attribute is not always same and varies with the type of product.

5.3.4 Optimal Winter Vegetable Formulation based on Assessed and Literature Data

Firstly, based on the findings obtained through 9-point hedonic scale method, the sample preference order was identified as WE2 > WA > WE1 > WC > WB > WE > WD. Further, despite not determining the quantitative inference of most important attribute, taste was qualitatively inferred as an important attribute to significantly influence the overall acceptability of the sample. Secondly, for the SDI method based sensory analysis, sample preference sequence was identified as WA > WE2 > WD > WE1 > WC > WB > WE. Also, the weightage of each main parameter namely TI, AI and PI on a sample's OS was determined through the SDI sensory scores. The TI was identified to exhibit maximum weightage in most cases followed by AI and PI. Thirdly, based on the fuzzy logic sensory data analysis, sample preference order was identified as WE2 > WA > WD > WB > WC > WE1 > WE. Further, overall sensory preference was also determined and aftertaste, consistency, aroma, mouthfeel and taste were identified to be highly important attributes for their sensitive contribution to the acceptability of the samples.

From the findings of all the three sensory techniques, WE2 with 50% vegetable mix, 20% corn flour and 30% spice can be identified as the best soup sample. Also, from the findings obtained through the three sensory evaluation techniques, it can be noticed that the most preferred samples i.e., WE2 and WA were the same for all three sensory techniques. However, for the remaining samples, the ranking order varied for all the three methods. This could be attributed to the varied preference by the subjects due to increased non-uniformity in the samples. With reduced preference of the samples, the assignment of ranks was subjected to variation in each method due to the higher variability in the sensory characteristics along with minimal differences among the samples. Further, the sensory attribute preference was identified to be almost similar for all the three methods in which taste was identified to be the most important. For the fuzzy logic analysis case, aftertaste and mouthfeel attributes were identified as highly important sensations of the taste attribute. Similar findings were reported for sensory analysis of soup by hedonic and fuzzy logic analysis. In these, both methods provided almost similar inferences regarding the sensory attribute importance on the acceptability of the sample (Sugumar & Guha, 2022). Finally, even though similar interpretations were achieved for all the three methods, few advantages and limitations have been apparent for each sensory method.

Firstly, even though 9-point hedonic scale provided inferences upon the preference and acceptability of samples, quantitative estimation of attribute weightage and importance was not possible. For instance, the sensory scores of various attributes of sample WE1 varied between 6.67 to 7.42. In these, aroma and appearance achieved maximum scores. However, taste and aftertaste achieved the minimum score. Despite a wide range of scores of individual attributes, an overall-acceptability score of 7 was obtained for the sample. For the case, it could not be determined whether aroma and appearance with maximum scores or taste and aftertaste with minimum score or among any other attributes for their sensitive influence upon the overall acceptability of the sample. Thus, there exists an individual bias in 9-point hedonic scale technique, and this varies with respect to the preference of each individual. However, this can be overcome through the SDI method. As we can see that taste index exhibited maximum weightage on overall acceptance of the product, it can now be correlated with the results of 9-point hedonic scale method that affirmed that the formulations which obtained lower scores for taste, aftertaste and mouthfeel parameters obtained lower overall acceptability, and the higher scores for taste, aftertaste and mouthfeel ascertained higher overall acceptability.

Similarly, the results of 9-point hedonic scale can also be correlated with the findings of fuzzy logic analysis. In these cases, aftertaste has been identified as the highly important sensory parameter. However, only through the findings of 9-point hedonic scale method, these inferences could not be obtained. Similar inferences can be observed for the case of other samples as well. Such limitations were also reported in a study conducted on the sensory acceptability of wild spinach and water leaf soup. In this study, the attribute that exhibited maximum influence on the overall-acceptability of the product could not be determined (leafy vegetables at 41.2% in 1500g soup as per Alozie & Ene- Obong, 2018). In another study conducted on jack fruit soup, qualitative inference of important attributes was reported by the authors but quantitative inference was not addressed (Islam et al., 2023). In this regard, it can be interpreted that 9-point hedonic scale method aids in the identification of sample preference and acceptability. However, the method could not quantify upon the importance or weightage of individual sensory attribute.

Secondly, for the SDI method, quantitative weightage of each main parameter could be determined along with the OS and DI value. These provide useful understanding with respect to the uniformity among the sensory parameters. However, in few cases, ranking or selection of the formulations may become quite tricky. For example, for the WA and WE2 samples, a minimum difference existed between the DI values, and a significantly greater difference existed between OS values of both the samples. However, the method provided useful inferences about important aspects such as weightage and uniformity of sensory attributes.

Thirdly, for the case of the fuzzy logic based sensory evaluation, inferences with respect to the sample and sensory attribute preference were obtained along with corresponding linguistic categories of acceptance and importance respectively. Even though fuzzy logic based sensory method assured few advantages with respect to the 9-point hedonic scale technique in terms of the order of importance of sensory attributes, the method did not ascertain upon the determination of the weightage of sensory parameters, a feature effectively demonstrated by the SDI method. Finally, based on all the three sensory techniques, sample WE2 (50% vegetable mix, 20% corn flour and 30% spice mix) was identified as the best sample. From the conducted analysis, it can be said that SDI method and fuzzy logic analysis possessed promising features with respect to 9-point hedonic scale technique. Among these, the SDI method demonstrated the determination of uniformity among sensory parameters and weightage of sensory parameters. These weights contributed to the overall acceptance of a sample.

5.4 Nutritional Composition and Nutrient Bio accessibility of Optimal Soup Formulations and Literature Reported Best Data

Table 5.7 summarizes the nutritional composition and invitro bio accessibility of antioxidant activity, total phenolic content, soluble protein content, Fe, Zn and Mn in the optimal summer and winter vegetable soup formulations. The detailed procedures being followed to determine the nutritional composition and nutrient bio accessibility have been presented in sections 2.2.4, 2.5.4, 2.5.6 and 2.5.7 of the Ph.D. thesis. Firstly, the moisture content and water activity of the optimal summer and winter soup samples was assessed to be 8.47%, 0.51 and 7.94%, 0.51 respectively. These values are higher in comparison to that of the soup mix with 25% vegetable mix, commercial soup mix and literature reported sample (pumpkin powder at 29.67% in a 67.4g soup mix as per (Dhiman et al., 2017). This can be attributed to the higher amount of vegetable mix (50%) content in these optimal soup mix formulations. Also, the water activity value is below the safe water activity level i.e., 0.6 to prevent spoilage by microorganisms (Rokhsana et al., 2007).

Table 5.7: Nutritional composition and in vitro nutrient bio accessibility of optimal soup formulations.

	Summer vegetable soup (SE)			Winter vegetable soup (WE2)			Mixed vegetable soup (knorr.in)	
Proximate and nutritional	**Per serving (10g soup mix)**	**Invitro bioavailability (Per 100 mL soup)**	**% RDA per serve**	**Per serving (10g soup mix)**	**Invitro bioavailability (Per 100 mL soup)**	**% RDA per serve**	**Per serving (11.25g mix)**	**% GDA per serve**
MC (%)	8.47 ± 0.02	-	-	7.94 ± 0.02	-	-	3.11 ± 0.06	-
a_w	0.51	-	-	0.51	-	-	0.25	-
Energy (kcal)	30.59	-	1.83	28.85	-	1.83	40	2
Antioxidant activity (%)	0.53 ± 0.02	0.04 ± 0.001	-	0.89 ± 0.02	0.04 ± 0.001	-	0.09 ± 0.02	-
Total phenols (mg)	29.21 ± 0.62	59.28 ± 3.95	-	35.61 ± 2.75	79.5 ± 4.04	-	12.16 ± 0.12	-
Vitamin C (mg)	32.62 ± 2.46	-	-	25.91 ± 1.54	-	-	6.60 ± 0.09	-
Soluble Protein (g)	0.17 ± 0.01	5.96 ± 0.05	0.72	0.14 ± 0.002	6.09± 0.04	0.72	1.1	-
Crude Protein (g)	1.52 ± 0.15	-		0.84 ± 0.02	-			
Fat (g)	0.03 ± 0.002	-	0.23	0.01 ± 0.002	-	0.23	0.7	1
Carbohydrate (g)	5.89 ± 0.29	-	-	6.21 ± 0.56	-	-	7.1	-
Ash (g)	1.32 ± 0.01	-	-	2.15 ± 0.01	-	-	-	-
Fe (mg)	0.05	0.006	0.03	0.02	0.003	0.01	-	-
Zn (mg)	0.32	0.17	1	0.17	0.12	0.7	-	-
Mn (mg)	0.06	0.04	-	0.05	0.02	-	-	-
Na (mg)	-	-	-	-	-	-	472	20

Further, the protein content of the developed samples was observed to be similar to the literature reported values for pumpkin soup. Also, the fat content was lower than the values reported in the literature (pumpkin powder at 29.67% in a 67.4g soup mix as per Dhiman et al., 2017). Further, antioxidant activity (0.53% for summer vegetable soup and 0.89% for winter vegetable soup), vitamin C content (32.6 mg for summer vegetable soup and 26.5 mg for winter vegetable soup) and total phenolics content (29.2 mg in summer vegetable soup and 34.6 mg in winter vegetable soup) were analyzed to be significantly higher than the values obtained for the soup mix formulations with 25% vegetable mix content and for the commercially available knorr mixed vegetable soup (0.09% antioxidant activity, 6.60 mg vitamin C and 12.16 mg total phenolic content). Higher antioxidant activity, total phenolic and vitamin C content can be attributed to the high amount of phenolics, vitamin C content and antioxidant activity of the vegetables utilized in the soup mix.

Further, the bio-accessible amount of total phenols in 100 mL of soup was identified to be 60.82 mg for summer vegetable soup and 79.51 mg for winter vegetable soup. The findings depict a higher amount of bio accessible phenols in digested samples in comparison to the dry soup mix samples prior to digestion. However, the bio accessible amount of the minerals (0.006 mg Fe, 0.17 mg Zn, 0.35 mg Mn in summer vegetable soup and 0.03 mg Fe, 0.11 mg Zn, 0.2 mg Mn in winter vegetable soup) in 100 mL of soup sample was observed to be lower in comparison to that of the dry soup mix (0.05 mg Fe, 0.32 mg Zn, 0.06 mg Mn in summer vegetable soup and 0.02 mg Fe, 0.17 mg Zn, 0.05 mg Mn in winter vegetable soup) prior to digestion. This enhancement in the phenolic compounds can be attributed to the better release of bound phenolic compounds due to heat treatment driven rupture of cell walls (Minatel et al., 2017). However, the reduction in bio accessibility of minerals can be attributed to the binding of the minerals with nutrient compounds such as phenols (Rousseau et al., 2020). Nevertheless, the developed soup mix was observed to have significantly higher amounts of nutrients in comparison to those assessed for the commercially available soup mix sample.

5.5 Summary

In this chapter, a trial-and-error methodology assisted sensory optimality-based identification of optimal composition of vegetable mix, corn flour and spice mix in the summer and winter vegetable soup mix formulations has been addressed. In summary, firstly, among all the developed soup mix formulations, for the case of both summer (40% spine gourd, 40% sponge gourd and 20% yardlong bean) and winter (40% ash gourd, 40% bottle gourd and 20% squash) vegetables-based formulations, soup formulations with 50% vegetable mix, 20% corn flour and 30% spice mix were identified as the best based on the sensory scores obtained with the three sensory evaluation techniques. However, for the winter vegetable-based soup mix formulation constituted with 50% vegetable mix, a dry mix to water reconstitution ratio of 1:22 was identified to affirm upon the most acceptable soup mix formulation.

Secondly, each sensory analysis approach provided useful inferences on product acceptability and preference. The novel score deviation (SDI) method has provided quantitative weightage of each assessed main parameter on the overall score of the sample. This aided in the determination of the parameter of major importance in achieving soup formulation with the highest overall score. The SDI method further provided inferences with respect to the uniformity among the sensory parameters. This was achieved through the deviation index values (DI) i.e., a set of values being analyzed only with the SDI method. A lower DI value indicated better uniformity among the sensory parameters and thus increased the level of confidence associated to the identification of the best soup formulation. However, a limitation observed is that in few cases, the ranking or selection of the formulations may become quite tricky when a minimal difference exists between the DI values and no difference or no significantly greater difference exists between overall scores of formulations. For the case of fuzzy logic analysis, inferences with respect to the sample and sensory attribute preference were obtained along with corresponding linguistic categories of acceptance and importance respectively. Despite fuzzy logic based sensory evaluation being able to exhibit few advantages with respect to the 9-point hedonic scale technique in terms of the order of importance of sensory attributes, the method did not ascertain upon the determination of the weightage of sensory parameters, a feature effectively demonstrated by the SDI method. Further, considering the complexity associated with fuzzy logic technique, the method is more suitable for the comparative sensory analysis of the final product with respect to the commercial product.

Finally, the identified optimal summer and winter vegetable soup formulations exhibited improved sensory scores (overall acceptability of 8, OS of 81.26, DI of 21.96 for the case of summer vegetable soup and overall acceptability of 8.1, OS of 81.35, DI of 17.79 for the case of winter vegetable soup) and nutritional characteristics in comparison to the summer and winter vegetable soup mixes constituted with 25% vegetable mix, 25% corn flour and 50% spice mix (7.70 hedonic overall acceptability, OS of 74.56, DI 19.28 for the case of summer vegetable soup and 7.48 hedonic overall acceptability score, OS of 74.76, DI of 14.92 for the case of winter vegetable soup).

Thereby, the best summer and winter vegetable soup mix formulations affirmed through trial-and-error methodology-based optimization have been further subjected to statistical based optimization in the following chapter. This has been addressed through the application of Response Surface Methodology based Mixture Model Design for the further optimization of the vegetable mix composition (50 wt%) of both summer and winter vegetable soups for a fixed choice of corn flour (20 wt%) and spice mix (30 wt%).

Chapter 6:

Mixture Model Methodology Based Optimization of Vegetable Mix Composition

Mixture Model Methodology Based Optimization of Vegetable Mix Composition

Overview of the Chapter

This chapter elucidates upon the results associated to the statistical optimization of the vegetable mix composition in the soup mix formulations. To do so, Response Surface Methodology (RSM) based Mixture Model Design was adopted. In the conducted studies, the vegetable mix composition (50 wt%) of the soup mix formulations was optimized for a fixed choice of corn flour and spice mix composition and as 20 wt% and 30 wt% respectively. After a brief overview in section 6.1, section 6.2 details upon the findings associated to the mixture model-based optimization of vegetable composition of the summer soup mix formulations. Further, the findings associated to the mixture model-based optimization of winter vegetable formulations have been elucidated in section 6.3. Sections 6.2 and 6.3 also provides insights with respect to the experimental design, selection of best fit model, Analysis of variance (ANOVA), numerical optimization and model validation. Section 6.4 summarizes the inferences obtained from the conducted studies with the mixture model-based optimization methodology. Further, section 6.5 summarizes the proximate and nutritional composition and in-vitro nutrient bio-accessibility of the optimal summer and winter vegetable-based soup mix formulations. Finally, section 6.6 presents the overall summary of the findings associated with the role of mixture model design in the compositional optimization of the vegetable soup mix formulations and in terms of the antioxidant activity and sensory scores of the soup formulations.

6.1 Introduction

In this chapter, the best identified summer and winter vegetable-based soup mix formulations from the previous chapter have been subjected to statistical optimization. Thereby, in the addressed objective of this chapter, only the vegetable mix composition of the best identified soup mix formulations was optimized. Since the previous chapter objective ascertained vegetable proportions optimality in the vegetable mix composition, the objective of this chapter is to assess upon the compositional optimization of the vegetable mix in terms of the sensory and nutritional aspects of the soup mix formulations. The statistical optimization was carried out with the RSM based D-optimal mixture model design. Since mixture model facilitates a flexible compositional optimization of the entire mixture or only a specific proportion of the entire mixture for fixed choices of other constituents, the mixture model has been chosen for the optimization of the vegetable composition in the soup mix formulations.

Accordingly, the vegetable mix composition being constituted with three vegetables (for a total wt% of 50%) was optimized for a fixed choice of corn flour (20 wt%) and spice mix (30 wt%) constituents. In other words, mixture model optimization facilitates three vegetables compositional optimization in such a way that the total weight % of the vegetables is always equal to 50%. Subsequently, the optimal vegetable mix composition was determined in terms of antioxidant activity (AA), overall acceptability (OA) and objective function of overall score (OS) and deviation index (DI) being represented as the OSDI. The detailed procedures adapted for the design of soup mix formulations, analysis of responses and optimization have been presented in section 2.6 of the Ph.D. thesis. The optimal formulations obtained with the mixture model design were further analysed for proximate and nutritional composition and in-vitro bio accessibility.

6.2 Mixture Model Methodology Based Optimality of Summer Vegetable Mix Composition

The identified best summer vegetable soup mix formulation in the previous chapter findings has been considered as a starting soup mix compositional palette for the optimization of vegetable mix composition with the RSM based mixture model design. Accordingly, three vegetables namely, spine gourd (SPIG), sponge gourd (SPOG) and yardlong bean (YB) were varied in the range of 10% - 30%, 10% - 30% and 5% - 20% respectively. Thus, the total weight of vegetables always corresponds to 50 wt% in each formulation. For all cases, the corn flour and spice mix constituents weight were fixed at 20% and 30% respectively. A detailed account of the spice mix has been presented in Table 2.4 of the Ph.D. thesis.

6.2.1 Experimental Design and Response Data of Summer Vegetable Formulations

Table 6.1 summarizes the experimental design with sixteen runs being generated from the Design expert software platform of the mixture model design. The alternate soup mix formulations as per the runs generated by the software were prepared and evaluated for the responses namely, AA, OS, OSDI. These have also been summarized in Table 6.1.

6.2.2 Model Fitness and ANOVA of the Responses of Summer Vegetable Formulations

The statistical analysis of the experimental findings summarized in Table 6.1 was carried out with the model fitness methodologies associated with the regression and Analysis of Variance (ANOVA) approaches. The model fitness studies findings have been presented in Table 6.2. Further, the best fit model parameters and ANOVA for all the responses have been presented in Table 6.3.

Table 6.1: A summary of results obtained with the mixture model design-based design of alternate summer vegetable soup formulations.

Sl. No	Formulation	Independent variables			Responses		
		A: SPIG (%)	B: SPOG (%)	C: YB (%)	AA (%)	OA	OSDI
1	MS1	10.596	19.404	20	0.5018	6.6	54.981
2	MS2	20.731	24.269	5	0.4984	7.5	69.396
3	MS3	24.495	15.886	9.619	0.4704	7.8	75.378
4	MS4	15.404	26.644	7.953	0.4922	7.9	76.300
5	MS5	12.951	23.456	13.593	0.5501	8.0	77.417
6	MS6	30	12.601	7.399	0.5286	7.7	72.481
7	MS7	10.596	19.404	20	0.5099	6.9	58.95
8	MS8	25.775	10.014	14.211	0.5303	7.4	67.768
9	MS9	18.946	18.304	12.750	0.5146	7.7	71.068
10	MS10	19.595	10.405	20	0.5253	7.5	68.088
11	MS11	20.731	24.269	5	0.5036	7.6	66.904
12	MS12	10.186	30	9.814	0.4816	7.0	59.006
13	MS13	25.103	19.897	5	0.5107	7.6	69.442
14	MS14	19.595	10.405	20	0.5304	7.0	62.804
15	MS15	30	12.601	7.399	0.5201	7.4	67.79
16	MS16	10.186	30	9.814	0.4899	7.2	63.984

Such statistical analyses were carried out to determine the effect of the three independent variables on the responses. Among all alternatives, a model can be considered to be best fit for a very high value of F value and very low value of the p-value ($p<0.05$). Accordingly, a greater and significant effect on the response variables can be assured. For the case of responses namely AA and OSDI, the cubic model was identified to be the best fit. However, for the OA, quadratic model was identified to be the most suitable. This is due to the significant p-value ($p<0.05$), insignificant lack of fit value ($p>0.05$), adjusted R^2 and predicted R^2 values for the mentioned models and responses (Table 6.3). Also, a p-value (probability value) lower than 0.05 affirmed a significant effect of the independent variables or interaction effect of independent variables or their interactions on the responses at a confidence level of 95% (Dalanta et al., 2021). Further, with the obtained model parameters, the variation in the responses namely, AA, OA and OSDI with a variation in spine gourd (A), sponge gourd (B) and yardlong bean (C) compositions can be expressed with the following regression expressions that were obtained from the Design Expert Software:

$$AA\ (\%) = +0.7214 \times A + 0.3960 \times B - 0.3416 \times C - 0.2234 \times AB + 1.43 \times AC + 2.09 \times BC - 2.74 \times ABC - 0.5933 \times AB(A-B) - 2.16 \times AC(A-C) - 0.9939 \times BC(B-C) \quad (6.1)$$

$$OA = +6.70 \times A + 6.63 \times B + 4.37 \times C + 3.94 \times AB + 7.62 \times AC + 6.32 \times BC \quad (6.2)$$

$$OSDI = +58.28 \times A + 50.13 \times B + 236.79 \times C + 266.04 \times AB - 334.73 \times AC - 113.68 \times BC + 213.60 \times ABC - 180.26 \times AB(A-B) + 357.32 \times AC(A-C) + 758.19 \times BC(B-C) \quad (6.3)$$

Table 6.2: RSM-MMD model fit data summary for the summer vegetable mix proportional optimization case study.

Response	**Model**	**Sequential p-value**	**Lack of fit p-value**	**Adjusted R^2**	**Predicted R^2**
AA%	Linear	0.0944	0.0019	0.1975	0.0879
	Quadratic	0.9943	0.0008	-0.0355	-0.4323
	Special Cubic	0.5533	0.0005	-0.1040	-0.7029
	Cubic	**< 0.0001**	**0.7102**	**0.9483**	**0.8789**
OA	Linear	0.0612	0.1047	0.2492	0.0486
	Quadratic	**0.0408**	**0.2646**	**0.5576**	**0.2252**
	Special Cubic	0.4165	0.2321	0.5451	0.0653
	Cubic	0.1085	0.8025	0.7343	0.4845
OSDI	Linear	0.0945	0.0474	0.1974	-0.0001
	Quadratic	0.0489	0.1137	0.5085	0.1704
	Special Cubic	0.3568	0.1008	0.5057	0.0071
	Cubic	**0.0383**	**0.7352**	**0.8001**	**0.5554**

A detailed analysis of the associated findings are as follows. Firstly, for the case of AA, interaction between AC, BC, ABC, AB(A-B) and AC(A-C) have been significant to influence upon the response. This is confirmed with the corresponding high F values (27.93, 88.65, 77.12, 51.73 and 49.12 respectively) and relevant p-values (<0.05). Also, the insignificant lack of fit value obtained for the response AA depicts an adequately fit model. Further, the adequacy of the model fit can also be determined from the values of coefficient of determination (R^2), adjusted-R^2 and predicted-R^2. While an R^2 value close to 1 indicates a good fit of the model, the R^2 value close to 0 indicates a poor fitness of the model. The adjusted-R^2 value evaluates upon the reliability of the correlation and model fit. The predicted-R^2 conveys how well a model can make predictions for new observations.

Table 6.3: Best fit model parameters and ANOVA for all responses in the MMD based case study for summer vegetable mix composition.

	AA (%) Cubic model		**OA Quadratic model**		**OSDI Cubic model**	
Source	**F Value**	**p-value**	**F Value**	**p-value**	**F Value**	**p-value**
Model	**31.58**	**0.0002**	**4.78**	**0.0172**	**7.67**	**0.0111**
Linear Mixture	**44.19**	**0.0003**	**5.92**	**0.0201**	**11.42**	**0.009**
AB	2.41	0.1717	**7.50**	**0.0209**	**9.23**	**0.0229**
AC	**27.93**	**0.0019**	**10.93**	**0.0079**	4.14	0.0881
BC	**88.65**	**< 0.0001**	**6.79**	**0.0262**	0.711	0.4315
ABC	**77.12**	**0.0001**	-	-	1.27	0.3037
AB (A-B)	**51.73**	**0.0004**	-	-	**12.90**	**0.0115**
AC (A-C)	**49.12**	**0.0004**	-	-	3.63	0.1054
BC (B-C)	5.73	0.0537	-	-	**9.01**	**0.0239**
Lack of Fit	0.1548	0.7102	1.81	0.2646	0.128	0.7352
R-Squared	0.97	-	0.70	-	0.92	-
Adj R-Squared	0.94	-	0.56	-	0.80	-
Pred R-Squared	0.87	-	0.22	-	0.55	-

The R^2, adjusted-R^2 and predicted-R^2 value of AA response variable were obtained as 0.97, 0.94 and 0.87 respectively. A difference of 0.069 between adjusted-R^2 and predicted-R^2 values conveys that since the difference value is lower than 0.2, the model adequacy is promising. Also, an adequate precision value of 21.30 was obtained. This is significantly greater than the desirable value (4) and thereby infers that the model is acceptable. Further, the regression equation (6.1) obtained for AA depicts the variation of AA with respect to the variation of sponge gourd (A), spine gourd (B) and yardlong bean (C) content in the investigated soup system.

Secondly, for the OA case, the interaction between AB, AC, BC were found to have a significant effect on the response. This is confirmed with high F values (7.50, 10.93 and 6.79 respectively) and relevant p-values (<0.05). The alteration in OA with respect to the independent variables has been represented by the regression equation (6.2). Also, the insignificant lack of fit value obtained for the response OA depicts an adequately fit model. Further, the model achieved a R^2 value of 0.7, and a difference of greater than 0.2 between the adjusted-R^2 (0.56) and predicted-R^2 (0.22). This conveys a poor prediction by the model. The obtained R-squared values indicate an adequate model fit but a difference of greater than 0.2 between the adjusted and predicted R-squared values. This conveys the inefficiency of the model in predicting new terms. The mentioned difference value being greater than 0.2 is possibly due to the higher subjectivity of the overall acceptability score. The scores are primarily dependent upon the individual perception of each sensory panel member. Thus, it is difficult to adequately predict new terms with even the best fit model. However, the model has obtained an adequate precision ratio of 6.75 which confirms an adequate signal to noise ratio.

Thirdly, for the case of OSDI, interaction between AB, AB (A-B) and BC (B-C) were found to have significant effect on the response with high F values and significant p-values (<0.05).

Also, the variation in OSDI with respect to the three independent variables can be observed from the regression equation (6.3). As per the ANOVA analysis, the R^2 and adjusted R^2 values were obtained as 0.92 and 0.8 respectively for the OSDI response. However, a predicted R^2 value of 0.55 was obtained. Subsequently, a difference of greater than 0.2 between the adjusted R^2 (0.80) and predicted R^2 (0.55) indicates a poor prediction by the model. Thus, the case is similar to the case of OA. However, despite a achieving lower predicted R^2 and greater difference between the adjusted and predicted R^2 values for both the cases, the predicted R^2 value obtained for OSDI response is significantly higher than that of OA. This conveys a better prediction of the OSDI response by the model in comparison to the OA response. Also, despite achieving a difference greater than 0.2 (adjusted R^2 – predicted R^2) in both the cases, the obtained difference was lower for OSDI (0.25) in comparison to OA (0.34). From these findings, a better model adequacy for the OSDI response in comparison to OA can be inferred. Further, an adequate precision value of 8.82 for the case of OSDI is higher than that of OA (6.75). Also, this value is greater than the desired value of 4 and thereby affirms an adequate signal to noise ratio. Such better model prediction and model adequacy parameters for the OSDI may have been obtained for the following reasons.

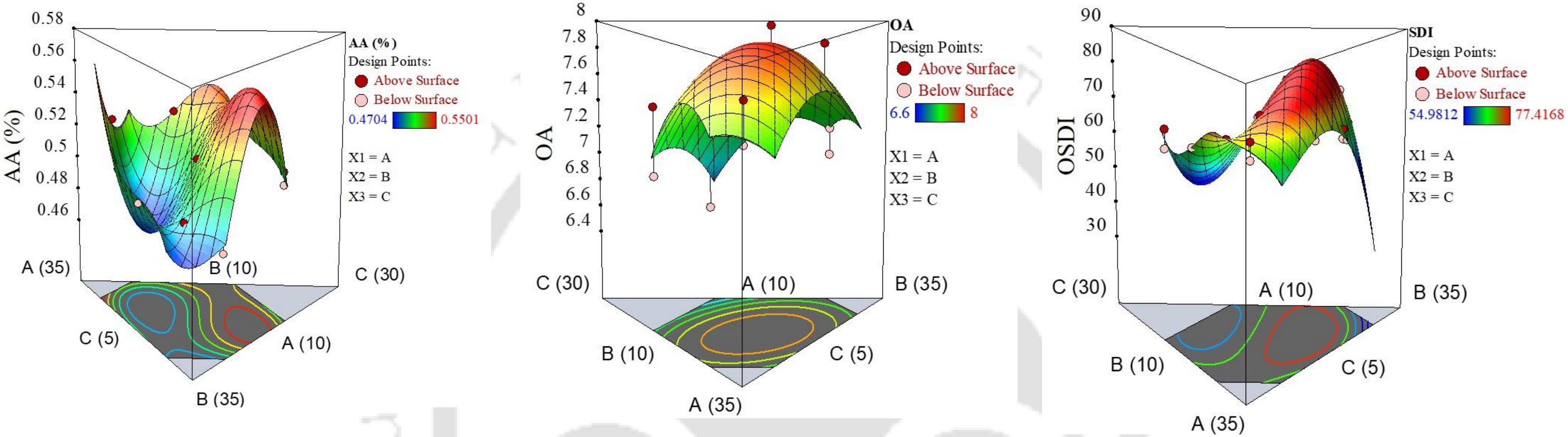
For the case of OSDI, the objective function of OS and DI, has been determined based on the sensory scores obtained for the main parameters and sub parameters (as per the score deviation (SDI) sensory evaluation method as per the procedure delineated in section 2.4.3.4 of the Ph.D. thesis). The OS is a function of the absolute and comparative scores obtained for the main parameters. The DI is a function of the absolute scores obtained for the sub parameters. For example, for the formulation MS5, the reported OSDI value of 77.417 is obtained based on the OS (80.29) and DI (7.18) values achieved for the formulation through sensory evaluation. These OS and DI value are again a function of the comparative (weightage out of 100) and absolute scores (individual score out of 100) provided for the main and sub parameters by the subjects during sensory evaluation. Thus, the overall OSDI score is always achieved by the consideration of the weightage given to each parameter by the subject. Since the obtained OSDI score takes into account both the weightage and individual scores of the main parameters and also the extent of uniformity among the various sub sensory parameters, a comparatively better repeatability or predictability could be achieved for the case of OSDI.

For the OA response case, the OA obtained for a soup formulation is considered to be a critical parameter for the assessment of the acceptability of a soup formulation. Also, it is an independent sensory parameter on its own during sensory evaluation. Despite being an independent sensory parameter, it is greatly influenced by the scores of the other sensory parameters. However, unlike the SDI method where the OS is determined through the consideration of weightage of individual parameters, the OA obtained through 9-point hedonic scale is independent of the scores of other sensory parameters. However, it is influenced by their respective scores. For example, for sample MS5, the OA is 8.0. However, the scores obtained for other sensory parameters namely taste, mouthfeel, aftertaste, aroma, appearance, consistency and uniformity are 7.8, 7.8, 7.8, 7.90, 7.80, 7.80 and 7.80 respectively. From these findings, it can be observed that even though an OA of 8.0 has been achieved, uncertainty exists with respect to the parameter that majorly influences the OA score. This is due to the fact that, the quantitative weightage of a parameter on the OA is not known and OA itself is an independent sensory parameter. Despite being an independent sensory parameter, every subject may have a different perception on the parameter that majorly influences the overall acceptability. However, this perception of the most important parameter or parameter with maximum weightage or influence on the overall acceptability varies greatly for each subject. Thus, in the 9-point hedonic scale method, unlike the OSDI, the weightage of the individual parameters on the OA cannot be interpreted on a quantitative basis. Thus, in this case, the scores which are greatly influenced by human perception is difficult to predict accurately. This is due to the variation of sensory perception for every person. All these factors could reason upon the comparatively better predictability of the OSDI.

Further, for the case of OA and OSDI, despite achieving lower R^2 values, the models can be considered to be acceptable as in most cases human behavior and human perception cannot be predicted accurately (Ozili, 2022). As per Ozili, 2022, in any studies that deal with human behavior such as social sciences or psychology, the ultimate goal of data modelling may not be able to predict the human behavior on the responses. However, other quantifiable independent variables may have a contrary influence. Thus, in such cases, an R^2 value of at least 0.1 has been reported to be acceptable on the condition that most of the independent variables shall be statistically significant. In this regard, the responses OA and OSDI although are influenced by human perception during sensory evaluation, they are not directly affected by human perception on its own as an independent variable. This is due to the fact that, any alteration in the responses is primarily due to an alteration in the independent variable's composition (three vegetables composition). Thus, the main goal of the optimization study has been to determine the significant effect of the vegetable's composition on the OA and OSDI scores which are indirectly influenced by the human perception but not solely on the human perception itself. Also, from the ANOVA data summarized in Table 6.3, it can be affirmed that most terms are statistically significant with a p-value lower than 0.05. Also, the obtained R^2 values are significantly higher than 0.1 (least acceptable in studies involving human perception) and thus the predicted models can be considered to be acceptable with the provided hypothesis and associated reasoning.

6.2.3 Model Graphs for the Responses obtained for Summer Vegetable Formulations

The response surface plots obtained for each response have been depicted in Figures 6.1a-6.1c Based on the response surface plots obtained for each response, it can be observed that the AA,



(a) (b) (c)

Figure 6.1. Response surface plots of a) AA b) OA c) OSDI in the MMD based summer vegetables soup formulations case study.

OA and OSDI increased with enhanced spine gourd (A) content to a certain extent and thereafter reduced with enhanced spine gourd content. Further, with an increase in sponge gourd (B) content to a certain extent, the responses increased. Thereafter, the responses reduced with an increase in the sponge gourd content. The responses AA, OA and OSDI initially decreased with an increase in the yardlong bean (C) content. Thereafter, they enhanced up to a certain constitution of the yardlong bean composition. This was followed by an eventual reduction of the response. Also, a high antioxidant activity has been assessed for the vegetable mix constitution with moderate levels of A (spine gourd), very high proportion of B (sponge gourd) and high proportion of C (yardlong bean). However, for moderate to high proportions of A, moderate to high proportions of B and moderate proportion of C, a lower antioxidant activity was assessed. The observed antioxidant activity trend could be attributed to the antioxidant property of individual vegetables being reported in section 3.3.2 of the Ph.D. thesis. For the case of OA and OSDI, higher sensory scores obtained for combination as moderate amount of A (spine gourd), higher amount of B (sponge gourd) and high amount of C (yardlong bean) could be attributed to the individual sensory properties of each vegetable. The corresponding findings have been delineated in section 2.4 of the Ph.D. thesis. As higher spine gourd content ensured only a marginally bitter aftertaste and since higher yardlong bean constitution ensured a strong vegetable flavor, the utility of these vegetables at higher proportions is likely to prompt reduced OA and OSDI scores.

6.2.4 Numerical Optimization and Model Validation of Summer Vegetable Formulations

The numerical optimization was conducted so as to maximize all the three responses with the independent variables being set in the specified range. Subsequently, 13.4% spine gourd, 23.2% sponge gourd and 13.4% yardlong bean was obtained as the optimum composition (MS) of summer vegetables. For the case, optimum values of responses with a best desirability of 0.816 was achieved. Corresponding responses predicted by the model were 0.548% AA, 7.63

OA and 77.42 OSDI. Further, for the validation of the model, experiments were conducted for the simulation based optimal composition of vegetables. Thereby, the experimental responses were obtained as 0.55% AA, 8.5 OA and 79.18 OSDI. The percentage difference between the predicted and actual values were evaluated to be lower than 5 percent for the case of AA (0.365) and OSDI (2.273), and greater than 10 percent for the case of OA (11.40). These findings confirm upon the optimality conveyed by the simulation model.

6.2.5 Literature Comparison

The summer vegetable soup mix formulation (MS) with optimal vegetable mix composition (13.4% spine gourd, 23.2% sponge gourd, 13.4% yardlong bean), 20% corn flour, 30% spice mix being achieved through MMD based optimization exhibited higher OA score (8.5) in comparison to the OA (6.42) reported for MMD optimized solanum nigrum leaves soup (3.964% leaf powder, 30.036% starch, 66% spice mix, Sugumar & Guha, 2020.

6.3 Mixture Model Methodology Based Optimality of Winter Vegetable Mix Composition`

To achieve the optimal winter vegetable mix composition with the mixture model design, the compositions of three winter vegetables namely, ash gourd (AG), bottle gourd (BOG) and squash (S) were varied in the range of 10% - 30%, 10% - 30% and 5% - 20% respectively. Also, the total weight of vegetables has been 50% in each formulation. In other words, corn flour and spice mix constituents were fixed at 20% and 30% respectively. Table 2.5 of the Ph.D. thesis presents a detailed account of the spice mix.

6.3.1 Experimental Design and Response Data of Winter Vegetable Formulations

The experimental design for the winter vegetable formulations with sixteen runs generated from the software platform (mixture model design) have been summarized in Table 6.4. The alternate soup mix formulations being suggested by the software assisted runs were prepared. Thereby, experimental responses for AA, OS, OSDI were obtained and summarized in Table 6.4.

6.3.2 Model Fitness and ANOVA of the Responses of Winter Vegetable Formulations

To determine the effect of the three independent variables on the responses, the experimental data summarized in Table 6.4 has been subjected to statistical analysis and with model fitness studies associated with the regression and ANOVA analysis. The model fitness parametric summary in terms of best fit model parameters and ANOVA data for all the responses have been presented in Table 6.5 and Table 6.6 respectively.

Table 6.4: A summary of results obtained with the MMD based design of alternate winter vegetable soup formulations.

Sl. No	Formulation	Independent variables			Responses		
		A: AG (%)	**B: BOG (%)**	**C: S (%)**	**AA (%)**	**OA**	**OSDI**
1	MW1	10.596	19.404	20	0.743	8.3	82.6705
2	MW2	20.731	24.269	5	0.875	7.9	79.721
3	MW3	24.495	15.886	9.619	0.829	7.25	80.3848
4	MW4	15.404	26.644	7.953	0.845	7.6	77.3226
5	MW5	12.951	23.456	13.593	0.791	8.25	81.5689
6	MW6	30	12.601	7.399	0.848	7.25	72.7408
7	MW7	10.596	19.404	20	0.72	7.85	82.3525
8	MW8	25.775	10.014	14.211	0.784	7.5	78.9322
9	MW9	18.946	18.304	12.750	0.804	7.75	79.2207
10	MW10	19.595	10.405	20	0.725	7.75	76.4322
11	MW11	20.731	24.269	5	0.86	7.5	79.4775
12	MW12	10.186	30	9.814	0.819	8.2	81.9723
13	MW13	25.103	19.897	5	0.874	7.85	77.7113
14	MW14	19.595	10.405	20	0.745	7.82	74.7684
15	MW15	30	12.601	7.399	0.825	7.5	74.3964
16	MW16	10.186	30	9.814	0.799	8	80.349

For the responses namely AA and OA, with a significant p-value (p<0.05) and insignificant lack of fit value (p>0.05), the linear model has been identified as the best fit. For the OSDI response case, special quartic model has been identified as the best fit model. Accordingly, the variation in the responses namely, AA, OA and OSDI with alteration in the independent variables i.e., ash gourd (A), bottle gourd (B) and squash (S) have been expressed with the following regression expressions that were obtained from the Design Expert software platform:

$$AA\ (\%) = +0.8680 \times A + 0.8608 \times B + 0.6449 \times C \tag{6.4}$$

$$OA = +7.17 \times A + 8.09 \times B + 8.13 \times C \tag{6.5}$$

$$OSDI = +59.06 \times A + 63.06 \times B + 41.92 \times C + 73.53 \times AB + 112.69 \times AC + 144.71 \times BC + 42.07 \times A^2BC - 554.11 \times AB^2C - 486.49 \times ABC^2 \tag{6.6}$$

Table 6.5: RSM-MMD model fit data summary for winter vegetable mix proportional optimization case study.

Response	Model	Sequential p-value	Lack of fit p-value	Adjusted R^2	Predicted R^2
AA%	Linear	**< 0.0001**	**0.8873**	**0.9501**	**0.9293**
	Quadratic	0.2224	0.9952	0.9574	0.9158
	Special Cubic	0.9325	0.9847	0.9527	0.9070
	Cubic	0.9864	0.6667	0.9305	0.8187
	Special Quartic	0.9669	0.9309	0.9412	0.9006
OA	Linear	**0.0017**	**0.5531**	**0.5669**	**0.4564**
	Quadratic	0.9218	0.3620	0.4626	0.1605
	Special Cubic	0.3960	0.3291	0.4513	-0.3793
	Cubic	0.1697	0.8550	0.6232	0.3800
	Special Quartic	0.1910	0.5554	0.5944	-0.2360
OSDI	Linear	0.0040	0.0177	0.5063	0.3473
	Quadratic	0.3032	0.0166	0.5467	0.2723
	Special Cubic	0.0071	0.0827	0.7842	0.6597
	Cubic	0.1722	0.0861	0.8510	-1.1190
	Special Quartic	**0.0012**	**0.7274**	**0.9240**	**0.8397**

Table 6.6: Best fit model parameters and ANOVA for all responses in the MMD based winter vegetable mix proportional optimization case study.

	AA (%) Linear model		**OA Quadratic model**		**OSDI Cubic model**	
Source	**F Value**	**p-value**	**F Value**	**p-value**	**F Value**	**p-value**
Model	143.82	<0.0001	10.82	0.0017	23.81	0.0002
Linear Mixture	**143.82**	**<0.0001**	**10.82**	**0.0017**	56.49	<0.0001
AB	-	-	-	-	**59.50**	**0.0001**
AC	-	-	-	-	**52.48**	**0.0002**
BC	-	-	-	-	**62.77**	**<0.0001**
A^2BC	-	-	-	-	0.2258	0.6491
AB^2C	-	-	-	-	**26.35**	**0.0013**
ABC^2	-	-	-	-	5.35	0.0540
Lack of Fit	0.3883	0.8873	0.9428	0.5531	0.3395	0.7274
R-Squared	0.97	-	0.62	-	0.96	-
Adj R-Squared	0.95	-	0.57	-	0.92	-
Pred R-Squared	0.93	-	0.46	-	0.84	-

A detailed account of the relevant findings has been presented as follows. Firstly, for the AA response, only the linear mixture was found to significantly influence the responses due to the response models being linear. The linear mixture of independent variables was significant with a p-value less than 0.0001 and F-value of 143.82. Further, for the case of AA, the R^2, adjusted-R^2 and predicted-R^2 were obtained as 0.96, 0.95 and 0.93 respectively. The obtained R^2 values are very close to 1 and thereby affirm a model with good fit. Also, the difference between the adjusted-R^2 and predicted-R^2 is lower than 0.2 (0.02). This confirms a good predictability of the response (AA) by the model for any new observations. Also, the data conveys good model adequacy. Also, the predicted-R^2 value indicates the predictability of new observations by the model (Dalanta et al., 2021). For example, a predicted-R^2 value of 0.93 indicates the ability of the model to explain 93% of the variability in the predicted data. Further, the model adequacy can also be affirmed through the adequate precision value of 27.0951, This value is promising due to being significantly greater than the desirable value of 4.

Secondly, for the OA response case, only linear mixture of independent variables was found to significantly influence the response. This is due to the regression model being linear. The linear mixture of independent variables was found to be significant with a low p-value of 0.0017 and good F-value of 10.82. Further, based on the ANOVA analysis, the R^2, adjusted-R^2 and predicted-R^2 were obtained as 0.62, 0.47 and 0.56 respectively. Unlike the AA case, for the OA response, the R^2 value were observed to be lower and not very close to 1. However, due to the response OA being significantly influenced by human perception, a lower R^2 value can be considered to be acceptable as in most cases human behavior and human perception may not always be predicted accurately (Ozili, 2022). Similar inferences have been obtained for the OA response of summer vegetable formulations. However unlike for the summer vegetable case, despite affirming low R^2 values, since the difference between the adjusted-R^2 and predicted-R^2 is 0.11 and lower than 0.2, model adequacy can be confirmed for the developed model. Further, the obtained adequate precision value of 7.9229 is greater than 4 and thereby affirms model adequacy.

Thirdly, for the OSDI response case, with high F-values and significant p-values (<0.05), the linear mixture of three independent variables and interaction between AB, AC, BC and AB^2C were assessed to exhibit significant influence on the response. Further, the R^2, adjusted-R^2 and predicted-R^2 values being obtained with the ANOVA analysis are 0.96, 0.92 and 0.84 respectively. Unlike the case of summer vegetables formulation optimization, the obtained predicted-R^2 value is higher and closer to 1. Similarly, unlike a difference value of greater than 0.2 being obtained between the adjusted-R^2 and predicted-R^2 values for the summer vegetable formulation optimization case, a lower value (0.08) has been obtained for the winter formulation study. This conveyed the adequacy of the model and prediction. The varied trend obtained for the OSDI response for summer and winter vegetable formulations can be correlated to the greater variability in the human perceptions which thereby influence the sensory preferences of the human participants. However, for both the summer and winter vegetable composition optimization cases, a better predictability and adequacy of the model has been observed for the OSDI in comparison to the OA. The chances for comparatively better predictability for the OSDI can be attributed to the known weightage of sensory parameters on the OS obtained through the SDI sensory evaluation method. Further, the model adequacy can also be confirmed through the adequate precision value of 14.6933 which is greater than the desired value of 4.

6.3.3 Model Graphs for the Responses obtained for Winter Vegetable Formulations

The response surface plots obtained for each response have been depicted in Figures 6.2a-6.2c. For the case of response AA, with an increase in the content of ash gourd (A) and bottle gourd (B) upto 25%, the AA did significantly increase. However, for an increase in the weight percent beyond 25% and upto 30%, the AA decreased marginally. However, with an increase in the content of squash (C), the AA exhibited a marginally reducing trend. The variation in AA with respect to the alteration in the proportions of A, B and C can be attributed to the antioxidant properties of each vegetable being delineated in sections 3.3.2 and 3.4 of the Ph.D. thesis. For example, dried ash gourd and bottle gourd vegetables possessed comparatively higher antioxidant activity in comparison to the dried squash vegetable. Thus, with an increase in the content of dried ash gourd and dried bottle gourd, the AA increased. In contrast, a continuous enhancement in the content of squash did result in the reduced proportions of ash gourd and bottle gourd. These may have reduced the AA. In summary, a high AA has been assessed for vegetable mix composition with moderate, high and low proportions of dried ash gourd, bottle gourd and squash vegetables respectively.

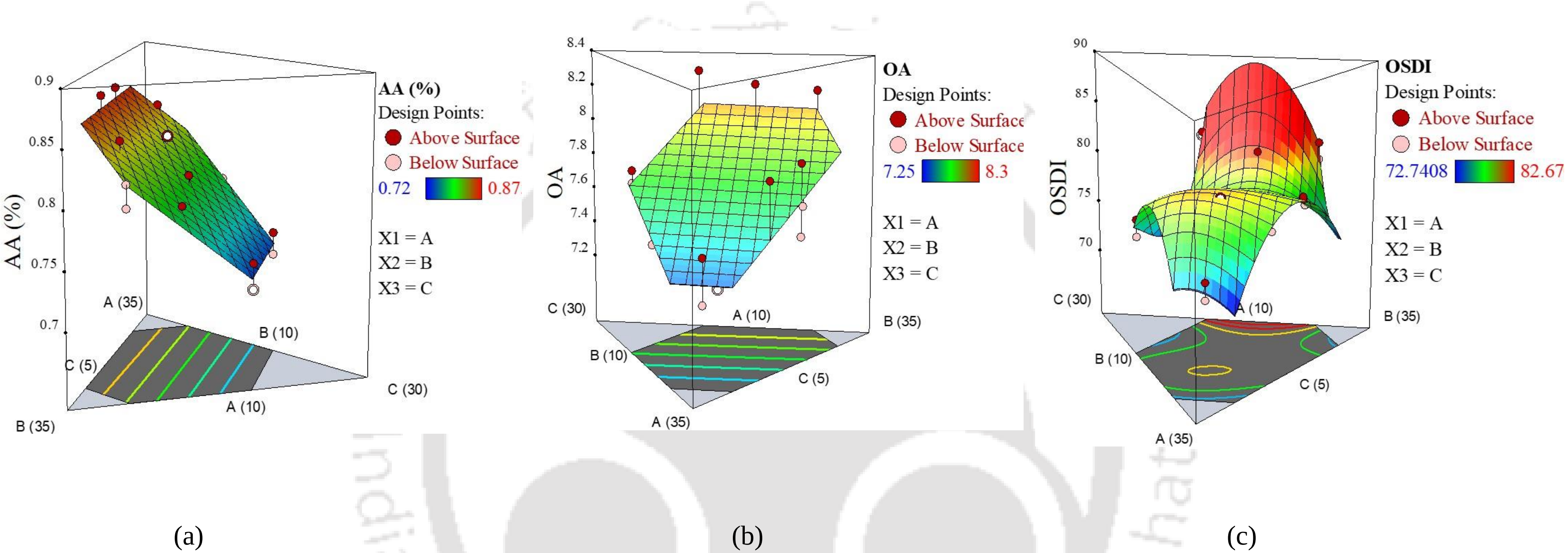


Figure 6.2. Response surface plots of a) AA b) OA c) OSDI in the MMD based winter vegetables soup formulations case study.

Based on the response surface plots obtained for the response OA, with an increase in the content of dried ash gourd (A) upto 20 wt%, the OA reduced. However, a further enhancement upto 25 wt% only resulted in a marginal enhancement in the OA. However, a further increase in the ash gourd content, did result in the reduced OA. Further, with an increase in bottle gourd (B) content upto 25 wt%, the OA increased. However, further enhancement of B resulted in the reduction of the OA. For the case of squash (S), the OA increased with an increase in the content of squash. These trends in the OA with respect to the alteration of A, B and C content can be correlated to the sensory characteristics of each vegetable being summarized in section 4.2 of the Ph.D. thesis. For example, as per the findings delineated in section 4.2 of the Ph.D. thesis, soup formulations constituted with ash gourd and squash depicted higher overall acceptability. This is followed by a marginally lower overall acceptability in the soup formulation constituted with bottle gourd. Thereby, based on the trend determined from the response surface plot, ash gourd being incorporated at a higher proportion did result in the reduced proportions of bottle gourd and squash. Thereby, the combined influence reduced the OA value. Thus, the incorporation of both bottle gourd and squash at lower proportions did result in a lower OA despite ash gourd being incorporated at a higher proportion. This can be due to the minimal contribution of bottle gourd and squash towards the OA of the soup. In contrary to this trend, incorporation of lower amount of ash gourd with moderately higher proportions of bottle gourd and squash did result in increased OA of the soup. Thereby, the OA trend can be correlated to the contribution of all three vegetables in the soup. In summary, lower proportion of ash gourd and moderate to high proportions of bottle gourd and squash ascertained a high OA for the vegetable mix-based soup formulation.

Based on the response surface plot obtained for OSDI, with an increase in ash gourd (A) content upto 25%, the OSDI decreased marginally. However, a further enhancement in the ash gourd (A) content reduced the OSDI. For the case of bottle gourd (B), maximum enhancement of

OSDI was observed at 20 to 25% constitution of bottle gourd (B). A further enhancement of bottle gourd content (B) only facilitated marginal enhancement in the OSDI. With an increase in the constitution of squash (C), the OSDI increased. In summary, the optimal value of OSDI has been assessed for a soup mix constituted with lower proportion of ash gourd and moderate to high proportions of bottle gourd and squash. The trend is in agreement with the trend inferred for the OA response.

6.3.4 Numerical Optimization and Model Validation of Winter Vegetable Formulations

Numerical optimization was conducted with the criteria to maximize all the three responses for the specified range alteration of the constitution of the three independent variables. Subsequently, the optimum composition (MW) of vegetables has been identified as 10% ash gourd, 29.7% bottle gourd and 10.3% squash. The corresponding optimum responses being predicted by the model were 0.815% AA, 8.10 OA and 82.67 OSDI and 0.789 desirability. Further, these predicted values were verified by conducting experiments at the simulation based optimal composition of vegetables. The corresponding responses were obtained as 0.836% AA, 8.3 OA and 82.97 OSDI. The percentage difference between the predicted and actual values has been assessed to be lower than 5 percent for AA (2.576), OA (2.469) and OSDI (0.363). Thus, the model based optimal compositions were experimentally validated.

6.3.5 Literature Comparison

The optimal winter vegetable soup mix formulation (MW) (10% ash gourd, 29.7% bottle gourd, 10.3% squash, 20% corn flour and 50% spice mix) exhibited best OA score (8.10). This is comparable to the OA (8.29) being reported for moringa and rice flour-based soup mix formulation being obtained through RSM based optimization (rice flour, moringa leaf powder, blended oil at 5.537g, 0.890g, 0.526g,Yadav et al., 2022).

6.4 Inferences obtained from Mixture Model Optimization

Based on the overall findings obtained from the mixture model methodology-based optimization of summer and winter vegetable mix compositions, the following inferences can be summarized. Firstly, with respect to the vegetables composition optimization, the mixture model facilitated a flexible optimization of only vegetable mix composition within 50% of the entire 100% mix and with corn flour and spice mix being chosen as a fixed choice of 25% and 30% respectively. Secondly, for the responses being considered for optimization, the mixture model-based optimization studies conveyed a lower predictability for few responses. For example, for the case of AA response, the model adequacy and predictability could be ascertained based on the significant p-value, insignificant lack of fit values, R^2, adjusted-R^2 and predicted-R^2 values obtained from the ANOVA analysis. However, for the case of OA response, lower R^2 values were obtained for both summer and winter vegetable composition optimization cases. For example, R^2 values obtained for the OA response which are lower than 0.7 in most cases do suggest a lower predictability of the model. Also, a greater difference between the adjusted-R^2 and predicted-R^2 values also suggest a lower adequacy of the developed model. Similar is the case for OSDI response being obtained for summer vegetable formulations. For the case, the difference between adjusted-R^2 and predicted-R^2 values is greater than 0.2. However, the R^2 and adjusted R^2 values are greater than 0.8 and are closer to 1. However, for the case of winter vegetable formulations, the R^2, adjusted-R^2 and predicted-R^2 values were as per the desired values. Despite such varied trend being obtained from the ANOVA analysis for the OA and OSDI responses, the lower R^2 value can still be considered for the model prediction and adequacy. This is due to the fact that OA and OSDI responses are primarily dependent upon the human perceptions and human behavior do vary significantly for every human subject. Thus, in such studies involving responses influenced by a human behavior such as sensory perceptions that vary significantly, the R^2 values of at least 0.1 can still be considered to be relevant to affirm model accuracy (Ozili, 2022).

Finally, in comparison to the OA response, a better model predictability and adequacy has been obtained for the OSDI response. This is apparent from the R^2 values obtained through the ANOVA of the data. This is primarily due to the promising feature of the SDI method in terms of the inclusion of DI to the OS in the objective function. Both OS and DI are functions of the weightage and individual scores of the sensory parameters. Such a possibility to opine upon the weightage evaluated by the subject for a greater uniformity among the sensory parameters through the evaluated DI can assist in better understanding of sensory parameters influence on the OS and acceptability of the formulation. Unlike, the SDI method, for the case of OA obtained through the 9-point hedonic scale method, the lower possibility to interpret the influence of individual sensory parameters on the OA score may not provide meaningful interpretation of the subject's perception. This might be a possible reason for a comparatively better model predictability and adequacy for the OSDI response in the conducted modelling studies.

6.5 Nutritional Composition of Optimal Soup Mix Formulations and Literature Reported Best Data

The findings associated to the moisture and nutritional composition and in-vitro bio accessibility being determined as per the procedures summarized in sections 2.2.4, 2.5.4, 2.5.6 and 2.5.7 of the Ph.D. thesis have been presented in Table 6.5. The optimal summer and winter vegetable mix compositions possessed moisture content and water activity of 8.41%, 0.49 and 7.92%, 0.50 respectively. Further, the soluble protein (0.18 g), crude protein (1.48 g) and fat content (0.02 g) were assessed to be 0.18g and 0.14g, 1.48 g and 1.06 g, 0.02 g and 0.01g for optimal summer and winter vegetable formulations respectively.

Table 6.7: Nutritional composition and in-vitro nutrient bio accessibility of MMD based optimal soup formulations.

	Summer vegetable soup (MS)			Winter vegetable soup (MW)		
Proximate and nutritional	**Per serving (10g soup mix)**	**In vitro bio accessibility (Per 100 mL soup)**	**% RDA per serve**	**Per serving (10g soup mix)**	**In vitro bio accessibility (Per 100 mL soup)**	**% RDA per serve**
MC (%)	8.41 ± 0.01	-	-	7.92 ± 0.01	-	-
a_w	0.49	-	-	0.50	-	-
Energy (kcal)	30.50	-	1.53	29.17	-	1.46
Antioxidant activity (%)	0.55 ± 0.02	0.04 ± 0.001	-	0.89 ± 0.02	0.03 ± 0.006	-
Total phenols (mg)	30.77 ± 1.26	59.28 ± 3.95	-	34.63 ± 1.24	89.19 ± 0.05	-
Vitamin C (mg)	33.83 ± 3.07	-	-	26.51 ± 1.97	-	-
Soluble Protein (g)	0.18 ± 0.01	5.96 ± 0.05	0.72	0.14 ± 0.002	6.17± 0.04	0.72
Crude Protein (g)	1.48 ± 0.02	-		1.06 ± 0.02	-	
Fat (g)	0.02 ± 0.002	-	0.23	0.01 ± 0.002	-	0.11
Carbohydrate (g)	5.92 ± 0.41	-	-	6.07 ± 0.21	-	-
Ash (g)	1.29 ± 0.01	-	-	2.20 ± 0.01	-	-
Fe (mg)	0.05	0.006	0.03	0.02	0.003	0.02
Zn (mg)	0.33	0.17	1	0.18	0.14	0.8
Mn (mg)	0.06	0.04	-	0.05	0.03	-
Na (mg)	-	-	-	-	-	-

The obtained values are observed to be similar to that of best soup formulations being identified in the previous chapter. Similarly, the antioxidant activity of optimal summer and winter vegetable formulations was identified as 0.55% and 0.89% respectively. The antioxidant activity assessed for optimal summer vegetable-based soup formulation was observed to be marginally lower than the findings reported for solanum nigrum leaves soup (3.964% leaf powder, 30.036% starch, 66% spice mix, Sugumar & Guha, 2020). In contrast, the antioxidant activity of optimal winter vegetable soup formulation was assessed to be higher in comparison to the antioxidant activity of the solanum nigrum leaves soup case (Sugumar & Guha, 2020). The higher antioxidant activity of developed soup mix formulation could be due to the higher proportion of vegetable mix being constituted with antioxidants rich vegetable sources.

The vitamin C content varied as 26.51 – 33.83 g. Further, the total phenolic content of in vitro digestion subjected liquid soup samples (59.28 mg and 89.19 mg for summer and winter soup formulations respectively) was found to be greater than the total phenolic content of dry soup mix samples (30.77 mg and 34.63 mg for optimal summer and winter formulations respectively). The enhanced total phenolic content in the liquid soup samples post digestion can be attributed to the better release of phenolic compounds. This is due to the cell wall rupture (Minetal et al., 2017). The total phenolic content of the optimal soup formulations is comparable to the total phenolic content (31.52 mg) being reported for solanum nigrum leaves based function soup mix (Sugumar & Guha, 2020). The obtained values for various nutritional constituents were observed to be similar to those of the soup mix formulations that were identified to be the best in the previous chapter. Based on the findings, it can be inferred that the alteration in the composition of vegetable mix within the 50% did not significantly alter the nutritional of the soup formulations. Similar has been the case for Fe, Zn and Mn content of the soup formulations. This, marginal or no alteration in the nutritional composition of MMD optimized soup formulations with respect to the trial-and-error optimized soup formulations could be due to the similar amount (50 wt%) of the total vegetable mix but with only compositional variation of vegetable content within the 50 wt%.

6.6 Summary

In this chapter, mixture model methodology-based optimization of vegetable mix composition of summer and winter vegetable-based soup mix formulations has been addressed. In summary, firstly, among the summer vegetable mix formulation, vegetable mix (50 wt%) constituted with 13.4% spine gourd, 23.2% sponge gourd and 13.4% yardlong bean has been identified as the optimum summer vegetable composition (MS) with optimum values of AA% (0.548%), OA (7.63) and OSDI (77.42). Similarly, for the case of winter vegetable-based formulations optimization, vegetable mix constitution (50 wt%) with 10% ash gourd, 29.7% bottle gourd and 10.3% squash has been obtained as the optimum winter vegetable composition (MW) for a set of optimum responses i.e., 0.815% AA, 8.10 OA and 82.67 OSDI. For both summer and winter vegetable soup mix formulations, the mixture model optimized formulations exhibited significantly improved sensory scores. This is especially relevant for the OSDI in comparison to the best trial and error-based soup formulations being achieved in the previous chapter. Despite, both OA and OSDI being influenced by human perception, a better model prediction in terms of R^2 values has been apparent for the OSDI case. Thus, a higher predictability of response for an alteration in the independent variables has been ascertained for the MMD optimization with respect to the OSDI response in comparison to OA response. Also, for the first time, the MMD based optimization of soup mix composition with respect to both sensory i.e., OA (obtained through 9-point hedonic scale method) and OSDI (obtained through novel SDI method) and nutritional i.e., AA parameters as responses has been addressed.

Secondly, for the case of optimal summer vegetable formulation, a significantly lower DI of 7.3 and a similar overall score of 80.34 has been achieved in comparison to the DI (21.96) and overall score (81.26) of trial and error based best summer formulation being reported in the previous chapter. Similarly, for the optimal winter vegetable formulation, a significantly lower DI (9.5) and higher overall score (86.77) in comparison to the DI (17.79) and overall score (81.35) of trial and error based best winter vegetable formulation were achieved. Thus, mixture model optimization affirmed optimum formulations with improved sensory characteristics in terms of uniformity among the sensory parameters and the overall score. However, with respect to the nutritional characteristics, only a marginal enhancement or no change has been apparent.

Following these good findings, the optimal summer and winter vegetable formulations achieved through mixture model-based optimization shall be further subjected for the replacement of corn flour content with alternate thickening agents. This will be addressed in the following chapter and through the trial-and-error based optimization of soup mix formulations being constituted with three alternate thickening agents in various combinations (0 to 100% within 20 wt % of thickening agent constitution) as a replacement to the corn flour and for fixed choices of vegetable mix (50 wt%) and spice mix (30 wt%).

Chapter 7:

Optimization of Thickening Agent Mix Composition

Optimization of Thickening Agent Mix Composition

Overview of the Chapter

This chapter elucidates upon the findings associated to the trial-and-error methodology-based optimality of thickening agent mix composition in the soup mix formulations. The corn flour content in the optimal summer and winter vegetables-based soup mix formulations being affirmed through MMD based optimization was replaced with alternate thickening agents namely chickpea flour (channa), rice flour and Bengal gram flour (sattu). To do so, the vegetable mix and spice mix composition were opted as a fixed choice (50 and 30 wt% respectively) and the alternate thickening agents' proportions (incorporated individually or as a combination of either any two or three mentioned thickening agents) was varied in the range of 0-100 wt% within the thickening agent mix composition (20 wt%) of a soup formulation. After a brief introduction in section 7.1, section 7.2 elucidates upon the findings associated to the optimal thickening agent mix composition of summer vegetable soup mix formulations. Further, the findings associated to the optimal thickening agent mix composition of winter vegetable soup mix formulations have been detailed in section 7.3. Section 7.4 and section 7.5 respectively details upon the findings associated to FTIR analysis and rheological characterization of the optimal soup mix formulations respectively. Section 7.6 summarizes the moisture, nutritional characteristics and in-vitro nutrient bio-accessibility of summer and winter vegetable soup mix formulations being prepared with the optimal thickening agent mix composition. Finally, section 7.7 presents the overall summary of the findings associated with the thickening agent mix composition optimization for the best constituted summer and winter vegetable-based soup mix formulations.

7.1 Introduction

The optimal summer and winter vegetable soup mix formulations with optimal vegetable mix compositions being achieved through MMD based optimization in the previous chapter have been further targeted for the optimization of thickening agent mix composition. To do so, the vegetable mix composition (50 wt%) and spice mix composition (30 wt%) were kept fixed and the thickening agent composition (20 wt% corn flour) was replaced with alternate thickening agents namely chickpea, rice and Bengal gram flour. Due to corn flour being known for its high carbohydrate content and glycemic index (GI), to achieve soup formulations with enhanced protein content and nutritional content, firstly the Ph.D. thesis targeted the addition of protein rich legume based thickening agents namely chick pea flour and Bengal gram flour. These two flours were chosen due to their abundant production in India. However, the sensory properties of preliminary trial formulations being constituted with only chick pea flour and Bengal gram flour as a replacement to the corn flour did not affirm desirable taste, mouthfeel, uniformity and consistency properties, Thereby, since the starch containing rice flour is well known for its positive contribution to the taste, mouthfeel and consistency properties of the soup formulations, it was incorporated along with chick pea and Bengal gram flours. Also, a study conducted by Nam et al., 2023 inferred that the rice flour in conjunction with the chick pea flour did positively contribute to the glycemic index of the soup. Accordingly, as an alternative to the corn flour, the abundantly produced rice flour was used along with chick pea and Bengal gram flours and for the realization of better organoleptic and nutritional characteristics (in terms of enhanced protein content and acceptable glycemic index). Further, the summer and winter vegetable soup mix formulations with optimal thickening agent mix composition were identified on the basis of sensory characteristics (obtained with the 9-point hedonic scale and SDI methods), carbohydrate and protein content to the corn flour.

Subsequently, the best formulations were evaluated for nutritional characteristics, in-vitro nutrient bio-accessibility and rheological characteristics.

7.2 Optimal Thickening Agent Mix Composition for Summer Vegetable Soup Mix Formulations

The 20 wt% corn flour content of the MMD based optimal summer vegetable-based soup mix formulation has been replaced with chickpea, rice and Bengal gram flour at various proportions (1 to 100% within 20 wt%). Accordingly, sixteen summer vegetable formulations were prepared with varied combinations of thickening agents (Table 2.6). In all the formulations being targeted, the vegetable mix composition and spice mix composition were fixed at 50 wt% and 30 wt% respectively. Further, the soup mixes were reconstituted with water in the ratio of 1:16 and were evaluated for sensory properties with the 9-point hedonic scale method and SDI method. The dry soup mixes were evaluated for carbohydrate, crude protein and soluble protein content. The detailed methodologies being adopted for sensory evaluation, carbohydrate and protein content estimation have been summarized in sections 2.4 and 2.5.4 of the Ph.D. thesis. Finally, the optimal thickening agent mix composition in terms of sensory characteristics, carbohydrate and protein content has been achieved.

7.2.1 9-Point Hedonic Scale and SDI Method based Sensory Analysis of Summer Vegetable Formulations with alternate Thickening Agent Mix Compositions

Table 7.1 presents the sensory scores being obtained with the 9-point hedonic scale method and SDI method for the summer vegetable formulations and with the altered thickening agent's constitution. Further, the SDI method-based rank assignment of the samples has been depicted in Figure 7.1. Based on the sensory scores being achieved through 9-point hedonic scale technique, sample TS4 (50% chickpea, 50% rice) achieved highest OA of 7.63. This is

Table 7.1: A summary of 9-point hedonic scale and SDI sensory scores for the summer vegetable formulations being prepared with alternate thickening agents (Chickpea, Rice and Bengal gram flours).

Sample	Taste	Mouth-feel	After-taste	Aroma	Appear-ance	Consis-tency	Uni-formity	Overall-acceptability	Score	DI	Average main parameter weightage out of 100 (S-DI)		
											Taste Index	Aroma	Physical Index
TS1	7.63±0.48	7.38±0.48	7.63±0.48	7.38±0.48	7.00±0.00	6.50±0.58	7.00±0.82	7.38±0.48	75.75	20.33	45	30	25
TS2	7.25±0.96	7.13±0.85	7.00±0.82	7.38±0.95	7.00±0.82	7.00±0.82	7.00±0.82	7.25±0.96	75.69	24.16	45	27.5	27.5
TS3	7.38±0.48	7.25±0.5	6.75±0.96	7.00±1.41	7.00±0.82	7.00±0.82	7.00±0.82	6.88±0.63	71.75	22.52	40	27.5	32.5
TS4	7.88±0.25	7.75±0.65	7.50±0.58	7.50±0.41	7.38±0.48	7.123±0.25	7.75±0.5	7.63±0.25	77.06	22.7	47.5	27.5	25
TS5	7.00±0.91	6.75±0.65	6.50±0.71	6.75±0.65	6.88±0.85	6.88±0.85	6.88±0.85	7.00±0.58	72	20.35	36.25	28.75	35
TS6	7.13±1.31	7.13±0.85	7.13±0.85	6.75±0.65	6.63±0.48	6.63±0.48	6.88±0.85	7.13±1.03	71.31	21.85	45	30	25
TS7	7.50±0.41	7.50±0.41	7.50±0.71	7.13±0.85	7.13±0.25	7.25±0.5	7.25±0.5	7.38±0.48	70.94	19.95	47.5	25	27.5
TS8	7.13±0.25	6.88±0.63	7.00±0.71	7.00±0.71	6.75±0.5	7.00±0.00	7.13±0.25	6.88±0.63	69.5	19.11	42.5	27.5	30
TS9	7.38±0.95	7.25±0.65	7.13±0.48	7.00±0.41	6.50±0.41	7.00±0.00	7.00±0.00	7.25±0.29	73.92	19.96	46.25	27.5	26.25
TS10	7.63±0.95	7.63±0.48	7.38±0.48	7.38±0.25	7.63±0.48	7.13±0.25	6.88±0.25	7.50±0.41	76.81	28.19	51.25	25	23.75
TS11	7.00±0.91	6.75±0.65	7.00±0.91	6.75±0.65	7.00±0.82	6.63±0.48	6.63±0.48	7.25±0.87	67.33	14.78	41.67	31.67	26.66
TS12	7.00±0.82	6.88±0.63	6.88±0.25	7.38±0.63	7.00±0.41	7.00±0.82	6.88±0.63	7.13±0.85	73.5	11.82	42.5	27.5	30
TS13	7.38±0.48	7.13±0.85	7.13±0.85	7.38±0.48	7.13±0.63	7.00±0.41	7.00±0.41	7.38±0.48	74	12.95	48.33	25	26.67
TS14	7.25±0.87	7.25±0.87	7.13±0.63	7.25±0.87	7.13±0.25	7.25±0.5	7.13±0.25	7.38±0.75	74.75	12.18	40	27.5	32.5
TS15	7.13±0.85	6.88±0.63	6.88±0.63	6.88±0.63	6.75±0.5	6.50±0.58	6.75±0.5	7.00±0.71	72.67	16.1	45	25	30
TS16	6.25±0.96	6.25±0.96	6.25±0.96	6.13±0.85	6.38±0.95	6.38±0.95	6.50±0.71	6.38±0.63	67.5	10.51	37.5	28.75	33.75

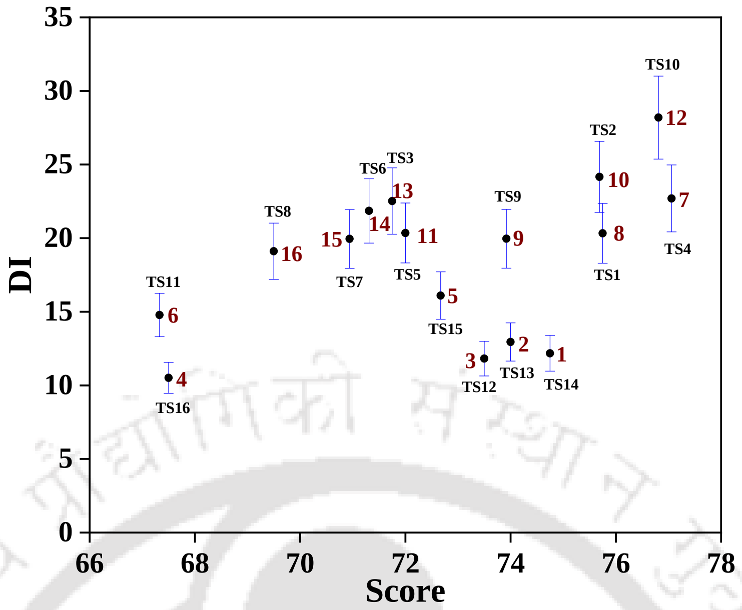


Figure 7.1. Plot depicting the SDI based ranking of summer formulations with alternate thickening agents (chickpea, rice and Bengal gram flours).

followed by sample TS10 (75% chickpea, 25% Bengal gram) with an OA of 7.50. Further, samples TS14 (17% chickpea, 66% rice, 17% Bengal gram), TS13 (66% chickpea, 17% rice, 17% Bengal gram), TS7 (25% chickpea, 75% rice) and TS1 (100% chickpea) achieved respective OA score of 7.38. Further, based on the SDI rank assignment, formulation TS14 (17% chickpea, 66% rice, 17% Bengal gram) achieved a rank of 1 (74.75 OS and 12.18 DI) followed by formulation TS13 (66% chickpea, 17% rice, 17% Bengal gram) with a rank of 2 (74 OS and 12.95 DI) and formulation TS12 (75% rice, 25% Bengal gram) with a rank of 3 (73.5 OS and 11.82 DI). Based on the sensory scores achieved with both the sensory evaluation techniques, the following inferences have been obtained. Firstly, even though TS4 and TS10 formulations achieved highest OA values with the 9-point hedonic scale method, these formulations were assigned respective ranks of 7 and 12 with the OS and DI values being obtained with the SDI method. This is primarily due to the high DI (22.7 for TS4 and 28.19 for

TS10) values being obtained for these formulations in comparison to the DI values obtained for other formulations. Despite achieving very high values for the OS (77.06 for TS4 and 76.81 for TS10), the high DI values obtained for these formulations indicate a greater non-uniformity among the sensory parameters in comparison to the other formulations. Based on the sensory scores being assigned by the subjects, for the case of TS4 formulation, a higher deviation from the mean was observed for the consistency and uniformity. These contributed majorly towards the non-uniformity of the scores. This higher deviation for the consistency and uniformity parameters was due to the noticeable differences in the particle distribution in the reconstituted soup constituting equal proportion of chickpea and rice flours. Similarly, for the case of sample TS10 (75% chickpea, 25% Bengal gram), a high deviation scores were apparent for the appearance and consistency sensory parameters.

Secondly, samples TS14 and TS13 which achieved OA of 7.38 with the 9-point hedonic scale method, were assigned respective ranks of 1 and 2. This was primarily due to the low DI values (12.18 for TS14 and 12.95 for TS13) being obtained for these formulations with a reasonably good OS value (74.75 for TS14 and 74 for TS13). Lower DI values obtained for these formulations convey a better uniformity among the sensory parameters. Thereby, formulations TS14 (17% chickpea, 66% rice, 17% Bengal gram) and TS13 (66% chickpea, 17% rice, 17% Bengal gram) have been identified as the summer vegetable formulations with optimal thickening agent mix composition. Also, it has been observed that the incorporation of chickpea, rice and Bengal gram in the summer vegetables (spine gourd, sponge gourd and yardlong bean) based formulations ascertained improved taste and uniformity in the reconstituted soups. Further, for both TS14 and TS13 sample cases, taste index (40 for TS14 and 48.33 for TS13) exhibited maximum weightage. This is followed by the physical index (27.5 for TS14 and 25 for TS13) and aroma index (32.5 for TS14 and 26.67 for TS13).

7.2.2 Carbohydrate and Protein Content of Summer Vegetable Soup Mix Formulations with alternate Thickening Agent Mix Compositions

Table 7.2 summarizes the carbohydrate and protein content of summer vegetable soup mixes being formulated with alternate combinations of thickening agents. The carbohydrate content of soup mix formulations varied from 40.11% to 71.57%. Highest carbohydrate content was achieved for the TS9 (25% chickpea, 75% Bengal gram). This is followed by TS14 formulation (17% chickpea, 66% rice, 17% Bengal gram). The lowest carbohydrate content was obtained for the TS1 sample (100% chickpea). This is followed by the TS13 sample (66% chickpea, 17% rice, 17% Bengal gram). It has been observed that, in most cases, formulations constituted with higher proportion of rice flour exhibited higher carbohydrate content. This may be due to the comparatively higher carbohydrate content of the rice flour in comparison to that of the chickpea and Bengal gram flours. Further, the crude protein and soluble protein contents varied between 18.21 % to 27.05% and 1.88% to 2.24% respectively. The obtained findings depicted a higher protein content for formulations constituted with chickpea and Bengal gram flours in comparison to the rice flour. This is primarily due to the higher protein content of the chickpea and Bengal gram flours. Among all formulations, the formulation with 17% chickpea, 66% rice, 17% Bengal gram (TS14) exhibited highest crude protein content. However, the same formulation exhibited a soluble protein content of 2.11%. This value is marginally lower than the soluble protein content (2.24%) exhibited by formulation prepared with 100% chickpea flour (TS1). Also, the soluble protein assessed for the formulation TS14 may be majorly contributed by the water-soluble albumin protein that exists in the chickpea flour. However, despite not being quantified, there may also be the presence of other salt soluble (globulin), alcohol soluble (prolamin) and residual proteins that prominently exist in the chick pea or chickpea flour (Soto-Madrid et al., 2023). Thereby, the formulation TS14 with highest protein content and best sensory scores has been identified as the summer vegetable soup mix formulation with the best thickening agent mix composition of 17%, 66%, 17% wt% of chickpea, rice, Bengal gram flours respectively. Further, the thickening agent composition of formulation TS14 (constituted with chickpea, rice and Bengal gram flours) has higher rice flour proportion and lower proportions of chickpea and Bengal gram flours. However, rice flour in comparison to the chickpea and Bengal gram flour is known for its higher glycemic index (GI).

The GI values of individual ingredients in the soup mix formulation and also the GI values being estimated through mix rule for the best formulations have been presented in Table 7.3. Formulation TS14 being constituted with higher proportion of rice flour (which is known for high GI) could be a possible reason for the higher GI value for the formulation TS14. Thereby, formulation TS13 (66% chickpea, 17% rice, 17% Bengal gram), which has also been identified as one of the best formulations based on the sensory analysis has also been considered as

Table 7.2: Carbohydrate and protein content summary of alternate summer vegetable soup mix formulations being prepared with alternate constitution of Chickpea, Rice and Bengal gram flours thickening agents.

Formulation (Chickpea, Rice, Bengal gram)	Carbohydrate (%)	Crude protein (%)	Soluble protein (%)
TS1 (100,0,0)	40.11±1.17	19.15±0.47	2.24±0.01
TS2 (0,100,0)	57.51±0.36	18.21±0.63	2.13±0.01
TS3 (0,0,100)	58.15±0.17	20.1±0.58	2.12±0.01
TS4 (50,50,0)	61.65±1.98	19.26±0.46	2.2±0.01
TS5 (50,0,50)	50.81±0.75	22.27±0.31	2.1±0.01
TS6 (0,50,50)	63.84±1.04	20.8±0.49	2.16±0.01
TS7 (25,75,0)	67.25±0.43	12.91±0.41	1.97±0.004
TS8 (75,25,0)	67.13±0.42	19.26±0.24	1.97±0.004
TS9 (25,0,75)	71.57±0.41	21.1±0.24	1.88±0.004
TS10 (75,0,25)	68.69±0.85	23±0.38	1.9±0.17
TS11 (0,25,75)	60.84±0.4	24.02±0.14	1.91±0.003
TS12 (0,75,25)	66.77±0.39	19.52±0.14	1.98±0.003
TS13 (66,17,17)	47.96±0.79	19.03±1.05	2.18±0.01
TS14 (17,66,17)	69.88±0.21	27.05±0.55	2.11±0.01
TS15 (17,17,66)	51.7±1.11	19.8±0.88	2.05±0.01
TS16 (33.5,33.5,33.5)	60.22±0.99	18.8±0.58	2.06±0.02

another summer formulation with optimal thickening agent mix composition with a lower GI. Even though formulation TS13 was constituted with rice flour, its lower proportion in the thickening agents mix might have contributed towards the lower GI of the formulation. Further, the low GI of chickpea flour may also contribute towards the comparatively lower GI of TS13 with respect to the TS14 formulation.

Table 7.3: GI values of individual ingredients and GI values estimated through mixing rule for the best soup mix formulations being constituted with various thickening agents.

Ingredient/ Formulation	Glycemic Index	Reference
TS14 (17% chickpea, 66% rice, 17% Bengal gram)	29.52	
TS13 (66% chickpea, 17% rice, 17% Bengal gram)	25.26	
TW8 (75% chickpea, 25% rice)	25.56	
MS (100% corn flour)	32.67	
MW (100% corn flour)	29.44	
Corn flour (Weikfield)	70	
Chickpea flour (Organic pulses)	32	
Bengal gram flour (Anoop)	15	
Rice flour (Manna)	72	
Onion powder (Only)	15	www.indiabetes.in glycemic-index.net
Garlic powder (Only)	30	
Ginger powder (Everest)	15	
Coriander powder (Everest)	32	
Tomato powder (Nature vibe)	35	
Milk powder (Nestle Everyday)	50	
Salt (Tata)	0	
Black pepper (Everest)	32	
Dried vegetable powders: Ash gourd Bottle gourd Squash Spine gourd Sponge gourd Yardlong bean	15-20	

Further, the resistant starch content and slowly digestible starch content are other important factors that influence the GI of foods. The resistant starch and slowly digestible starch aids in the resistance for the starch digestion or slower digestion of starch in the human gut. Thereby, the parameter positively influences the GI. Based on the findings reported by Chung et al., 2008 and Srikaeo & Sangkhiaw, 2014, chickpea and Bengal gram flour exhibit higher resistant starch content in comparison to the rice flour. Thereby, the lower GI value for TS13 formulation being estimated through the mixing rule could be attributed to the resistant starch and GI values of each thickening agent and their proportions.

In summary, formulations TS14 and TS13 have been identified as summer vegetable formulations with the best thickening agent mix composition in terms of sensory properties, carbohydrate and protein content. Also, the carbohydrate content of TS14 formulation was assessed to be higher than the carbohydrate content (59.20%) of the optimal summer vegetable soup mix constituted with corn flour as thickening agent (identified through MMD based optimization in Chapter 6 of the Ph.D. thesis). However, for the TS13 sample case, a much lower carbohydrate content was assessed. This could be primarily due to the higher proportion of chickpea flour. However, both TS14 and TS13 formulations exhibited higher protein content in comparison to the optimal summer vegetable soup being constituted with the corn flour (14.8% crude protein and 1.80% soluble protein). This is primarily due to the incorporation of protein rich chickpea and Bengal gram flours in the TS14 and TS13 formulations.

7.2.3 Literature Comparison

The best identified formulations, TS14 (17% chick pea, 66% rice, 17% Bengal gram) and TS13 (66% chick pea, 17% rice, 17% Bengal gram) exhibited good OA (7.38) score. This is comparable to the OA score (7.62) exhibited by literature reported soup mix being formulated with rice flour and pumpkin (20g pumpkin powder, 5g roasted moong dhal, 15g tomato powder, 2g dried pea, 2g dried spinach, 2g dried carrot, 3.4g spice, 10g rice as per Dhiman et al., 2017). Further, the TS14 and TS13 formulations were assessed with higher protein content in comparison to the protein content (10.50%) being reported for the pumpkin soup incorporated with rice flour. This could be due to the higher protein content of Chick pea and Bengal grams flours in the TS14 and TS13 formulations.

7.3 Optimal Thickening Agent Mix Composition for Winter Vegetable Soup Mix Formulations

To achieve the desired objective for the case, similar procedures as mentioned in section 7.2 of the Ph.D. thesis has been followed. Accordingly, sixteen winter vegetable formulations with varied proportions of chickpea, rice and Bengal gram flour were prepared and as per the compositions summarized in Table 2.6 in the Ph.D. thesis. Further, the soup mixes were reconstituted with water in the ratio of 1:22 and were evaluated for sensory properties with the 9-point hedonic scale method and SDI method. The dry soup mixes were evaluated for carbohydrate, crude protein and soluble protein contents. The detailed methodologies being adopted for sensory evaluation, carbohydrate and protein content estimation have been summarized in sections 2.4 and 2.5.4 of the Ph.D. thesis. Finally, the optimal thickening agent mix composition in terms of sensory characteristics, carbohydrate and protein content has been achieved.

7.3.1 9-Point Hedonic Scale and SDI Method based Sensory Analysis of Winter Vegetable Formulations with alternate Thickening Agent Mix Compositions

The sensory scores of alternate winter vegetable soup mix formulations being obtained with the 9-point hedonic scale method and SDI method have been presented in Table 7.4. Based on the 9-point hedonic scale sensory evaluation, TW8 (75% chickpea, 25% rice) formulation achieved highest OA of 7.63. This is followed by TW14 (17% chickpea, 66% rice, 17% Bengal gram) formulation with an OA of 7.50. Subsequently, formulations TW10 (75% chickpea, 25% Bengal gram), TW11 (25% rice, 75% Bengal gram), TW16 (33.5% chickpea, 33% rice, 33.5% Bengal gram) achieved OA scores of 7.38. Further, SDI method-based ranking of winter vegetable formulations with alternate thickening agent mix composition has been depicted in Figure 7.2.

Based on the findings obtained with the SDI method, formulation TW8 (75% chickpea, 25% rice) was assigned rank 1. This is followed by formulation TW14 (17% chickpea, 66% rice, 17% Bengal gram) (assigned rank 2). Subsequently, TW7 (25% chickpea, 75% rice), TW5 (50% chickpea, 50% Bengal gram) and TW13 (66% chickpea, 17% rice, 17% Bengal gram) were assigned respective ranks of 3, 4 and 5 and as per their OS and DI values. Further, the

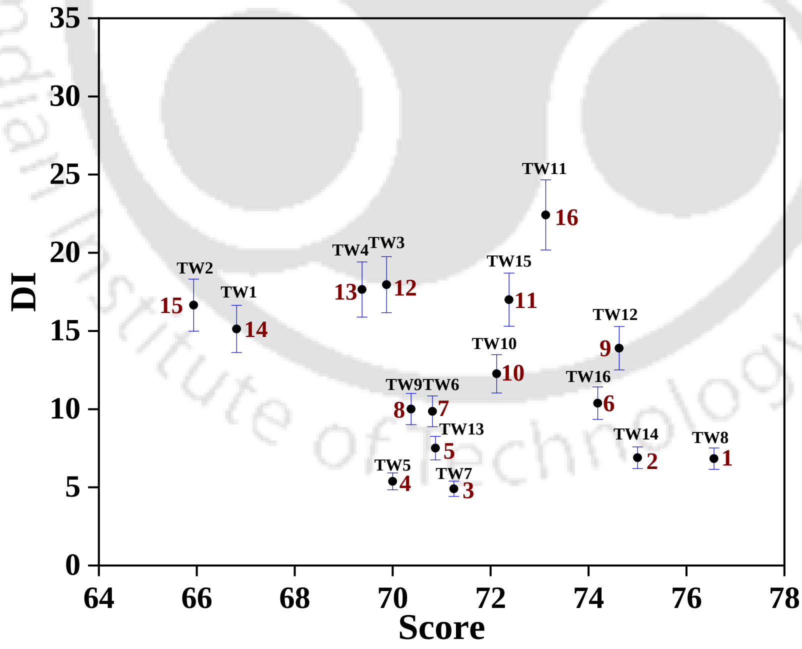


Figure 7.2. Plot depicting the SDI based ranking of winter formulations with alternate thickening agents (chickpea, rice and Bengal gram flours).

Table 7.4: A summary of 9-point hedonic scale and SDI sensory scores for the winter vegetable formulations being prepared with alternate thickening agents (Chickpea, Rice and Bengal gram flours).

Sample	Taste	Mouth-feel	After-taste	Aroma	Appear-ance	Consis-tency	Uni-formity	Overall-acceptability	Score	DI	Average main parameter weightage out of 100 (S-DI)		
											Taste Index	Aroma	Physical Index
TW1	7.00±0.82	6.88±0.85	6.63±0.95	6.75±0.5	6.75±0.29	6.75±0.5	6.75±0.5	6.88±0.63	66.81	15.13	41.25	31.25	27.25
TW2	6.50±1.08	6.38±0.95	6.50±1.08	6.25±0.65	6.50±1.00	6.50±1.00	6.50±1.00	6.50±1.08	65.94	16.65	40	30	30
TW3	7.00±0.71	6.88±0.25	7.13±0.63	6.75±0.29	7.13±0.63	6.75±0.50	6.88±0.25	7.00±0.41	69.88	17.96	41.25	27.5	31.25
TW4	6.75±0.87	6.75±0.29	6.75±0.29	6.75±0.29	6.88±0.85	7.00±0.82	6.88±0.25	6.88±0.63	69.38	17.65	42.5	26.25	31.25
TW5	7.25±0.5	7.00±0.00	7.00±0.00	7.00±0.00	6.88±0.25	7.00±0.00	7.00±0.00	7.13±0.25	70.00	5.38	41.25	28.75	30
TW6	7.00±0.41	7.13±0.48	7.13±0.48	7.13±0.25	7.13±0.25	7.00±0.00	7.13±0.25	7.25±0.29	70.81	9.86	41.25	31.25	27.5
TW7	7.00±0.00	7.00±0.00	7.00±0.00	7.00±0.00	7.00±0.00	6.75±0.50	6.75±0.5	6.875±0.25	71.25	4.90	45	26.25	28.75
TW8	7.5±0.58	7.5±0.41	7.5±0.58	7.25±0.50	7.25±0.50	7.50±0.58	7.13±0.25	7.63±0.48	76.56	6.84	47.5	28.75	23.75
TW9	7.00±0.71	7.25±0.65	7.25±0.65	7.13±0.63	7.00±0.41	6.88±0.25	7.00±0.41	7.13±0.75	70.38	10.01	43.75	32.5	23.75
TW10	7.25±0.5	7.50±0.58	7.38±0.75	7.25±0.50	7.25±0.50	7.25±0.50	7.25±0.50	7.38±0.48	72.13	12.26	41.25	27.5	28.75
TW11	7.25±0.87	7.375±0.75	7.375±0.75	7.375±0.75	7.375±0.75	7.375±0.75	7.25±0.50	7.38±0.75	73.13	22.42	47.5	27.5	25
TW12	7.00±0.65	6.875±0.50	6.875±0.75	7.375±0.50	7.00±0.50	7.00±0.45	6.88±0.25	7.13±0.48	74.63	13.90	46.25	25	28.75
TW13	7.38±0.63	7.50±0.71	7.00±0.71	7.00±0.82	7.00±0.82	7.20±0.27	7.13±0.25	7.19±0.55	70.88	7.51	46.25	27.5	26.25
TW14	7.25±0.50	7.38±0.48	7.50±0.58	7.00±0.00	7.25±0.50	7.20±0.45	7.00±0.00	7.50±0.58	75.00	6.89	48.75	25	26.25
TW15	7.13±0.63	7.25±0.87	7.50±0.91	7.25±0.50	7.38±0.75	7.30±0.45	7.25±0.87	7.25±0.87	72.38	17.00	43.75	25	31.25
TW16	7.63±0.95	7.50±1.00	7.25±0.50	7.25±0.50	7.25±0.50	7.40±0.55	7.50±1.00	7.38±0.48	74.19	10.38	51.25	26.25	22.5

following inferences have been obtained in the identification of optimal thickening agent mix composition through the 9-point hedonic scale method and SDI method based sensory evaluation methodology.

Firstly, based on both the 9-point hedonic scale method and SDI method, the TW8 sample has been identified as the best due to its highest OA (7.63), highest OS (76.56) and lower DI (6.84). Although TW8 formulation achieved marginally higher DI values in comparison to the TW7 (4.90) and TW5 (5.38) formulations, the TW8 formulation was assigned rank 1 due to its higher OS. Also, only a marginal difference (within the 10% range) exists in the DI value of TW8 formulation with respect to the DI values of TW7 and TW5 formulations. This conveys a good uniformity among the sensory parameters of the TW8 formulation along with the highest OS value. In other words, TW8 formulation has better acceptability traits. Further, TW14 formulation which has been identified as the second formulation with best thickening agent composition exhibited marginally lower OS and higher DI in comparison to the TW8 formulation. Also, based on the 9-point hedonic scale method, the TW8 formulation exhibited higher sensory scores in terms of all the sensory parameters and in comparison to the TW8 formulation.

It has been observed that the incorporation of rice flour along with the chickpea flour did improve the taste and uniformity properties of the soup formulation. However, for the case of Bengal gram flour incorporated with both chickpea and rice flour ascertained marginally reduced appearance and uniformity properties for the winter vegetable soup formulations. This could be primarily due to the dark colour of the soups being contributed by the Bengal gram flour and enhanced thicker status of the reconstituted soup.

Secondly, the TW10, TW11 and TW16 formulations with OA scores of 6.38 with the 9-point hedonic scale method have been assigned higher ranks. This is based on the OS and DI scores obtained with the SDI method. These formulations had lower OS and higher DI values in comparison to those achieved for TW8 formulation. Based on the sensory scores obtained for the sub parameters with the SDI method, it has been assessed that the consistency, satisfaction and uniformity have majorly contributed towards the higher DI of the formulations in comparison to the TW8 formulations. Among the three alternate thickening agents, in most formulation cases, the incorporation of Bengal gram flour at higher proportion did result in lower scores for the consistency and uniformity parameters. Finally based on the obtained sensory scores, TW8 formulation being constituted with 75% chickpea and 25% rice flour has been identified as the winter vegetable formulation with best thickening agent mix composition. Further, taste index (47.5) exhibited maximum weightage on the OS of TW8 sample. This is followed by aroma index (28.75) and physical index (23.75).

7.3.2 Carbohydrate and Protein Content of Winter Vegetable Soup Mix Formulations with alternate Thickening Agent Mix Compositions

The carbohydrate and protein content of winter vegetable soup mix formulations being constituted with alternate thickening agent mix compositions have been summarized in Table 7.5. The carbohydrate content of alternate winter soup mix formulations varied between 52.03% (TW10 (75% chickpea, 25% Bengal gram)) to 68.78% (TW14 sample (17% chickpea, 66% rice, 17% Bengal gram)). Similar to the case of summer vegetable formulations with alternate thickening agents, higher carbohydrate content was achieved for the winter vegetable formulations being constituted with higher proportion of rice flour. This is attributed to the high carbohydrate content of the rice flour thickening agent. Similar carbohydrate content (69.35%) was reported for moringa soup being constituted with rice flour (rice flour, moringa powder, carrot, peas at 45.94%, 7.38%, 15.35%, 7.88% as per Yadav et al., 2022). Further, TW8 sample (75% chickpea, 25% rice) being identified as the best through the sensory analysis

Table 7.5: Carbohydrate and protein content summary of alternate winter vegetable soup mix formulations being prepared with alternate constitution of Chickpea, Rice and Bengal gram flour thickening agents.

TA in formulation (Chickpea, Rice, Bengal gram)	Carbohydrate (%)	Crude protein (%)	Soluble protein (%)
TW1 (100,0,0)	60.81±0.21	13.63±0.24	1.61±0.005
TW2 (0,100,0)	61.53±2.43	11.01±0.14	1.21±0.005
TW3 (0,0,100)	55.12±0.22	14.28±0.14	1.31±0.005
TW4 (50,50,0)	53.81±0.25	13.68±0.25	1.53±0.003
TW5 (50,0,50)	61.79±0.15	13.20±0.20	1.35±0.005
TW6 (0,50,50)	56.92±0.23	12.76±0.25	1.26±0.004
TW7 (25,75,0)	52.81±0.18	11.02±0.36	1.32±0.004
TW8 (75,25,0)	62.76±0.22	12.24±0.20	1.51±0.003
TW9 (25,0,75)	67.40±0.19	15.79±0.25	1.33±0.003
TW10 (75,0,25)	52.03±0.16	14.89±0.22	1.43±0.003
TW11 (0,25,75)	58.05±0.20	14.96±0.11	1.23±0.004
TW12 (0,75,25)	62.45±0.25	12.82±0.25	1.27±0.003
TW13 (66,17,17)	56.03±0.15	14.89±0.43	1.66±0.003
TW14 (17,66,17)	68.78±0.19	11.78±0.28	1.13±0.005
TW15 (17,17,66)	63.08±0.20	13.18±0.24	1.28±0.004
TW16 (33.5,33.5,33.5)	68.29±0.19	13.70±0.29	1.45±0.004

possessed 62.76% carbohydrate content. The carbohydrate content of TW8 sample has been assessed to be marginally higher than the carbohydrate content of winter vegetable-based soup mix formulation being constituted with corn flour (identified as best in the Chapter 6 of the Ph.D. thesis). Further, while carbohydrate content of rice flours is known for its significant influence on the GI that effects the blood glucose, study conducted by Nam et al., 2023 conveyed a favourable influence of the rice flour-based carbohydrates on the GI upon its utility along with chickpea flour. In other words, the inclusion of rice flour as an ingredient in the chickpea flour would not significantly enhance the GI. This is a promising aspect of the formulation. The crude protein content and the soluble protein content of alternate soup mix formulations varied as 11.01% to 15.79% and 1.13% to 1.66% respectively. A higher protein content was apparent for the formulations incorporated with higher proportions of chickpea

flour and Bengal gram flour. This is mainly due to the high protein content contributed by these flours. Similar trend was observed for the summer vegetable-based soup mix formulations case. However, the protein content of winter vegetable-based soup mix formulations was observed to be marginally lower than that of the summer vegetable formulations case. This trend was also observed for the summer and winter vegetable-based soup mix formulations being constituted with corn flour as thickening agent.

Further, formulation TW8 with best thickening agent mix composition possessed 12.24% crude protein content and 1.51% soluble protein content. The obtained values are higher than that of the winter vegetable soup mix formulation constituted with corn flour (10.60% crude protein and 1.40% soluble protein) and identified as best in the Chapter 6 of Ph.D. thesis.

7.3.3 Literature Comparison

The winter vegetable formulation identified to be constituted with best thickening agent mix composition (75% channa, 25% rice) exhibited OA (7.63 out of 9). This is comparable to literature reported OA (42.3 out of 50) for vegetable soup supplemented with chick pea flour (chick pea, potato, barley, tomato, carrot, spice mix at 35%, 22%, 18%, 5%, 14%, 6% as per Abdel-Haleem & Omran, 2014), pumpkin soup with rice flour (OA of 7.62) (Dhiman et al., 2017) and cow pea pumpkin soup (OA of 7.4) (Mungofa & Beswa, 2024). However, the developed soup exhibited a marginally lower OA in comparison to the OA reported for rice flour based moringa soup (5.537g rice flour, 0.89g moringa powder, 0.526g blended oil, 1.85g carrot, 0.95g peas, 0.65g salt, 0.65g sugar, 1g spices) (Yadav et al., 2022) and moong dal and Malabar spinach based vegetable soup (4g Malabar spinach powder, 20g moong dal powder, 16g vegetable powder, 10g corn flour, 50g spice mix) (Singh & Sonkar, 2024). Further, the developed soup formulation (TW8) exhibited marginally lower carbohydrate content and higher protein content in comparison to the literature reported carbohydrate and protein content of rice flour based moringa soup (Yadav et al., 2022). The observed trend could be due to the incorporation of rice flour along with the chick pea flour. Such a choice contributed to a higher protein content and lower carbohydrate content.

7.4 FTIR Analysis of Summer and Winter Vegetable Soup Mix Formulations with Optimal Thickening Agent Mix Composition

Figure 7.3 depict the FTIR spectra for the best identified summer and winter vegetable soup mix formulations being constituted with the corn flour (MS and MW from Chapter 6 of Ph.D. thesis) and alternate thickening agents (TS14, TS13 and TW8). For all cases, the FTIR spectra figure depicts the peaks obtained for both the dry soup mix and liquid soup formulations. For all the best formulation cases, peaks were observed at 3600-3000 cm^{-1}, 2924-2931 cm^{-1}, 1630-1647 cm^{-1}, 1360-1418 cm^{-1} and 1014-1026 cm^{-1}. Firstly, the peak observed for all the samples at 3600-3000 cm^{-1} convey upon the presence of hydroxyl (O-H) group and its interaction with water molecules. The band centred at about 3285-3323 cm^{-1} could suggest the medium strength bond between the hydroxyl groups of starch chains with water molecules. Secondly, the peaks observed at 2924-2931 cm^{-1} could be attributed to the presence of lipids. However, a strong intensity was not apparent. Thirdly, the peaks observed for various formulations at 1630-1647 cm^{-1} can be attributed to the Amide I region of the proteins. A stronger peak intensity was observed for the liquid soup samples constituted with chickpea, rice and Bengal gram flour. This can be attributed to the higher protein content of chickpea and Bengal gram flours and associated quantitative inferences in terms of crude protein and soluble protein content. Fourthly, the peaks corresponding to 1360-1418 cm^{-1} could be attributed to the CH_2 bending with the presence of cellulose (Ying et al., 2017). This may be attributed to the dried vegetable mix incorporated in the soup mix formulations. Finally, the prominent peaks observed between

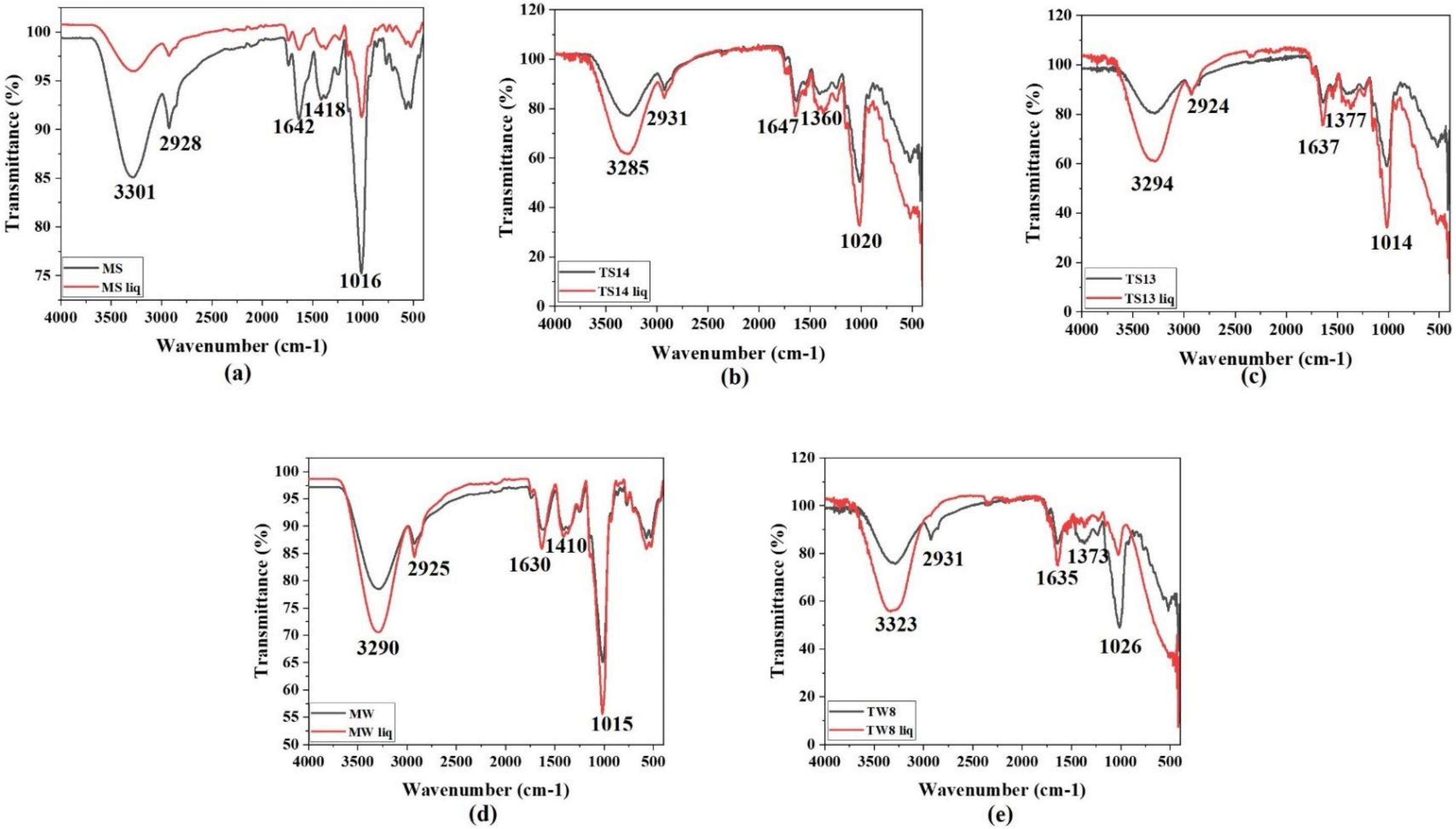


Figure 7.3. FTIR spectra of best vegetable soup mix formulations being constituted with corn flour and alternate thickening agents for summer vegetables ((a) corn flour (b) wt% of 17% chickpea, 66% rice, 17% Bengal gram (c) wt% of 66% chickpea, 17% rice, 17% Bengal gram) and winter vegetables (d) corn flour (e) wt% of 75% chickpea, 25% rice.

1014-1026 cm^{-1} corresponds to the C-O stretching and C-C stretching with the presence of carbohydrates. Peaks with greater intensity were observed for the vegetable soup mix formulations being constituted with corn flour than those achieved for the formulations constituted with chickpea, rice and Bengal gram flours. This conveys the stronger role of starch in altering the peak intensities (Garcìa et al., 2021).

7.5 Rheological Characteristics of Summer and Winter Vegetable Soup Mix Formulations Constituted with Optimal Thickening Agent Mix Composition

The rheological behaviour of best summer and winter vegetable soup mix formulations constituted with corn flour and alternate thickening agent mix composition has been depicted in Figure 7.4. Further, the flow behaviour characteristics being determined through power law model has been depicted in Figure 7.5. Firstly, based on the steady state rheological characteristics being obtained with the shear rate vs viscosity plot, and for all the best summer and winter vegetable soup mix formulations being constituted with various thickening agents, the apparent viscosity reduced with an increase in the shear rate from 0.1 to 300 s^{-1}.

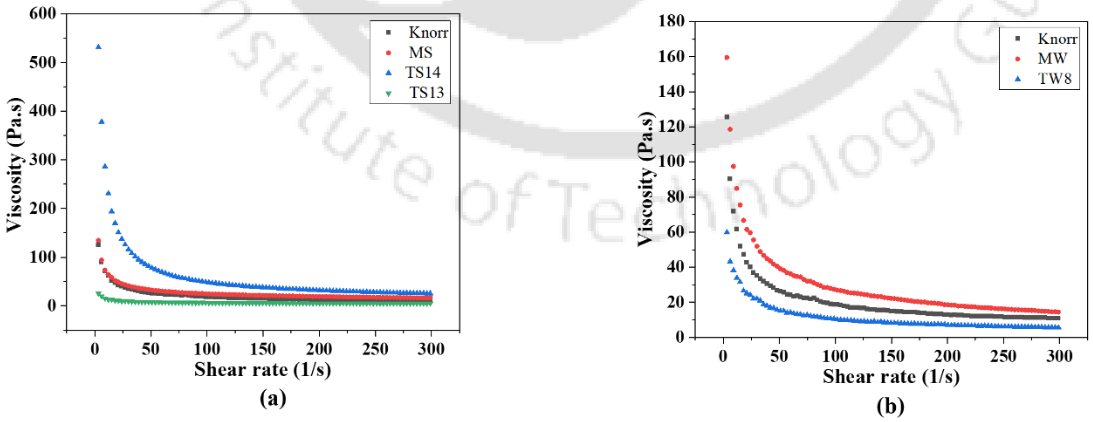


Figure 7.4. Steady state rheological characteristics of best alternate (a) summer vegetable and (b) winter vegetable soup mix formulations.

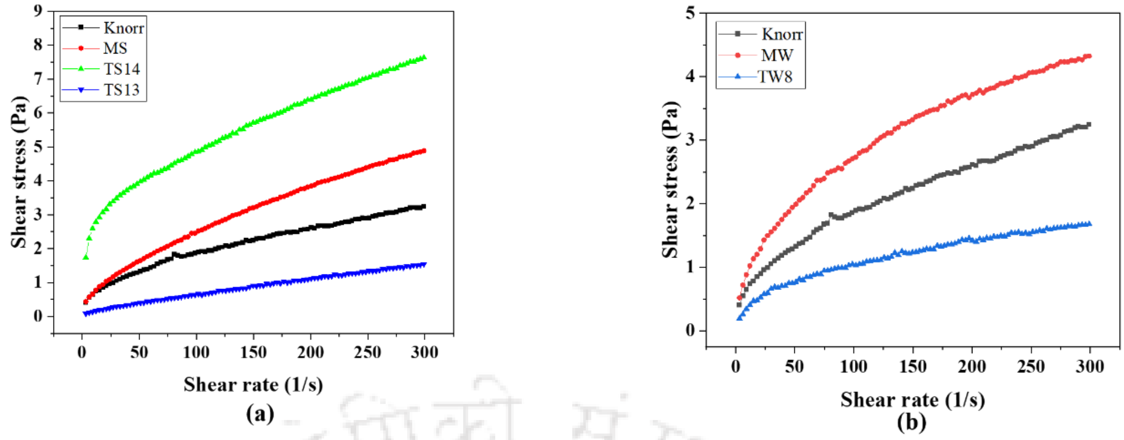


Figure 7.5. Power law model-based flow behaviour plots for the best case of (a) summer vegetable and (b) winter vegetable soup mix formulations.

Further, the obtained trend in Figure 7.4 affirms that the soup formulations exhibited non-Newtonian pseudoplastic behaviour. Similar trend has been reported by Abdel-Haleem & Omran, 2014, and for the soup formulation being constituted with legumes. Further, for both summer and winter vegetable soup mix cases, formulations with higher carbohydrate content exhibited higher apparent viscosity. Thereby, following this trend, for the case of summer formulations, the soup formulation being constituted with 66% rice flour, 17% chickpea, 17% Bengal gram flour exhibited highest apparent viscosity (531.71 Pa.s). This is followed by soup formulations incorporated with 100% corn flour and 66% chickpea flour (134.55 Pa.s), 17% rice flour, 17% Bengal gram flour (25.78 Pa.s). For the case of winter vegetable formulations, soup mix constituted with 100% corn flour exhibited highest apparent viscosity (159.52 Pa.s). This is being followed by the soup mix constituted with 75% chickpea flour, 25% rice flour (59.89 Pa.s) The obtained trend could also be correlated with the qualitative inferences obtained from the FTIR analysis and in terms of the starch and carbohydrate group peaks being observed at about 1014-1026 cm^{-1} for alternate soup formulations.

Further, with respect to the shear rate vs shear stress plots being depicted in Figure 7.5, the flow behaviour index (n) values for all the soup formulations varied between 0.322 to 0.6925 (lower than 1) for R^2 values ranging between (0.9854 to 0.9986). The obtained values indicate pseudoplastic shear thinning behaviour of the soup formulations, a property being apparent for most soup products (Chavan et al., 2015). Since the primary focus of the conducted investigations was to determine the flow behaviour of the developed soups, only the power law model was considered for the fitness studies with the experimentally measured rheological data. Further, based on the literature reported data (Mondal et al., 2020), power law model has been identified as an appropriate model to best describe the soup's flow behaviour. All the best identified soup mix formulations exhibited rheological characteristics that are comparable to that achieved for the commercially available Knorr mixed vegetable soup formulation.

7.6 Nutritional Composition of Soup Mix Formulations with Optimal Thickening Agent Mix Composition and Comparison with Literature Data

Table 7.6 summarizes the moisture, nutritional and in-vitro bio-accessible nutrient characteristics of summer and winter vegetable soup mix formulations and with optimal thickening agent mix compositions. Based on the obtained findings, it has been observed that the antioxidant activity, TPC, soluble protein and crude protein content of the best soup formulations are higher than that of the optimal summer (0.55% AA, 30.77mg TPC, 0.18g soluble protein) and winter vegetable (0.89% AA, 34.63mg TPC, 0.14g soluble protein) soup mix formulations being constituted with corn flour and also the commercial Knorr mixed vegetable soup. This could be due to the greater amounts of nutrients that exist in the thickening agents namely chickpea, rice and Bengal gram flour in comparison to the corn flour. Further, the TPC was also assessed to be higher in comparison to the TPC (52.31 mg/100g) of literature reported soup formulation (5.537g rice flour, 0.89g moringa powder, 0.526g blended oil, 1.85g

Table 7.6: A summary of the nutritional parameters of the vegetable soup mix formulations with optimal thickening agent mix composition.

Formulation (Chickpea, Rice, Bengal gram)	MC (%)	a_w	Energy (kcal)	AA %	TPC (mg)	Soluble Protein (g)	Crude Protein (g)	Carbohydrates (g)	Fat (g)	Glycemic index (Mixing rule)
TS14 (17,66,17) per 10g dry mix	7.69	0.45	39.16	0.72±0.004	36.30±0.04	0.21±0.001	2.71±0.15	6.99±0.02	0.04±0.002	29.52
TS14 (17,66,17) per 100 mL soup (in vitro)	-	-	-	0.15±0.002	43.93±2.32	6.27±0.04	-	-	-	
% RDA per serve	-	-	1.96	-	-	0.86		-	0.31	
TS13 (66,17,17) per 10g dry mix	6.46	0.43	27.34	0.68±0.01	35.34±0.04	0.22±0.001	1.90±0.05	4.80±0.08	0.06±0.004	25.26
TS13 (66,17,17) per 100 mL soup (in vitro)	-	-	-	0.15±0.002	41.51±2.77	6.06±0.04	-	-	-	
% RDA per serve	-	-	1.37	-	-	0.77		-	0.46	
TW8 (75,25,0) per 10g dry mix	7.95	0.45	30.45	1.00±0.01	48.16±0.03	0.15±0.003	1.22±0.02	6.28±0.02	0.05±0.002	25.56
TW8 (75,25,0) per 100 mL soup (in vitro)	-	-	-	0.16±0.01	53.01±2.82	6.05±0.04	-	-	-	
% RDA per serve	-	-	1.52	-	-	0.70		-	0.38	

carrot, 0.95g peas, 0.65g salt, 0.65g sugar, 1g spices, Yadav et al., 2022). Further, the bio-accessible amounts of AA (0.15% to 0.16%) have been analysed to be higher (4 to 5 times) in comparison to the values achieved with the corn flour based optimal soup mix formulations (being reported in the Chapter 6 of the Ph.D. thesis). However, the bio-accessible amounts of TPC were comparable to the soup formulations being constituted with the corn flour. Also, the bio-accessible amount of protein (6.06 to 6.27g) was marginally higher than that of the soup mix formulations being constituted with corn flour. Further, the in-vitro protein digestibility was comparable to that of the vegetable soup being constituted with chickpea flour (chick pea, potato, barley, tomato, carrot, spice mix at 35%, 22%, 18%, 5%, 14%, 6% and as per Abdel-Haleem & Omran, 2014 where a higher in-vitro protein digestibility was reported for soup mix constituted with chickpea (chickpea) flour.

7.7 Accelerated Storage Stability of Best Soup Mix Formulations

The best formulations achieved through Mixture model (MMD) based optimization (MS and MW) and best formulations achieved through trial-and-error based thickening agent composition optimization (TS14, TS13 and TW8) were subjected to accelerated storage stability study under 38±2 ^{o}C and 90% relative humidity (RH). To determine the storage stability of the soup mix formulations, the moisture sorption kinetics were studied. This is followed by the shelf-life estimation. Thereafter, using first order degradation kinetics, half-time for antioxidant activity was evaluated.

7.7.1 Moisture and Water activity Characteristics of Soup Mix Formulations Stored at Accelerated Storage Condition

With increasing storage time, the moisture and water activity properties of the mentioned soup mix formulations tend to get altered with respect to varied storage time period. Table 7.7 and

Table 7.8 summarize the moisture content and water activity characteristics of soup mix formulations being stored at accelerated and ambient conditions respectively. At the accelerated storage condition and for all the samples, the moisture content increased from an initial moisture content of about 0.065 – 0.073 kg water/ kg dry solid) to about 0.105 – 0.120 kg water/ kg dry solid after 28 days of storage. However, for the samples stored at ambient condition, the moisture content altered upto 0.073 – 0.086 kg/ kg dry solid. The faster attainment of critical moisture content (0.12 kg water/ kg dry solid) in the samples stored at accelerated storage could be due to the sensitive influence of the higher combinations of temperature and relative humidity conditions in the storage environment. The greater permeability of moisture content from the packaging material could be another reason for faster increase in moisture content at accelerated storage. However, the water activity values were assessed to be lower than the 0.6 limit even for the case of 28 days based accelerated storage.

Further, for the case of samples stored at ambient condition, the moisture content and water activity (0.47 to 0.49) were assessed to be well within the levels of prescribed moisture content (0.12 kg water/ kg dry solid) (WHO, 2017) and 0.6 water activity. However, the usage of laminated packaging materials could facilitate reduced rate of moisture absorption. Thereby, safer levels of moisture content and water content can be affirmed during prolonged storage. Further, the enhanced moisture content and water activity of the soup mix formulations with storage time period conveys the hygroscopic nature of the developed soup mix formulations. A similar trend has been reported for the herbal beverage prepared with *Centella asiatica* powder being subjected to storage under accelerated and ambient conditions (Bala et al., 2023) and mango powder being subjected to storage under accelerated condition (Jaya & Das, 2005). However, a lower moisture content of the products was reported in comparison to the moisture content assessed for the soup mix samples.

Table 7.7: A summary of moisture content and water activity characteristics of soup mix formulations being stored at accelerated condition.

Storage day	MS (50 wt% vegetable mix, 20 wt% corn flour, 30 wt% spice mix)		TS14 (50 wt% vegetable mix, 20 wt% TA (17 wt% chick pea, 66 wt% rice, 17 wt% Bengal gram), 30 wt% spice mix)		TS13 (50 wt% vegetable mix, 20 wt% TA (66 wt% chick pea, 17 wt% rice, 17 wt% Bengal gram), 30 wt% spice mix)		MW (50 wt% vegetable mix, 20 wt% corn flour, 30 wt% spice mix)		TW8 (50 wt% vegetable mix, 20 wt% TA (75 wt% chick pea, 25 wt% rice) , 30 wt% spice mix)	
	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)
0	0.069 ± 0.001	0.39 ± 0.001	0.065 ± 0.002	0.40 ± 0.000	0.066 ± 0.006	0.41 ± 0.005	0.073 ± 0.005	0.42 ± 0.000	0.072 ± 0.009	0.41 ± 0.000
7	0.095 ± 0.008	0.45 ± 0.005	0.083 ± 0.008	0.46 ± 0.000	0.086 ± 0.005	0.46 ± 0.000	0.095 ± 0.008	0.45 ± 0.000	0.094 ± 0.012	0.46 ± 0.006
14	0.097 ± 0.006	0.49 ± 0.000	0.093 ± 0.003	0.48 ± 0.005	0.091 ± 0.005	0.50 ± 0.000	0.101 ± 0.014	0.52 ± 0.005	0.106 ± 0.007	0.51 ± 0.000
21	0.103 ± 0.007	0.51 ± 0.000	0.104 ± 0.009	0.52 ± 0.000	0.103 ± 0.008	0.53 ± 0.000	0.115 ± 0.004	0.54 ± 0.000	0.119 ± 0.006	0.54 ± 0.005
28	0.112 ± 0.007	0.55 ± 0.005	0.105 ± 0.012	0.55 ± 0.005	0.118 ± 0.006	0.56 ± 0.005	0.118 ± 0.007	0.57 ± 0.005	0.120 ± 0.011	0.56 ± 0.005

Table 7.8: A summary of moisture content and water activity characteristics of soup mix formulations being stored at ambient condition.

Storage day	MS		TS14		TS13		MW		TW8	
	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)	Moisture content (kg water/ kg dry solid)	Water activity (a_w)
0	0.069 ± 0.001	0.39 ± 0.000	0.065 ± 0.002	0.40 ± 0.000	0.066 ± 0.006	0.41 ± 0.000	0.073 ± 0.005	0.42 ± 0.005	0.072 ± 0.009	0.41 ± 0.000
7	0.071 ± 0.004	0.40 ± 0.000	0.066 ± 0.001	0.41 ± 0.005	0.067 ± 0.005	0.43 ± 0.000	0.074 ± 0.003	0.43 ± 0.000	0.075 ± 0.012	0.43 ± 0.005
14	0.081 ± 0.002	0.41 ± 0.000	0.068 ± 0.005	0.41 ± 0.005	0.069 ± 0.002	0.43 ± 0.000	0.079 ± 0.010	0.44 ± 0.000	0.077 ± 0.007	0.45 ± 0.000
21	0.082 ± 0.006	0.43 ± 0.000	0.072 ± 0.007	0.43 ± 0.000	0.071 ± 0.004	0.44 ± 0.000	0.082 ± 0.008	0.46 ± 0.000	0.080 ± 0.006	0.46 ± 0.005
28	0.086 ± 0.002	0.47 ± 0.005	0.075 ± 0.010	0.48 ± 0.000	0.073 ± 0.005	0.48 ± 0.005	0.083 ± 0.006	0.48 ± 0.005	0.082 ± 0.011	0.49 ± 0.000

The higher moisture content of the soup mix samples could be due to the formulations being constituted with a mixture of several ingredients that are known to have varied levels of moisture content.

7.7.2 Shelf-life Prediction of Soup Mix Formulations being Stored at Accelerated Storage Condition

The shelf-life of the soup mix formulations being stored under accelerated conditions (38±2 ^{o}C and 90% RH) was determined using expression 2.33 presented in Chapter 2 of the Ph.D. thesis. For the for MS, TS14, TS13, MW and TW8 formulations, the initial moisture content varied as 0.069, 0.065, 0.066, 0.073 and 0.072 kg water/ kg dry solid respectively. Further, 0.12 kg water/ kg dry solid was considered to be the critical moisture content of the samples. This is primarily due to the soup mix being constituted with a mixture of various ingredients being assessed for their safer moisture content as 12 to 15%. Also, since lump formation in the soup mix samples was observed for the case of moisture content beyond 12% (0.12 kg water/ kg dry sample), the critical moisture content was considered to be 0.12 kg water/ kg dry sample for the developed soup mix formulations. Further, at the critical moisture content, MS, TS14, TS13, MW and TW8 formulations were were assessed with water activity values of 0.56, 0.57, 0.56, 0.57 and 0.56 respectively.

Also, the permeability (K) of packaging material was determined as 1.02 x 10^{-7}kg/m^2/day/Pa. This was obtained with the slope of the straight-line fit of the plot between storage time and weight gained by silica gel placed in the packaging material and stored at 38±2 ^{o}C (Figure H1 in Appendix H). And, for all cases, the low-density polyethylene (LDPE) zipper pouch area was 0.014 m^2. Further, based on the steam table data, saturation vapour pressure of water at 40 ^{o}C was taken as 6980.5 Pa. Based on the moisture content of the samples, the dry weight of the solids varied between 0.00464 to 0.00468 kg. Finally, the predicted shelf-life values were 70, 78, 74, 66 and 66 days for the MS, TS14, TS13, MW and TW8 samples respectively. The obtained findings affirm a stable shelf-life for two months at accelerated conditions of higher combination of temperature and humidity. The predicted shelf-life values are observed to be lower than the value (114 days) reported for mango powder (Jaya & Das, 2005). This could possibly be due to the formulation being constituted with mixture of different ingredients that tend to exhibit varied moisture and water activity characteristics during the storage period. Further, the shelf-life could be enhanced through the usage of a packaging material with better barrier properties. Thereby, moisture migration can be profoundly altered in the favour of the storage condition.

7.7.3 Antioxidant Activity Degradation Kinetics of Best Formulations at Accelerated Storage Condition and Ambient Temperature

The antioxidant activity of soup mix formulations being assessed during various stages of storage (both accelerated and ambient) have been summarized in Table 7.9. Firstly, for both cases of accelerated and ambient temperature storage conditions, the findings depict a decreasing trend of antioxidant activity with prolonged storage period. For the case of accelerated storage condition, the AA reduced in the range of 20.8 to 28% for a storage period of 28 days. The reduction in antioxidant activity was maximum for the case of MS and MW samples and minimum for the TS14 sample. Both TW8 and TS13 samples had intermediate reduced AA trend. However, upon storage at the ambient condition, the AA reduced in the range of 10 to 12%. From these observations, it can be affirmed that the higher combination of temperature and humidity exhibited significant influence on the degradation of antioxidant activity. Similar observations were reported for the herbal drink formulation being prepared with the *Centella asiatica* powder (Bala et al., 2023). Thereby, with an increase in the relative humidity and storage time, antioxidant activity of the soup mix formulations reduced.

Table 7.9: Antioxidant Activity of best soup mix formulations being stored at accelerated and ambient storage conditions.

Storage day/ Half degradation time	**MS**		**TS14**		**TS13**		**MW**		**TW8**	
	38 ºC, 90% RH	**Ambient Temperature**	**38 ºC, 90% RH**	**Ambient Temperature**	**38 ºC, 90% RH**	**Ambient Temperature**	**38 ºC, 90% RH**	**Ambient Temperature**	**38 ºC, 90% RH**	**Ambient Temperature**
0	0.50 ± 0.002	0.50 ± 0.002	0.72 ± 0.006	0.72 ± 0.006	0.68 ± 0.004	0.68 ± 0.004	0.89 ± 0.010	0.89 ± 0.010	0.95 ± 0.009	0.95 ± 0.009
7	0.47 ± 0.005	0.49 ± 0.006	0.70 ± 0.008	0.71 ± 0.008	0.66 ± 0.005	0.67 ± 0.009	0.81 ± 0.008	0.87 ± 0.002	0.89 ± 0.012	0.92 ± 0.006
14	0.41 ± 0.007	0.48 ± 0.014	0.62 ± 0.004	0.69 ± 0.002	0.58 ± 0.008	0.65 ± 0.007	0.70 ± 0.012	0.83 ± 0.002	0.77 ± 0.008	0.89 ± 0.006
21	0.39 ± 0.009	0.46 ± 0.004	0.59 ± 0.008	0.67 ± 0.006	0.53 ± 0.010	0.63 ± 0.003	0.65 ± 0.003	0.82 ± 0.006	0.74 ± 0.007	0.86 ± 0.006
28	0.36 ± 0.006	0.44 ± 0.013	0.57 ± 0.019	0.64 ± 0.004	0.52 ± 0.007	0.61 ± 0.007	0.64 ± 0.008	0.79 ± 0.005	0.73 ± 0.010	0.85 ± 0.005
$t_{1/2}$ (Days)	57	150	76	165	64	173	55	161	68	169

Further, the effect of storage on antioxidant activity was determined through first-order degradation kinetics and the half-time was determined for all considered samples and for both storage conditions (Table 7.7). The reaction rate constant (k) which was obtained from the slope of time versus ln(A) plot was used to determine the half-time of antioxidant activity for the best samples. For the case of accelerated storage condition, highest half-time (76 days) was achieved for TS14 sample and the lowest half-time (55 days) was achieved for MW sample. However, at ambient storage, highest half-time (173 days) was affirmed for TS13 sample and the lowest half-time was affirmed for the MS sample (150 days). Thereby, the findings affirm that for the case of ambient condition storage, MS, TS14, TS13, MW and TW8 samples can be inferred to be stable for minimum storage period of 150 days (up to 5 months), as the antioxidant activity has been accounted to reduce by 50% to the original value for this time period. With antioxidant activity being one of important quality parameters, a higher antioxidant activity after mentioned storage period indicates good retention of the number of antioxidants. This conveys the formulations to be a stable product in terms of the shelf-life and nutritional characteristics. Further, even for the case of accelerated storage condition, a half-time of up to 60 days (2 months) has been affirmed for the best mentioned formulations.

7.8 Summary

This chapter addressed the identification of best thickening agent mix composition as a replacement for the corn flour in both summer and winter vegetable soup mix formulation cases. In summary, firstly, for the summer vegetable soup formulation case, 20% thickening agent mix constituting of the wt % of 17% chickpea, 66% rice, 17% Bengal gram (OA of 7.38, OS of 74.75 and DI of 12.18) and wt % of 66% chickpea,17% rice, 17% Bengal gram (OA of 7.38, OS of 74 and DI of 12.95) were identified as the best for the soup formulations being constituted with 50% vegetable mix (13.4% spine gourd, 23.2% sponge gourd, 13.4% yardlong bean) and 30% spice mix (11.67% onion powder, 11.67 garlic powder, 5% ginger powder, 5% coriander powder, 5% black pepper powder, 26.67% salt, 25% milk powder, 10% tomato powder) and reconstitution ratio of 1:16. Similarly, for the winter vegetable soup formulation case, 20% thickening agent mix being constituted with the wt% of 75% chickpea, 25% rice (OA of 7.63, OS of 76.56 and DI of 6.84) was identified as the best for soup formulation being constituted with 50% vegetable mix (10% ash gourd, 29.7% bottle gourd, 10.3% squash) and 30% spice mix (5% onion powder, 5% garlic powder, 1.67% ginger powder, 1.67% coriander powder, 5% black pepper powder, 58.33% salt, 16.67% milk powder, 6.67% tomato powder) and reconstitution ratio of 1:22.

Secondly, the formulations with best thickening agent mix composition exhibited DI values comparable to that of optimal vegetable soup mix formulations being constituted with the corn flour. However, marginally lower OS values were obtained and all the formulations exhibited acceptable sensory properties. Thirdly, all the formulations being identified as the best in this chapter exhibited higher AA, TPC and protein content in comparison to the soups constituted with the corn flour. Also, the soup formulation exhibited up to 5 times higher in-vitro bio accessible antioxidant activity (0.15 to 0.16%) in comparison to that of soup mix formulations constituted with corn flour (0.03 to 0.04% antioxidant activity). Further, the formulation exhibited lower estimated GI values in comparison to the soup mix formulation being constituted with the corn flour. Also, the developed formulations have been constituted with gluten free ingredients in contrast to the commercial Knorr mixed vegetable soup being constituted with refined wheat flour (source of gluten) as a thickening agent. Finally, all the best formulations incorporated with corn flour as well as alternate thickening agent mix composition exhibited pseudoplastic shear thinning behaviour with a flow behaviour index value lower than 1. Further, the moisture content of the soup mix samples enhanced with storage time. Thereby, the formulations have been inferred to exhibit hygroscopic behavior.

Further, for all the best samples being constituted with corn flour (MMD optimized) (MS and MW) and alternate thickening agents (TS14, TS13 and TW8), with respect to antioxidant activity degradation kinetics, the half-time varied from 55 – 68 days and 150 – 173 days respectively for the cases of ambient and accelerated storage conditions.

In summary, through adaptation of a systematic approach for soup formulation compositional optimization, the thesis evolved upon the development of soup mix formulations with higher proportions of vegetable mix (50 wt%) in combination with cereal and legume based thickening agent mix (20 wt%) and spice mix (30 wt%). Finally, the significant findings of the Ph.D. thesis work provide important inferences on the applicability of the novel score deviation sensory technique and optimization studies to achieve up on widely acceptable soup mix formulations in terms of both sensory and nutritional characteristics.

Chapter 8:

Conclusions and Future Work

Conclusions and Future Work

Overview of the Chapter

In this chapter, section 8.1 summarizes the important conclusions being inferred from the research work addressed in the Ph.D. thesis. Further section 8.2 outlines the possible scope for future work in the selected field of research.

8.1 Conclusions

Based on the experimental investigations being addressed in the Ph.D. thesis, few important conclusions were derived with respect to the stage-by-stage optimization of ingredient composition of mixed vegetable soup mix formulations. In this regard, the best formulations achieved at various stages of the soup mix formulation development research and the associated key findings have been presented in Tables 8.1 and 8.2 of the chapter. Thereby, a brief summary of the conclusions of the Ph.D. thesis has been listed in the following sub-sections.

8.1.1 Moisture and Nutritional Characteristics of Optimally Tray Dried Summer and Winter Vegetables

- Among the summer vegetables, tray dried powders of pointed gourd (0.99%/mg AA, 171.35 mg/100g TPC, 237.54 mg/100g VITC), spine gourd (1.01%/mg AA, 241.22 mg/100g TPC, 733.68 mg/100g VITC) and yardlong bean (0.95%/mg AA, 273.90 mg/100g TPC, 150.08 mg/100g VITC) possessed highest nutrients.
- Among dried winter vegetables, tray dried powders of ash gourd (1.01%/mg AA, 332.50 mg/100g TPC, 362.19 mg/100g VITC), bitter gourd (0.97%/mg AA, 247.34

Table 8.1: A summary of the best summer and winter vegetable soup mix formulations being inferred from the Ph.D. thesis investigations.

S. No.	Target	Best formulation	10g soup mix		
			Dried vegetable powder mix	**Thickening agent**	**Spice mix**
1a	**Identification of best vegetable mix combination** Trial-and-error	**Summer (SF20)** Reconstitution ratio 1:16	**25%** (1g spine gourd, 1g sponge gourd, 0.5g yardlong bean)	**25%** (2.5g corn flour)	**50%** (0.5g onion, 0.5g garlic, 0.5g ginger, 0.25g coriander, 0.25g black pepper, 1.25g salt, 1.25g milk powder, 0.5g tomato powder)
1b		**Winter (WF9)** Reconstitution ratio 1:18	**25%** (1g ash gourd, 1g bottle gourd, 0.5g squash)		
2a	**Vegetable, corn flour, spice mix optimization** Trial-and-error	**Summer (SE)** Reconstitution ratio 1:16	**50%** (2g spine gourd, 2g sponge gourd, 1g yardlong bean)	**20%** (2g corn flour)	0.35g onion, 0.35g garlic, 0.15g ginger, 0.15g coriander, 0.15g black pepper, 0.8g salt, 0.75g milk powder, 0.3g tomato powder **(Summer-30%)** 0.15g onion, 0.15g garlic, 0.05g ginger, 0.05g coriander, 0.15g black pepper, 1.75g salt, 0. 5g milk powder, 0.2g tomato powder **(Winter-30%)**
2b		**Winter (WE2)** Reconstitution ratio 1:22	**50%** (2g ash gourd, 2g bottle gourd, 1g squash)		
3a	**Vegetable mix optimization** Mixture model design	**Summer (MS)** Reconstitution ratio 1:16	**50%** (1.34g spine gourd, 2.32g sponge gourd, 1.34g yardlong bean)	**20%** (2g corn flour)	
3b		**Winter (MS)** Reconstitution ratio 1:22	**50%** (1g ash gourd, 2.97g bottle gourd, 1.03g squash)		
4a	**Thickening agent mix optimization** Trial-and-error	**Summer (TS14)** Reconstitution ratio 1:16	**50%** (1.34g spine gourd, 2.32g sponge gourd, 1.34g yardlong bean)	**20%** (0.34g chick pea, 1.32g rice, 0.34g Bengal gram)	
4b		**Summer (TS13)** Reconstitution ratio 1:16	**50%** (1.34g spine gourd, 2.32g sponge gourd, 1.34g yardlong bean)	**20%** (1.32g chick pea, 0.34g rice, 0.34g Bengal gram)	
4c		**Winter (TW8)** Reconstitution ratio 1:22	**50%** (1g ash gourd, 2.97g bottle gourd, 1.03g squash)	**20%** (1.5g chick pea, 0.5g rice)	

Table 8.2: A summary of sensory and nutritional characteristics of best reported summer and winter vegetable soup mix formulations in the Ph.D. thesis.

S. No.	Target	Best formulation	Notable Inferences	
			Sensory Inferences	**Nutritional Characteristics**
1a	**Identification of best vegetable mix combination** Trial-and-error	**Summer (SF20)** Reconstitution ratio 1:16	OA: 7.70 OS: 74.56, DI: 19.28	AA: 0.5%, TPC: 24.78 mg/10g, vitamin C: 17.3 mg/10g
1b		**Winter (WF9)** Reconstitution ratio 1:18	OA: 7.48 OS: 74.76, DI: 14.92	AA: 0.83%, TPC: 27.98 mg/10g, vitamin C: 14.7 mg/g
2a	**Vegetable, corn flour, spice mix optimization** Trial-and-error	**Summer (SE)** Reconstitution ratio 1:16	OA: 8.00 OS: 81.26, DI: 21.96	AA: 0.53%, TPC: 29.21 mg/10g, vitamin C: 32.62 mg/10g
2b		**Winter (WE2)** Reconstitution ratio 1:22	OA: 8.10 OS: 81.35, DI: 17.79	AA: 0.89%, TPC: 35.61 mg/10g, vitamin C: 25.91 mg/10g
3a	**Vegetable mix optimization** Mixture model design	**Summer (MS)** Reconstitution ratio 1:16	OA: 8.5 OS: 80.43, DI: 7.3	AA: 0.55%, TPC: 30.77 mg/10g, vitamin C: 33.83 mg/10g In-vitro AA: 0.04%, TPC: 59.28 mg/ 100mL
3b		**Winter (MS)** Reconstitution ratio 1:22	OA: 8.3 OS: 86.77, DI: 9.5	AA: 0.89%, TPC: 34.63 mg/10g, vitamin C: 36.51 mg/10g In-vitro AA: 0.03%, TPC: 89.19 mg/ 100mL
4a	**Thickening agent mix optimization** Trial-and-error	**Summer (TS14)** Reconstitution ratio 1:16	OA: 7.38 OS: 74.75, DI: 12.18	AA: 0.72%, TPC: 36.30 mg/10g In-vitro AA: 0.15%, TPC: 49.93 mg/ 100mL, protein: 6.27 mg/100mL
4b		**Summer (TS13)** Reconstitution ratio 1:16	OA: 7.38 OS: 74.00, DI: 12.95	AA: 0.68%, TPC: 35.34 mg/10g In-vitro AA: 0.15%, TPC: 41.51 mg/ 100mL, protein: 6.06 mg/100mL
4c		**Winter (TW8)** Reconstitution ratio 1:22	OA: 7.63 OS: 76.56, DI: 6.84	AA: 1.00%, TPC: 48.16 mg/10g In-vitro AA: 0.16%, TPC: 53.01 mg/100mL, protein: 6.05 mg/100mL

mg/100g TPC, 559.26 mg/100g VITC) and bottle gourd (1.02%/mg AA, 261.76 mg/100g TPC, 143.45 mg/100g VITC) possessed highest nutrients.

- Blanching followed by drying treatment resulted in a lower drying time in comparison to only drying treatment of all the vegetables.
- Among dried summer vegetables, lowest optimal drying time of 8h has been inferred for both spine gourd and yardlong bean vegetables and for respective moisture contents of 6.83% and 4.90%.
- Among blanched dried summer vegetables, lowest drying time of 8h was affirmed for spine gourd vegetable at a moisture content of 5.96%.
- Among dried winter vegetables, lowest drying time of 8h was attained for both beans and pumpkin and at 7.72% and 7.21% moisture content respectively.
- For all the vegetables, drying treatment resulted in higher retention of antioxidant activity in comparison to the blanching combined with drying treatment.
- Among all blanched dried vegetables, maximum retention of antioxidant activity (AA) was observed for spine gourd vegetable (98.02%) and minimum was assessed in beans vegetable (17.14). However, most vegetables exhibited an AA retention greater than 50%.

8.1.2 Identification of Best Summer and Winter Vegetable Mix Combinations for Soup Mix Formulations

- The preliminary trial experiments based standardized soup mix formulation constitutes 25% vegetable mix, 25% corn flour and 50% spice mix (10% onion powder, 10% garlic powder, 10% ginger powder, 5% coriander powder, 5% black pepper powder, 25% salt, 25% milk powder, 10% tomato powder). The soup formulations were prepared with a reconstitution ratio of 1:16 and 1:18 for the summer and winter vegetables cases respectively.

- The developed soup mix formulations with 25% vegetable mix, 25% corn flour and 50% spice mix exhibited better sensory scores, AA, TPC and vitamin C in comparison to the commercial Knorr mixed vegetable soup.
- The score deviation (SDI) method provided useful inferences upon the weightage contributed by each sensory parameter towards the OS of a formulation and uniformity within sensory parameters in terms of DI value. This aided in the identification of best formulations with higher levels of confidence.

8.1.3 Optimization of Trial-and-Error Methodology Based Soup Mix Formulations

- As per SDI method, taste index (TI) exhibited maximum weightage on the OS of the best summer (48.80) and winter (46.67) vegetable-based soup mix formulations. This is followed by aroma index (AI) and physical index (PI).
- As per fuzzy logic analysis, for the SE sample case, the taste parametere was identified as the extremely important sensory parameter with highest similarity index value. Similarly, for the WE2 sample case, aftertaste attained highest similarity value for the highly important category. Quantitative weightage could not be inferred through fuzzy logic analysis.
- Finally, best soup mix formulations being constituted with 50% vegetable mix, 20% corn flour and 30% spice mix exhibited improved sensory characteristics in comparison to soup mix formulations (SF20 and WF9) being constituted with 25% vegetable mix, 25% corn flour and 50% spice mix.
- The enhancement in vegetable mix proportion significantly improved taste and aroma properties of the soup mix formulations.

8.1.4 Mixture Model Methodology Based Optimization of Vegetable Mix Composition

- As per response surface methodology (RSM) based mixture model design (MMD) optimization, optimum values of AA (0.548%), OA (7.63) and OSDI (objective function of OS and DI) (77.42) were achieved with a desirability of 0.816 for the MS sample with optimum winter vegetable mix composition.
- Similarly, for the MW sample with optimum vegetable mix composition, optimum values of AA (0.815), OA (8.10) and OSDI (82.67) were achieved with a desirability of 0.789.
- For both MS and MW sample cases, significantly improved sensory scores (especially in terms of OSDI) were achieved in comparison to the SE and WE2 sample cases being identified through trial-and error optimization.
- A significantly lower DI was achieved for both MS (7.30) and MW (9.5) samples in comparison to the SE and WE2 sample cases. This indicated better uniformity among the sensory parameters of MS and MW samples. Thereby, alteration in vegetable mix composition within the 50 wt% significantly improved sensory properties. However, only a marginal or no change has been apparent for the case of nutritional characteristics.
- A better model prediction in terms of R^2 values was achieved for OSDI case in comparison to the OA case.

8.1.5 Optimization of Trial-and Error Methodology Based Thickening Agent Mix Composition

- Summer (TS14 and TS13) and winter (TW8) vegetable-based soup mix formulations being constituted with alternate combinations of thickening agents i.e., channa, rice and sattu flour exhibited upto 5 times higher in-vitro bio-accessible antioxidant activity in comparison to the best summer (MS) and winter (MW) vegetable-based soup mix formulations being constituted with corn flour.

- The TS14 and TS13 formulations respectively exhibited lower estimated glycemic index (GI) values of 29.52 and 25.26 respectively in comparison to the estimated GI value of the MS formulation (32.67). Similarly, TW8 formulation exhibited a lower estimated GI value of 25.56 in comparison to the estimated GI value of 29.44. Thereby, the replacement of corn flour thickening agent with channa, rice and sattu flour could result in lower GI.
- For the TS14 formulation case, TI (40) exhibited maximum weightage followed by PI (32.5) and AI (27.5). For the TS13 formulation case, TI (48.33) followed by PI (26.67) and AI (25) was assessed. For the TW8 formulation case, TI (47.5) exhibited maximum weightage followed by AI (28.75) and PI (23.75).
- The incorporation of rice flour along with chick pea flour improved the taste and uniformity properties of the soup formulation. However, the incorporation of Bengal gram flour at higher proportion resulted in reduced scores for appearance and uniformity parameters.
- All the best identified reconstituted soup formulations exhibited pseudoplastic shear thinning behaviour with flow behaviour index values (n) lower than 1.
- At both accelerated storage and ambient condition storage, the moisture content and water activity of the soup mix formulations enhanced with an increase in the storage time period. This observation affirmed hygroscopic nature of developed soup mix formulations.
- The antioxidant activity degradation was validated through first order degradation kinetics. At the accelerated storage condition (38±2 °C and 90% RH), the half-time for

antioxidant activity degradation was evaluated as 57, 76, 64, 55 and 68 days for MS, TS14, TS13, MW and TW8 samples respectively.

- At ambient storage condition, the half-time for antioxidant activity degradation was assessed as 150, 165, 173, 161 and 169 days for MS, TS14, TS13, MW and TW8 samples respectively.

In summary, optimal dried vegetable soup mix formulations being constituted with abundant Indian vegetable produces and cereal and legume based thickening agents have been successfully developed in the Ph.D. thesis. This was achieved through stage-by-stage formulational optimization studies that targeted the design of novel score deviation sensory evaluation technique and with the trial-and-error based and statistical based optimization techniques. *The developed soup formulations were targeted to meet the nutritional requirements of a wider group of consumers. Since the soup preparation is easy, their best organoleptic features further render them to be relevant for wider consumption. Also, they are expected to facilitate ease of consumption and good digestibility in the human digestive system. Thus, it is anticipated that the optimally prepared soups could be readily accepted by children, professionals, housewives and even elderly people. Further, since the utilized vegetables and the legume-based thickening agents are well known for their lower glycaemic index, the optimally prepared soups can be concluded to be beneficial for consumers with diabetics and similar ailments.*

8.2 Future Work

Based on the extent of objective and subjective being summarized in the Ph.D. thesis, the following areas of research can be further explored:

a) Further research targeting the reduction in processing time of vegetables through techniques such as microwave drying and spray drying of vegetable slurries can be targeted and conducted. The efficacy of these techniques towards the development of value-added products with dried vegetable produces can be studied.

b) Various other millet and legume based thickening agents as replacement to corn flour and refined wheat flour being incorporated in commercially available soup products can be evaluated for their effect on the functional, sensory, nutritional and rheological properties of soups.

c) Statistical optimization targeting non-MMD based compositional optimization of all vegetables or vegetable, thickening agent and spice composition can be targeted and studied.

d) The three vegetables-based optimization study of the PhD thesis can be further extended to upto 5 to 6 vegetables. Thereby, complexity in the formulational research through a hierarchical approach or a randomized design-based approach can be targeted and conducted.

e) Fortification of the soup mix with other micronutrients and functional compounds can be considered for the development of a functional soup mix product.

f) In the Ph.D. thesis, accelerated storage stability of the developed soup mix formulations has been studied in terms of moisture content, water activity and antioxidant activity. However, further studies can be conducted to study the effect of long-term storage on the sensory and microbial characteristics on the shelf life of the dried vegetable soup mix products. Further, role of alternate packaging materials such as high-density polyethylene (HDPE) and laminated pouches on the shelf life of soup mix products can be investigated in the near future.

g) All the developed soup formulations have been compared with Knorr mixed vegetable soup in terms of organoleptic properties, nutritional composition, in-vitro nutrient bio accessibility and rheological properties. Further, cost analysis was not conducted as cost evaluation is highly complex subject that requires scalability and costs of man power, electricity and packaging. These require detailed techno-economic analysis and associated studies, which are beyond the scope of the Ph.D. thesis being set as the evaluation of the organoleptic and nutritional properties of alternate soup formulations. However, future research investigations can address such issues and accordingly benchmarks can be set for the commercialization of the conducted research.

In summary, the Ph.D. thesis has several dimensions in which soup mix formulational research can be conveniently addressed in academic and research frameworks.

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Publications

1. Publications

a. Akasapu, K., Uppaluri, R.V.S. (2024) "Role of score-deviation, hedonic and fuzzy logic sensory approaches for the development and identification of optimal vegetable mix soups ". International Journal of Gastronomy and Food Science, 37, 100982.

b. Akasapu, K., Uppaluri, R.V.S. (2023) "Efficacy of Score Deviation method as a novel sensory evaluation technique for the identification of optimal mixed vegetable soup formulations ". International Journal of Gastronomy and Food Science, 100761.

c. Akasapu, K., Uppaluri, R.V.S. (2023). "Nutritional Efficacy Based Vegetables Selection for the Development of Ready to Cook Soup Mix Formulations", Agro and Food Processing Technologies: Proceedings of North-east Research Conclave (NERC) 2022, Springer Nature, 157-192.

2. Articles Submitted/ Under Decision

a. Akasapu, K., Uppaluri, R.V.S. "Mixture model methodology based compositional optimality of vegetable soup mix formulation and its antioxidant activity degradation kinetics-based shelf-life prediction.

b. Akasapu, K., Uppaluri, R.V.S. "Investigating the effect of legume and rice flour thickening agents as potential alternatives to corn flour-based vegetable soups.

3. Conference Presentations

a. Akasapu, K., Uppaluri, R.V.S., (2023) " Hedonic, score deviation and fuzzy logic sensory analysis techniques for the development of optimal vegetable mix soup formulations: A comparative study and future insights", 5th ISPFVF, 22-23 June, 2023, Kuala Lumpur, Malaysia.

b. Akasapu, K., Uppaluri, R.V.S., (2023) " Development and characterization of optimal mixed vegetable soup formulation", National Conference on Underutilized Food Resources: Nutrient Composition, Value Addition and Quality Assurance, 25-26 May 2023, Mizoram University.

c. Akasapu, K., Uppaluri, R.V.S., (2022) " Nutritional efficacy-based vegetables selection for the development of ready to cook soup mix formulations development", North-east Research Conclave (NERC 2022), 20-22 February 2022, IIT Guwahati.

Appendix

Appendix A: Standardization Phase Methodology and Associated Findings

The standardization phase involved the affirmation of the proportion of each ingredient of the soup mix composition. This was conducted through the conduct of preliminary trial experiments. The aim of such experiments was to achieve the standardized soup mix composition in terms of the specified quantities of dried vegetable, corn flour and spice mix. The standardized composition was achieved as per the overall acceptability of the alternate preliminary formulations that were assessed with the 9-point hedonic scale sensory analysis methodology. Table A1 and Table A2 respectively summarize the ingredient composition of alternate soup formulations and 9-point hedonic scale based overall acceptability scores for the alternate preliminary soup mix formulations.

Table A1: A summary of the preliminary soup mix formulations with varied ingredient compositions for the assessment of the standardized soup mix formulation.

S.No.	Ingredients Amount (g)	P1	P2	P3	P4	P5	P6	P7	P8
1	Vegetable	2.5	4	2.5	4	2.5	4	2.5	4
2	Corn flour	2.5	3	2.5	3	2.5	3	2.5	3
3	Onion powder	0.15	0.1	0.5	0.3	0.25	0.15	0.25	0.15
4	Garlic powder	0.15	0.1	0.5	0.3	0.25	0.15	0.25	0.15
5	Ginger powder	0.10	0.05	0.5	0.3	0.25	0.15	0.25	0.15
6	Tomato powder	-	-	0.5	0.3	-	-	0.3	0.18
7	Coriander powder	-	-	0.25	0.15	-	-	0.15	0.09
8	Black pepper	0.10	0.05	0.25	0.15	0.15	0.1	0.15	0.09
9	Milk powder	0.5	0.3	1.25	0.75	1	0.6	1	0.6
10	Salt	3	1.8	1.25	0.75	1.75	1.05	2.5	1.5
11	Cumin powder	-	-	-	-	0.1	0.05	0.15	0.09
12	Vegetable oil	1	0.5	-	-	1.25	0.75	-	-

Table A2: Overall acceptability scores of the preliminary soup mix formulations in the phase of the standardized soup mix formulation assessment.

Formulation	Overall acceptability
P1	7.00±1.72
P2	6.5±1.50
P3	7.90±1.25
P4	7.20±1.65
P5	7.50±1.75
P6	7.0±1.35
P7	6.8±1.02
P8	6.0±0.98

Appendix B: Score Deviation Method Sensory Evaluation Form and Sample Calculation

Score Deviation Method Sensory score sheet

Name: ____________________________________ **Date:**

The soup sensory parameters have been categorized into three main criteria namely Taste Index (TI), Aroma Index (AI) and Physical Index (PI). The TI and PI have been further categorized into three sub criteria, being mentioned as follows:

Main Criteria	**Taste Index**	**Aroma Index**	**Physical Index**
Sub Criteria	Satisfaction	-	Appearance
	Mouthfeel		Consistency
	After taste		Uniformity

For the provided soup samples, kindly evaluate the above-mentioned criteria and provide absolute score for each criteria (individually out of 100) and comparative score for main criteria (total 100).

Score card for main criteria

Score type	**Main Criteria**	**F1**
Absolute	**Taste Index**	88 (*a1*)
	Aroma Index	90 (*a2*)
	Physical Index	86 (*a3*)

Score type	**Main Criteria**	**F1**
Comparative	**Taste Index**	40 (*b1*)
	Aroma Index	30 (*b2*)
	Physical Index	30 (*b3*)

Score cards (absolute score) for sub criteria

Score type	Main Criteria	Sub Criteria	F1
Absolute	Taste Index	Satisfaction	88 (*Si*)
		Mouthfeel	90 (*Mi*)
		After taste	91 (*Ai*)

Score type	Main Criteria	Sub Criteria	F1
Absolute	Physical Index	Appearance	89 (*APi*)
		Consistency	91 (*Ci*)
		Uniformity	92 (*Ui*)

Sample Calculation for the Score Deviation Method (SDI)

For a specific case, the sample score sheet of SDI method ascertains absolute score of taste index (*a1*): 88; absolute score of aroma index (*a2*): 90; absolute score of physical index (*a3*): 86; comparative score of taste index (*b1*): 40; comparative score of aroma index (*b2*): 30; comparative score of physical index (*b3*): 30; absolute score of satisfaction (*Si*): 88; absolute score of mouthfeel (*Mi*): 90; absolute score of aftertaste (*Ai*): 91; absolute score of appearance (*APi*): 89; absolute score of consistency (*Ci*): 91; absolute score of uniformity (*Ui*): 92.

The following parameters were determined for the specific case and with the SDI method:

Using equation 2.7,

$$OS = \left(\frac{88}{100}\right)40 + \left(\frac{90}{100}\right)30 + \left(\frac{86}{100}\right)30$$

$$OS = 88$$

Using equation 2.12,

$$Ts = 88 + 90 + 91$$

$$Ts = 269$$

Using equation 2.9,

$$Sm = \frac{88 \times 100}{269}$$

$$Sm = 32.71$$

Using equation 2.10,

$$Mm = \frac{90 \times 100}{269}$$

$$Mm = 33.46$$

Using equation 2.11,

$$Am = \frac{91 \times 100}{269}$$

$$Am = 33.83$$

Using equation 2.16,

$$Ps = 89 + 91 + 92$$

$$Ps = 272$$

Using equation 2.13,

$$APm = \frac{89 \times 100}{272}$$

$$APm = 32.72$$

Using equation 2.14,

$$Cm = \frac{91 \times 100}{272}$$

$Cm = 33.46$

Using equation 2.15,

$$Um = \frac{92 \times 100}{272}$$

$Um = 33.82$

Xm, the mean is 33.3 if each sub-parameter under TI and each sub-parameter under PI ideally exhibited equal weightage out of 100.

Therefore, using equation 2.8, the devation index is determined as:

$$DI = \frac{[(|32.71-33.3|)+(|33.46-33.3|)+(|33.83-33.3|)+(|32.72-33.3|)+(|33.46-33.3|)+(|33.82-33.3|)]}{33.3} \times 100$$

$$DI = \frac{[(|-0.59|) + (|0.16|) + (|0.53|) + (|-0.58|) + (|0.16|) + (|0.52|)]}{33.3} \times 100$$

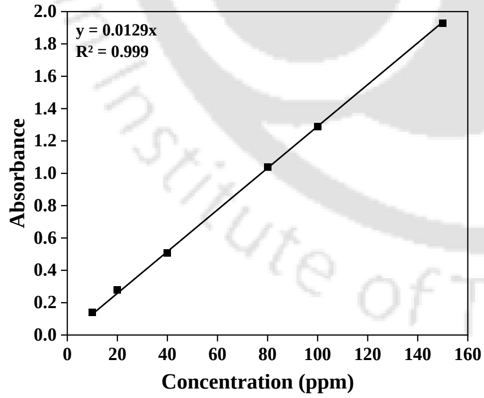
$$DI = \frac{0.59 + 0.16 + 0.53 + 0.58 + 0.16 + 0.52}{33.3} \times 100$$

$DI = 7.6$

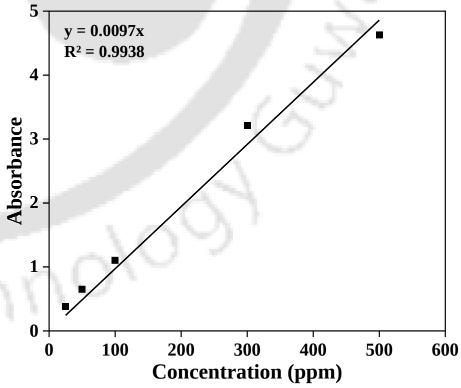
Using a combination of OS and DI, the SDI method aims to assess and rank alternate soup mix formulations. Further details with respect to the followed methodology for the ranking purpose have been presented in the respective sections of the Ph.D. thesis.

Appendix C: Calibration Curves for the Determination of Soluble Protein and Total Phenolic Contents

To determine the soluble protein content and total phenolic content, the absorbance of the dried and liquid soup samples was measured using a UV Spectrophotometer (Make: SHIMADZU; Model: UV-2600) and at wavelengths of 595 nm and 750 nm respectively. Further, to determine the concentration of the said nutrients, calibration curves were prepared for various concentrations of the standard solution versus absorbance. For the determination of the soluble protein content in the samples, calibration curves for standard concentrations in the range 10-150 ppm have been prepared (illustrated in Figure C1(a)). Similarly, for the determination of total phenolic content in the samples, calibration curves for the standard concentrations of 25, 50, 100, 300 and 500 ppm have been prepared (illustrated in Figure C1(b)). Thereby, the concentration of unknown samples can be determined with the regression expressions mentioned in the figures.



(a)



(b)

Figure C1. Calibration curve for the determination of (a) soluble protein, and (b) total phenolic content.

Appendix D: Sample Calculations for the Determination of Proximate and Nutritional Characteristics Assessment

The sample calculations for the determination of proximate and nutritional characteristics of the vegetable samples and soup mix formulations have been presented as follows.

a) Moisture content: Weight of initial sample taken (M_s): 1.023 g; weight of oven dried sample (M_d): 0.951 g

Using eq. (2.1),

$$MC(\%) = \frac{1.023 - 0.951}{0.951} \times 100 = 7.04\%$$

b) Yield: Weight of fresh sample (M_f): 40 g; weight of tray dried sample (M_s): 2.24 g

Using eq. (2.2),

$$Yield(\%) = \frac{2.24}{40} \times 100 = 5.60\%$$

c) Crude fibre: Weight of fresh sample (M_s): 1 g; weight loss during ignition (M_l): 0.247 g

Using eq. (2.3),

$$Crude\ fibre(\%) = \frac{0.247}{1} \times 100 = 24.7\%$$

d) Antioxidant activity: Absorbance of control (A_c): 0.407; absorbance of sample (A_s): 0.101

Using eq. (2.4),

$$Antioxidant\ activity(\%) = \frac{0.407 - 0.101}{0.407} \times 100 = 75.18\%$$

$$Antioxidant\ activity(\%) = \frac{75.18}{weight\ of\ dry\ matter\ in\ 100\ mg\ smaple}$$

$$Antioxidant\ activity(\%) = \frac{75.18}{95} = 0.72\%\ in\ absolute\ dry\ basis\ sample$$

e) **Vitamin C content:** Volume of ascorbic acid consumed (C_1): 3.55 mL; volume of sample extract consumed (C_2): 0.15 mL; weight of the sample taken (M_s): 0.1 g

Using eq. (2.5),

$$Vitamin\ C\left(\frac{mg}{100g}\right) = \frac{0.5 \times 0.15 \times 20 \times 100}{3.55 \times 5 \times 0.1} = 84.51\ mg/100g$$

$$Vitamin\ C\left(\frac{mg}{100g}\right) = \frac{84.51 \times 100}{weight\ of\ dry\ matter}$$

$$Vitamin\ C\left(\frac{mg}{100g}\right) = \frac{84.51 \times 100}{95} = 89.32\frac{mg}{100g}\ dry\ mass\ basis\ of\ sample$$

f) **Crude protein:** Titration value: 15.6 mL; sample weight: 1 g

Using eq. (2.27),

$$Nitrogen\ (\%) = \frac{14.01 \times 0.1 \times 15.6 \times 100}{1 \times 1000} = 2.19\%$$

$$Crude\ protein\ (\%) = 2.19 \times 6.25 = 13.66\%$$

g) **Carbohydrate content:** Absorbance of standard (A_{std}): 0.625; absorbance of sample (A_s): 0.908

Using eq. (2.28),

$$Carbohydrate(\%) = \frac{0.908}{0.625} \times 25 = 34.98\%$$

h) **Fat content:** Weight of extract (W_e): 0.028 g; weight of sample (W_s): 5 g

Using eq. (2.29),

$$Fat\ (g) = \frac{0.028}{5} \times 100 = 0.56\ g$$

i) **Ash content:** Weight of ash (W_{ash}): 0.796 g; initial weight of sample (W_s): 4.771 g

Using eq. (2.30)

$$Ash(\%) = \frac{0.796}{4.771} \times 100 = 16.69\%$$

Appendix E: Nutritional Characteristics of Optimally Dried Summer and Winter Vegetables

A holistic characterization of selected summer and winter vegetables after being subjected to to either drying or blanching followed by drying treatment has been targeted and addressed in Chapter 3 of the Ph.D. thesis. The optimal drying time (DT) have been assessed in terms of the moisture content (MC) and antioxidant activity (AA) of the treated vegetables. Subsequently, the optimally dried and blanched dried vegetables have been evaluated for crude fibre (CF), soluble protein (SP), total phenolic content (TPC) and vitamin C (VITC) content Tables E1, E2, E3, E4, E5 and E6 summarize the findings associated to the moisture and nutritional characteristics of optimally dried (D) and blanched-dried (BD) samples of green beans, pumpkin, squash, ridge gourd, snake gourd and sponge gourd vegetables respectively. The tables also summarize the findings assessed for fresh (F) and blanched (B) vegetable samples and best reported literature data.

Table E1: Moisture and nutritional characteristics data of fresh and optimally treated green beans vegetable.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	91.76 ± 0.78[a]	NA	NA	95.13 ± 0.08[c]	28.26 ± 1.64[a]	0.43 ± 0.04[c] (0.04 ± 0.003)	272.75 ± 3.31[a]	100.28 ± 3.95[b] (8.26 ± 0.33)
	D	7.72 ± 0.6[b]	08	10.06	95.35 ± 0.12[b]	13.18 ± 0.36[b]	0.7 ± 0.01[a]	292.20 ± 10.24[a]	142.45 ± 3.52[a]
	B	92.06 ± 0.50[a]	NA	NA	96.24 ± 0.08[a]	14.57 ± 0.84[b]	0.67 ± 0.05[b]	224.62 ± 16.58[b]	96.97 ± 4.10[b]
	BD	5.83 ± 0.26[c]	08	9.24	96.09 ± 0.11[a]	9.15 ± 0.04[c]	0.12 ± 0.01[d]	154.36 ± 7.66[c]	85.75 ± 3.45[c]
Isabelle et al., 2010	F	90.39	-	-	-	-	-	-	(8.6)
Stangeland et al., 2009	F	-	-	-	-	-	(0.02)	-	-
Manzoor et al., 2019	BD	13.96	05	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; $n = 3$).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table E2: Moisture and nutritional characteristics data of fresh and optimally treated pumpkin vegetable.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	91.20 ± 0.03[b]	NA	NA	89.18 ± 0.15[b]	15.00 ± 0.49[b]	0.07 ± 0.04[c]	215.17 ± 11.85[a]	207.00 ± 3.70[a] (18.22 ± 0.33)
	D	7.21 ± 0.42[c]	08	6.00	90.16 ± 0.08[a]	15.94 ± 0.75[a]	0.31 ± 0.01[a]	143.69 ± 1.70[c]	135.60 ± 3.51[b]
	B	91.95 ± 0.05[a]	NA	NA	89.83 ± 0.13[a]	8.50 ± 0.10[c]	0.06 ± 0.06[c]	173.32 ± 4.85[b]	114.31 ± 4.04[c]
	BD	5.08 ± 0.38[d]	08	3.75	90.11 ± 0.47[a]	7.16 ± 0.38[d]	0.19 ± 0.01[b]	34.76 ± 5.43[d]	120.68 ± 3.43[c]
Isabelle et al., 2010	F	-	-	-	-	-	-	-	(14.12)
Fadupin et al., 2014	B	90.60	-	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; $n = 3$).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table E3: Moisture and nutritional characteristics data of fresh and optimally treated squash vegetable.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	93.06 ± 0.34^a	NA	NA	95.25 ± 0.12^b	19.50 ± 0.47^a	0.29 ± 0.12^b	163.90 ± 0.86^a	78.43 ± 4.66^b
	D	7.78 ± 0.08^c	09	6.33	95.78 ± 0.07^a	13.34 ± 0.36^b	0.47 ± 0.02^a	166.57 ± 6.98^a	89.60 ± 3.53^a
	B	92.45 ± 0.12^b	NA	NA	95.34 ± 0.12^b	7.83 ± 0.24^c	0.10 ± 0.04^c	102.87 ± 2.09^b	42.28 ± 4.31^d
	BD	5.45 ± 0.11^d	09	3.60	95.84 ± 0.08^a	7.51 ± 0.37^c	0.11 ± 0.01^c	76.32 ± 5.00^c	69.52 ± 3.44^c
Shara & Mussa, 2019	F	-	-	-	-	-	-	-	75.56
	B	-	-	-	-	-	-	-	38
Kiharason et al., 2017	BD	15.15	7.25	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; $n = 3$).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table E4: Moisture and nutritional characteristics data of fresh and optimally treated ridge gourd vegetable.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	91.20 ± 0.03^a	NA	NA	92.06 ± 0.39^b	21.58 ± 0.10^a	0.58 ± 0.10^a	135.90 ± 9.37^b	128.04 ± 6.40^a (11.27 ± 0.56)
	D	7.43 ± 0.04^c	12	4.05	97.96 ± 0.34^a	18.43 ± 0.06^b	0.62 ± 0.08^a	170.76 ± 5.26^a	99.41 ± 3.51^b
	B	90.30 ± 1.40^b	NA	NA	98.26 ± 0.43^a	9.31 ± 0.27^c	0.16 ± 0.19^b	91.05 ± 1.62^d	77.44 ± 3.35^c (7.51 ± 0.33)
	BD	6.09 ± 0.06^d	10	1.87	97.91 ± 0.61^a	9.49 ± 0.01^c	0.36 ± 0.02^b	124.42 ± 4.16^c	67.99 ± 3.46^d
Shinde et al., 2016	F	-	-	-	-	-	-	-	(13)
Gajera et al., 2014	B	-	-	-	-	-	-	-	(6.99)
Shinde et al., 2016	BD	4.00	08	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; $n = 3$).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table E5: Moisture and nutritional characteristics data of fresh and optimally treated snake gourd vegetable.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	95.12 ± 0.04^{b}	NA	NA	93.27 ± 0.97^{b}	20.68 ± 0.98^{a}	0.10 ± 0.03^{b}	320.40 ± 43.82^{a}	107.75 ± 13.53^{b}
	D	6.82 ± 0.24^{c}	11	4.29	98.74 ± 0.44^{a}	14.79 ± 0.48^{b}	0.66 ± 0.01^{a}	167.06 ± 1.92^{b}	203.55 ± 3.49^{a}
	B	96.05 ± 0.05^{a}	NA	NA	97.88 ± 0.61^{a}	15.82 ± 0.45^{b}	0.80 ± 0.16^{a}	179.22 ± 13.14^{b}	190.17 ± 16.47^{a}
	BD	5.94 ± 0.01^{d}	09	2.73	97.90 ± 0.99^{a}	6.85 ± 0.03^{c}	0.16 ± 0.003^{b}	100.83 ± 4.78^{c}	103.82 ± 3.46^{b}
Gajera et al., 2014	F	64	-	-	-	-	-	-	-
	B	-	-	-	-	-	-	-	(6.99)
Shinde et al., 2016	BD	4.00	08	-	-	-	-	-	-

Superscripted means in a column differ significantly ($p < 0.05$; $n = 3$).
Values in parentheses refer to nutritional composition with respect to wet weight.

Table E6: Moisture and nutritional characteristics data of fresh and optimally treated sponge gourd vegetable.

Reference	Treat-ment	MC (%WB)	DT (h)	Yield (%)	CF (%)	SP (mg/g DM)	AA (%/mg DM)	TPC (mg/g DM)	VITC (mg/100g DM)
This work	F	94.79 ± 0.12^{b}	NA	NA	96.63 ± 0.44^{a}	25.85 ± 0.48^{a}	0.63 ± 0.17^{a}	283.62 ± 12.87^{b}	111.74 ± 6.24^{a}
	D	7.56 ± 0.03^{c}	12	6.00	96.82 ± 0.29^{a}	17.82 ± 0.18^{c}	0.78 ± 0.11^{a}	164.31 ± 0.64^{c}	117.83 ± 7.04^{a}
	B	96.36 ± 0.20^{a}	NA	NA	93.12 ± 1.03^{b}	24.76 ± 0.85^{b}	0.37 ± 0.16^{b}	413.50 ± 24.69^{a}	98.02 ± 8.94^{b}
	BD	5.73 ± 0.08^{d}	11	1.72	95.97 ± 0.76^{a}	7.99 ± 0.16^{d}	0.36 ± 0.10^{b}	169.87 ± 4.93^{c}	77.69 ± 5.98^{c}

Superscripted means in a column differ significantly ($p < 0.05$; $n = 3$).

Appendix F: Sensory and Nutritional Characteristics (Mixing Rule) of Summer and Winter Vegetable Based Mixed Soup Formulations

The findings associated to the identification of best summer and winter vegetable mix combinations for the soup mix formulations have been discussed in Chapter 4 of the Ph.D. thesis. Among the twenty summer and twenty winter vegetable based alternate soup formulations, five summer and five winter vegetable formulations were screened based the sensory scores obtained with the 9-point hedonic scale and score deviation (SDI) techniques. The screened formulations were further considered for the estimation of various nutritional characteristics with the mixing rule (as per equation 2.6 in the Ph.D. thesis). Table F1 summarizes the estimated antioxidant activity, total phenolic content, vitamin C content and soluble protein content values for the screened summer and winter vegetable formulations. Further, Table F1 also presents the sensory scores assessed for the screened formulations with 9-point hedonic scale method and SDI method. Further, Table F2 and F3 summarize the respective 9-point hedonic scale based sensory scores assessed for various sensory parameters of the mixed summer and winter vegetable soups being targeted and assessed in Chapter 4 of the Ph.D. thesis.

Table F1: Sensory scores and mixing rule based nutritional composition of screened summer and winter vegetable formulations.

Formulation	AA (%)	TPC (mg/g)	VC (mg/g)	SP (mg/g)	SDI method		Hedonic Overall Acceptability	Rank (SDI method)	Rank (Hedonic)
					Score	Deviation Index			
SF20 SPIG:SPOG:YB	0.90	203.24.46	1.99	12.93	74.13	19.28	7.70	1	2
SF10 PG:SPOG:YB	0.91	189.04	1.72	14.95	68.25	20.78	7.65	3	3
SF19 SG:SPOG:YB	0.77	187.33	1.59	12.35	71.04	22.22	7.05	2	8
SF14 SPIG:SPOG:RG	0.83	182.61	1.89	14.13	69.38	34.57	7.75	7	1
SF9 PG:SPIG:YB	0.98	206.05	2.47	11.13	66.54	21.30	6.90	4	11
WF9 AG:BOG:S	0.91	270.92	2.20	11.16	73.88	14.92	7.48	1	4
WF8 AG:P:BOG	0.73	242.83	2.28	12.73	73.67	14.96	7.50	2	2
WF10 AG:P:S	0.62	223.79	2.17	13.27	76.04	16.85	7.50	3	2
WF20: BOG:P:S	0.63	195.49	1.30	13.31	72.46	18.64	7.69	6	1
WF4 AG:S:BS	0.73	258.07	2.09	11.57	74.18	15.42	7.00	4	8

Table F2: 9-point hedonic scale method based sensory scores of mixed summer vegetable soups.

Formu-lation	Taste	Mouthfeel	Aftertaste	Aroma	Appearance	Consistency	Uniformity	Overall acceptability	Rank
C	6.4±1.58	6.6±1.43	6±1.89	6.3±2	7±1.7	7.3±1.49	7.1±1.52	6.6±1.26	17
SF1	6.7±1.06	6±1.49	6.2±1.69	6.8±1.48	6.7±1.49	5.5±1.08	5.7±1.42	6.3±1.4	20
SF2	6.5±1.08	6.4±1.35	5.9±1.1	6.55±1.26	6.6±1.17	5.6±0.97	5.9±1.37	6.45±0.96	18
SF3	7.1±0.91	6.8±1.4	6.55±0.9	6.9±1.52	7±1.33	6.3±1.16	6.5±1.08	6.9±0.91	11
SF4	6.42±1.73	6.4±1.84	6.18±1.37	6.25±1.14	5.85±1.63	5.7±1.42	5.45±1.71	5.8±1.7	21
SF5	6.55±1.67	6.3±1.64	6.2±1.69	6.7±1.49	6.35±1.6	6.72±1.44	6.75±1.48	6.9±1.6	11
SF6	7.26±1.2	7.25±0.98	7.3±1.06	7.75±1.59	6.9±1.29	6.9±1.45	6.58±1.64	7.45±0.98	4
SF7	6.95±1.38	6.75±1.38	6.85±1.45	6.4±1.65	6.4±1.51	6.2±1.23	6.05±1.61	6.85±1.42	15
SF8	7.4±0.84	7.4±0.97	7.15±1	7±1.05	6.65±0.94	7.05±1.07	7±1.22	7.35±1.03	5
SF9	6.67±1.09	6.64±1.04	6.33±1.31	7.03±1.31	6.75±1.51	6.75±1.36	6.4±1.51	6.9±1.2	11
SF10	7.4±0.57	7.3±0.79	7.2±1.14	6.7±1.49	7.3±1.32	6.9±1.26	6.75±1.4	7.65±1.23	3
SF11	7.2±1.67	7.05±1.12	7.2±0.92	7±1.13	6.6±1.2	6.5±0.97	6.65±1.13	6.95±1.12	9
SF12	6.85±1.25	6.8±1.14	6.5±1.25	6.75±1.01	7.15±0.67	6.5±0.88	6.55±1.12	6.8±0.89	16
SF13	7.1±0.94	7.1±0.77	7.1±0.74	7.05±0.8	6.7±0.67	6.85±0.91	6.6±1.26	7.1±1.02	6
SF14	7.75±0.72	7.8±0.59	7.75±0.75	7.3±0.79	7.7±0.86	7.3±1.14	7.2±1.34	7.75±0.68	1
SF15	6.95±0.93	7.2±1.01	6.95±1.12	6.9±1.07	7±1.27	6.8±1.23	6.55±1.52	7.1±0.99	6
SF16	7±1.33	7.4±1.15	6.85±1.33	6.9±1.13	6.65±1.29	6.75±1.51	6.55±1.34	6.95±1.3	9
SF17	6.1±1.52	6.1±1.68	6.05±1.59	6.55±1.26	6.55±1.26	6.55±1.32	6.65±1.27	6.35±1.47	19
SF18	7.15±1	7.1±0.97	7.1±1.13	6.65±1.43	7.2±1.21	7.05±1.26	7.25±1.06	6.9±1.22	11
SF19	7.45±1.07	7.4±1.05	7.05±1.19	6.95±0.83	6.9±1.2	6.65±1.18	6.8±1.06	7.05±0.98	8
SF20	7.4±1.1	7.5±1.08	7.5±1	7.2±1.06	7.4±1.2	7.4±1.07	7.45±0.9	7.7±0.98	2

Table F3: 9-point hedonic scale method based sensory scores of mixed winter vegetable soups.

Formu-lation	Taste	Mouthfeel	Aftertaste	Aroma	Appearance	Consistency	Uniformity	Overall acceptability	Rank
C	6.4±1.58	6.6±1.43	6±1.89	6.3±2	7±1.7	7.3±1.49	7.1±1.52	6.6±1.26	10
WF1	3.75±1.67	5.44±1.72	4.06±2.6	6.25±1.49	5.56±1.12	5.19±1.41	5.13±0.95	5±1.28	21
WF2	6.83±1.12	6.48±1.34	6.81±1.46	7.13±1.03	6.56±1.18	6.4±0.97	6.09±1.26	6.75±1.13	9
WF3	6.98±1.48	7.06±1.47	6.79±1.42	6.75±1.49	6.74±1.11	6.73±1.14	6.85±1.31	7.13±1.22	6
WF4	7±1.51	7.19±1.19	6.63±1.51	6.63±1.41	6.81±1.41	6.5±1.04	6.59±1.27	7±1.34	8
WF5	5.88±1.36	6.04±1.44	5.93±1.69	6.38±1.48	6.25±1.75	6.31±1.53	6.35±1.73	6.29±1.64	15
WF6	6±1.31	6.16±1.38	5.93±1.69	6.25±1.56	6.38±1.69	6.31±1.53	6.48±1.65	6.41±1.56	13
WF7	6.4±0.97	6.21±1.05	6.36±0.85	6.56±1.35	6.31±1.28	6.63±1.19	6.48±1.39	6.35±0.73	14
WF8	7.25±0.8	7.1±0.9	7.38±1.03	7.06±1.21	7.13±1.03	6.94±1.32	7.04±1.39	7.5±0.89	2
WF9	7.53±0.91	7.31±0.84	7.54±1.01	7.06±1.15	7.1±0.98	7±1.1	7.11±1.23	7.48±0.75	4
WF10	7.23±1.53	7.06±1.47	7.31±1.56	7.04±1.16	7.63±1.25	7.61±1.2	7.25±1.04	7.5±1.25	2
WF11	5.69±1.39	5.56±1.21	5.25±1.81	6.44±1.08	5.88±0.69	6.21±1.18	6.31±1.19	5.44±1.57	20
WF12	5.48±1	6.1±0.77	5.4±2.22	6.35±1.22	6.15±1.01	6.1±1.27	6.25±1.46	5.54±1.45	19
WF13	5.93±1.3	6.09±0.9	5.93±1.44	6.64±0.95	6.73±1.2	6.88±1.22	6.81±1.25	6.09±1.38	17
WF14	5.63±0.92	5.88±0.79	5.63±1.33	6±0.89	6.19±1.13	6.19±0.84	6.38±0.92	5.75±1.49	18
WF15	7.25±0.46	6.94±0.18	7.13±0.58	6.81±1.13	6.75±1.31	6.5±1.16	6.69±1.41	7.25±0.85	5
WF16	7.25±0.65	6.94±0.68	7.19±0.92	6.75±1.16	6.75±1.16	6.75±1.13	6.63±1.16	7.13±0.79	6
WF17	6.81±1.07	6.56±1.24	6.25±0.93	6.81±1	6.19±1.33	6.19±0.84	6.25±0.89	6.56±1.02	11
WF18	6.13±1.16	6.13±1.13	5.88±0.88	6.19±1.46	6.19±1.41	6.56±1.45	6.44±1.35	6.13±1.16	16
WF19	6.19±1.28	6.19±0.92	6±1.16	6.56±1.24	6.69±1.33	6.88±1.09	6.63±1.06	6.44±1.12	12
WF20	7.63±1.38	7.31±1.53	7.31±1.53	7.13±1.46	7.31±1.36	7.19±1.41	7.06±1.66	7.69±1.41	1

Appendix G: Nutritional Characteristics of Spice Mix Compositions and Individual Thickening Agents

In the following table (Table G1), the nutritional characteristics of spice mix compositions of summer and winter vegetable soup mix formulations (affirmed through trial-and-error methodology optimization in Chapter 5 of the Ph.D. thesis) and individual thickening agents have been summarized. The data has been provided to compare with the mentioned parameters of the overall best summer and winter soup mix formulations.

Table G1: Nutritional characteristics of spice mix compositions and individual thickening agents.

Ingredient	AA %	TPC (mg/100g)	Soluble Protein (g/100g)	Crude Protein (g)	Carbohydrates (g)
Summer spice mix	0.41±0.007	250.72±2.77	2.05±0.05	25.47±0.20	62.30±0.78
Winter spice mix	0.46±0.010	373.73±2.09	1.88±0.04	14.37±0.24	41.57±0.40
Corn flour	0.04±0.004	2.64±0.65	0.59±0.004	14.21±2.19	84.34±1.82
Chick pea flour	0.08±0.010	320.61±1.96	2.58±0.03	27.10±1.21	56.69±1.14
Rice flour	0.02±0.001	40.03±2.85	0.61±0.003	11.71±2.13	81.08±4.14
Bengal gram flour	0.04±0.001	135.57±1.73	1.74±0.06	29.25±0.35	59.47±2.48

Appendix H: Permeability of LDPE Zipper Pouch Packaging Material

The permeability (K) of the low-density polyethylene (LDPE) zipper pouch being used as the packaging material for the developed soup mix formulations was determined with the expression 2.34 in the Ph.D. thesis. Accordingly, the K value was determined with the slope of the straight-line fit of the plot of storage time and weight gained by silica gel placed in the packaging material and stored at 38±2 °C. Figure H1 illustrates the fitness plot.

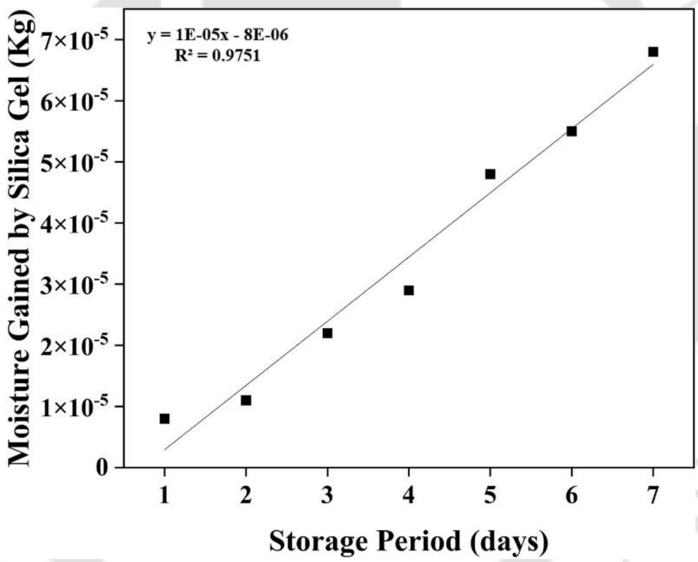


Figure H1: Moisture gain permeability plot for the silica gel sample stored in the zipper pouch at accelerated storage condition.

Appendix I: Summary of Identified Best Soup Mix Formulations – Images, Description and Composition

Table I1 summarizes the images, description and composition of the identified best vegetable soup formulations. These formulations have been constituted with corn flour, cereal and legume based thickening agents.

Table I1: A summary of the identified best vegetable soup mix formulations and their images

Soup Image	Description and Composition
	**Mixture model (MMD) optimized summer vegetable soup** **MS:** 5g veg mix (Powders - 1.34g spine gourd, 2.32g sponge gourd and 1.34g yardlong bean), 2g corn flour & 3g spice mix **Overall acceptability (OA): 8.5, Overall score (OS): 80.43, Deviation Index (DI): 7.30**
	**MMD optimized winter vegetable soup** **MW:** 5g veg mix (Powders - 1g ash gourd, 2.97g bottle gourd, 1.03g squash), 2g corn flour& 3g spice mix **OA: 8.3, OS: 86.77, DI: 9.50**

Soup Image	Description and Composition
	**Summer vegetable soup mix with best alternate thickening agent mix** **TS 14:** 5g veg mix (Powders - 1.34g spine gourd, 2.32g sponge gourd and 1.34g yardlong bean), 0.34g chickpea flour, 1.32g rice flour, 0.34g Bengal gram flour & 3g spice mix **OA: 7.38, OS: 74.75, DI: 12.18**
	**Summer vegetable soup mix with best alternate thickening agent mix** **TS 13:** 5g veg mix (Powders - 1.34g spine gourd, 2.32g sponge gourd and 1.34g yardlong bean), 1.32g chickpea flour, 0.34g rice flour, 1.32g Bengal gram flour & 3g spice mix **OA: 6.88, OS: 74.00, DI: 12.95**
	**Winter vegetable soup mix with best alternate thickening agent mix** **TW8:** 5g veg mix (Powders - 1g ash gourd, 2.97g bottle gourd, 1.03g squash), 1.5g chickpea flour, 0.5g rice flour & 3g spice mix **OA: 7.63, OS: 76.56, DI: 6.84**

Appendix J: Schematic Representation of the Tray Drying System

Figure J1 presents the schematic if the tray drying system utilized for the drying of the fresh vegetable produces.

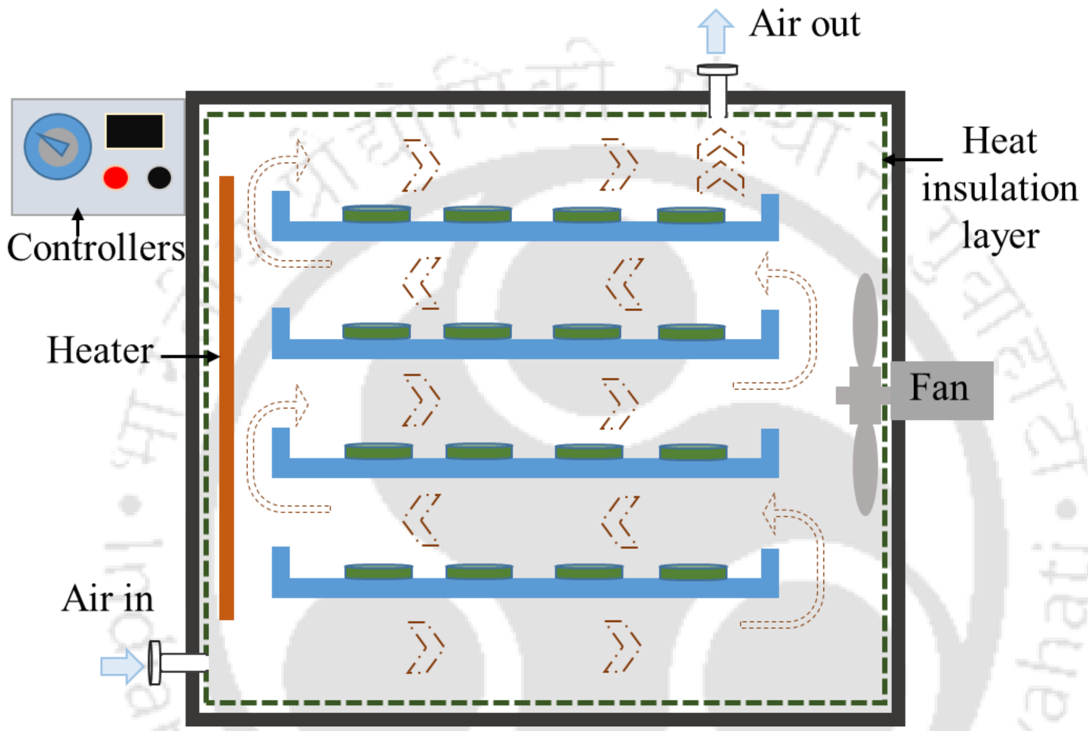


Figure J1. Schematic of the tray dryer system.